ND2013

2013 International Nuclear Data Conference for Science and Technology

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Agenda

Sunday March 3, 2013

Time	Room	Activity
1 PM-7 PM	Lenox	Registration
5 PM-7 PM	Lenox	Welcome reception

Monday March 4, 2013

Time	Met East	Met West	Empire East	Empire West	Central Park East
8:15 AM	Welcome Herman M. Sonzogni A.				
8:30 AM	Opening Chadwick M.				
9:15 AM	Savard, G.				
10:00 AM	Coffee Break Lenox				
10:30 AM	Haight, R.	Briggs, J.	Sun, W.	Brown, A.	Jacqmin, R.
11:00 AM	Nelson, R.	Marshall, M.	Carlson, B.	Lister, C.	Carlson, A.
11:20 AM		Casoli, P.	Nakayama, S.	Tabor, S.	Pereslavtsev, P.
11:40 AM	Hirose, K.	Gonzalez-Romero, E.	Palumbo, A.	Stuchbery, A.	Pigni, M.
12:00 PM	Lunch Break				
1:30 PM	Schillebeeckx, P.	Liu, R.	Koning, A.	Rykaczewski, K.	Chadwick, M.
2:00 PM	Leal, L.	Santos, A.	Martini, M.	Chen, J.	Tonchev, A.
2:20 PM	Mughabghab, S.	Lorenz, T.	Konobeev, A.	Domula, A.	Feng, J.
2:40 PM	Janeva, N.	Zanini, L.	Nobre, G.	Bisch, C.	Lestone, J.
3:00 PM	Coffee Break Lenox				
3:30 PM	Hill, T.	Descalle, M.	Lampoudis, C.	Algora, A.	Firestone, R.
4:00 PM	Snyder, L.	Cabellos, O.	Yashima, H.	Karny, M.	Rossbach, M.
4:20 PM	Loveland, W.	Murray, L.	Schumann, D.	Van Isacker, P.	Al-Adili, A.
4:40 PM	Meharchand, R.	Maeda, S.	Gooden, M.	Fijalkowska, A.	Gilbert, M.
5:00 PM	Wood, L.	Oberstedt, S.	Kino, K.	Nica, N.	Basunia, S.
5:15 PM	Stave, S.	Gauld, I.	Jansson, K.	Singh, B.	Hurst, A.
5:30 PM	Lee, H.	Zhu, T.	Massarczyk, R.		Wiedeking, M.
5:45 PM		Peneliau, Y.	Gheorghe, A.		Valenta, S.
6:00-8:00 PM	Poster Session Central Park West				

Tuesday March 5, 2013

Time	Met East	Met West	Empire East	Empire West	Central Park East
8:30 AM	Salvatores, M.				
9:15 AM	Heng, Y.				
10:00 AM	Coffee Break Lenox				
10:30 AM	Forrest, R.	Kahler, S.	Leeb, H.	Jang, J.	Sanami, T.
11:00 AM	Tuli, J.	Mosteller, R.	Neudecker, D.	Huber, P.	Gunsing, F.
11:20 AM	Mattoon, C.	Navarro, J.	Rising, M.	Johnson, T.	Fotiadis, N.
11:40 AM	Smith, M.	Leong, L.	Sabouri, P.	Onillon, A.	Kimura, A.
12:00 PM	Lunch Break				
1:30 PM	Brown, D.	Kondev, F.	Leray, S.	Fallot, M.	Blain, E.
2:00 PM	Hale, G.	Devlin, M.	Cerutti, F.	Keefer, G.	Kwan, E.
2:20 PM	Ge, Z.	Regan, P.	Pronskikh, V.	Cucoanes, A.	Nakamura, S.
2:40 PM	Summers, N.	Kroll, J.	Matsumura, H.	Estienne, M.	Negret, A.
3:00 PM	Coffee Break Lenox				
3:30 PM	Chiaveri, E.	Santamarina, A.	Hashimoto, S.	Spahn, I.	Faust, H.
4:00 PM	Cano Ott, D.	Lee, Y.	Benstead, J.	Weidner, J.	Wolinska-Cichocka, M.
4:20 PM	Mingrone, F.	Gould, C.	Jeynes, C.	Engle, J.	Tornow, W.
4:40 PM	Tsinganis, A.	Kumar, A.	Hawari, A.	Labalme, M.	Makii, H.
5:00 PM	Belloni, F.	Ochiai, K.	Voinov, A.	Haddad, F.	Meierbachtol, K.
5:15 PM	Mendoza Cembranos, E.	Herrero, J.	Odsuren, M.	Sounalet, T.	Cortina-Gil, D.
5:30 PM	Tarrio, D.	Alhassan, E.		Guertin, A.	Matarranz, J.
5:45 PM	Mathieu, L.	Sogbadji, R.			Novak, J.
6:00-7:00 PM	Poster Session Central Park West				

Wednesday March 6, 2013

Time	Met East	Met West	Empire East	Empire West	Central Park East
8:30 AM	Capote, R.				
9:15 AM	McNabb, D.				
10:00 AM	Coffee Break Lenox				
10:30 AM	Audi, G.	Fischer, U.	Ormand, W.	Wender, S.	Ratkiewicz, A.
11:00 AM	Jokinen, A.	Avrigeanu, V.	Bouland, O.	Watanabe, Y.	Ducasse, Q.
11:20 AM	Wang, M.	Sawan, M.	Avrigeanu, M.	Oishi, K.	Chiba, S.
11:40 AM	Dilling, J.		Guo, H.	Nichols, A.	
12:00 PM	Lunch Break				
1:30 PM	Dupont, E.	Bess, J.	Trkov, A.	Mills, R.	Wallner, A.
2:00 PM	Beck, B.	Ene, D.	Kunieda, S.	Kim, G.	Youinou, G.
2:20 PM	Otsuka, N.	Hammer, B.	Iwamoto, O.	Pentilla, H.	Hori, J.
2:40 PM	Patel, N.	Jansky, B.	Sobes, V.	Tovesson, F.	Lee, J.
3:00 PM	Coffee Break Lenox				
3:30 PM	Lestone, J.	Katakura, J.	Noguere, G.	Dillmann, I.	Ledoux, X.
4:00 PM	Williams, D.	Kibedi, T.	Kodeli, I.	Woods, P.	Junghans, A.
4:20 PM	Ullmann, J.	MacCormick, M.	Iwamoto, H.	Lederer, C.	Dagan, R.
4:40 PM	Laptev, A.	Pritychenko, B.	Martinez Gonzalez, J.	Walters, W.	Mastinu, P.
5:00 PM	Bielewicz, M.	Birch, M.	Duan, J.	Praena, J.	Katabuchi, T.
5:15 PM	Roig, O.	Kim, H.	Shim, H.	Rogers, A.	Belgya, T.
5:30 PM	Chyzh, A.	Marquez Damian, J.		Weiss, C.	Massey, T.
5:45 PM		Perry, R.		Bertolli, M.	Perdue, B.

Thursday March 7, 2013

Time	Met East	Met West	Empire East	Empire West	Central Park East	Central Park West
8:30 AM	Bauge, E.					
9:15 AM	Thoennessen, M.					
10:00 AM	Coffee Break Lenox					
10:30 AM	Harada, H.	Sublet, J.	De Saint Jean, C.	Chiba, G.	Ferrari, A.	Roubtsov, D.
11:00 AM	Guber, K.	Arcilla, R.	Rochman, D.	Singh, B.	Sakama, M.	Vasiliev, A.
11:20 AM	Terada, K.	Cornock, M.	Sjostrand, H.	Miernik, K.	Porras, I.	Ye, T.
11:40 AM	Bahran, R.	Kondo, K.	F. da Cruz, D.	Tain, J.	Fassbender, M.	Chang, G.
12:00 PM	Lunch Break					
1:30 PM	Talou, P.	Grzywacz, R.	Gondolo, P.	Rubio, B.	Ruan, X.	Palmiotti, G.
2:00 PM	Vogt, R.	McCutchan, E.	Altstadt, S.	Kojima, Y.	Sekimoto, S.	Hoblit, S.
2:20 PM	Litaize, O.	Scielzo, N.	Paris, M.	Aprahamian, A.	Utsunomiya, H.	Ivanova, T.
2:40 PM	Nishio, K.	Caballero-Folch, R.	Kasagi, J.	Mougeot, X.	Siem, S.	Archier, P.
3:00 PM	Coffee Break Lenox					
3:30 PM	Guerrero, C.	Fukushima, M.	Kawano, T.	Serot, O.	Cizewski, J.	Helariutta, K.
4:00 PM	Fraval, K.	Yamano, N.	Iwamoto, N.	Jain, A.	Holden, N.	Shigyo, N.
4:20 PM	Mosby, S.	Diez, C.	Alhassid, Y.	Solders, A.	Barthelemy, R.	Hermanne, A.
4:40 PM	Wright, T.	Jouanne, C.	Han, Y.	Taieb, J.	Johnson, A.	De Napoli, M.
5:00 PM	Barbagallo, M.	Mashnik, S.	Betak, E.	Simutkin, V.	Kriek, J.	Yang, S.
5:15 PM	Massimi, C.	Ferran, G.	Stetcu, I.	Dore, D.	Canella Avelar, A.	Vlastou-Zanni, R.
5:30 PM	Diakaki, M.	Ferroukhi, H.	Plujko, V.	Sage, C.		Khandaker, M.
5:45 PM		Kerby, L.	Kornilov, N.	Arnold, C.		Bevilacqua, R.

Friday March 8, 2013

Time	Met East	Met West	Empire East	Empire West	Central Park East	Central Park West
8:30 AM	Igashira, M.					
9:15 AM	Plompen, A.					
10:00 AM	Coffee Break Lenox					
10:30 AM	Hambsch, F.	White, M.	Williams, M.		Norris, M.	Cormon, S.
11:00 AM	Carjan, N.	van der Marck, S.	Varet, S.		Wilcox, B.	Schier, W.
11:20 AM	Benlliure, J.	Chiesa, D.	Arbanas, G.		Feldman, G.	Kitatani, F.
11:40 AM		Lomakov, G.	Holmes, J.		Neumann, S.	Kim, Y.
12:00 PM	Closing Herman M. Sonzogni A.					
12:30 PM	ND2013 adjourns					

We thank you for attending and we wish you a safe trip home

ND2013 Local Organizing Committee

Talks Schedule

Monday, March 4, 2013

Welcome
Room: Met East at 8:15 AM
M. Herman and A. Sonzogni - NNDC - BNL

Session AA Opening Talk and Plenary Monday
Room: Met East at 8:30 AM
Chair: Roberto Capote, IAEA
8:30 AM, Chadwick, M. *CIELO, A Future Collaborative International Evaluated Library* Opening Talk
9:15 AM, Savard, G. *CARIBU: A New Facility for the Production and Study of Neutron-Rich Isotopes*

Session BA Neutron Cross Section Measurements
Room: Met East at 10:30 AM
Chair: Frank Gunsing, CEA Saclay
10:30 AM, Haight, R. *The Prompt Fission Neutron Spectrum Measurement Program at LANSCE*
11:00 AM, Nelson, R. *Neutron-Induced Gamma-Ray Reference Cross Section Measurements with GEANIE at LANSCE*
11:40 AM, Hirose, K. *Cross Section Measurement of* $^{237}Np(n,\gamma)$ *at J-PARC/MLF/ANNRI*

Session BB Integral Experiments
Room: Met West at 10:30 AM
Chair: John Bess, INL
10:30 AM, Briggs, J. *Integral Benchmark Data for Nuclear Data Testing Through the Icsbep and IRPhEP*
11:00 AM, Marshall, M. *Evaluation of Delayed Critical ORNL Unreflected HEU Metal Sphere*
11:20 AM, Casoli, P. *Characterization of the CALIBAN and PROSPERO Critical Assemblies Neutron Spectrums for Integral Measurements Experiments*
11:40 AM, Gonzalez-Romero, E. *Accurate Nuclear Data For Sustainable Nuclear Energy from the ANDES Project*

Session BC Nuclear Reaction Models
Room: Empire East at 10:30 AM
Chair: Helmut Leeb, Vienna TU
10:30 AM, Sun, W. *A Regional Coupled-channel Dispersive Optical Potential for Fe Isotopes*
11:00 AM, Carlson, B. *Exclusive Multiple Emission Cross Sections in the Hybrid Monte Carlo Pre-Equilibrium Model*
11:20 AM, Nakayama, S. *Cross Section Calculation of Deuteron-Induced Reactions Using Extended CCONE Code*
11:40 AM, Palumbo, A. *EMPIRE: A Reaction Model Code for Nuclear Astrophysics*

Session BD Nuclear Structure and Decay
Room: Empire West at 10:30 AM
Chair: Chris Gould, North Carolina SU
10:30 AM, Brown, A. *The Nuclear Shell Model and Nuclear Data*
11:00 AM, Lister, C. *Precise Data on A=10 nuclei for Benchmarking Modern ab-initio Theories of Nuclear Structure*

11:20 AM, Tabor, S. *Cross-shell Excitations in Neutron-Rich s-d Shell Nuclei*
11:40 AM, Stuchbery, A. *New Model for ab initio Calculation of Atomic Radiations in Nuclear Decay*

Session BE Evaluated Nuclear Data Libraries
Room: Central Park East at 10:30 AM
Chair: David Brown, NNDC - BNL
10:30 AM, Jacqmin, R. *Status of the JEFF File Project*
11:00 AM, Carlson, A. *Improvements and Extensions of the Nuclear Data Standards*
11:20 AM, Pereslavtsev, P. *New Evaluation of n+^{63,65}Cu Nuclear Cross Section Data up to 200 MeV Neutron Energy*
11:40 AM, Pigni, M. *Evaluation of Tungsten Neutron Cross Sections in the Resolved Resonance Region*[1]

Session CA Neutron Resonances
Room: Met East at 1:30 PM
Chair: Boris Pritychenko, NNDC - BNL
1:30 PM, Schillebeeckx, P. *Evaluation of Neutron Resonance Cross Section Data at GELINA*
2:00 PM, Leal, L. *^{239}Pu Resonance Evaluation for Thermal Benchmark System Calculations*
2:20 PM, Mughabghab, S. *Recent Investigations and Findings about the 2d- and 3d-Neutron Strength Functions*
2:40 PM, Janeva, N. *Averaging the Neutron Cross Sections in the Unresolved Resonance Region*

Session CB Integral Experiments
Room: Met West at 1:30 PM
Chair: Russell Mosteller
1:30 PM, Liu, R. *Progress of Integral Experiments in Benchmark Fission Assemblies for Blanket of Hybrid Reactor*
2:00 PM, Santos, A. *Three Heavy Reflector Experiments in the IPEN/MB-01 Reactor: Stainless Steel, Carbon Steel, and Nickel.*
2:20 PM, Lorenz, T. *Analytics of the Radionuclide Inventory Produced in Lead Targets by Proton Irradiation*
2:40 PM, Zanini, L. *Online Production and Release Rates of Volatile Isotopes in a Pb/Bi Target Irradiated at ISOLDE and Post-Irradiation Analysis*

Session CC Nuclear Reaction Models
Room: Empire East at 1:30 PM
Chair: Toshihiko Kawano, LANL
1:30 PM, Koning, A. *From Nuclear Physics to Nuclear Systems: New Possibilities with TALYS*
2:00 PM, Martini, M. *Improved Nuclear Inputs for Nuclear Model Codes Based on the Gogny Interaction*
2:20 PM, Konobeev, A. *Improved Simulation of the Pre-Equilibrium Triton Emission in Nuclear Reactions Induced by Nucleons*
2:40 PM, Nobre, G. *Towards a coupled-channel optical potential for rare-earth nuclei*

Session CD Nuclear Structure and Decay
Room: Empire West at 1:30 PM
Chair: Alejandro Algora, IFIC Valencia
1:30 PM, Rykaczewski, K. *Decay Studies of 238U Fission Products at the HRIBF*
2:00 PM, Chen, J. *Search for Fission Decays of High-K Isomers in ^{254}Rf**
2:20 PM, Domula, A. *New Nuclear Structure and Decay Results in the ^{76}Ge-^{76}As System*

2:40 PM, Bisch, C. *Development of a System for Measuring the Shape of β Spectra Using a Semiconductor Si Detector*

Session CE Fission Yields
Room: Central Park East at 1:30 PM
Chair: Morgan White, LANL
1:30 PM, Chadwick, M. *Fission Product Yields for Fast and 14 MeV Neutrons*
2:00 PM, Tonchev, A. *Fission Product Yield Study of ^{235}U, ^{238}U and ^{239}Pu Using Dual-Fission Chambers*
2:20 PM, Feng, J. *Mo-99, Nd-147, Zr-95 and Ba-140 Yields from Fission of U-235 Induced by 0.57, 1.0 and 1.5 MeV Neutrons*
2:40 PM, Lestone, J. *Energy Dependence of Plutonium Fission-Product Yields and Average Fragment Total Kinetic Energies*

Session DA Time Projection Chamber
Room: Met East at 3:30 PM
Chair: Berta Rubio, IFIC - Valencia
3:30 PM, Hill, T. *The Fission Time Projection Chamber Project*
4:00 PM, Snyder, L. *Measuring the α/SF Branching Ratio of ^{252}Cf with the NIFFTE Time Projection Chamber*
4:20 PM, Loveland, W. *Characterization and Preparation of Multi-Isotope Actinide Sources and Targets: The Fission Time Projection Chamber*
4:40 PM, Meharchand, R. *Commissioning the NIFFTE Time Projection Chamber: the $^{238}U/^{235}U$ (n,f) Cross-Section Ratio*
5:00 PM, Wood, L. *An Ethernet-Based Data Acquisition System for the NIFFTE Time Projection*
5:15 PM, Stave, S. *The Data Analysis Framework for the NIFFTE Time Projection Chamber*
5:30 PM, Lee, H. *^{6}Li-Glass Detector Response Study For Low-Energy Prompt Fission Neutrons at LANSCE*

Session DB Benchmark and Testing
Room: Met West at 3:30 PM
Chair: David Brown, NNDC - BNL
3:30 PM, Descalle, M. *Verification and Validation of LLNL's Evaluated Nuclear Data Library (ENDL2011)*
4:00 PM, Cabellos, O. *Testing JEFF-3.1.1 and ENDF/B-VII.1 Decay and Fission Yield Nuclear Data Libraries with Fission Pulse Neutron Emission and Decay Heat Experiments*
4:20 PM, Murray, L. *Measurement of Gamma Energy Distributions and Multiplicities Using STEFF*
4:40 PM, Maeda, S. *Gamma Heat Rate Evaluation for Material Irradiation Test in The Experimental Fast Reactor Joyo*
5:00 PM, Oberstedt, S. *New Prompt Fission γ-ray Data in Response to the OECD/NEA High Priority Request*
5:15 PM, Gauld, I. *Validation and Testing of ENDF/B-VII Decay Data*
5:30 PM, Zhu, T. *Application of the PSI-NUSS Tool for Estimation of Nuclear Data Related K-eff Uncertainties for the OCED/NEA WPNCS UACSA Phase 1 Benchmark*
5:45 PM, Peneliau, Y. *^{239}Pu Prompt Fission Neutron Spectra Impact on a Set of Criticality and Experimental Reactors Benchmarks*

Session DC Neutron Cross Section Measurements
Room: Empire East at 3:30 PM
Chair: Caroline Nesaraja, ORNL
3:30 PM, Lampoudis, C. *^{238}U Neutron Capture Cross Section Measurements in the Unresolved Energy*

Region at the GELINA Facility
4:00 PM, Yashima, H. *Measurements of Neutron Capture Cross Section for ^{74}Se, ^{76}Se and ^{77}Se at KURRI-LINAC*
4:20 PM, Schumann, D. *Cross Sections and Excitation Functions for the Production of Long-Lived Radionuclides*
4:40 PM, Gooden, M. *Partial Cross Sections of Neutron-Induced Reactions on ^{nat}Cu at E_n = 6,8,10,12,14 and 16 MeV for $0\nu\beta\beta$ Background Studies*
5:00 PM, Kino, K. *Measurement of Capture Gamma Rays from the Tc-99 Neutron Resonances at the J-PARC/ANNRI*
5:15 PM, Jansson, K. *Measuring Light-Ion Production and Fission Cross Sections Versus Elastic np-Scattering at the Upcoming NFS Facility*
5:30 PM, Massarczyk, R. *Dipole Strength in Xenon Isotopes*
5:45 PM, Gheorghe, A. *Absolute Cross Sections for Proton Induced Reactions on ^{147,149}Sm Below Coulomb Barrier*

Session DD Nuclear Structure and Decay
Room: Empire West at 3:30 PM
Chair: Kim Lister, University of Massachusets
3:30 PM, Algora, A. *Total Absorption Study of Beta Decays Relevant for Nuclear Applications and Nuclear Structure*
4:00 PM, Karny, M. *First Results from the Modular Total Absorption Spectrometer at the HRIBF*
4:20 PM, Van Isacker, P. *Correlations Between Nuclear Charge Radii, E0 Transitions and Summed M1 Strengths*
4:40 PM, Fijalkowska, A. *First Total Absorption Spectroscopy Measurement of the Beta Decay of ^{139}Xe*
5:00 PM, Nica, N. *Further Test of Internal-Conversion Theory with a Measurement in $^{119}Sn^m$*
5:15 PM, Singh, B. *Gamma-ray Spectroscopy of ^{30}P*

Session DE Neutron Cross Section Measurements
Room: Central Park East at 3:30 PM
Chair: Said Mughabghab, NNDC - BNL
3:30 PM, Firestone, R. *Measurement and Analysis of Gamma-ray Cross Sections*
4:00 PM, Rossbach, M. *Determination of (n,γ) Cross Sections of ^{241}Am by PGAA*
4:20 PM, Al-Adili, A. *Impact of Prompt-Neutron Corrections on Final Fission-Fragment Distributions*
4:40 PM, Gilbert, M. *Neutron Irradiation Experiments: Automated Processing and Analysis of γ-Spectra*
5:00 PM, Basunia, S. *Determination of the $^{151}Eu(n,\gamma)^{152m1,g}Eu$ and $^{153}Eu(n,\gamma)^{154}Eu$ Reaction Cross Sections at Thermal Neutron Energy*
5:15 PM, Hurst, A. *New Measurement of the Thermal-Capture Cross Section for the Minor Isotope ^{180}W*
5:30 PM, Wiedeking, M. *The Photon Strength Function at Low Energies*
5:45 PM, Valenta, S. *Recent Results on Studying Photon Strength Functions in Rare-Earth Nuclei*

Tuesday, March 5, 2013

Session EA Plenary Tuesday
Room: Met East at 8:30 AM
Chair: Andrej Trkov, Jozef Stefan Institute
8:30 AM, Salvatores, M. *WPEC SG33 on: Methods and Issues for the Combined Use of Integral Experiments and Covariance Data*
9:15 AM, Heng, Y. *Electron-Antineutrino Disappearance Seen by Daya Bay Reactor Neutrino Experiment*

Session FA Diseminations, New Formats and International Collaborations
Room: Met East at 10:30 AM
Chair: Balraj Singh, McMaster U.
10:30 AM, Forrest, R. *Developments of the EXFOR Database: Possible New Formats*
11:00 AM, Tuli, J. *Nuclear Structure Databases and Services at NNDC*
11:20 AM, Mattoon, C. *A New Infrastructure for Handling Nuclear Data*
11:40 AM, Smith, M. *Cloud Computing for Nuclear Data*

Session FB Benchmark and Testing
Room: Met West at 10:30 AM
Chair: Oscar Cabellos, Madrid PU
10:30 AM, Kahler, S. *Integral Data Testing of ENDF/B-VII.1 Files - Success Stories and Need to Improve Stories*
11:00 AM, Mosteller, R. *Comparison of ENDF/B-VII.1 and ENDF/B-VII.0 Results for the Expanded Criticality Validation Suite for MCNP and for Selected Additional Criticality Benchmarks*
11:20 AM, Navarro, J. *A Feasibility and Optimization Study to Design a Nondestructive ATR Fuel Permanent Scaning System to Determine Cooling Time and Burnup*
11:40 AM, Leong, L. *Validation of Cross Sections with Criticality Experiment and Reaction Rates: The Neptunium Case*

Session FC Nuclear Data Covariances
Room: Empire East at 10:30 AM
Chair: Pavel Oblozinsky, Slovak Academy of Sciences
10:30 AM, Leeb, H. *Full Bayesian Evaluation Technique for Angle-Differential Data*
11:00 AM, Neudecker, D. *Advanced Uncertainty Quantification for Fission Observables*
11:20 AM, Rising, M. *Uncertainty Quantification of Prompt Fission Neutron Spectra using the Unified Monte Carlo Method*
11:40 AM, Sabouri, P. *Propagation of Nuclear Data Uncertainties in PWR Burnup Pin-Cell Deterministic Calculations using the Total Monte Carlo Approach*

Session FD Nuclear Reactor Antineutrinos
Room: Empire West at 10:30 AM
Chair: Muriel Fallot, Subatech
10:30 AM, Jang, J. *Results of Reactor Neutrino Measurement from RENO*
11:00 AM, Huber, P. *Nuclear Data in the θ_{13} measurement by the Daya Bay Reactor Experiment*
11:20 AM, Johnson, T. *Reactor Neutrino Spectrum Modeling from the Latest ENDF Nuclear Data Library*
11:40 AM, Onillon, A. *Reactor and Antineutrino Spectrum Calculations for the Double Chooz First Phase Results*

Session FE Cross Section Measurements
Room: Central Park East at 10:30 AM
Chair: S. Basunia, LBNL
10:30 AM, Sanami, T. *Target Mass Dependency of Light Mass Fragment Energy Spectra for Intermediate Energy Proton Induced Reaction*
11:00 AM, Gunsing, F. *Spin Measurements of Neutron Resonances of ^{87}Sr for Level Density Studies*
11:20 AM, Fotiadis, N. *Measurements of Partial γ-ray Cross Sections in $^{60}Ni(n, xnypz\alpha\gamma)$ Reactions*
11:40 AM, Kimura, A. *Measurements of Neutron-Capture Cross-Sections of ^{118}Sn with J-PARC/MLF/ANNRI*

Session GA Evaluated Nuclear Data Libraries
Room: Met East at 1:30 PM
Chair: Tokio Fukahori, Subatech
1:30 PM, Brown, D. *Status of the ENDF/B Nuclear Data Library*
2:00 PM, Hale, G. n+^{12}C *Cross Sections from an R-Matrix Analysis of Reactions in the* ^{13}C *System*
2:20 PM, Ge, Z. *New Version of Chinese Evaluated Nuclear Data Library CENDL-3.2 and the Development Methodology of Nuclear Data Evaluation in China*
2:40 PM, Summers, N. *Overview of the 2011 Release of the Evaluated Nuclear Data Library (ENDL2011)*

Session GB Nuclear Structure and Decay
Room: Met West at 1:30 PM
Chair: Alan Nichols, University of Surrey
1:30 PM, Kondev, F. *Gamma-ray Spectroscopy using Rare Isotope Sources*
2:00 PM, Devlin, M. *New Half-Life Measurements for Millisecond Isomers at LANSCE*
2:20 PM, Regan, P. *Using LaBr3 Gamma-ray Detectors for Precision Measurements of Nuclear Excited State Lifetimes in the 100ps - 10ns Regime*
2:40 PM, Kroll, J. *Scissors Mode Strength in Rare Earth Nuclei Studied from (n,γ) reaction*

Session GC Accelerator Applications
Room: Empire East at 1:30 PM
Chair: Alfredo Ferrari, CERN
1:30 PM, Leray, S. *Recent Developments of the Liège Intra Nuclear Cascade Model in View of its Use into High-Energy Transport Codes*
2:00 PM, Cerutti, F. *Beam-machine Interaction at the CERN LHC*
2:20 PM, Pronskikh, V. *Simulation of Radiation Quantities for Accelerator-Based Experiments*
2:40 PM, Matsumura, H. *Material Activation Benchmark Experiments at the NuMI Hadron Absorber Hall in Fermilab*

Session GD Nuclear Reactor Antineutrinos
Room: Empire West at 1:30 PM
Chair: Elizabeth McCutchan, NNDC - BNL
1:30 PM, Fallot, M. *The Detection of Reactor Antineutrinos for Reactor Core Monitoring: an Overview*
2:00 PM, Keefer, G. *Development of a High Precision Beta Spectra Generator Using the Latest Nuclear Databases*
2:20 PM, Cucoanes, A. *The Nucifer Experiment*
2:40 PM, Estienne, M. *Contribution of Recently Measured Nuclear Data to Reactor Antineutrino Energy Spectra Predictions*

Session GE Neutron Cross Section Measurements
Room: Central Park East at 1:30 PM
Chair: Stanislav Hlavac, Slovak Academy of Sciences
1:30 PM, Blain, E. *Measurement of Fission Neutron Spectrum and Multiplicity using a Double Time-of-Flight Setup*
2:00 PM, Kwan, E. *Prompt Fission γ Rays Measured Using Liquid Scintillators*
2:20 PM, Nakamura, S. *Cross Section Measurements of the Radioactive* ^{107}Pd *and Stable* $^{105,108}Pd$ *nuclei*
2:40 PM, Negret, A. *The Limits of the GAINS Spectrometer*

Session HA Neutron Cross Section Measurements
Room: Met East at 3:30 PM
Chair: Yaron Danon, RPI
3:30 PM, Chiaveri, E. *The CERN n_TOF facility: Neutron Beams Performances for Cross Section Measurements*
4:00 PM, Cano Ott, D. *Measurement of the Neutron Capture Cross Section of the Fissile Isotope* ^{235}U *with the CERN n_TOF Total Absorption Calorimeter and a Fission Tagging Based on Micromegas Detectors*
4:20 PM, Mingrone, F. *Measurement of the* ^{238}U *Radiative Capture Cross Section with* C_6D_6 *at the n_TOF CERN Facility*
4:40 PM, Tsinganis, A. *Measurement of the* $^{240,242}Pu(n,f)$ *Cross Section at the CERN n_TOF Facility*
5:00 PM, Belloni, F. *A Micromegas Detector for Neutron Beam Imaging at the n_TOF Facility at CERN*
5:15 PM, Mendoza Cembranos, E. *Measurement of the* ^{241}Am *and the* ^{243}Am *Neutron Capture Cross Sections at the n_TOF Facility at CERN*
5:30 PM, Tarrio, D. *Fission Fragment Angular Distribution for Th-232(n,f) at the CERN n_TOF Facility*
5:45 PM, Mathieu, L. *Measurement of the 233U(n,g) and 233U(n,f) Cross Sections in the Resonance Region*

Session HB Nuclear Power Applications
Room: Met West at 3:30 PM
Chair: Andrei Trkov, Jozef Stefan Institute
3:30 PM, Santamarina, A. *Improvement of* ^{238}U *Inelastic Scattering Cross-Section for an Accurate Calculation of Large Commercial Reactors*
4:00 PM, Lee, Y. *Investigation of Nuclear Data Libraries with TRIPOLI-4 Monte Carlo Code for Sodium-Cooled Fast Reactors*
4:20 PM, Gould, C. *Nuclear Data and the Oklo Natural Nuclear Reactors*
4:40 PM, Kumar, A. *Identification of Energy Regions for Maximising the Fertile-To-Fissile Conversion in Thorium Fuel Cycles Using Point-Wise Energy Cross Sections in an Actinide Depletion Code*
5:00 PM, Ochiai, K. *Remarks on KERMA Factors in ACE files*
5:15 PM, Herrero, J. *Nuclear Data Uncertainty Propagation to Reactivity Coefficients of Sodium Fast Reactor*
5:30 PM, Alhassan, E. *Assessing the Impact of Pb and Pu Cross Section Data Uncertainties on Safety Parameters of a Low Power Lead Cooled Reactor*
5:45 PM, Sogbadji, R. *Neutronic Study of Burnup, Radiotoxicity, Decay Heat and Basic Safety Parameters of Mono-reycling of Americium in French PWR*

Session HC Nuclear Reaction Models
Room: Empire East at 3:30 PM
Chair: Brett Carlson, Instituto Tecnologico de Aeronautica
3:30 PM, Hashimoto, S. *New Approach for Nuclear Reaction Model in Combination of Intra-Nuclear Cascade and DWBA*
4:00 PM, Benstead, J. *Calculations of Compound Nucleus Spin-Parity Distributions Populated via the (p,t) Reaction in Support of Surrogate Reaction Measurements*
4:20 PM, Jeynes, C. *Evaluation of Non-Rutherford Alpha Elastic Scattering Cross-Section for Silicon*
4:40 PM, Hawari, A. *Modern Techniques for Inelastic Thermal Neutron Scattering Analysis*
5:00 PM, Voinov, A. *Level Density Options for Hauser-Feshbach Model Calculations from an Experimental Point of View*
5:15 PM, Odsuren, M. *Statistical Model Analysis of* (n,α) *and (n,p) Cross Sections Averaged Over the Fission Neutron Spectrum*

Session HD Cross Section Measurements
Room: Empire West at 3:30 PM
Chair: Mike Herman, NNDC - BNL
3:30 PM, Spahn, I. *Investigation of d- and Alpha-Induced Nuclear Reactions for the Production of Radioisotopes of Bromine and Iodine for Medical Application*
4:00 PM, Weidner, J. *Nuclear Data for ^{227}Ac Production Below 200 MeV by Proton Bombardment of Thorium*
4:20 PM, Engle, J. *Cross Sections for Proton Induced Reactions on Thorium at 800 MeV*
4:40 PM, Labalme, M. *Nuclear Fragmentation Measurements for Hadrontherapy: 95MeV/u ^{12}C Reactions on H, C, Al, O and ^{nat}Ti Targets*
5:00 PM, Haddad, F. *Strontium-82 Production at ARRONAX*
5:15 PM, Sounalet, T. *Electrodeplating of Gallium 69 for the Production of Gallium 68 for the Nuclear Medicine at ARRONAX*
5:30 PM, Guertin, A. *Th-232 (d, 4n) Pa-230 Cross-Section Measurements at ARRONAX Facility*

Session HE Experimental Facilities and Techniques
Room: Central Park East at 3:30 PM
Chair: Robert Haight, LANL
3:30 PM, Faust, H. *Verification of the Thermodynamic Model in Nuclear Fission: the New Spectrometer FIPPS*
4:00 PM, Wolinska-Cichocka, M. *Modular Total Absorption Spectrometer at the HRIBF*
4:20 PM, Tornow, W. *Measurements of the $(n, 2n)$ Reaction Cross Section of ^{181}Ta from 8 MeV to 14.5 MeV*
4:40 PM, Makii, H. *Development of Anti-Compton $LaBr_3(Ce)$ Spectrometer for Measurement of Surrogate Reaction*
5:00 PM, Meierbachtol, K. *Development of an Ionization Chamber for the Spider Fission Fragment Detector*
5:15 PM, Cortina-Gil, D. *CALIFA, a Calorimeter for the R3B/FAIR experiment*
5:30 PM, Matarranz, J. *Atomic Number Determination of Fission Products by Digital Techniques*
5:45 PM, Novak, J. *Fast Neutron Laboratory of the NPI Řež: Neutron Measurement Techniques*

Wednesday, March 6, 2013

Session IA Plenary Wednesday
Room: Met East at 8:30 AM
Chair: Pavel Oblozinsky, Slovak Academy of Sciences
8:30 AM, Capote, R. *Physics of Neutron Interaction with U-238 Nucleus: New Developments and Challenges*
9:15 AM, McNabb, D. *Plasma Nuclear Science: Nuclear Science in Hot, Dense, and Dynamic Laboratory Plasmas*

Session JA Atomic Masses
Room: Met East at 10:30 AM
Chair: Jose Luis Tain, IFIC - Valencia
10:30 AM, Audi, G. *The 2012 Atomic Mass Evaluation and the Mass Tables*
11:00 AM, Jokinen, A. *Precision Atomic Mass Measurements for Nuclear Data Applications*
11:20 AM, Wang, M. *Mass Measurements of Short-lived Nuclei at HIRFL-CSR*
11:40 AM, Dilling, J. *Precision Mass Measurements for Nuclear Physics Application and Metrology*

Session JB Fusion Applications
Room: Met West at 10:30 AM
Chair: Jean-Christophe Sublet, UK AEA
10:30 AM, Fischer, U. *The Activities of the European Consortium on Nuclear Data Development and Analysis for Fusion*
11:00 AM, Avrigeanu, V. *Consistent Account of Fast Neutron Induced α-particle Emission*
11:20 AM, Sawan, M. *Benchmarking of the FENDL-3 Neutron Cross-Section Data Starter Library for Fusion Applications*

Session JC Nuclear Reaction Models
Room: Empire East at 10:30 AM
Chair: Patrick Talou, LANL
10:30 AM, Ormand, W. *A Modern Code System for Hauser-Feshbach Modeling Based on a Monte Carlo Framework*
11:00 AM, Bouland, O. *The Impact of Intermediate Structure on the Average Fission Cross Section Calculations*
11:20 AM, Avrigeanu, M. *Unitary Account of Nuclear Reaction Mechanisms for Deuteron-Induced Activation at Low and Medium Energies*
11:40 AM, Guo, H. *Application of the Continuum Discretized Coupled Channels Method to Nucleon-Induced Reactions on $^{6,7}Li$ for Energies up to 150 MeV*

Session JD Space and Medical Applications
Room: Empire West at 10:30 AM
Chair: Francesco Cerutti, CERN
10:30 AM, Wender, S. *Accelerator Testing for Neutron-Induced Failures in Semiconductor Devices*
11:00 AM, Watanabe, Y. *Nuclear Reaction Models Responsible for Simulation of Neutron-Induced Soft Errors in Microelectronics*
11:20 AM, Oishi, K. *Benchmark Experiment of Dose Rate Distribution Around Gamma Knife Medical Apparatus*
11:40 AM, Nichols, A. *Nuclear Data Requirements for Medical Applications - Recent Contributions and Future Requirements as Formulated Under the Auspices of the International Atomic Energy Agency*

Session JE Surrogate Reactions
Room: Central Park East at 10:30 AM
Chair: Jolie Cizewski, Rutgers
10:30 AM, Ratkiewicz, A. *Validating (d,pγ) as a Surrogate for Neutron Capture on Unstable Nuclei*
11:00 AM, Ducasse, Q. *Neutron-induced Capture Cross Sections of Actinides via the Surrogate-Reaction Method*
11:20 AM, Chiba, S. *Surrogate Research at JAEA/Tokyo Tech*

Session KA Diseminations, New Formats and International Collaborations
Room: Met East at 1:30 PM
Chair: Jag Tuli, NNDC - BNL
1:30 PM, Dupont, E. *Working Party on International Nuclear Data Evaluation Co-operation (WPEC)*
2:00 PM, Beck, B. *International Effort to Define a New Nuclear Data Structure*
2:20 PM, Otsuka, N. *Toward More Complete and Accurate Experimental Nuclear Reaction Data Library (EXFOR) - International Collaboration Between Nuclear Reaction Data Centres (NRDC)*

2:40 PM, Patel, N. *Structure for Storing Properties of Particles (POP)*

Session KB Integral Experiments
Room: Met West at 1:30 PM
Chair: Mohamed Sawan, University of Wisconsin
1:30 PM, Bess, J. *What If Lady Godiva Was Wrong?*
2:00 PM, Ene, D. *Shielding Design Calculations for the ESS Target Station High Activated Components*
2:20 PM, Hammer, B. *Distribution of Radionuclides in MEGAPIE, a Proton Irradiated LBE Target*
2:40 PM, Jansky, B. *Measured and Calculated Iron Filtered Neutron Spectra Using Different Data Libraries for Calculation*

Session KC Evaluated Nuclear Data Libraries
Room: Empire East at 1:30 PM
Chair: Tim Johnson, NNDC - BNL
1:30 PM, Trkov, A. *Current Status of Evaluated Nuclear Data of Mn-55*
2:00 PM, Kunieda, S. *R-matrix Analysis for n+^{16}O Cross-Sections up to $E_n = 6.0$ MeV with Covariance*
2:20 PM, Iwamoto, O. *Progress in Developing Nuclear Reaction Calculation Code CCONE for Higher Energy Nuclear Data Evaluation*
2:40 PM, Sobes, V. *New Resolved Resonance Region Evaluations for ^{63}Cu and ^{65}Cu to Support Nuclear Criticality Safety Analyses*

Session KD Fission Yields
Room: Empire West at 1:30 PM
Chair: Alan Nichols, University of Surrey
1:30 PM, Mills, R. *Uncertainty Propagation of Fission Product Yield Data in Spent Fuel Inventory Calculations*
2:00 PM, Kim, G. *Mass Yield Distribution in the 45- and 80-MeV Bremsstrahlung-Induced Fission of ^{232}Th*
2:20 PM, Pentilla, H. *Independent Isotopic Product Yields in 25 MeV and 50 MeV Charged Particle Induced Fission of ^{238}U and ^{232}Th*
2:40 PM, Tovesson, F. *SPIDER: A New Instrument for Fission Fragment Yield Measurements*

Session KE Neutron Cross Section Measurements
Room: Central Park East at 1:30 PM
Chair: Alexandru Negret, IFIN-HH
1:30 PM, Wallner, A. *Neutron-Induced Reactions on U and Th - New Cross-Section Measurements via AMS*
2:00 PM, Youinou, G. *MANTRA: An Integral Reactor Physics Experiment to Infer the Capture Cross-Sections of Actinides and Fission Products in Fast and Epithermal Neutron Spectra*
2:20 PM, Hori, J. *Measurements of Capture Gamma Rays from the Neutron Resonances of ^{74}Se and ^{77}Se at J-PARC/MLF/ANNRI*
2:40 PM, Lee, J. *Measurements of Thermal Neutron Capture Cross Sections of ^{136}Ce, $^{156,158}Dy$, and ^{168}Yb*

Session LA Neutron Cross Section Measurements
Room: Met East at 3:30 PM
Chair: Franz-Josef Hambsch, EC-JRC-IRMM
3:30 PM, Lestone, J. *Plutonium and Uranium Prompt-Fission-Neutron Energy Spectra (PFNS) from the Analysis of Neutron Data from two US Nuclear Explosions*

4:00 PM, Williams, D. *A New Measurement of the Neutron Capture Cross Section of* ^{235}U *Below 5 keV*
4:20 PM, Ullmann, J. *Neutron Capture Cross Sections and Gamma Emission Spectra from Neutron Capture on* $^{234,236,238}U$ *measured with DANCE.*
4:40 PM, Laptev, A. *Neutron-Induced Fission Cross Section Measurements at LANSCE*
5:00 PM, Bielewicz, M. *Measurements relevant to high energy neutron spectrum (> 10 MeV) by using Yttrium threshold detectors*
5:15 PM, Roig, O. *Neutron Capture Reaction on* ^{173}Lu *Isotope at DANCE*
5:30 PM, Chyzh, A. *Precision Measurement of Neutron Capture in* ^{238}Pu *at DANCE*

Session LB Evaluated Nuclear Data Libraries
Room: Met West at 3:30 PM
Chair: Jag Tuli, NNDC - BNL
3:30 PM, Katakura, J. *Development of JENDL Decay and Fission Yield Data Libraries*
4:00 PM, Kibedi, T. *Table of* E0 *Electronic Factors for Conversion Electron Probabilities*
4:20 PM, MacCormick, M. *Survey and Evaluation of the Isobaric Analog States*
4:40 PM, Pritychenko, B. *Systematics of Evaluated Double-Beta Decay Half-Life Times*
5:00 PM, Birch, M. *Method of Best Representation for Averages in Data Evaluation*
5:15 PM, Kim, H. *Neutron Cross Section Evaluation of Tantalum and Tungsten*
5:30 PM, Marquez Damian, J. *An Evaluation of the Scattering Law For Light and Heavy Water in ENDF-6 Format, Based on Experimental Data and Molecular Dynamics*
5:45 PM, Perry, R. *The Production and Performance of JEFF3.1.2 Nuclear Data Libraries in ANSWERS Codes*

Session LC Nuclear Data Covariances
Room: Empire East at 3:30 PM
Chair: Emil Betak, Slovak Academy of Sciences
3:30 PM, Noguere, G. *On the Use of Zero Variance Penalty Conditions for the Generation of Covariance Matrix Between Model Parameters*
4:00 PM, Kodeli, I. *Evaluation of Uncertainties in* β_{eff} *by Means of Deterministic and Monte Carlo Methods*
4:20 PM, Iwamoto, H. *Sensitivity and Uncertainty Analysis for Minor Actinide Transmuters with JENDL-4.0*
4:40 PM, Martinez Gonzalez, J. *Propagation of Neutron Cross Section, Fission Yield, and Decay Data Uncertainties in Depletion Calculations*
5:00 PM, Duan, J. *Uncertainty Study of Nuclear Model Parameters for the* $n+^{56}Fe$ *Reactions in the Fast Neutron Region Below 20 MeV*
5:15 PM, Shim, H. *Monte Carlo Sensitivity and Uncertainty Analysis with Continuous-Energy Covariance Data*

Session LD Nuclear Astrophysics
Room: Empire West at 3:30 PM
Chair: Ani Aprahamian, University of Notre Dame
3:30 PM, Dillmann, I. *The "Karlsruhe Astrophysical Database of Nucleosynthesis in Stars" project - Status and Prospects*
4:00 PM, Woods, P. *Nuclear Spectroscopic Data for Nuclear Astrophysics*
4:20 PM, Lederer, C. *Neutron Capture Reactions for the Astrophysical s-process in the Fe/Ni Region*
4:40 PM, Walters, W. *The* $A = 130$ *Solar-System r-process Abundance Peak - from Initial Build-Up to Decay Back to* β*-stability*

5:00 PM, Praena, J. *Measurement of the Thulium Stellar Cross Section at kT=30 keV by Activation with an Innovative Method*
5:15 PM, Rogers, A. *Beta Decay in The Region Of Neutron-Deficient* $^{69,70,71}Kr$
5:30 PM, Weiss, C. *The (n, α) Reaction in the S-Process Branching Point* ^{59}Ni
5:45 PM, Bertolli, M. *Uncertainties in Astrophysical β-decay Rates from the FRDM*

Session LE Experimental Facilities and Techniques
Room: Central Park East at 3:30 PM
Chair: Enrico Chiaveri, CERN
3:30 PM, Ledoux, X. *The Neutrons For Science facility at SPIRAL-2*
4:00 PM, Junghans, A. *Fast Neutron Induced Reactions at the Nelbe Time-Of-Flight Facility*
4:20 PM, Dagan, R. *Impact of the Energy Dependent DDXS on Determination of Resonance Parameters*
4:40 PM, Mastinu, P. *The LENOS Project at Laboratori Nazionali di Legnaro of INFN-LNL*
5:00 PM, Katabuchi, T. *A New Signal Processing Technique for Neutron Capture Cross Section Measurement Based on Pulse Width Analysis*
5:15 PM, Belgya, T. *Neutron Flux Characterization of the Cold Beam PGAA-NIPS Facility at the Budapest Research Reactor*
5:30 PM, Massey, T. *New Method for Measurement of Neutron Detector Efficiency up to 20 MeV*
5:45 PM, Perdue, B. *Development of an Array of Liquid Scintillators to Measure the Prompt Fission Neutron Spectrum at LANSCE*

Thursday, March 7, 2013

Session MA Plenary Thursday
Room: Met East at 8:30 AM
Chair: Mark Chadwick, LANL
8:30 AM, Bauge, E. *Connecting the dots, or nuclear data in the age of supercomputing*
9:15 AM, Thoennessen, M. *Exploring new neutron-rich nuclei with the Facility for Rare Isotope Beams*

Session NA Neutron Cross Section Measurements
Room: Met East at 10:30 AM
Chair: Allan Carlson, NIST
10:30 AM, Harada, H. *Capture Cross-section Measurement of* ^{241}Am *at J-PARC/MLF/ANNRI*
11:00 AM, Guber, K. *Neutron-Induced Cross Sections Measurements Of Calcium*
11:20 AM, Terada, K. *Measurements of keV-Neutron Capture Cross Sections and Capture Gamma-Ray Spectra of Pd Isotopes*
11:40 AM, Bahran, R. *Isotopic Mo Neutron Total Cross Section Measurements in the Energy Range 1 to 620 keV*

Session NB Benchmark and Testing
Room: Met West at 10:30 AM
Chair: Ulrich Fischer, Karlsruhe IT
10:30 AM, Sublet, J. *TENDL-2012 Processing, Verification and Validation Steps*
11:00 AM, Arcilla, R. *Use of a Continuous Integration and Deployment Software to Automate Nuclear Data Verification and Validation*
11:20 AM, Cornock, M. *Benchmarking of ENDF/B-VII and JENDL-4.0 in the Fast Neutron Range*
11:40 AM, Kondo, K. *Re-analysis of Fusion Relevant Benchmark Experiments Using Recent Nuclear Data Libraries*

Session NC Nuclear Data Covariances
Room: Empire East at 10:30 AM
Chair: Sam Hoblit, NNDC - BNL
10:30 AM, De Saint Jean, C. *Estimation of Nuclear Reaction Model Parameter Covariances and the Related Neutron Induced Cross Sections with Physical Constraints*
11:00 AM, Rochman, D. *Uncertainty Propagation with Fast Monte Carlo Techniques*
11:20 AM, Sjostrand, H. *Propagation of Nuclear Data Uncertainties for ELECTRA Burn-Up Calculations*
11:40 AM, F. da Cruz, D. *Total Monte-Carlo Method Applied to a Pressurized Water Reactor Fuel Assembly - Quantification of Uncertainties due to* $^{235,238}U$, $^{239,240,241}Pu$ *and Fission Products Nuclear Data Uncertainties*

Session ND Beta Delayed Neutrons
Room: Empire West at 10:30 AM
Chair: Alejandro Sonzogni, NNDC - BNL
10:30 AM, Chiba, G. *Sensitivity Analysis for Reactor Stable Period Induced by Positive Reactivity Using One-Point Adjoint Kinetic Equation*
11:00 AM, Singh, B. *First Compilation and Evaluation of Beta-Delayed Neutron Emission Probabilities and Associated Half-lives in the Non-Fission Region* $(A \leq 72)$
11:20 AM, Miernik, K. *Beta-decay Study of Neutron-Rich Isotopes* ^{93}Br *and* ^{93}Kr
11:40 AM, Tain, J. *New Beta-Delayed Neutron Measurements in the Light-Mass Fission Group*

Session NE Space and Medical Applications
Room: Central Park East at 10:30 AM
Chair: Sylvie Leray, CEA Saclay
10:30 AM, Ferrari, A. *The FLUKA Code: Developments and Challenges for High Energy and Medical Applications*
11:00 AM, Sakama, M. *Correlation Between Asian Dust (yellow dust) and Specific Radioactivities of Fission Products Including in Airborne Samples in Tokushima, Shikoku Island, Japan, due to the Fukushima Nuclear Accident*
11:20 AM, Porras, I. $^{33}S(n,\alpha)$ *Cross Section Measurement at n_TOF: Implications in Neutron Capture Therapy*
11:40 AM, Fassbender, M. *Production of High Specific Activity* ^{186}Re *for Cancer Therapy Using* $^{nat,186}WO_3$ *Targets in a Proton Beam*

Session NF Nuclear Power Applications
Room: Central Park West at 10:30 AM
Chair: Winfried Zwermann, GRS
10:30 AM, Roubtsov, D. *Reactivity Impact of* ^{2}H *and* ^{16}O *Elastic Scattering Nuclear Data for Critical Systems with Heavy Water*
11:00 AM, Vasiliev, A. *Nuclear Data Library Effects on High-Energy to Thermal Flux Shapes around PWR Control Rod Tips*
11:20 AM, Ye, T. *Prompt Time Constants of a Reflected Reactor*
11:40 AM, Chang, G. *ATR HEU and LEU Core Kinetics Parameters Calculation by MCNP5 Version 1.60 Adjoint-Weighted Method*

Session OA Nuclear Fission
Room: Met East at 1:30 PM
Chair: Stephan Pomp, Uppsala University
1:30 PM, Talou, P. *Monte Carlo Hauser-Feshbach Calculations of Prompt Fission Neutrons and Gamma Rays*
2:00 PM, Vogt, R. *Event-by-Event Fission Modeling of Prompt Neutrons and Photons from Neutron-Induced and Spontaneous Fission with FREYA*
2:20 PM, Litaize, O. *Investigation of* $n+^{238}U$ *Fission Observables*
2:40 PM, Nishio, K. *Study for Heavy-Ion Induced Fission for the Heavy Element Synthesis*

Session OB Beta Delayed Neutrons
Room: Met West at 1:30 PM
Chair: Balraj Singh, McMaster U.
1:30 PM, Grzywacz, R. *Beta Delayed Neutron Spectroscopy on the r-process Path*
2:00 PM, McCutchan, E. *A New Approach to Estimating the Probability for* β *Delayed Neutron Emission*
2:20 PM, Scielzo, N. *Beta-delayed Neutron Spectroscopy with Trapped Ions*
2:40 PM, Caballero-Folch, R. *New Measurements in the Neutron Rich Region Around N=126 for* β*-decay and* β*-delayed Neutron Emission Data at GSI-FRS*

Session OC Nuclear Astrophysics
Room: Empire East at 1:30 PM
Chair: Boris Pritychenko, NNDC - BNL
1:30 PM, Gondolo, P. *Wanted! Nuclear Data for Dark Matter Astrophysics*
2:00 PM, Altstadt, S. *Experimental Studies of the* $^{13,14}B(n,\gamma)$ *Rates for Nucleosynthesis Towards the r process*
2:20 PM, Paris, M. *R-matrix Analysis of Reactions in the* ^{9}B *Compound System*
2:40 PM, Kasagi, J. *Astrophysical* $S_{bare}(E)$ *Factor of the* $^{6}Li+d$ *and* $^{7}Li+p$ *Reactions*

Session OD Nuclear Structure and Decay
Room: Empire West at 1:30 PM
Chair: Tibor Kibedi, Australian National University
1:30 PM, Rubio, B. *Determination of absolute Gamow Teller transition probabilities in exotic fp-shell nuclei*
2:00 PM, Kojima, Y. *Half-life Measurements of Excited Levels in Fission Products Around a Mass Number of 150*
2:20 PM, Aprahamian, A. *TBA*
2:40 PM, Mougeot, X. *Evidence for the Exchange Effect in Low-Energy Beta Decays*

Session OE Cross Section Measurements
Room: Central Park East at 1:30 PM
Chair: Rian Bahran, RPI
1:30 PM, Ruan, X. *Nuclear Data Measurement Activities at CIAE*
2:00 PM, Sekimoto, S. *Measurements of Neutron Cross Sections for Chromium, Yttrium and Terbium at 197 MeV*
2:20 PM, Utsunomiya, H. *Partial Photoneutron Cross Sections for* $^{207,208}Pb$
2:40 PM, Siem, S. *Experimental Level Densities and Gamma Strength Functions with the Oslo Method*

Session OF Nuclear Data Adjustment
Room: Central Park West at 1:30 PM
Chair: Alain Santamarina, CEA Cadarache
1:30 PM, Palmiotti, G. *Multigroup Cross Section Adjustment Based on ENDF/B-VII.0 Data*
2:00 PM, Hoblit, S. *Towards unified reaction cross sections through assimilation of integral and differential experiments.*
2:20 PM, Ivanova, T. *Uncertainty Assessment for fast Reactors Based on Nuclear Data Adjustment*
2:40 PM, Archier, P. *New JEFF-3.2 Sodium Neutron Induced Cross-Sections Evaluation for Neutron Fast Reactors Applications: from 0 to 20 MeV*

Session PA Neutron Cross Section Measurements
Room: Met East at 3:30 PM
Chair: Peter Schillebeeckx, EC-JRC-IRMM Geel
3:30 PM, Guerrero, C. *Investigation of Neutron-Induced Reactions at n_TOF: Overview of the 2009-2012 Experimental Program*
4:00 PM, Fraval, K. *Analysis of $^{241}Am(n,\gamma)$ Cross Section with C_6D_6 Detectors at the n_TOF facility (CERN)*
4:20 PM, Mosby, S. *Neutron Capture Cross Section of ^{239}Pu*
4:40 PM, Wright, T. *High-precision measurement of the $^{238}U(n,\gamma)$ cross section with the Total Absorption Calorimeter (TAC) at nTOF, CERN*
5:00 PM, Barbagallo, M. *Results on the ^{236}U Neutron Cross Section from the n_TOF Facility*
5:15 PM, Massimi, C. *New Measurement of the $^{25}Mg(n, \gamma)$ Reaction Cross Section*
5:30 PM, Diakaki, M. *Measurement of the $^{237}Np(n,f)$ Cross Section with the MicroMegas Detector*

Session PB Benchmark and Testing
Room: Met West at 3:30 PM
Chair: Skip Kahler, LANL
3:30 PM, Fukushima, M. *Benchmark Calculations for Reflector Effect in Fast Cores by Using the Latest Evaluated Nuclear Data Libraries*
4:00 PM, Yamano, N. *Analysis of the Neutronic Properties of the Prototype FBR Monju Based on Several Evaluated Nuclear Data Libraries*
4:20 PM, Diez, C. *Impact on Advanced Fuel Cycle and its Irradiated Fuel due to Nuclear Data Uncertainties and Comparison Between Libraries*
4:40 PM, Jouanne, C. *Sensitivity of the Shielding Benchmarks on Variance-Covariance Data for Scattering Angular Distributions*
5:00 PM, Mashnik, S. *MCNP6 Fission Cross Section Calculations at Intermediate and High Energies*
5:15 PM, Ferran, G. *Development Progress of the GAIA Nuclear Data Processing Software*
5:30 PM, Ferroukhi, H. *Study of Nuclear Decay Data Contribution to Uncertainties in Heat Load Estimations for Spent Fuel Pools*
5:45 PM, Kerby, L. *Preequilibrium Emission of Light Fragments in Spallation Reactions*

Session PC Nuclear Reaction Models
Room: Empire East at 3:30 PM
Chair: Roberto Capote, IAEA - NDS
3:30 PM, Kawano, T. *Numerical Simulations for Low Energy Nuclear Reactions to Validate Statistical Models*
4:00 PM, Iwamoto, N. *Theoretical Analysis of Gamma-ray Strength Function for Pd Isotopes*
4:20 PM, Alhassid, Y. *Statistical Properties of Nuclei by the Shell Model Monte Carlo Method*

4:40 PM, Han, Y. *The Theoretical Calculation of Actinide Nuclear Reaction Data*
5:00 PM, Betak, E. *Cluster Emission for the Pre-Equilibrium Exciton Model with Spin Variables*
5:15 PM, Stetcu, I. *Angular Momentum Distribution of Fission Fragments*
5:30 PM, Plujko, V. *Average Description of Dipole Gamma-Transitions in Hot Atomic Nuclei*
5:45 PM, Kornilov, N. *On the Mechanism of Neutron Emission in Fission (2013)*

Session PD Fission Yields
Room: Empire West at 3:30 PM
Chair: Herbert Faust, Institut Laue-Langevin
3:30 PM, Serot, O. *Fission Activities Around the Lohengrin Mass Spectrometer*
4:00 PM, Jain, A. *Conservation of Isospin in n-Rich Fission Fragments*
4:20 PM, Solders, A. *Accurate Fission Data for Nuclear Safety*
4:40 PM, Taieb, J. *Fission Fragments Yield Measurement in Reverse Kinematics at GSI, the SOFIA Experiment*
5:00 PM, Simutkin, V. *Experimental Neutron-Induced Fission Fragment Mass Yields of ^{232}Th and ^{238}U at Energies from 10 to 33 MeV*
5:15 PM, Dore, D. *FALSTAFF : a New Tool for Fission Fragment Characterization*
5:30 PM, Sage, C. *Measurements of the Mass and Isotopic Yields of the 233U(nth,f) Reaction at the Lohengrin Spectrometer*
5:45 PM, Arnold, C. *Precision Velocity Measurements of Fission Fragments Using the SPIDER Detector*[1]

Session PE Nuclear Physics Education
Room: Central Park East at 3:30 PM
Chair: Peggy Norris, Black Hills State University
3:30 PM, Cizewski, J. *The Stewardship Science Academic Alliance: A Model of Education for Fundamental and Applied Low-Energy Nuclear Science*
4:00 PM, Holden, N. *Educational Outreach Efforts at the NNDC*
4:20 PM, Barthelemy, R. *Recruitment and Retention of Students in the Nuclear Sciences: A Study of the Gender Gap Between Physics and Astronomy*
4:40 PM, Johnson, A. *Student Undifferentiated Views of Ionizing Radiation and Trouble With Atoms*
5:00 PM, Kriek, J. *Comparing Knowledge Based Views of Pre-Service Teachers with Experts on Nuclear Physics*
5:15 PM, Canella Avelar, A. *Harmonization of Curricula in Nuclear Education: Could One Fit for All?*

Session PF Cross Section Measurements
Room: Central Park West at 3:30 PM
Chair: Heikki Pentilla, University of Jyvaskyla
3:30 PM, Helariutta, K. *Study of Nuclear Reactions Between ^{235}U Target and Proton or ^{3}He Beam at Low Energies*
4:00 PM, Shigyo, N. *Measurement of 100- and 290-MeV/u Carbon Incident Neutron Production Cross Sections for Carbon, Nitrogen and Oxygen*
4:20 PM, Hermanne, A. *Deuteron Induced Reactions on Rare Earths: Experimental Excitation Functions and Comparison with Code Results*
4:40 PM, De Napoli, M. *Carbon Fragmentation Measurements and Validation of the Geant4 Nuclear Reaction Models for Hadrontherapy*
5:00 PM, Yang, S. *Measurement of Isomeric Yield Ratio for $^{nat}Sm(\gamma,xn)^{143m,g}Sm$ Reaction with Bremsstrahlung Energies*
5:15 PM, Vlastou-Zanni, R. *New Measurements of the $^{241}Am(n,2n)^{240}Am$ Cross Section*

5:30 PM, Khandaker, M. *Activation Cross Sections of Deuteron Induced Nuclear Reactions on Natural Titanium up to 24 MeV*
5:45 PM, Bevilacqua, R. *Double Differential Cross Sections for Light-Ion Production from C, O, Si, Fe and Bi Induced by 175 MeV Quasi-Monoenergetic Neutrons*

Friday, March 8, 2013

Session QA Plenary Friday
Room: Met East at 8:30 AM
Chair: Elizabeth McCutchan, NNDC - BNL
8:30 AM, Igashira, M. *A Nuclear Data Project on Neutron Capture Cross Sections of Long-Lived Fission Products and Minor Actinides*
9:15 AM, Plompen, A. *Minor Actinides, Major Challenges: The Need and Benefits of International Collaboration in Nuclear Data*

Session RA Nuclear Fission
Room: Met East at 10:30 AM
Chair: Ramona Vogt, ORNL
10:30 AM, Hambsch, F. *Fission Fragment Yield, Cross Section and Prompt Neutron and Gamma Emission Data from Actinide Isotopes*
11:00 AM, Carjan, N. *Dynamical Scission Model*
11:20 AM, Benlliure, J. *Investigating the Dynamics of Fission at High Excitation Energy in Reactions Induced by Relativistic Protons and Deuterons on Lead*

Session RB Benchmark and Testing
Room: Met West at 10:30 AM
Chair: Marie-Anne Descalle, LLNL
10:30 AM, White, M. *Seeking Reproducibility in Fast Critical Assembly Experiments*
11:00 AM, van der Marck, S. *Benchmarking TENDL-2012*
11:20 AM, Chiesa, D. *Bayesian statistical analysis applied to NAA data for neutron flux spectrum determination*
11:40 AM, Lomakov, G. *Verification of Current Version of ABBN Constants and CONSYST Code in Calculation of Criticality Benchmarks*

Session RC Nuclear Data Covariances
Room: Empire East at 10:30 AM
Chair: Robin Forrest, IAEA
10:30 AM, Williams, M. *Applications of Nuclear Data Covariances to Criticality Safety and Spent Fuel Characterization*
11:00 AM, Varet, S. *Pseudo-measure Simulations and Shrinkage for the Experimental Cross-Section Covariances Optimisation*
11:20 AM, Arbanas, G. *Inverse Sensitivity/Uncertainty Methods Development for Nuclear Fuel Cycle Applications*
11:40 AM, Holmes, J. *Generation of an $S(\alpha,\beta)$ Covariance Matrix by Monte Carlo Sampling of the Phonon Frequency Spectrum*

Session RE Nuclear Physics Education
Room: Central Park East at 10:30 AM

Chair: Andy Johnson, South Dakota Center for Math and Science
10:30 AM, Norris, M. *The Davis-Bahcall Scholars Program: Instilling the Qualities of STEM Leadership in the Youth of South Dakota*
11:00 AM, Wilcox, B. *Active Learning in Upper-Division Physics Courses*
11:20 AM, Feldman, G. *The Science of Nuclear Materials: A Modular, Laboratory-Based Curriculum*
11:40 AM, Neumann, S. *What Students Think About Nuclear Radiation - Before and After Fukushima*

Session RF Safeguards and Security
Room: Central Park West at 10:30 AM
Chair: Krzysztof Rykaczewski, ORNL
10:30 AM, Cormon, S. *Determination of the Sensitivity of the Antineutrino Probe for Reactor Core Monitoring*
11:00 AM, Schier, W. *Prototype Neutron Portal Monitor Detector*
11:20 AM, Kitatani, F. *Analysis of Pu Isotope in Melted Fuel by Neutron Resonance Transmission: Examination by Linear Absorption Model*
11:40 AM, Kim, Y. *Reactor Monitoring with a Short Baseline Neutrino Detector*

Closing Remarks
Room: Met East, 12 PM- 12:30 PM
Herman M. and A. Sonzogni A.

Book of Abstracts

Session AA Opening Talk and Plenary Monday
Monday March 4, 2013
Room: Met East at 8:30 AM
Chair: Roberto Capote, IAEA
AA 1 8:30 AM Opening Talk

CIELO, A Future Collaborative International Evaluated Library

M.B. Chadwick, T. Kawano
Los Alamos National Laboratory
M.W. Herman, B. Pritychenko, et al.
Brookhaven National Laboratory
E.Bauge
CEA/DIF, Bruyeres-le-Chatel, France
R. Capote, R. Forrest
IAEA, Vienna

This talk and paper presents considerations by the international community on the benefits to developing a worldwide evaluated nuclear database CIELO, which could be achieved through a collaborative effort comprised of subject matter experts from across the various evaluation projects. For over a year there has been discussion on this topic amongst leaders participating within the NEA/WPEC and IAEA nuclear data meetings. CIELO is envisaged as initially a collaborative effort amongst evaluators, eventually becoming the world's most accurate recommended nuclear reaction data resource, benefiting from the broad capabilities in different areas of nuclear reaction physics and computation across the world. To create such a capability will be a major challenge for the participating countries, requiring collaboration and peer review at an unprecedented level. The presentation will first summarize some of the main advantages behind this idea. These include: (1) A goal of a better, more accurate, product, as compared to the existing evaluated databases; (2)A database that benefits from the "peer review" coming from the engagement of specialized teams comprised of subject matter experts; (3) A way to pool resources in technical areas where countries may be loosing capabilities to retirement; (4) An endorsement of the concept that the evaluated data aim to reflect our best understanding of physical reality - there is only one correct answer! At the May 2012 WPEC meeting there was an agreement amongst participating projects to initiate a "pilot project", where various members from the evaluation projects will work in 2012, 2013 to identify the main areas of discrepancy amongst the existing evaluated databases (ENDF, JEFF, JENDL, BRONDL, CENDL, etc), and amongst the measured data, for a set of 20-30 key - most important - isotopes. In this talk and paper we will document our findings. This set of documented nuclear data discrepancies will highlight future collaborative work that will be needed to advance our understanding, and to facilitate the possibility of a future CIELO. Furthermore, the experience we have over the next 1-2 years will provide valuable lessons to guide development of a collaboration model - and governance model - for a future CIELO. To be specific, we will describe the current level of agreement/disagreement between fission (cross sections and prompt neutron spectra), inelastic and elastic scattering, capture, and (n,2n) reactions for certain key isotopes, that will include 235,238U, 239Pu, 56Fe, 16O, and 1H. We will highlight the origin of such differences: experimental data, model calculations, etc. And we will suggest how teams of subject matter experts could more rapidly advance our understanding of these cross sections and start to resolve discrepancies. We note that we expect the final author list for this paper will include all who contribute, include many from the ENDF, JEFF, JENDL, BROND, and CENDL, projects.

AA 2 9:15 AM

CARIBU: A New Facility for the Production and Study of Neutron-Rich Isotopes

G. Savard, S. Caldwell, J. Clark, D. Lascar, A. Levand, R. Pardo, J. Van Schelt, R. Vondrasek, B. Zabransky
Physics Division, Argonne National Laboratory

CARIBU, a new facility for the production, separation and post-acceleration of fission fragments, is now operational at Argonne National Laboratory's ATLAS superconducting linac accelerator facility. CARIBU utilizes a large high-intensity gas catcher to slow down and thermalize fission recoils from a 1 Ci 252Cf source and efficiently extract them as a low emittance 50 keV radioactive beam. That beam is then mass separated by a high-resolution magnetic isobar separator selecting a specific species that can then be either sent to a low-energy experimental area for decay and ground-state studies, or post-accelerated through ATLAS for in-beam studies. The CARIBU extraction principle is universal, over 70 different neutron-rich isotopes were separated and used for physics measurements in the first 6 months of operation, and the observed yield is independent of chemical properties so that all species populated by Californium fission are accessible. Program in mass measurements and decay spectroscopy are ongoing and a new ion-trap-based method for the detection of beta-delayed neutrons is being tested. The talk will present the CARIBU facility, its operating principles, the beams that have already been extracted, and the results obtained, particularly with respect to the large sample of new masses obtained for very neutron-rich isotopes. Capabilities and future measurements of interest to nuclear data will be highlighted. This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract number DE-AC02-06CH11357.

Session BA Neutron Cross Section Measurements
Monday March 4, 2013
Room: Met East at 10:30 AM
Chair: Frank Gunsing, CEA Saclay
BA 1 10:30 AM

The Prompt Fission Neutron Spectrum Measurement Program at LANSCE

R. C. Haight, H. Y. Lee, T. N. Taddeucci, J. M. O'Donnell, B. A. Perdue, N. Fotiades, M. Devlin, J. L. Ullmann, A. Laptev, T. Bredeweg, M. Jandel,R. O. Nelson, S. A. Wender, M. C. White
Los Alamos Neutron Science Center,
C. Y. Wu, E. Kwan, A. Chyzh, R. Henderson, J. Gostic
Lawrence Livermore National Laboratory

The prompt neutron spectrum from neutron-induced fission needs to be known in designing new fast reactors, predicting criticality for safety analyses, and developing techniques for global security application. A program to measure this spectrum for neutron-induced fission of ^{239}Pu is underway at the Los Alamos Neutron Science Center. The goal is to obtain data on the shape of the spectrum with 5% uncertainty over the emitted neutron energy range of 50 keV to 12 MeV with additional data below and above this range. The incident neutron energy range will be from 0.5 to 30 MeV. At present, the experimental data base of fission neutron spectra is very incomplete and has significant discrepancies [1]. Most of the data in present evaluated libraries are based on the approach of the Los Alamos Model [2]. The present program is intended to validate these models and to provide improved data for applications. Our approach is based on a double time-of-flight experiment where fission neutrons are detected by arrays of neutron detectors to increase the solid angle and also to investigate possible angular dependence of the fission neutrons. A new flight path at WNR/LANSCE has been constructed with a "get-lost" pit below the fission chamber. A

multi-foil Parallel Plate Avalanche Counter contains the ^{239}Pu and gives much better timing and much less neutron scattering than fission chambers used by us in the past. We are developing two arrays of neutron detectors, one based on liquid organic scintillators and the other on ^{6}Li-glass detectors. The range of fission neutrons detected by organic liquid scintillators extends from about 600 keV to well over 1 MeV, with the lower limit being defined by the limit of pulse-shape discrimination. The ^{6}Li-glass detectors have a range from very low energies to about 1 MeV, where their efficiency then becomes small. Waveform digitizers are used for data acquisition. The status of this program including results of initial experimental measurements will be presented. This work benefits from the LANSCE accelerator facility and is supported by the U.S. Department of Energy under contracts DE-AC52-06NA25396 (LANL) and DE-AC52-07NA27344 (LLNL). [1] P. Talou et al., Nucl. Sci. Eng. **166**, 254 (2010). [2] D. G. Madland and J. R. Nix, Nucl. Sci. Eng. 81, 213 (1982).

BA 2 11:00 AM

Neutron-Induced Gamma-Ray Reference Cross Section Measurements with GEANIE at LANSCE

R. O. Nelson, N. Fotiades, M. Devlin
LANSCE-NS, Los Alamos Neutron Science Center, Los Alamos, NM 87545

Accurate reference cross sections simplify accurate measurements by allowing relative measurements to be performed. Many of the experiment-related variables cancel in such relative measurements simplifying the analysis. Work on neutron-induced gamma-ray measurements at LANSCE convinced us that most gamma-ray reference cross sections were not accurate beyond the 5% level and often the uncertainties were much larger. In the past few years we have worked to improve the accuracy of some long-used gamma-ray cross sections, and to develop more reliable and more accurate reference cross sections. Through this work, we have improved the uncertainties on some cross sections and are now working to refine data for new reference cross sections that we expect will improve the accuracy obtained and ease of use. The Li(n,n'γ=478keV) and Ti(n,n'γ=984keV) partial gamma-ray cross sections together may provide reliable cross sections covering the neutron energy range, 1 MeV $<$ En $<$ 14 MeV. Several other candidates were examined in this search and found unacceptable for a variety of reasons. The rationale behind these choices will be discussed and the present status of the data will be described. This work benefits from the LANSCE accelerator facility and is supported by the U.S. Department of Energy under contract DE-AC52-06NA25396.
Presenting author: Matt Devlin

BA 3 11:40 AM

Cross Section Measurement of ^{237}Np(n,γ) at J-PARC/MLF/ANNRI

K. Hirose, K. Furutaka, K.Y. Hara, H. Harada, A. Kimura, T. Kin, F. Kitatani, M. Koizumi, S. Nakamura, M. Ohshima, Y. Toh
Japan Atomic Energ Agency
M. Igashira, T. Katabuchi, M. Mizumoto
Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology, Japan
T. Kamiyama, K. Kino, Y. Kiyanagi
Graduate School of Engineering, Hokkaido University, Japan
J. Hori
Research Reactor Institute, Kyoto University, Japan

The cross section of the ^{237}Np(n, γ) reaction has been measured in an energy range from 10 meV to 1 keV at the Japan Proton Accelerator Research Complex (J-PARC). The NaI(Tl) spectrometer installed in the accurate neutron-nucleus reaction measurement instrument (ANNRI) was used for the measurement. The relative cross section was obtained using the neutron spectrum measured by the ^{10}B(n, α_1) reaction. The absolute value of the cross section was deduced by normalizing the relative cross section to the evaluated value in JENDL-4.0 at the first resonance. In this presentation, the obtained results for the cross section, the Westcott factor and the resonance analysis are reported. This work was supported by JSPS KAKENHI Grant Number 22226016.

Session BB Integral Experiments
Monday March 4, 2013
Room: Met West at 10:30 AM
Chair: John Bess, INL
BB 1 10:30 AM

Integral Benchmark Data for Nuclear Data Testing Through the Icsbep and IRPhEP

J. Blair Briggs and John D. Bess
Idaho National Laboratory
Jim Gulliford
OECD Nuclear Energy Agency

The status of the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and International Reactor Physics Experiment Evaluation Project (IRPhEP) was last discussed directly with the nuclear data community at ND-2007. Since ND 2007, integral benchmark data that are available for nuclear data testing has increased significantly. The contents of the International Handbook of Evaluated Criticality Safety Benchmark Experiments have increased from 442 evaluations (38,000 pages) containing benchmark specifications for 3955 critical, subcritical, or k-infinity configurations to 550 evaluations (over 65,000 pages) containing benchmark specifications for over 4700 critical, subcritical, or k-infinity configurations. The number of criticality-alarm-placement / shielding evaluations has increased from 23 to 24 and fundamental physics evaluations from 20 to 24 in the 2012 edition of the ICSBEP Handbook. Approximately 15 new evaluations and 150 additional configurations are expected to be added to the 2013 edition of the Handbook. Since ND 2007, the contents of the International Handbook of Evaluated Reactor Physics Benchmark Experiments has increased from 16 different experimental series that were performed at 12 different reactor facilities to 68 experimental series that were performed at 36 reactor facilities. Significant additions of reactor physics measurement data have also been made to previously published evaluations. The status of the ICSBEP and the IRPhEP will be discussed, selected benchmark configurations that have been added to the ICSBEP and IRPhEP Handbooks since ND 2007 will be highlighted. A preview of the new benchmark evaluations that will appear in the September 2013 edition of the ICSBEP Handbook will also be provided. The future of both projects will be outlined.

BB 2 11:00 AM

Evaluation of Delayed Critical ORNL Unreflected HEU Metal Sphere

Margaret A. Marshall, John D. Bess
Idaho National laboratory
Thomas M. Murray
University of Utah

In 1971 and 1972 experimenters at the Oak Ridge Critical Experiment Facility performed critical experiments using an unreflected metal sphere of highly enriched uranium (HEU). The sphere used for the criticality experiments, originally used for neutron leakage spectrum measurements by General Atomic Company, consisted of three main parts and were assembled with a vertical assembly machine. Two configurations were tested. The first was nearly spherical with a nominal radius of 3.467 inches and had a reactivity of 73.1 ± 2.0 cents. The sphere parts were then re-machined as a sphere with a nominal radius of 3.4425 inches. This assembly had a reactivity of -23 cents. When 16 surface mass adjustment buttons were added the reactivity of the 3.4425-inch-nominal-radius sphere the reactivity was increased to 12.4 cents. The method, dimensions, and uncertainty of the critical experiment were extensively recorded and documented. The original purpose of the experiments was for comparison to GODIVA I experiments. The ORNL unreflected HEU Metal Spheres have been evaluated for inclusion in the International Handbook of Evaluated Criticality Safety Benchmark Experiments (expected to be in the September 2013 edition).
Presenting author: John D. Bess

BB 3 11:20 AM

Characterization of the CALIBAN and PROSPERO Critical Assemblies Neutron Spectrums for Integral Measurements Experiments

P. Casoli, N. Authier and X. Jacquet
Commissariat à l'Energie Atomique et aux Energies Alternatives, CEA, DAM, VALDUC, F-21120 Is sur Tille, France
J. Cartier
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CALIBAN and PROSPERO are two metallic critical assemblies managed by the Criticality, Neutron Science and Measurement Department located on the French CEA Research Center of Valduc. Both cores are made of highly enriched uranium alloys. PROSPERO core is surrounded by a depleted uranium reflector. Each reactor is composed of two cylindrical blocks which can be placed in contact and of four control rods which allow the reactor to be driven and to reach delayed criticality. CALIBAN and PROSPERO assemblies are suited for integral measurements in fission neutron spectrums: in particular, each reactor is fitted with a central cavity where small size samples can be irradiated. Several integral experiments have been carried out in the past or more recently on these facilities: fission yields evaluation of several actinides [1], reactivity worth measurements by the perturbation method for fissile isotopes or non fissile elements [2]... Accurate descriptions and models of the reactors, and particularly a CALIBAN benchmark published in the ICSBEP handbook [3], are available and allow sharp analyses of these experiments. However, to improve even further theses analyses, a higher knowledge of the neutron spectrums provided by the reactor is needed. That is why studies to characterize theses spectrums have been performed for many years and are still under progress. Several unfolding methods, based on activation foils measurements, have been recently developed and applied to characterize CALIBAN and PROSPERO neutron spectrums [4-5]: iterative perturbations, maximum entropy, Bayesian calibration, etc. In this article will be given a description of the CALIBAN and PROSPERO reactors and a short presentation of the integral experiments recently carried out on theses facilities. Then, unfolding methods used to characterize reactors neutron spectrums will be presented. Finally, results will be discussed and compared.
[1] P. Casoli et al, Measurements of Actinide-Fission Product Yields in Caliban and Prospero Metallic Core Reactor Fission-Neutron Fields, Journal of ASTM International, Vol. 9, No. 4, Paper ID JAI104018, 2012. [2] B. Richard, Reactivity Worth Measurements on Fast Burst reactor CALIBAN - Description and

Interpretation of Integral Experiments for the Validation of Nuclear Data, Proceedings of PHYSOR 2012, Knoxville (TN), USA, April 15-20, 2012. [3] N. Authier et al, Bare Highly Enriched Uranium Fast Burst Reactor CALIBAN, HEU-MET-FAST-080, International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA Nuclear Science Committee, 2007. [4] X. Jacquet et al, New Measurements and the Associated Unfolding Methodologies to Characterize the Caliban Pulsed Reactor Cavity Neutron Spectrum by the Foil Activation Method, Journal of ASTM International, Vol. 9, No. 3, Paper ID JAI104020, 2012. [5] J. Cartier et al, Bayesian Calibration of Reactor Cavity Neutron spectrum, to be published in the proceedings of M&C 2013, May 05-09, 2013.

BB 4 11:40 AM

Accurate Nuclear Data For Sustainable Nuclear Energy from the ANDES Project

Enrique M. Gonzalez-Romero

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, CIEMAT. Madrid (Spain), on behalf of the ANDES Euratom project.

The ANDES FP7-EURATOM project, Accurate Nuclear Data for nuclear Energy sustainability, intends to address the nuclear data needs associated to the new reactors and new fuel cycles supported by SNETP, in its strategic research agenda and in the ESNII proposal, taking into account the priority lists for nuclear data from NEA/OECD, FP6-EURATOM projects EUROTRANS-NUDATRA and CANDIDE. ANDES combines a reduced group of selected differential measurements, the improvement in uncertainties and covariance's within the evaluation process and the validation of present and new data libraries using integral experiments, to bring most critical nuclear data to the level of accuracies required by the new reactors and system promoted by ESNII and the SNETP. In addition, a specific work package will improve the prediction capabilities of high-energy transport codes for the design of ADS, developing better models and performing a few selected measurements. The research of ANDES is particularly relevant for P & T and other sustainability components of the fuel cycle because the involvement of isotopes, materials and concepts not widely included in present reactors and often lacking of required accuracy and operational experience. The progress and preliminary results of the project will be presented in this paper, including:

- Accurate new measurements of capture and other cross sections for minor actinides like ^{241}Am, major actinides like ^{238}U, fission cross sections of Pu and minor actinides, and for other inelastic cross sections,
- Recent developments on data evaluation tools, particularly to include uncertainty and covariance matrices, as well as updates of simulation tools to facilitate the regular use of these covariances in standard problems,
- Comparisons of new calculation tools, data and codes, with criticality and experimental reactor benchmarks as well as with dedicated integral experiments, and feedback to evaluators and measurement programs,
- Recent validation of high energy reaction models, new data from neutrons beyond 100 MeV and progress in the high energy reactions models for improving accuracy and extending the energy range of applicability.

Finally an outlook of the additional results expected by the end of the project will also be included.

Session BC Nuclear Reaction Models
Monday March 4, 2013
Room: Empire East at 10:30 AM
Chair: Helmut Leeb, Vienna TU
BC 1 10:30 AM

A Regional Coupled-channel Dispersive Optical Potential for Fe Isotopes

Weili Sun, *Institute of Applied Physics and Computational Mathematics, Beijing 100094, China.* Rui Li, *Graduate School, China Academy of Engineering Physics, Beijing, 100088, China.* E. Soukhovitskii, *Joint Institute for Power and Nuclear Research, 220109, Minsk, Belarus.* J. M. Quesada, *Universidad de Sevilla, Apartado Postal 1065, E-41080 Sevilla, Spain.* R. Capote, *NAPC-Nuclear Data Section, International Atomic Energy Agency, Vienna, A-1400, Austria.*

A regional Lane-consistent dispersive coupled-channel nucleon optical potential for Iron is suggested. Realistic saturated coupling for ^{54,56,58}Fe was built using soft-rotator nuclear wave functions with the nuclear Hamiltonian parameters adjusted to reproduce low-lying collective levels of these isotopes. All experimental optical data: neutron total, nucleon reaction cross sections and angular distributions for ^{54,56,58}Fe are described with reasonable accuracy up to 200 MeV incident energies. The E2 and E3 γ-transition probabilities between low-lying collective levels are also well reproduced. Moreover the potential described well the quasielastic (p,n) reaction with excitation of IAS states, proving that isovector potential terms are reliable to predict the right isotopic dependence of the potential. In general, good agreement between experimental data and calculation is achieved for both collective levels and nucleon interaction data, showing this suggested potential being self-consistent.

BC 2 11:00 AM

Exclusive Multiple Emission Cross Sections in the Hybrid Monte Carlo Pre-Equilibrium Model

B. V. Carlson, L. Brito, D. F. Mega
Instituto Tecnológico de Aeronáutica, São José dos Campos SP, Brazil
R. Capote
Nuclear Data Section, International Atomic Energy Agency, Vienna, Austria
M. Herman
National Nuclear Data Center, Brookhaven National Laboratory, Upton NY, USA
M. E. Rego
Instituto de Pesquisas Energéticas/CNEN, São Paulo SP, Brazil

Griffin's exciton model [1] of pre-equilibrium emission and Blann's hybrid model [2] have proven extremely successful in describing the energy dependence and, to a certain extent, the angular dependence of nucleon and composite particle emission in pre-equilibrium reactions. However, the conceptual basis of these models was called into question by Bisplinghoff already some time ago [3]. In response to Bisplinghoff, Blann proposed the hybrid Monte Carlo simulation model (HMS) [4], which uses only the densities of available states for creation and decay of single particle-hole pairs. An additional advantage of the HMS model compared to earlier ones is that it easily permits multiple emissions from the precompound nucleus. The model was later extended, in collaboration with Chadwick, to the double-differential HMS [5]. This extension is based on the Chadwick-Obložinský prescription for approximating the energy-angular distribution of available two-particle-one-hole states [6,7]. We have recently developed a Monte Carlo algorithm to calculate this distribution exactly [8]. The Monte Carlo decay algorithm used by Blann and Chadwick does not permit the calculation of exclusive cross sections because it does not take into account the relative rate of decay of the particle-hole pairs produced in the excitation process. We show how the algorithm can be easily modified to take these into account [9] and develop expressions that permit the calculation of total (precompound + compound) exclusive cross sections. Calculations within the exclusive double differential HMS model using either approximate or exact energy-angular distributions can be performed using the nuclear reaction model code EMPIRE-3.1 (Rivoli) [10].

[1] J. J. Griffin, Phys. Rev. Lett. **17** (1966) 57. [2] M. Blann, Phys. Rev. **21** (1968) 1357. [3] J. Bisplinghoff, Phys. Rev. C **33** (1986) 1569. [4] M. Blann, Phys. Rev. C **54** (1996) 1341. [5] M. Blann and M. B. Chadwick, Phys. Rev. C **57** (1998) 233. [6] M. B. Chadwick and P. Obložinský, Phys, Rev. C **46** (1992) 2028. [7] M. B. Chadwick and P. Obložinský, Phys, Rev. C **50** (1994) 2490. [8] B. V. Carlson and D. F. Mega, EPJ Web of Conferences **21**, 09001 (2012). [9] C. A. Soares Pompéia and B. V. Carlson, Phys. Rev. C **74** (2006) 054609. [10] M. Herman, R. Capote, M. Sin, A. Trkov, B. V. Carlson, P. Obložinský, C. Matoon, H. Wienke, S. Hoblit, Young-Sik Cho, V. Plujko, V. Zerkin, EMPIRE-3.1, available online at http://www.nndc.bnl.gov/empire/.

BC 3 11:20 AM

Cross Section Calculation of Deuteron-Induced Reactions Using Extended CCONE Code

Shinsuke Nakayama, Shouhei Araki, Yukinobu Watanabe
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In recent years, research and development of intensive accelerator-driven neutron sources lead to renewed interest in the study of deuteron-induced reactions.The neutron sources with deuteron-induced reactions on light nuclei (^{7}Li, ^{9}Be, ^{12}C, etc.) are proposed for various neutron beam applications such as irradiation testing of fusion reactor materials, boron neutron capture therapy (BNCT), and production of radioisotopes for medical use. Thus, comprehensive nuclear data of deuteron-induced reactions over the wide incident energy and target mass number ranges are necessary for accurate estimation of neutron yields and induced radioactivity in the engineering design of accelerator-driven neutron sources. In the case where experimental data are not available, theoretical model calculations play an important role in nuclear data evaluation. To meet the request, a comprehensive code for nuclear data evaluation, CCONE [1], is extended so that deuteron-induced reactions can be taken into account for energies up to 200 MeV. In the extension, we use the continuum discretized coupled-channels (CDCC) theory for elastic breakup reaction and the Glauber model for stripping reaction to continuum in order to investigate deuteron breakup processes over the wide target mass number [2]. In addition, a DWBA approach is also used for stripping reaction to bound states in the residual nucleus.Sequential particle emission from highly excited compound and residual nuclei is calculated using conventional statistical Hauser-Feshbach and exciton models. The extended CCONE has been applied to cross section calculations of (d,xn) and (d,xp) reactions[3,4,5]. Particularly a systematic trend of nucleon production is investigated by paying attention to the dependences of target mass number and deuteron incident energy. Moreover, activation cross sections for several structural materials, such as Fe, Ni, Cu, and so on, are calculated and compared with available experimental data to demonstrate the extended CCONE code.

[1] O. Iwamoto, "Development of a Comprehensive Code for Nuclear Data Evaluation, CCONE, and Validation Using Neutron-Induced Cross Sections for Uranium Isotopes", J. Nucl. Sci. Technol. **44 (5)**, 687 (2007). [2] T. Ye et al.,"Analysis of inclusive (*d,xp*) reactions on nuclei from ^{9}Be to ^{238}U at 100 MeV", Phys. Rev. C **84**, 054606 (2011). [3] J. R. Wu, C. C. Chang, and H. D. Holmgren, "Charged-particle spectra: 80 MeV deuterons on ^{27}Al and ^{58}Ni and 70 MeV deuterons on ^{90}Zr, ^{208}Pb, and ^{232}Th", Phys. Rev. C **19**, 370 - 390 (1979). [4] M. Ieiri et al., "Polarization transfer measurements for the (*d,px*) reaction at $E_d = 65$ MeV and the reaction mechanism for the protons in the continuum", Nucl. Phys. A **504**, 477 - 510 (1989). [5] D. Ridikas et al., "Inclusive proton production cross sections in (*d,xp*) reactions induced by 100 MeV deuterons", Phys. Rev. C **63**, 014610 (2000).

BC 4 11:40 AM

EMPIRE: A Reaction Model Code for Nuclear Astrophysics

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The nuclei heavier than Fe/Ni are mainly synthesized via neutron capture reactions. For the s-process, cross sections are normally measured via the activation and TOF technique. There have been experimental deterrents in precisely determining the peak (and/or measurements are over a restricted range) and data has been normalized using cross sections from evaluated libraries. Unlike the s-process, the r-process path lies far from stability and is a complex reaction path described by a huge network involving several thousand reactions (of importance in determining the upper end of the nucleosynthesis flow, the superheavy elements (SHE) require an accurate fission topology (i.e. fission barriers) [1]). The cross sections of ^{186,187,188}Os(n,γ), ^{64,68,70}Zn(n,γ), ^{197}Au(n,γ), ^{244}Cm(n,f), ^{232}Th(n,γ),(n,f) and ^{233}U(n,f) are calculated using EMPIRE [2] to show the versatility of the code in its good agreement to available data. The neutron deficient p-nuclei, shielded from neutron capture, are mainly synthesized by photodisintegration reactions. In the hot (T9 = 2-3) photon bath where they are produced, there is a reprocessing of initial s-seed [3] material. In the lab, it is often the capture reaction that is measured. Although the trends for the (nγ,) cross section curves are similar for the experimental and evaluated, deviations (in the resonance range) occur. The situation has traditionally been worse for the α-capture data. One possibility for the discrepancy could arise from the α-optical potential. In order to correctly model the abundances (such as p-process simulations which consider about 20,000 reactions), accurate cross sections are required for reaction rate calculations. The calculated cross sections and S-factors (whose treatment has been recently implemented into EMPIRE) for ^{102}Pd(p,γ) , ^{120}Te(α,n),(p,n),(p,γ), ^{130}Ba(α,γ),(α,n), ^{190}Pt(n,γ) (no S-factor) and ^{92}Mo[4](α,n) will be compared to available data.
[1] J. Erler et al., Phys. Rev. C 85, 025802 (2012) [2] M. Herman et al, Nucl. Data Sheets, 108 (2007) 2655-2715 [3] M. Wiescher, private communication, (2006) [4] C. Fr´ohlich et al., PRL 96, 142502 (2006).

Session BD Nuclear Structure and Decay
Monday March 4, 2013
Room: Empire West at 10:30 AM
Chair: Chris Gould, North Carolina SU
BD 1 10:30 AM

The Nuclear Shell Model and Nuclear Data

B. Alex Brown
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I will present an overview of results obtained with the configuration interaction (CI), shell-model, approach to nuclear structure. The talk will focus on which regions of the nuclear chart and what types of nuclear data can be considered. The present status of NuShellX@MSU will be shown. The NuShellX code was written by W. D. M. Rae (Garsington, England). NuShellX@MSU includes wrapper codes for model space and Hamiltonian inputs, and outputs that include graphical comparisons to data form the nuclear data base.

BD 2 11:00 AM

Precise Data on A=10 nuclei for Benchmarking Modern ab-initio Theories of Nuclear Structure

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A new generation of ab-initio calculations, based on realistic two- and three-body forces, is having a profound impact on our view of how nuclei work. They can address issues surrounding the topology of the mean field, the origin of effective forces (like the spin-orbit interaction and tensor forces) and the causes of cluster and pairing correlations. To improve the numerical methods, and the parameterization of 3-body forces, new precise data are needed. Measurements of mass and RMS radii probe the static properties of the wave functions, while electromagnetic transitions are very sensitive to the dynamics which drive mixing between configurations. Many of the states have not been studied since the 1960's and the measurements can be significantly improved, especially in driving down systematic uncertainties. We have made a series of precise (<3%) measurements of electromagnetic transitions in A=10 nuclei ^{10}C, ^{10}B and ^{10}Be using the Doppler Shift method carefully. Many interesting features can be reproduced including the strong α-clustering and configuration mixing. The isospin symmetry of the wave functions in this triplet can be tested. We will report on what we have learned and the challenges that lie in the future, both in experiment and in theory. This work was supported by the DOE Office of Nuclear Physics under Contracts No. DE-AC02-06CH11357 and No. DE-AC02-98CH10946, Grant No. DE-FG02-94-ER40834, and SciDAC Grant No. DE-FC02-07ER41457.

BD 3 11:20 AM

Cross-shell Excitations in Neutron-Rich s-d Shell Nuclei

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The nuclei ^{34}P and ^{31}Si have been studied following the fusion of ^{18}O with ^{18}O and detected with Gammasphere and the Microball, doubling the previously known experimental data. Of particular interest are the structures based on excitations outside the s-d shell. In ^{34}P only the ground state and first two excited

states have predominantly s-d structure. The next 16 excited states have negative parity involving at least one f-p shell neutron, while the long lifetimes of the top states suggest multiple f-p shell excitations. The slightly lower neutron excess of ^{31}Si leads to a more balanced number of positive- and negative-parity states observed. In both nuclei the energies of the negative-parity states were overpredicted by the WBP cross-shell interaction which was originally constructed for A 22. A reduction of the 0f7/2 and 1p3/2 single-particle energies adjusted to fit 32P (WBP-a)[1] led to good agreement with the negative-parity states in both ^{34}P and ^{31}Si. In fact the agreement is as good as for the pure s-d states. At this point the frontier in understanding lies with the 2-particle-2-hole states because calculations with the WBP-a interaction over-predict the 2p-2h states by 2 MeV. Since any further reduction in the single-particle energies for the f-p shell would spoil the good agreement with the 1p-1h states, a possible solution lies with the 2-body matrix elements. We are investigating whether some adjustment of the 2-body matrix elements could increase the correlation energy for 2p-2h structures to bring down their energies without affecting the 0p-0h and 1p-1h states. A better characterization of cross-shell interactions would improve the predicitability of shell model calculations for the very neutron-rich nuclei to be seen with FRIB.
[1] P.C. Bender, *et al.* Phys. Rev. C **85**, 044305 (2012).

BD 4 11:40 AM

New Model for *ab initio* Calculation of Atomic Radiations in Nuclear Decay

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Unstable atomic nuclei release excess energy through various radioactive decay processes by emitting particles (e.g. neutron, alpha, beta) or electromagnetic radiation (gamma-ray photons). Most of the applications of nuclear isotopes make use of the interactions of their radiations passing through material, which depend on the type (photons, neutral or charged particles) and the transferred energy. The ionizing radiation produced by radioisotopes goes beyond the alpha, beta and gamma radiation from the nuclear decay. A cascade of Auger electrons is often emitted in the atomic relaxation process following a nuclear event. This radiation is particularly important for medical applications [1]. Since the early 70s, when the use of Auger electrons for cancer therapy was first suggested (see the review by Howell [2]), considerable advances have been made in understanding the radiobiological effect of low energy electrons. On the other hand, a comparison of the calculated Auger yields for selected radioisotopes [3] has identified significant differences between the various computational models. These differences stem from differences in the physical assumptions of the models as well as differences in the adopted atomic transition rates and energies. In this paper we review the current knowledge on Auger emission rates in nuclear decay and present a new *ab initio* model which evaluates the transition energies and rates from first principles using the GRASP2k [4] and RATIP [5] codes. A full Monte Carlo approach was adopted to treat the stochastic nature of the creation of the primary atomic vacancies after nuclear decay, as well as for the subsequent propagation of vacancies. Our first numerical results on selected medical radioisotopes will be presented.
[1] A.L. Nichols, S.M. Qaim, R.C. Noy, *Summary Report Technical Meeting on Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data*, AEA Nuclear Data Section, INDC(NDS)-0596 (2011) [2] R.W. Howell, Journal of Radiation Biology, **84**, 959 (2008) [3] B.Q. Lee, T. Kibédi, A.E. Stuchbery, K.A. Robertson, Computational and Mathematical Methods in Medicine (2012), in press, doi:10.1155/2012/651475 [4] P. Jönsson, X. He, C. Froese Fischer, I. P. Grant, Computer Physics Communications **177**, 597 (2007) [5] S. Fritzsche, Computer Physics Communications **183**, 1525 (2012)

Session BE Evaluated Nuclear Data Libraries
Monday March 4, 2013
Room: Central Park East at 10:30 AM
Chair: David Brown, NNDC - BNL
BE 1 10:30 AM

Status of the JEFF File Project

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The latest developments of the Joint Evaluated Fission and Fusion file project (JEFF) are presented. The focus is on the preparation of the JEFF-3.2 neutron library, which is to be released in 2013. We outline the motivations and guiding principles for updating the current JEFF-3.1 evaluations, in connection with various users' needs and applications. We describe the preparation process, which began with the assembly of a first test file in 2011. The latest version of this (general purpose) test file contains well over 100 new or updated evaluations, including the following nuclides: ^{235}U, ^{238}U, ^{237}Np, ^{239}Pu, ^{240}Pu, ^{231}Am; and isotopes of Na, Fe, Cr, Mn, Ta, W, Hf, Gd. These updates consolidate the progress made in nuclear measurements, models, and codes, as well as trends derived from many validation studies. This represents a multi-year effort by many groups, especially the work on the actinides, as the files have been updated in the resolved resonance, unresolved resonance, and higher energy regions. Improvements also include more gamma production data and the inclusion of recent evaluations from the TENDL library which replace missing or outdated evaluations. An important development is the production of covariance data for the JEFF-3.2 general purpose file. These contributions build upon the R & D investment made over the past ten years by different organizations, for the consistent and systematic assessment of errors, with the objective of including uncertainty information in evaluated files. Special purpose files, including proton- and deuteron-induced data, fission product yield and radioactive decay data, are also in the process of being updated, as well as activation data. Results of preliminary tests are discussed. These changes are expected to yield improved results for fission and fusion applications, while preserving the satisfactory LWR performance achieved with the JEFF-3.1 libraries. Longer-term plans are briefly outlined.

BE 2 11:00 AM

Improvements and Extensions of the Nuclear Data Standards

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In an effort to maintain the quality of the neutron cross section standards, an IAEA Data Development Project was initiated to provide a mechanism for allowing new experimental data and improvements in evaluation procedure to be used in new evaluations of the neutron standards. This Project has broadened its range of activities beyond that of the traditional activities related to the cross section standards by including work on extending the energy ranges of the standards and also "reference data" that are not so widely used as the standards but can be very useful in the measurements of certain types of cross sections. Ongoing work in this Project has included the following activities: an update of the experimental data to be used in cross section standards evaluations, testing of the uncertainties obtained in the international standards evaluation, a study of different smoothing procedures for standards, improvements in the gold capture cross section at energies below where it is considered a standard but is used in capture cross section measurements for astrophysical applications, work on reference prompt gamma-ray production cross sections for fast neutron-induced reactions, and combining measurements of the ^{235}U thermal neutron fission spectrum with the evaluation of the ^{252}Cf spontaneous fission neutron spectrum with the aim of deriving an improved ^{235}U thermal neutron fission spectrum. The work done in each of the activities in this project will be discussed.

BE 3 11:20 AM

New Evaluation of n+^{63,65}Cu Nuclear Cross Section Data up to 200 MeV Neutron Energy

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Vladimir Sobes, Luiz Leal
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New high energy neutron cross section data have been evaluated for the stable copper isotopes ^{63,65}Cu in the energy range from 1-10^{-11} up to 200 MeV. The new evaluation provides a complete and consistent set of reaction data as required for the nuclear analyses of existing and planned facilities including various transport, heating, shielding and radiation damage calculations. An automated procedure developed at KIT for nuclear data evaluations makes use of nuclear model results and different experimental data, including differential and relevant integral ones. The TALYS-1.4 computer code is used to generate a full set of nuclear reaction data for neutron energies from 0.001 to 200 MeV. TALYS includes many nuclear reaction models that increase it flexibility and enables high quality model calculations starting from keV to intermediate and high neutron energies. The statistical Hauser-Feshbach theory is applied for the compound nuclear reactions and the two-component exciton model is used for the description of the pre-equilibrium reactions. The nuclear level densities are calculated within generalized superfluid model. The optical model calculations are performed with ECIS-06 code implemented in TALYS making use of default optical model potentials (OMPs) for neutrons and protons, external OMPs for deuterons and alphas and newly developed OMPs for tritons and helions. New resonance parameters evaluations for n+^{63,65}Cu including covariance data were done with the SAMMY code. This evaluation is based on the new measurements performed at GELINA on enriched isotopic copper samples for the capture cross sections and on old measurements preformed at the Oak Ridge Electron Linear Accelerator (ORELA) on highly enriched isotopic copper samples for the neutron transmission. The reaction cross sections obtained with TALYS calculations were compared against available experimental data. Validated reaction cross-section data from the European Activation File (EAF-2010) were adopted as far as suitable for the evaluation in the neutron energy range below 20 MeV. The Kalbach systematics was used for the description of the

angular distributions in the continuum double-differential particle emission spectra. The new evaluations provide covariance matrices for all reaction cross sections up to 200 MeV to enable uncertainty analyses with the data files. This covariance data are based on the nuclear model results in combination with relevant experimental data using the Unified Monte Carlo Approach as implemented in the BEKED computer code of KIT. General purpose data files for n+^{63,65}Cu for neutron energies from 1-10^{-11} to 200 MeV were generated in accordance with ENDF-6 format rules. The data files were checked with the standard ENDF checker utilities and processed with NJOY/ACER for calculations with the MCNP code. Intensive benchmarking of the files was then performed by analyses of integral experiments as available in the SINBAD data base. These data files, produced in the frame of the European fusion program, finally will be made available for inclusion in the JEFF nuclear data library. This work has been supported by Fusion for Energy (F4E), Barcelona, under the grant contract F4E-FPA-168-01.

BE 4 11:40 AM

Evaluation of Tungsten Neutron Cross Sections in the Resolved Resonance Region[1]

M. T. Pigni, L. C. Leal, M. E. Dunn, K. H. Guber

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Following the series of recent measurements on tungsten isotopes performed at the GEel LINear Accelerator (GELINA) by Lampoudis et al. [1] and the work presented at the PHYSOR 2012 conference in Knoxville, Tennessee [2], the aim of this paper is to present resonance evaluations for total and capture cross sections on ^{182,183,184,186}W in the neutron energy range of thermal energy up to several keV. The Bayesian fitting method implemented in the *R*-matrix SAMMY code [3] was used to generate a comprehensive, albeit still preliminary, set of neutron resonance parameters with related correlations and cross-section covariance data. In the analyzed energy range, this work almost doubles the Resolved Resonance Region (RRR) present in the latest US nuclear data library, ENDF/B-VII.1 [4]. Experimental conditions such as resolution function, finite size sample, nonuniform thickness, and nuclide abundances of sample, multiple scattering, self-shielding, normalization, background, and Doppler broadening were taken into account. In thermal energy range, we utilized the recently published Atlas of Neutron Resonances [5] as well as the tabulated neutron scattering lengths [6] as a source of information on scattering and capture cross sections, and resonance integral. In view of the interest in tungsten metal for several distinct types of nuclear applications, the emphasis of this paper is also on the performance of the calculated cross sections in criticality benchmarks. In the current ENDF/B-VII.1 nuclear data library, the tungsten isotope evaluations performed by Trkov et al. [7] were tested on the base of benchmark models taken from the SINBAD [8] and the ICSBEP [9] compilation. We intend to repeat the analysis for a number of benchmarks involving neutron flux in the intermediate energy range and, therefore, sensitive to the updated and extended resonance evaluations for ^{182,183,184,186}W. [1] Notice: This abstract has been authored by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The U.S. Department of Energy Nuclear Criticality Safety Program sponsored the work that is presented in this paper.

[1] C. Lampoudis et al., "Neutron Total and Capture Cross Section of Tungsten Isotopes," ND2010: International Conference on Nuclear Data for Science and Technology, Jeju Island, Korea (2010). [2] M. T. Pigni et al.,"^{183}W Resonance Parameter Evaluation in the Neutron Energy Range up to 5 keV," PHYSOR 2012

Advances in Reactor Physics Linking Research, Industry, and Education, Knoxville, TN, April 15 20, 2012. [3] N. M. Larson, *Updated Users' Guide for SAMMY: Multilevel R-Matrix Fits to Neutron Data Using Bayes' Equations*, Report ENDF-364 and ORNL/TM-9179/R6, Oak Ridge National Laboratory, Oak Ridge, TN (May 2003). Also report ORNL/TM-9179/R7 (2006). [4] M. B. Chadwick et al., "ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data," *Nuclear Data Sheets*, **112**, 2887 (2011). [5] S. F. Mughabghab, *Atlas of Neutron Resonances: Thermal Cross Sections and Resonance Parameters*, Elsevier Publisher, Amsterdam (2006). [6] Neutron Scattering Lengths found at http://www.ati.ac.at/~neutropt/scattering/table.html. [7] A. Trkov et al., "Covariances of Evaluated Nuclear Cross Section Data for ^{232}Th, ^{180,182,183,184,186}W and ^{55}Mn," *Nuclear Data Sheets*, **112**, 3098 (2011). [8] P. Batistoni et al., "Neutronics Benchmark Experiment on Tungsten," *J. Nucl. Materials*, **329 333**, 683 (2004). [9] ICSBEP 2006, *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, Technical Report NEA/NSC/DOC(95)03, NEA Nuclear Science Committee, Nuclear Energy Agency, OECD 2006, Paris, France.

Session CA Neutron Resonances
Monday March 4, 2013
Room: Met East at 1:30 PM
Chair: Boris Pritychenko, NNDC - BNL
CA 1 1:30 PM

Evaluation of Neutron Resonance Cross Section Data at GELINA

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Over the last decade, the EC - JRC - IRMM, in collaboration with other institutes such as INRNE Sofia, INFN Bologna, IPPE Obninsk and ORNL, has made an intense effort to improve the quality of neutron-induced cross section data in the resonance region. These improvements relate to both the infrastructure of the facility and the measurement, data reduction and analysis procedures. As a result total and reaction cross section data in the resonance region with uncertainties better than 0.5% and 2%, respectively, can be produced together with evaluated data files for both the resolved and unresolved resonance region. A special format has been developed to provide the experimental data with full covariance information. The format is very convenient to account for all uncertainty components whilst avoiding bias effects when model parameters are determined by least squares adjustment of experimental data. The methodology to produce full ENDF compatible files, including covariances, will be illustrated by the production of resolved resonance parameter files for Cd and W and an evaluation for ^{197}Au in the unresolved resonance region. The latter, which is part of a project to improve the ^{197}Au(n,γ) cross section standard, will be explained in detail, starting from the data reduction up to a parameterization of averaged cross section data based on the R-matrix formalism combined with level statistical model distributions.

CA 2 2:00 PM

^{239}Pu Resonance Evaluation for Thermal Benchmark System Calculations

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Analyses of thermal plutonium solution critical benchmark systems have indicated a deficiency in the 239Pu resonance evaluation. To investigate possible solutions to this issue, the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) Working Party for Evaluation Cooperation (WPEC) established Subgroup 34 to focus on the reevaluation of the 239Pu resolved resonance parameters. In addition, the impacts of the prompt neutron multiplication (nubar) and the prompt neutron fission spectrum (PFNS) have been investigated. The objective of this paper is to present the results of the 239Pu reevaluation effort. In the 1980s and early 1990s, Derrien et al. [1] performed a 239Pu evaluation in a collaborative work, including CEA and ORNL. At that time, due to computer limitations for data storage and processing, a decision was made to split the resonance region in three parts, namely, 10-5 eV to 1 keV, 1 keV to 2 keV, and 2 keV to 2.5 keV. The evaluation was accepted for inclusion in the ENDF and JEFF nuclear data libraries and is still included in the latest releases of ENDF, the ENDF/B-VII.1, and the JEFF-3.1 libraries. While the evaluation was performed based on high-resolution data, mainly transmission data [2] measurements taken at the Oak Ridge Electron Linear Accelerator (ORELA) at ORNL, no benchmark testing was done at the time the evaluation was released. Later, benchmark calculations indicated deficiencies in the 239Pu evaluation in reproducing integral results. Additional issues with the previous evaluation can be attributed to the use of three distinct sets of resonance parameters. Specifically, the cross sections calculated at the energy boundary of two consecutive, disjoint resonance parameter sets could be different, leading to a discontinuity. Another concern relates to data uncertainty assessments using resonance parameter covariance data. For data uncertainty analyses, the use of a single resonance parameter set covering the entire energy region is preferable because the disjoint set of resonance parameters does not permit the determination of uncertainty correlations in the entire energy region. Hence, the decision was made to combine the three sets of resonance parameters and redo the evaluation. The task of generating a single resolved resonance region was achieved because computer resources have improved substantially since the previous 239Pu evaluation effort. As a result, a resonance parameter evaluation was completed at ORNL in 2008 by Derrien, and this 239Pu evaluation covers the energy range 10-5 eV to 2.5 keV [3]; however, the evaluation was unable to improve benchmark results and was not proposed for inclusion in either the ENDF or JEFF project. At about the same time as the work was being performed at ORNL, Bernard et al. [4] at CEA/Cadarache performed a reevaluation of the 239Pu resonance parameters and nubar. Since the resonance evaluation for the whole energy region was not available, the work performed by Bernard was based on the JEFF-3.1 evaluation (i.e., with the three disjoint sets of resonance parameters). Bernard's 239Pu evaluation improved the results of benchmark calculations; however, the evaluation did not provide resonance parameter covariance data. By building upon the previous 239Pu evaluation work efforts, WPEC Subgroup 34 has been able to produce a new 239Pu evaluation that provides improved benchmark performance for thermal plutonium solution systems. The final paper will describe the procedure used in reevaluating the 239Pu resonance parameters. The computer code SAMMY was used in the analysis of the differential data. The resonance parameters of Reference [3], covering the energy region 10-5 eV to 2.5 keV, were used in the evaluation. The performance of the new evaluation in benchmark calculations will be presented.

The U.S. Department of Energy Nuclear Criticality Safety Program and the OECD/NEA data bank

sponsored the work presented in this paper.
[1] H. Derrien, G. De Saussure, and R. B. Perez, Nucl. Sci. Eng. 106, 434, 1990; H. Derrien, J. Nucl. Sci. Technol. 30, 845, 1993. [2] J. A. Harvey et al., Proc. International Conference on Nuclear Data for Science and Technology, Mito, Japan, May 30-June 3, 1988. [3] H. Derrien, L. C. Leal, and N. M. Larson, Neutron Resonance Parameters and Covariance Matrix of 239Pu, ORNL/TM-2008/123, Oak Ridge National Laboratory, Oak Ridge, Tenn., September 2008. [4] D. Bernard et al., "239Pu Nuclear Data Improvements in Thermal and Epithermal Neutron Ranges," Proc. International Conference on Nuclear Data for Science and Technololgy, Nice, France April 22-27, 2007.

CA 3 2:20 PM

Recent Investigations and Findings about the 2d- and 3d-Neutron Strength Functions

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These comprehensive detailed investigations were recently undertaken because of the scarcity of available data on neutron d-wave strength functions and the desire to obtain much-needed precise quantities. This information is obtained by the least-squares method by fitting total cross section measurements in the keV to 3 MeV neutron energy region, which is expressed in terms of the scattering radius, R', the s-, p-, d-, f-wave neutron strength functions, neutron penetrabilities and phase shifts. The present results for the average resonance parameters reveal the following findings:

- The 2d peak is observed for the first time at mass number, A = 51.
- Due to nuclear deformation effects, the 3d peak is depressed producing two maxima, located at A = 152 and 170, with similarity to the s-wave case [1].
- Except for the deformed region, the results of spherical optical model calculations for the d-wave strength functions well describe the present data for A = 48 - 200.
- The derived R', s- and p-wave neutron strength functions are in very good agreement with those derived from the resolved energy region [1].
- However, the d-wave strength functions are generally discrepant with available data compiled in [1].
- Quite a few d-wave data are derived here for the first time.
- A comparison with the very few d-wave data, obtained from the resolved resonances, showed good agreement.

The methodology and its application to optical model calculations and generation of covariance quantities with the aid of this model will be discussed. Several examples of least-squares fits to the available data will be presented and the systematics of the d-wave strength functions will be graphically displayed. In addition, an explanation for the discrepancies with previous data, which were derived from capture and total cross section measurements, will be given.
[1] S.F. Mughabghab, Atlas of Neutron Resonances, Elsevier (Holland), 2006.

CA 4 2:40 PM

Averaging the Neutron Cross Sections in the Unresolved Resonance Region

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The improvement of the theoretical methods for evaluation of modern and most accurate neutron resonance data in the URR is targeted to better description of the resonance structure in this energy region. Existence of the resonant cross sections structure in the URR is proved with different values of the measured transmission function through a various sample thickness and those calculated with the evaluated average resonance parameters. In addition the transmission data measured with thick sample filters give main information for the contribution of s-, p- and d-wave in the average cross sections and supply sufficient information for the potential scattering cross section (effective scattering radius). A statistical model based on Wigner's R-matrix theory, developed and applied for calculation and analysis of experimental data (average cross sections and their functional) in this energy region is used [1,2]. Its main advantage is that it offers an analytical solution even for nonlinear functional (observables) of the cross sections, such as transmission and self-indication ratios and the capability of accounting for the resonance effects in a real reactor medium. The energy-dependent neutron cross sections computed by average resonance parameters from ENDF show a typical intermediate structure that corresponds to a transition from an existing resonance cross section structure, but smoothed because of the wide experimental resolution into a flat cross section. The effect of the neutron strength functions fluctuations on the total and capture cross sections values has been investigated. The impact of the energy fluctuating s-strength function [1] on reaction rate, self-shielding factor for total and transport cross section, and especially their temperature dependence, had been evaluated. Analysing neutron absorption data performed on a sample with a finite thickness in the URR it is necessary to account for a reduction of the incident neutron flux due to the neutron scattering and (or) absorption in the target. A new procedure for accounting of the self-shielding and multiple scattering corrections in measured neutron absorption yield was proposed in the region of unresolved resonances. Model of the periodical resonant cross sections structure is the basis on the computational procedure. It is important here to stress on the lack of experimental data for the structure characteristics of average cross sections and the search of interference minima in the experiments with relatively thick targets with the beam attenuation of 100 to 1000 times. From thick sample measurements can be obtained - measured values of the averaged cross sections, average transmission and self-indication functions at an arbitrary thickness n, as well as the integrals over sample thickness n that are related to self-shielding factors. The extremely high neutron flux at spallation neutron sources enable new, up to now impossible, experiments in neutron physics. In nuclear data field the transmission and self-indication measurements with thick sample and sufficient attenuation of neutron beam could result in top quality measured values of resonance neutron cross sections modified by self-shielding neutron spectrum.

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[1] N Koyumdjieva, N Janeva, A.A. Lukyanov, J. Phys. G: Nucl. Part. Phys. 37 (2010) 075101 [2] N Koyumdjieva, N Janeva, Progress in Nuclear Energy, 54 (2012), pp. 171-176

Session CB Integral Experiments
Monday March 4, 2013
Room: Met West at 1:30 PM
Chair: Russell Mosteller
CB 1 1:30 PM

Progress of Integral Experiments in Benchmark Fission Assemblies for Blanket of Hybrid Reactor

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In the conceptual design of the blanket in a fusion-fission hybrid reactor for energy production, the sub-critical blanket consists of natural uranium and light water. To validate nuclear data and code of neutronics calculation for the blanket design, integral neutronics experiments in three sets of benchmark fission assemblies simulating the blanket have being performed. The spherical assemblies consist of three layers of depleted uranium shells and some layers of polyethylene shells, separately. Between each shell is a layer of polyethylene. A D-T fusion neutron source is centered of an assembly. In the assemblies, the plutonium production rates are measured by depleted uranium foils and an HPGe gamma spectrometer. The uranium fission rates are measured by a depleted uranium fission chamber. The leakage neutron spectra from the assemblies are measured by a liquid scintillation detector. The experimental results among three assemblies are compared and discussed. The experimental uncertainties in all the results are analyzed. The measured results are compared to the calculated ones with MCNP code and ENDF/B-VI library data.

CB 2 2:00 PM

Three Heavy Reflector Experiments in the IPEN/MB-01 Reactor: Stainless Steel, Carbon Steel, and Nickel.

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The heavy reflector experiments performed in the IPEN/MB-01 research reactor facility comprise a set of critical configurations employing the standard 28x26-fuel-rod configuration. The heavy reflector either Stainless Steel, Carbon Steel or Nickel plates was placed at one of the faces of the IPEN/MB-01 reactor. Criticality is achieved by inserting the control banks BC1 and BC2 to the critical position. 32 plates around 0.3 mm thick were used in all the experiment. The chosen distance between last fuel rod row and the first laminate for all types of laminates was 5.5 mm. Considering initially the SS case, the experimental data reveal that the reactivity decreases up to the sixth plate and after that it increases, becomes nearly zero (which was equivalent to initial zero excess reactivity with zero plates) for the 21 plates case and reaches a value of 154.91 pcm when the whole set of 32 plates are inserted in the reflector. This is a very striking result because it demonstrates that when all 32 plates are inserted in the reflector there is a net gain of reactivity. The reactivity behavior demonstrates all the physics events already mentioned in this work. When the number of plates are small (around 6), the neutron absorption in the plates is more important than the neutron reflection and the reactivity decreases. This condition holds up to a point where the neutron reflection becomes more important than the neutron absorption in the plates and the reactivity increases. The experimental data for the Carbon Steel and Nickel case shows the main features of the SS case, but for the Carbon Steel case the reactivity gain is small, thus demonstrating that Carbon Steel or essentially iron has not the reflector capability as the SS laminates do. The measured data of Nickel plates show a higher reactivity gain, thus demonstrating that Nickel is a better reflector than Iron and Stainless Steel. The theoretical analysis employing MCNP5 and ENDF/B-VII.0 show that the SS calculated results are in a good agreement to the experimental results. Contrary to that Carbon Steel and Nickel results show good results up to fifteen plates and after that a systematic overprediction. The calculated results suggesting Chromium is somehow compensating the results of Iron and Nickel.

CB 3 2:20 PM

Analytics of the Radionuclide Inventory Produced in Lead Targets by Proton Irradiation

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At Paul Scherrer Institut (*PSI*) a proton accelerator is driving a 1 MW class research spallation neutron source, *SINQ*. In this facility the proton beam with energy of 560 MeV and a beam current of 1.5 mA is fully stopped in a bulk target consisting about 350 steel- or zircaloy-clad-lead rods. After an irradiation period of about two years, large amounts of radionuclides are produced. In order to evaluate the risks and safety-relevant aspects concerning the operation, decommissioning and disposal of the highly activated targets, the precise knowledge of the radionuclide inventory is of essential importance. Special attention will be drawn to α-emitting and long-lived isotopes. Moreover, samples from these targets can serve as sources for extraction of very rare isotopes, needed for scientific experiments in nuclear astrophysics and basic nuclear physics e.g. ^{148}Gd, ^{146}Sm and ^{154}Dy [1]. Due to the complexity of the involved nuclear reactions, theoretical predictions of the radionuclide inventory are difficult and require benchmarking to improve the models and calculation codes. Within the *EC*-funded projects *HINDAS* [2] and *EUROTRANS (WP NUDATRA)* [3] essential progresses could be achieved concerning the development of codes and models, especially *TALYS* and *INCL4/ABLA*, to get reliable nuclear data, in particular for the target materials such as lead and bismuth. Experimental data from integral experiments for verification are urgently needed. The here reported work is aimed to figure out an extensive chemical separation procedure to determine quantitatively the target's nuclide inventory and its radial and depth distribution. Due to the varying proton fluxes at different positions in the target, a strong correlation to the production rates of radioisotopes is expected. As a first step, a detailed gamma-analysis of multiple samples of positions with different distances to the beam centre was carried out. After the dissolution in nitric acid, chemical separation procedures for α- and long-lived β-emitting isotopes, e.g. $^{208/209/210}$Po, ^{129}I and ^{36}Cl, were applied. First results will be presented. The project is funded by the Swiss National Science Foundation (*SNSF*).

[1] D. Schumann, J. Neuhausen, J. Phys. G, 35 (2008) 014046. [2] Hindas Final Report, FIS5-00150. [3] Report of the Numerical results from the Evaluation of the nuclear data sensitivities, FP-7 IP-EUROTRANS.

CB 4 2:40 PM

Online Production and Release Rates of Volatile Isotopes in a Pb/Bi Target Irradiated at ISOLDE and Post-Irradiation Analysis

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For liquid metal spallation neutron targets it is crucial to know the composition and amount of volatile radionuclides that are released from the target during operation. It is also important to know the total amount produced, which can be possibly released in case of accident. One notable case is for Pb/Bi targets (LBE) where different radionuclides can be produced, notably noble gases (Ar, Kr, Xe isotopes), and other

volatile isotopes such as Cd, Br, I, Hg, and Po. We reported previously on the results of an irradiation experiment performed at ISOLDE on an LBE target [1]. The results were compared with predictions from the latest versions of the FLUKA and MCNPX codes using different options for the intra-nuclear cascades and evaporation/fission models. Subsequently, the irradiated target was transported to PSI and examined. Investigations of both the tantalum target structure, and in particular the beam window, and of the lead-bismuth eutectic, were performed using several experimental techniques. Concerning the lead-bismuth, mass spectrometry analysis indicated that the amount of noble gases is at the level of 0.1% of the generated amount, in agreement with the expectations. The polonium content was measured with alpha spectroscopy and results in good agreement with Monte Carlo calculations. In this paper we present the final results from the different measurements, and discuss implications for spallation target design in light of the strong interest in this material for Accelerator Driven Systems and for the European Spallation Source.
[1] Y. Tall *et al.*, Volatile elements production rates in a proton-irradiated molten lead-bismuth target, Proceedings of the International Conference on Nuclear Data for Science and Technology, April 22-27, Nice, France, 2007.

Session CC Nuclear Reaction Models
Monday March 4, 2013
Room: Empire East at 1:30 PM
Chair: Toshihiko Kawano, LANL
CC 1 1:30 PM

From Nuclear Physics to Nuclear Systems: New Possibilities with TALYS

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A revolutionary nuclear data system is presented which connects basic experimental and theoretical nuclear data to a large variety of nuclear applications. This software system, built around the TALYS nuclear model code, has several important outlets:

- The TENDL nuclear data library: complete isotopic data files for 2430 nuclides for incident gamma's, neutrons and charged particles up to 200 MeV, including covariance data, in ENDF and various processed data formats. In 2013, TENDL has reached a quality nearing, equalling and even passing that of the major data libraries in the world. It is based on reproductibility and is built from the best possible data from any source.

- Total Monte Carlo: an exact way to propagate uncertainties from nuclear data to integral systems, by employing random nuclear data libraries and transport, reactor and other integral calculations in one large loop. For example, the entire ICSBEP database can now be predicted including uncertainty estimates.

- Automatic optimization of nuclear data to differential and integral data simultaneously by combining the two features mentioned above, and a combination of Monte Carlo and sensitivity analysis.

Both the differential quality, through theoretical-experimental comparison of cross sections, and the integral performance of the entire system will be demonstrated. The impact of the latest theoretical modeling additions to TALYS on differential nuclear data prediction will be outlined, while integral validation will be presented for criticality benchmarks, safety-related (Doppler and void) coefficients, burnup, radiotoxicity, 14 MeV structural material shielding for fusion, and proton-induced medical isotope production. Comparisons with the major world libraries will be shown. The effect of various uncertainty methods on the results will be discussed. Since the system is designed with a high level of QA and reproducibility and at the same time is based on high quality experimental and theoretical nuclear physics, we expect that the features mentioned above will soon play an important role in the analysis of any nuclear application.

CC 2 2:00 PM

Improved Nuclear Inputs for Nuclear Model Codes Based on the Gogny Interaction

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The need for cross sections far from the valley of stability, for applications such as nuclear astrophysics or future nuclear facilities, challenges the robustness as well as the predictive power of nuclear reaction models. Traditionally, cross section predictions rely on more or less phenomenological approaches, depending on parameters adjusted to generally scarce experimental data or deduced for systematic relations. While such predictions are expected to be reliable for nuclei not too far from the experimentally accessible regions, they are clearly questionable when dealing with exotic nuclei. To improve the predictive power of nuclear model codes, one should use more fundamental approaches, relying on sound physical bases, when determining the nuclear inputs (ingredients) required by the nuclear models. Thanks to the high computer power available today, all these major ingredients have been microscopically or semi-microscopically determined, starting from the information provided by a Skyrme effective (and efficient) nucleon-nucleon interaction. These microscopic inputs have shown their ability to compete with the traditional methods as such, but also when they are used in actual nuclear cross sections calculations. We will discuss the current efforts made to improve the predictive power of such microscopic inputs using a more coherent nucleon-nucleon interaction, namely the finite range Gogny force.
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CC 3 2:20 PM

Improved Simulation of the Pre-Equilibrium Triton Emission in Nuclear Reactions Induced by Nucleons

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A new approach is proposed for the calculation of non-equilibrium triton energy distributions in nuclear reactions induced by nucleons of intermediate energies. It combines models describing the nucleon pick-up, the coalescence and the triton knock-out processes. Emission and absorption rates for excited particles are represented by the pre-equilibrium hybrid model. The model of Sato, Iwamoto, Harada is used to

describe the nucleon pick-up and the coalescence of nucleons from exciton configurations starting from (2p,1h) states. The model of triton knock-out is formulated taking into account the Pauli principle for the nucleon-triton interaction inside a nucleus. The contribution of the direct nucleon pick-up is described phenomenologically. Multiple pre-equilibrium emission of tritons is also accounted for. The calculated triton energy distributions are compared with experimental data for targets from 12C to 209Bi. The role of the optical potential in the modelling of triton emission is discussed. Numerical calculations were performed using the modified ALICE/ASH code [1].
[1] C.H.M. Broeders, A.Yu. Konobeyev, Yu.A. Korovin, V.P. Lunev, M. Blann, ALICE/ASH, Report FZKA 7183, 2006; http://bibliothek.fzk.de/zb/berichte/FZKA7183.pdf

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CC 4 2:40 PM

Towards a coupled-channel optical potential for rare-earth nuclei

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In order to accurately describe the observed outcomes of a nuclear reaction, a more fundamental theory that explicitly takes into accont the internal degrees of fredom of nuclei must be applied. In this context, the coupled-channel theory is a natural way of treating nonelastic channels, in particular those arising from collective excitations, defined by nuclear deformations. Proper treatment of such excitations is often essential to the accurate description of reaction experimental data. Previous works have applied different models to specific nuclei with the purpose of determining angular-integrated cross sections. In this work, we present an extensive study of the effects of collective couplings and nuclear deformations on integrated cross sections as well as on angular distributions in a consistent manner for neutron-induced reactions on nuclei in the rare-earth region. This specific subset of the nuclide chart was chosen precisely because of a clear static deformation pattern. We analyze the convergence of the coupled-channel calculations regarding the number of states being explicitly coupled. A model for deforming the spherical Koning-Delaroche optical potential as function of quadrupole and hexadecupole deformations is also proposed, inspired by the work done in Ref. [1]. We demonstrate that the obtained results of calculations for total, elastic, inelastic, and capture cross sections, as well as elastic and inelastic angular distributions correspond to a remarkably good agreement with experimental data for scattering energies above around a few MeV.
[1] F. S. Dietrich, I. J. Thompson, and T. Kawano, Phys. Rev. **C85**, 044611 (2012)

Session CD Nuclear Structure and Decay
Monday March 4, 2013
Room: Empire West at 1:30 PM
Chair: Alejandro Algora, IFIC Valencia
CD 1 1:30 PM

Decay Studies of 238U Fission Products at the HRIBF (Oak Ridge)*

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A summary of many studies on the decay of neutron-rich nuclei performed at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory will be given. Examples of the impact of the results on nuclear structure, astrophysics and applied studies will be discussed. Beams of neutron-rich nuclei were produced at the HRIBF using high-resolution on-line mass separation [Beene2011] following proton-induced fission of 238U. Several techniques were used to enhance the isobaric purity of these beams: charge exchange, molecular extraction of GeS and AsS [Stracener2003], laser resonance ionization of Ga [Liu2012], and post-acceleration followed by ranging-out in gas of the mono-energetic beam components [Gross2005]. Decay of very neutron-rich isotopes of several elements between Z = 29 Cu and Z = 63 Eu were studied u sing beta-gamma-neutron spectroscopy methods, mostly at the Low-energy Radioactive Ion Beam Spectroscopy Station (LeRIBSS) [Rykaczewski2009]. The results include the first determination of half-life for 82Zn, 83Zn, 85Ga [Madurga2012], 86Ga [Grzywacz2012], and 86Ge [Mazzocchi2012] as well as a new measurement of the 93Br half-life [Miernik2012] that is in conflict with the adopted value. Several beta-gamma and beta-n-gamma decay schemes were obtained for the first time or greatly expanded, e.g., 73Cu [Paulauskas2012] through 75Cu [Ilyushkin2011] and 77Cu [Ilyushkin 2009], up to N=50 79Cu [Korgul2012]. The experiments with post-accelerated negative ions of Cu and Ga [Winger2009, Winger2010, Korgul2012] and with positive ions of Zn [Padgett2010] and Br [Miernik2012] resulted in the precise determination of absolute beta-delayed branching ratios that are in many cases, substantially larger than previously reported. The HRIBF studies of beta-delayed neutron emission were enhanced recently by the measurement of the energy of the neutrons. Decays of over 25 beta-delayed neutron precursors were measured with the time-of-flight neutron array Versatile Array for Neutron Detection at Low Energy (VANDLE) [Grzywacz2012a] at LeRIBSS allowing us to study the beta-strength function distribution above the neutron separation energies in daughter nuclei. Studies of the beta-strength function were expanded by measurements using the recently commissioned Modular Total Absorption Spectrometer (MTAS) [Rykaczewski2012]. MTAS is the first segmented total absorption array having an active volume at least seven times larger than any previous spectrometer resulting in superior efficiency [Wolinska2013]. The decays of over 20 fission products have been measured at the HRIBF with MTAS [Karny2013]. Activities included 86Br, 87Br, 89Kr, 90Kr, 137I, 137Xe and 139Xe that are listed among highest priority nuclei for decay heat measurements established by the OECD Nuclear Energy Agency assessment [NEA2007]. The comparison of the spectra and the MTAS simulated response based on existing nuclear data shows a large excess of high-energy gamma radiation [Fijalkowska2012, Karny2013] in most cases. The presentation will include quoted references to original publications.

*This work supported by the U.S. Department of Energy Office of Nuclear Physics.

[1] J.R. Beene *et al.*, J. Phys. G: Nucl. Part. Phys. **38**, 024002, (2011) and references therein.

CD 2 2:00 PM

Search for Fission Decays of High-K Isomers in ^{254}Rf*

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Nuclei in the transfermium region near the $Z = 100$ and $N = 152$ subshell gaps are predicted to be well deformed with an axially-symmetric shape. Their single-particle spectra are dominated by high-K orbitals near both the proton and neutron Fermi surfaces. These conditions favor the presence of high-K, multi-quasiparticle states at relatively low excitation energies, some of which can be expected to be long-lived due to the conservation of the K quantum number. Two-quasiparticle K^π=8^- isomers are observed in several even-even N=150 isotones, from ^{244}Pu ($Z = 94$) to ^{252}No ($Z = 102$), and those have been associated with the *two-quasineutron* $\nu^2(7/2^+[624], 9/2^-[734])$ configuration. In the heavier Rf ($Z = 104$) isotopes, the proton Fermi level is located between the $\pi 7/2^-[514]$ and $\pi 9/2^+[624]$ orbitals, and hence, one may expect a *two-quasiproton* K^π=8$^-$ state at low excitation energy. Multi-quasiparticle blocking calculations predict that in ^{254}Rf ($N = 150$) the *two-quasineutron* and *two-quasiproton*, K^π=8$^-$ configurations compete for favored yrast status, with the one lowest in energy expected to be a long-lived K-isomer. In addition, calculations predict a particularly favored K^π=16$^+$ four-quasiparticle state at 1.95 MeV formed by the coupling of the two K^π=8$^-$ configurations. This is a candidate for an even longer-lived state in ^{254}Rf, which is analogous to the K^π=16$^+$ ($T_{1/2}$=31 y) isomer in the rare-earth nucleus ^{178}Hf. Since the ^{254}Rf ground state disintegrates by spontaneous fission with a relatively short lifetime ($T_{1/2}$=23 (3) μs), identification of these high-K states is particularly worthwhile, as they can provide direct evidence for the role that K-isomers may play in the enhanced stability of super-heavy nuclei. We have carried out a search for the predicted two- and four-quasiparticle states in ^{254}Rf using the ^{50}Ti + ^{206}Pb heavy-ion fusion-evaporation reaction and the Argonne Fragment Mass Analyzer (FMA). A 242.5 MeV ^{50}Ti beam with an intensity of ~200 pnA was provided by the ATLAS accelerator. The recoiling reaction products were transported to and separated by the FMA, identified by their m/q ratio using a Parallel Grid Avalanche Counter detector and implanted into a 160-by-160-strip Double-sided Silicon Strip Detector (DSSD) at the FMA focal plane. Spatial and time correlations between implanted nuclei and their subsequent fission decays were detected within a single DSSD pixel. Analysis of such events allowed characterization of the decaying state. The data from this experiment will be presented and the results will be discussed. *This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

CD 3 2:20 PM

New Nuclear Structure and Decay Results in the ^{76}Ge-^{76}As System

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The process of neutrinoless double beta decay ($0\nu\beta\beta$) plays a key role in modern neutrino physics. The experiments on the ^{76}Ge-$0\nu\beta\beta$-decay using germanium-semiconductors are at the forefront in this field. Due to the extremely low count rates expected for this rare decay, any kind of background event in the detector, especially at energies close to $Q_{\beta\beta} = 2039$ keV has to be avoided. Therefore, a careful investigation on the neutron-induced background was carried out. In this contribution the results of the search for a potentially existing 2040.7 keV gamma-ray, which occurs due to de-excitation of the 69^{th} excited state of ^{76}Ge, will be presented. In order to verify the existence of this weak transition the gamma rays occurring due to the β-decay of the short living ^{76}Ga ($T_{1/2} = 32.6$ s) into ^{76}Ge was studied. Therefore, the 14 MeV high-flux DT neutron generator of the TU Dresden, equipped with an automatic pneumatic sample transport system, was employed. Furthermore, first and new results on cross sections for inelastic neutron scattering into the 69^{th} excited state of ^{76}Ge, measured at the GAINS setup of the IRMM in Geel, will be shown. The decay of ^{68}Ge is a major source of intrinsic background nuclides in germanium semiconductor detectors. This nuclide is produced from other germanium isotopes in ^{x}Ge(n,jn)^{68}Ge reactions induced by cosmogenic

neutrons. First measurements for the production cross section of ^{68}Ge with fast quasi monoenergetic neutrons ($E_n > 20$ MeV) were performed at iThemba LABS using the activation foil method. Within these studies on ^{76}Ge, the electron capture of ^{76}As has been observed for the first time, whose results will be presented.

CD 4 2:40 PM

Development of a System for Measuring the Shape of β Spectra Using a Semiconductor Si Detector

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The study of the shape of β spectra is experiencing a resurgence of interest having been little studied since the late 1970s. Precise knowledge of the shape of energy spectra, coupled with well established uncertainties, are sought by users from the nuclear power industry (decay heat calculations), medical care sector (dose calculations) or ionizing radiation metrology (reduction of uncertainties in activity measurements using the liquid scintillation technique). As the primary laboratory for measurement of radioactivity in France, the Laboratoire National Henri Becquerel (LNHB) requires a computer code to meet the demands of users, which should be validated against experiment. Hence, an operational device using a semiconductor Si detector (easy to implement, linear response function, good energy resolution) has been developed in order to measure spectra shape and to quantify the uncertainties. The main difficulties arise because the spectra may be distorted by the detection system (detector efficiency, non-linearity of electronics) and physical phenomena (thickness and homogeneity of the source, detector dead zones, angle of incidence, scattering and backscattering, bremsstrahlung). The entire setup has been designed to attempt a measurement of the true spectral shape, by limiting sources of deformation (ultra-thin source, ultra vacuum, detector cooled to liquid nitrogen temperature, low scattering materials, limitation of microphonics). Finally, our attention is focused particulary on the two main components of the experimental device, i.e. the detection chamber and source holder. These have been studied by Monte-Carlo calculations (GEANT4) to determine the geometry and materials least likely to scatter electrons. This paper describes the experimental setup and presents the first results.

Session CE Fission Yields
Monday March 4, 2013
Room: Central Park East at 1:30 PM
Chair: Morgan White, LANL
CE 1 1:30 PM

Fission Product Yields for Fast and 14 MeV Neutrons

M.B. Chadwick
Los Alamos National Laboratory

This presentation will summarize recent Los Alamos fission product yield work in experiment [1], theory, and evaluation [2], that culminated in work we recently incorporated into ENDF/B-VII.1 [3]. The poster will focus on describing recent developments in experiment, and theory, since we published our results, and will describe how these works relate to our recent ENDF/B-VII.1 evaluations. There are 2 main questions we are trying to settle through additional work: (1) We proposed energy dependencies for plutonium FPY over the fast neutron energy region, from 0.5 - 2 MeV. These are needed to accurately

infer plutonium burnup from fission product measurements; (2) There are systematic differences in the magnitude of key FPY for plutonium. Although Livermore's recent evaluations now agree with LANL's, the CEA measurements from Laurec et al still show a 5-10% systematic difference with the US data. We are trying to resolve this discrepancy. The main experimental efforts being pursued are at TUNL (Triangle University Nuclear Laboratory) - a collaboration between Duke University , LANL, and LLNL; at LANL (new detectors being built at LANSCE) and by LANL at the Nevada critical assemblies. This contribution will summarize these results.

1. H. Selby et al., Nucl Data Sheets 111, 2891 (2010); MacInnes, NDS 112, 3135 (2011) 2. M.B. Chadwick et al., Nucl Data Sheets 111, 2923 (2010) 3. M.B. Chadwick et al., Nucl Data Sheets 112, 2887 (2010)

CE 2 2:00 PM

Fission Product Yield Study of ^{235}U, ^{238}U and ^{239}Pu Using Dual-Fission Chambers

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In order to resolve long-standing differences between LANL and LLNL regarding the correct fission basis for analysis of nuclear test data [1,2], a collaboration between TUNL/LANL/LLNL has been formed to perform high-precision measurements of neutron induced fission product yields. The main goal is to make a definitive statement about the energy dependence of the fission product yields to an accuracy of better than 2-3% between 1 and 15 MeV, where experimental data are very scarce. At TUNL, we have completed the design, fabrication and testing of three dual fission chambers dedicated for ^{235}U, ^{238}U, and ^{239}Pu. The dual-fission chambers were used to make measurements of the fission product activity relative to the total fission activity, as well as for high-precision absolute fission yield measurements. The activation method was employed, utilizing the mono-energetic neutron beams available at TUNL. Neutrons of 4.6, 9.0, and 14.5 MeV were produced via the ^{2}H$(d,n)^3$He reaction, and for neutrons at 14.8 MeV, the ^{3}H$(d,n)^4$He reaction was used. After activation, the induced γ-ray activity of the fission product yields was measured for three months using high-resolution HPGe detectors in a low-background environment. Results for the yield of sixteen fission fragments for ^{235}U, ^{238}U, and ^{239}Pu and a comparison to available data at other energies are reported. For the first time results are now available for neutron energies between 1.5 and 14 MeV.

Corresponding author: A. Tonchev

[1] M.B. Chadwick and others, Nucl. Data Sheets 111, 2923 (2010) [2] H.D. Selby and others, Nucl. Data Sheets 111, 2891 (2010)

CE 3 2:20 PM

Mo-99, Nd-147, Zr-95 and Ba-140 Yields from Fission of U-235 Induced by 0.57, 1.0 and 1.5 MeV Neutrons

J. Feng, Y. Yang, S. Liu, Y. Liu
China Institute of Atomic Energy

The chain yields of fission products, ^{99}Mo, ^{95}Zr, ^{147}Nd and ^{140}Ba were determined for the fission of ^{235}U induced by 0.57 MeV, 1.0 MeV and 1.5 MeV neutrons. Absolute fission rates were monitored with a double-fission chamber. Fission product activities were measured by HPGe γ-ray spectrometry. MCNP IVB was applied to simulate neutron spectrum in the Uranium samples, and the effects of all kinds of secondary neutrons on fission yield data were discussed. The yields data were compared with those of other labs. Our results are in agreement with those of ANL within the scope of experimental uncertainties after necessary corrections.

CE 4 2:40 PM

Energy Dependence of Plutonium Fission-Product Yields and Average Fragment Total Kinetic Energies

J. P. Lestone, T. T. Strother
Los Alamos National Laboratory

Methods have been developed to extrapolate measured first-chance fission-product yields and average fragment total kinetic energies to higher incident-neutron energies where second, third, and forth chance fission are of importance. The yields for fragment mass near the asymmetric peaks at A 100 and A 138 decrease with increasing incident-neutron energy, while the yields for symmetry fragments, and fragments with masses less than A 96 and more than A 146 increase with increasing incident-neutron energy. Predictions are made for the energy dependence of plutonium fission-product yields. These are compared to the limited available data. A prediction is made for the average total kinetic energy of ^{239}Pu(n,f) fission fragments, up to a neutron energy of 20 MeV. These predictions will be tested in the next few years by the SPIDER collaboration at Los Alamos.

Session DA Time Projection Chamber
Monday March 4, 2013
Room: Met East at 3:30 PM
Chair: Berta Rubio, IFIC - Valencia
DA 1 3:30 PM

The Fission Time Projection Chamber Project

Tony Hill, the NIFFTE Collaboration
INL

New high-precision fission experiments have become a priority within the low-energy nuclear community. Modern sensitivity calculations have revealed unacceptable liabilities in some of the underlying fundamental nuclear data and have provided target accuracies for new measurements that are well beyond what can be delivered using current experimental technologies. A potential breakthrough in the precision barrier for these measurements is the deployment of a Time Projection Chamber (TPC). TPC detector systems were originally developed within the particle physics community and have played a central role in that field for nearly 25 years. A group of 6 universities and 4 national laboratories have undertaken the task of building the first TPC designed specifically for the purpose of measuring fission cross sections. In this talk, I will present the motivation for the fission TPC concept, a few details of the device and why we think an improvement on 50 years of fission experiments can be accomplished.

DA 2 4:00 PM

Measuring the α/SF Branching Ratio of ^{252}Cf with the NIFFTE Time Projection Chamber

Lucas Snyder, the NIFFTE Collaboration
LLNL

Fission reactions are particularly complicated quantum systems and current nuclear theory lacks the necessary predictive power to calculate many of the fundamental quantities associated with the process. The neutron induced fission cross section is one experimentally measured value of particular importance in the calculation and simulation of nuclear fuel cycles. The NIFFTE collaboration is developing a fission Time Projection Chamber intended to measure energy dependent neutron induced fission cross sections of the major and minor actinides to an uncertainty of better than 1%. The fission TPC will address many of the systematic uncertainties associated with past and current detector systems used to measure the neutron induced fission cross section by providing detailed 3-dimensional images of ionizing particles such as fission fragments and alpha particles. To establish the particle tracking and identification abilities of the fission TPC in the development phase, the α-decay and spontaneous fission of ^{252}Cf was observed with a partial TPC. Preliminary results of an analysis of the α/SF branching ratio of ^{252}Cf will be presented.

DA 3 4:20 PM

Characterization and Preparation of Multi-Isotope Actinide Sources and Targets: The Fission Time Projection Chamber

W. Loveland
Oregon State University

The preparation and characterization of actinide sources and targets for use if nuclear data elated projects involves special challenges. These challenges involve securing sufficiently pure materials for target preparation, characterizing those materials, preparing the usually thin sources and targets and characterizing the resulting sources and targets. No where are these challenges more evident than in the fabrication of sources and targets for the Fission Time Projection Chamber (TPC) where the announced goal is to make precise, accurate cross section measurements of fission cross sections with uncertainties of less than one percent. The challenges/opportunities of the TPC are in the plan to measure the ratios of cross sections ^{235}U(n,f)/^{238}U(n,f)/^{239}Pu(n,f)/^{1}H(n,p)) by simultaneously measuring all these reactions using a single target. This requires multi-isotopic targets where all the different target nuclei are separated spatially. The TPC, a tracking device, has to be able to track a given reaction product to a specific point on the multi-isotopic target. Unusual "pointing resolution" sources are needed to characterize the TPC resolution. Inherent in all the measurements is the need to have thin uniform actinide deposits/foils whose chemical and isotopic composition is well-known. We present the results of the use of AFM, XRD, XRF and SEM to obtain this information for actinide targets prepared by vacuum volatilization and molecular plating

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DA 4 4:40 PM

Commissioning the NIFFTE Time Projection Chamber: the ^{238}U/^{235}U (n,f) Cross-Section Ratio

Rhiannon Meharchand, on behalf of the NIFFTE collaboration
Los Alamos National Laboratory

Nuclear data play a fundamental role in reactor and weapons calculations, and the uncertainties in nuclear data propagate into other calculated quantities. Therefore, it is imperative that data uncertainties are minimized and well understood. To this end, the Neutron Induced Fission Fragment Tracking Experiment (NIFFTE) collaboration is developing a Time Projection Chamber (TPC) to measure fission cross sections with unprecedented accuracy. The NIFFTE TPC marks the first application of TPC technology in fission research. The miniaturization and modification of existing technologies — as well as the development of new systems for this specific application — is a challenging endeavor. Frequent evaluation is required as new hardware and software capabilities are implemented. To evaluate progress, the TPC is tested in beam at the Los Alamos Neutron Science Center (LANSCE) Weapons Neutron Research (WNR) facility. LANSCE-WNR, a spallation neutron source, provides a white neutron spectrum ranging from hundreds of keV to hundreds of MeV. Since 2010, the TPC has been loaded with actinide samples and blank backings and has collected in-beam engineering data while readout capabilities were gradually increased. In 2010, data were collected on ^{238}U and ^{natural}C samples, with 64 then 192 active channels (1/93 and 1/31 of the fully instrumented TPC, respectively). In late 2011 and early 2012, data were collected on ^{238}U, ^{235}U, ^{239}Pu, and ^{natural}Al samples, with 496 active channels (1/12 full TPC). In late 2012, data will be collected on ^{238}U, ^{235}U, ^{239}Pu, and plastic samples, with 2976 active channels (1/2 full TPC). An overview of the NIFFTE TPC experiments performed at LANSCE and preliminary results for the ^{238}U/^{235}U neutron-induced fission cross section ratio will be presented. This work was performed under the auspices of the U.S. Department of Energy by Los Alamos National Security, LLC under contract DE-AC52-06NA25396 and by Lawrence Livermore National Security, LLC under contract DE-AC52-07NA27344. LA-UR-12-23658.

DA 5 5:00 PM

An Ethernet-Based Data Acquisition System for the NIFFTE Time Projection

L. Wood, the NIFFTE Collaboration
Pacific Northwest National Laboratory, Richland, WA 99352, U.S.A.

When fully instrumented, the NIFFTE Time Projection Chamber will consist of nearly 6000 channels, each of which requires a preamplifier, ADC, and digital readout. To minimize channel cost and size, the EtherDAQ data acquisition system utilizes off-the shelf FPGA and Ethernet fiber technology. This application of commercially-available components made it possible to meet the requirements of the DAQ system with considerably less development cost and time than the a customized ASIC solution, and provides considerable flexibility in the final design. The detailed design and current status of the preamplifier and EtherDAQ boards will be discussed.
Presenting author: Sean Stave

DA 6 5:15 PM

The Data Analysis Framework for the NIFFTE Time Projection Chamber

S. Stave, the NIFFTE Collaboration
Pacific Northwest National Laboratory, Richland, WA 99354, U.S.A.

The NIFFTE collaboration has developed a time projection chamber to study neutron-induced fission events by tracking and identifying fission fragments in three dimensions as they traverse a gas volume. This talk will provide an overview of the analysis software that has been developed by the NIFFTE collaboration, as well as examples of its success in analyzing data taken at LANL.

DA 7 5:30 PM

^{6}Li-Glass Detector Response Study For Low-Energy Prompt Fission Neutrons at LANSCE

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Prompt-fission-neutron spectra for neutron-induced fission reactions on uranium and plutonium isotopes are important for nuclear applications. Currently available sets of low-energy neutron data (below 1 MeV) on ^{239}Pu show an experimental uncertainty as large as 30 % and discrepancy in spectral shape [1,2,3]. As an effort to improve the quality of data, we have used ^{6}Li-glass scintillation detectors at the Los Alamos Neutron Science Center. To better understand the response of ^{6}Li-glass detectors in the energy range from 50 keV to 1 MeV, measurements of well-known spontaneous-fission neutrons from a ^{252}Cf source were done in the neutron-beam flight path. Similar measurements with a ^{7}Li-glass detector were used to assess gamma-ray background yields. Results were compared with Monte Carlo simulations (MCNP-PoliMi) and they show good agreement. Preliminary prompt-fission-neutron spectra on ^{235}U measured with ^{6}Li-glass detectors at the newly constructed flight path for reducing low-energy down scattering neutron background will be presented. This work benefits from the LANSCE accelerator facility and is supported by the U.S. Department of Energy under contracts DE-AC52-06NA25396 (LANL) and DE-AC52-07NA27344 (LLNL). LA-UR number: 'LA-UR-12-23508'
[1] A. Lajtai, J. Kecskemeti, J. Safar, P. Dyachenko, and V. M. Piksaikin, Proc. Int. Conf. Nuclear Data for Basic and Applied Science, Santa Fe, New Mexico, May 13-17, 1985, **p. 613**, P. G. Young, R. E. Brown, G. F. Auchampaugh, P. W. Lisowski, and L. Stewart, Eds., Gordon and Breach Science Publishers (1985). [2] H. Werle and H. Bluhm, Jour. Nucl. Ener. **26**, 165 (1972). [3] A.A. Bojtsov, A.F. Semenov, and B.I. Starostov, **pp. 294** in Proc. All Union Conf. on Neutron Physics, 2-6 October 1983, Kiev, Moscow (1984).

Session DB Benchmark and Testing
Monday March 4, 2013
Room: Met West at 3:30 PM
Chair: David Brown, NNDC - BNL
DB 1 3:30 PM

Verification and Validation of LLNL's Evaluated Nuclear Data Library (ENDL2011)

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Nuclear Engineering Department, University of California, Berkeley, CA

Over the past several years, the Lawrence Livermore National Laboratory (LLNL) Physics Division has been developing a python-based automated test suite for nuclear data verification and validation that has been applied to ENDL2011, the latest edition of LLNL's evaluated nuclear database. The automated test suite provide three distinct functionalities: 1) a database can be generated from a repository of input decks that can then be queried with a set of user-defined parameters such as target isotope or class of benchmark experiments. 2) The list of selected cases can then be run automatically on LLNL cluster queuing system, and 3) the run results can be compared to data or results from other cross-section libraries. New benchmark

test problems for three LLNL codes Mercury (Monte Carlo), Amtran and Ardra (Sn) have been added to the V & V test suite. In particular, thermal critical assemblies and a set of IPPE Activation Ratio experiments from the ICSBEP database, and a large set of LLNL pulsed spheres experiments have been added. Work is ongoing to add more experiments as well as MCNP6 models. The latest developments in the tests suite automation and results of ENDL2011 V & V will be presented. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. *Now at Brookhaven National Laboratory, Upton, NY

DB 2 4:00 PM

Testing JEFF-3.1.1 and ENDF/B-VII.1 Decay and Fission Yield Nuclear Data Libraries with Fission Pulse Neutron Emission and Decay Heat Experiments

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CIEMAT, Spain

The aim of this work is to test the present status of Evaluated Decay Data and Fission Yield data libraries to predict the decay heat and the neutron emission rate, average neutron energy and neutron delayed spectra after a neutron fission pulse. These calculations are compared with documented experimental values. Calculations were performed with JEFF-3.1.1 and ENDF/B-VII.1. In addition, uncertainty propagation calculations of the current uncertainties in these Nuclear Data Libraries are also performed. Decay heat, neutron emission and their uncertainties are predicted with an updated version of ACAB code (NEA-1839 ACAB-2008). For decay heat, beta, gamma and total contribution are analyzed. Due to ultimate TAGS data, the previous calculations are repeated taken into account this new data. For delayed neutron emission, each isotope able to emit delayed neutrons following beta decay is taken into account. These results are compared with the ones furnished by libraries themselves through the "Keepin formulation", which is an experimental-based approach with reliable results used since 50's in nuclear reactor design. Acknowledgements: The research leading to these results has received funding from the European Atomic Energy Community's 7th Framework Programme in the ANDES project under grant agreement No. 249671. It has also been partially funded by the specific collaborative agreement between CIEMAT and UNED/UPM in the area of "High level waste transmutation".

DB 3 4:20 PM

Measurement of Gamma Energy Distributions and Multiplicities Using STEFF

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Prompt gamma ray energy distributions and multiplicities released during thermally induced fission of ^{235}U are measured using STEFF (SpecTrometer for Exotic Fission Fragments). Thermal neutrons are

provided by the high-flux reactor at the ILL, Grenoble. STEFF is a unique 2E2v device that uses a coincidence timing method to measure the emission of prompt gamma rays as a function of the fragment mass and energy. Following scission, the fission fragments contain excitation energy that is released via prompt neutron and gamma ray emission as the fragment decays to its ground state. STEFF contains an array of 11 NaI detectors around the uranium target providing a 6.8% photopeak detection efficiency for acceptance of gamma rays released within 1ns of the scission time. STEFF also consists of 7 NE213 detectors, which detect the emission of prompt neutrons, the release of which is associated with reduction of fragment energy and, to a lesser extent, fragment spin. Using STEFF, the gamma ray energies and multiplicity have been measured as a function of mass, with a mass resolution of 4% and a gamma-ray energy range up to 8 MeV. This experiment acts as a direct response to the NEA high priority demand which requires more accurate knowledge of heating caused by gamma emission in the next generation of nuclear reactors.

DB 4 4:40 PM

Gamma Heat Rate Evaluation for Material Irradiation Test in The Experimental Fast Reactor Joyo

S. Maeda, H. Naito, T. Soga, C. Ito, T. Aoyama
Japan Atomic Energy Agency

One of the primary missions of the experimental fast reactor Joyo is to perform irradiation tests of fuel and materials to support development of fast reactors. In a material irradiation test, it is essential to give a precise characterization of the irradiation field, considering not only neutron fluence and displacements per atom (dpa) but also temperature. The main heat source in a material irradiation test is the gamma heating of surrounding materials, such as stainless steels constituting the irradiation rig including the irradiation specimen and capsule. Accurate core and temperature calculation methods are required for predicting the gamma heat rate and other key performance parameters for irradiation tests in Joyo. In order to evaluate the gamma heating spatial distribution in fast reactors, it was needed to consider whole components of gamma intensity. However, delayed gamma ray yield data of all actinides are not prepared in the evaluated nuclear data files such as ENDF or JEDNL. Therefore, the modified neutron/gamma cross section constant based on JENDL-2 were developed in the previous study in Joyo and the gamma heat rate increase approximately 40% by considering the delayed gamma intensity as evaluated by Yoshida [1]. In this study, the new neutron/gamma cross section constants based on JENDL-3.2 and JENDL-4.0 are being developed. To evaluate all gamma ray effect, delayed gamma yield were added to JENDL-3.2 and JENDL-4.0. Based on these modified JENDL-3.2 and JENDL-4.0, the MCNP-type library for Mote Carlo transport calculations, JSSTDL and MATXSLIB-type library (100 neutron groups and 40 gamma groups) for conventional discrete ordinate multi-group transport code were generated. In this modification, the prompt gamma ray yield data which was given only for U-235, U-238 and Pu-239 in JENDL-3.2 were prepared for all actinides. Through the neutron and gamma ray coupling calculations for Joyo core based on the transport theory as a fixed source problem, it was made clear that the gamma flux and heat rate increase approximately 40% by considering the delayed gamma intensity in both JENDL-3.2 and JENDL-4.0. The effect of lack of the prompt gamma ray yield data except for U-235, U-238 and Pu-239 in JENDL-3.2 is approximately 10%. The calculated gamma heat rates were verified against measured data by the on-line irradiation rigs, which name is instrumented assembly (INTA), loaded in the Joyo core fuel region. In the INTA, online thermocouples were equipped surface and inside of insulated irradiation capsules. First, temperature of an irradiation specimen in each capsule was evaluated using the finite element method code FINAS with a capsule model in RZ geometry, taking into account the sodium temperature measured by the thermocouple at surface of the capsule as a boundary condition. By using a heat transfer calculation, temperature distribution in a capsule was converted to gamma heat rate. It was confirmed that the calculated gamma heat rates agreed with the measurements within 5%.

[1] Yoshida, T. *et al.*, "Calculation of the Delayed Fission Gamma-Ray Spectra from U-235, -238, Pu-239, -240, and Pu-241; Tabular Data," JAERI-M-89-037 (1989).

DB 5 5:00 PM

New Prompt Fission γ-ray Data in Response to the OECD/NEA High Priority Request

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With the potential of advanced nuclear reactors, a better understanding of the fission process is required. Since four out of six of the impending Generation-IV reactors are fast ones, the excessive heat deposition requires an innovative core design. Approximately 10% of the deposited heat is due to γ-ray energy, from which about 40% is due to prompt fission γ-rays. According to Rimpault et al. [1], the uncertainty with respect to the γ heating should not exceed 7.5% to adequately model these cores. Using the present evaluated data leads to an underestimation of the γ-heating by up to 28% for the main reactor isotopes, ^{235}U and ^{239}Pu. Since the underlying experimental data dates back to the early 1970s, the OECD/NEA has included an urgent request for new experimental data in its High Priority Data Request List [2]. The Nuclear Physics Unit of the European Commission Joint Research Centre together with co-workers has taken up the challenge to respond to the OECD request and started a measurement programme on prompt fission γ-rays. During recent years we have started this programme by carrying out thorough studies of new and highly efficient γ-ray detectors based on cerium-doped lanthanum-halide and cerium-bromide crystals, aiming at very fast timing in conjunction with a good energy resolution [3,4]. In the final setup we achieve very good separation of prompt fission γ-rays from the prompt fission neutron component in a very compact source-detector geometry, which removes a possible source of uncertainties. After about four decades since the experiments were performed whose results are still used for current evaluations, we present new spectral prompt fission γ-ray data from the reactions ^{252}Cf(SF) [5] and ^{235}U(n$_{th}$, f). We will also report on γ-ray data as a function of fission-fragment mass and total kinetic energy. Based on our new findings we recommend to replace the current ENDF/B-VII evaluation for ^{252}Cf(SF) as well as for ^{238}U(n,f) and ^{241}Pu(n,f).

Presenting author: F-J. Hambsch

[1] G. Rimpault, in: P. Rullhusen (Ed.), Proceedings of the Workshop on Nuclear Data Needs for Generation IV, Antwerp, Belgium, World Scientific, ISBN 981- 256-830-1, 2006, April 2005, p. 46 [2] G. Rimpault, A. Courcelle, D. Blanchet, Comment to the HPRL:IDH.3 and H.4,
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DB 6 5:15 PM

Validation and Testing of ENDF/B-VII Decay Data

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Oak Ridge National Laboratory

The nuclear decay library developed for the Oak Ridge Isotope Generation and Depletion (ORIGEN) code released within the SCALE 6.1 code system [1] was upgraded from ENDF/B-VI.8 to -VII.0. Used internationally by industry, regulatory agencies and research for design and safety studies involving irradiated nuclear materials, ORIGEN solves for the transmutation and decay of more than 2300 nuclides. Recent experience with ENDF/B-VII.0 library has identified a number of serious deficiencies in the evaluated decay data files, initially identified in the ^{238}U decay series [2], but also found to impact fission product decay schemes and decay energy release. To address the deficiencies in the decay data released in SCALE 6.1, Oak Ridge National Laboratory (ORNL) has developed an ORIGEN decay library based on the most recent ENDF/B-VII.1 evaluations. This paper describes a validation and test suite developed to evaluate decay data performance and initial results obtained using ENDF/B-VI.8, -VII.0, and -VII.1 libraries. The tests include the thorium 4n, neptunium 4n+1, uranium 4n+2, and actinium 4n+3 decay series, as well as experimental benchmarks including destructive isotopic assay measurements [3] and integral decay heat measurements for full-length fuel assemblies [4]. In addition, measurements of β and γ energy release and spectra for times of < 1 to 10^5 s after fission are applied to evaluate the fission product decay data [5]. These tests will form the basis of future performance evaluation of ENDF/B decay data at ORNL and processing of the data for use in SCALE.

[1] RSICC Computer Code Collection, CCC-732, 2011. "SCALE: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design," Technical Report ORNL/TM-2005/39, Version 6.1, Oak Ridge National Laboratory. [2] http://www.nndc.bnl.gov/exfor/endfb7.1_decay.jsp [3] G. Ilas, I.C. Gauld, and G. Radulescu, "Validation of new depletion capabilities and ENDF/B-VII data libraries in SCALE," *Annals of Nuclear Energy*, **46**, 43 (2012). [4] F. Sturek, L. Agrenius, and O. Osifo, "Measurements of Decay Heat in Spent Nuclear Fuel at the Swedish Interim Storage Facility," Clab, Svensk Karnbranslehantering AB, R-05-62, December 2006. [5] "Assessment of Fission Product Decay Data for Decay Heat Calculations, "International Evaluation Co-operation, Volume 25, NEA/WPEC-25, Nuclear Energy Agency (2007).

DB 7 5:30 PM

Application of the PSI-NUSS Tool for Estimation of Nuclear Data Related K-eff Uncertainties for the OCED/NEA WPNCS UACSA Phase 1 Benchmark

Ting Zhu, Alexander Vasiliev, Hakim Ferroukhi

Paul Scherrer Institut

At the Paul Scherrer Institut, a methodology for the propagation of nuclear data uncertainties into criticality safety calculations with the Monte Carlo code MCNP(X), titled as PSI-NUSS, is under development. The primary purpose is to provide a complementary and innovative option for the assessment of nuclear data related uncertainties versus the traditional approach commonly applied in many state-of-the-art criticality safety evaluation (CSE) methodologies and which relies on estimating biases/uncertainties based on comprehensive validation studies against representative critical benchmark experiments. A description of the PSI-NUSS methodology, as well as its assessment against the more rigorous and theoretically grounded Total Monte Carlo methodology developed at NRG, is presented in an accompanying paper. In the present paper, the PSI-NUSS methodology is applied to quantify nuclear data uncertainties for the OCED/NEA WPNCS UACSA Phase 1 benchmark. One underlying reason is that the previous PSI CSE contribution for this benchmark was based on using a more conventional approach involving 'engineering guesses' in order to

estimate uncertainties in the calculated effective multiplication factor caused by nuclear data uncertainties. Therefore, as the PSI-NUSS methodology aims precisely at integrating a more rigorous treatment of these types of uncertainties for CSE, its application to the UACSA benchmark Phase I is conducted here with two main objectives. First, the nuclear-data related uncertainty component is estimated and compared to results obtained by other participants using different codes/libraries and methodologies. Secondly, the estimated k-eff uncertainty is compared to the results obtained with the previously employed approach. Outlook for further verification and validation studies for the PSI-NUSS methodology is presented and the eventual updates of the overall PSI CSE methodology are discussed.

DB 8 5:45 PM

^{239}Pu Prompt Fission Neutron Spectra Impact on a Set of Criticality and Experimental Reactors Benchmarks

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Many nuclear data are investigated today to improve the calculation predictions of the new neutron transport simulation codes. With the new generation of nuclear power plants (GEN IV project), one expects to reduce the calculation uncertainties, mainly the uncertainties coming from nuclear data which are still very important before adjustment. In France, some future nuclear power plants will use MOX fuel, either in Sodium Fast Reactors or in Gas Cooled Fast Reactors. The knowledge of ^{239}Pu cross sections and other nuclear data is crucial issue to reach this in order to decrease these uncertainties. The Prompt Fission Neutron Spectra (PFNS) for this isotope are part of this challenge (an IAEA working group is dedicated to PFNS) and the work presented here deals with this particular topic. The main international data (i.e. JEFF-3.1.1, ENDFB-7.0, JENDL-4.0, BRC-2009) have been considered and compared with two different spectra, the ones coming from the works of Maslov and Kornilov. Other spectra are also examined, coming from the fission process Monte Carlo simulation code, FIFRELIN. The spectra are first compared by calculating their mathematical moments in order to characterize them. Then, a reference calculation using the whole JEFF-3.1.1 evaluation file is performed and compared with another calculation performed with a new evaluation file, in which the data block containing the fission spectra (MF=5, MT=18) is replaced by the one that is to be tested (one for each evaluation). A set of benchmarks is used to analyze the effects of PFNS, covering criticality cases and mock-up cases in different neutron flux spectra (thermal spectrum, intermediate spectrum and fast spectrum). Data from many ICSBEP experiments are used (PU-SOL-THERM, PU-MET-FAST, PU-MET-INTER and PU-MET-MIXED) and French mock-up experiments are also investigated (EOLE for thermal neutron flux spectrum and MASURCA for the fast neutron flux spectrum). A sensitivity analysis is performed on some of these benchmarks with the European neutronics code package ERANOS/PARIS in order to confirm and understand the origin of the discrepancies. The study shows that many experiments are very sensitive to the PFNS, and that for high leakage thermal criticality cases the discrepancy between international evaluation files spectra and Kornilov spectra can reach 800 pcm. A neutronics analysis is proposed to explain this huge discrepancy. For fast spectrum cases, Maslov's and Kornilov's spectra have a negative effect, between some dozens of pcm to around 300 pcm.
Presenting author: O. Litaize

Session DC Neutron Cross Section Measurements
Monday March 4, 2013

Room: Empire East at 3:30 PM
Chair: Caroline Nesaraja, ORNL
DC 1 3:30 PM

^{238}U Neutron Capture Cross Section Measurements in the Unresolved Energy Region at the GELINA Facility

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The issue of nuclear data uncertainties impact on the design and fuel cycle performances on innovative nuclear systems (generation IV, Accelerator Driven Systems), created the need to improve specific nuclear data via experiments and/or theory. Although ^{238}U is one of the most extensively studied nuclide in terms of neutron data, the recent demands require accuracy in the energy region between 10 keV to 1 MeV, lower than 4%. A set of neutron capture experiments based on the time-of-flight technique were performed, in order to determine the ^{238}U capture cross section in the unresolved resonance region. The GELINA facility of the Institute for Reference Materials and Measurements (IRMM) served as the neutron source. A pair of C_6D_6 liquid scintillators was used to register the prompt gamma rays emerging from the uranium sample. The analysis of the experimental data is based on the total energy principle applied in combination with the pulse height weighting technique. The experimental details along with the analysis process are described and results are presented in comparison to the existing data. The present measurements are part of the European FP7 program ANDES.

DC 2 4:00 PM

Measurements of Neutron Capture Cross Section for ^{74}Se, ^{76}Se and ^{77}Se at KURRI-LINAC

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Selenium-79 is one of the most important long-lived fission products in the transmutation study. However, there is no experimental data of neutron-capture cross sections for ^{79}Se because it is difficult to prepare its sample. Therefore, we have started a systematic measurement of neutron capture cross sections and gamma-ray spectra of stable Se isotopes in order to improve the evaluated neutron capture cross sections of ^{79}Se. In this work, we measured the neutron capture cross sections ^{74}Se, ^{76}Se and ^{77}Se in the neutron energy range from 0.01 eV to 10 keV. The measurements have been performed by the neutron time-of-flight (TOF) method using the 46 MeV electron linear accelerator at the Research Reactor Institute, Kyoto University(KURRI-LINAC). The neutron capture gamma-rays emitted from sample were detected by a total absorption spectrometer consisting of twelve $Bi_4Ge_3O_{12}$(BGO) scintillators, which was placed at a distance of 12.7 m from the photo-neutron source of the KURRI-LINAC. Since base line fluctuations of signals from the BGO spectrometer were caused by the strong bremsstrahlung (gamma flush) synchronized with the accelerator pulse, a data taking system based on digital signal processing (DSP) technique was employed to correct them. A data set of TOF and pulse height (PH) was obtained by analyzing of waveform of the signals. A relative cross sections for ^{74}Se, ^{76}Se and ^{77}Se was obtained from the TOF spectra discriminated by the PH spectra and the incident neutron flux on the capture sample determined by the

^{10}B(n, alpha) standard cross section, and then normalized by the evaluated value of capture cross section at the thermal neutron energy in JENDL-4.0. These results will be compared with other experimental and evaluated values. This work was supported by JSPS KAKENHI Grant Number 22226016.

DC 3 4:20 PM

Cross Sections and Excitation Functions for the Production of Long-Lived Radionuclides

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Lead and lead-based alloys are - among others - considered as target materials for high power spallation neutron sources, either as a part of the driver device in accelerator driven systems (ADS) or as a scientific facility for neutron applications. At the Paul Scherrer Institute (PSI), solid lead targets have been used very successfully already for more than 10 years in the Swiss Neutron Source SINQ on a Megawatt level. In 2006, also at PSI, a demonstration experiment had been performed showing the qualification of the liquid metal alloy Lead-Bismuth Eutectic (LBE) as suitable target material (MEGAwatt PIlot Experiment to MEGAPIE). A very recently launched project at SCK-CEN Mol (Belgium), aimed to demonstrate the feasibility of ADS on an industrial scale (MYRRHA), uses also LBE as target material. LBE is as well foreseen as preferred target material for the development of radioactive beams at CERN-ISOLDE. Besides the knowledge on target and structure material behavior under extreme conditions - e.g. corrosion due to the liquid aggregate state of the metal, embrittlement, radiation damage and many others - also the radionuclide inventory, induced during the proton irradiation by a broad variety of nuclear reactions, is of vital importance for both a safe operation of the facility and a final or intermediate disposal of the waste. Theoretical predictions based on several nuclear reaction models estimate the amount of produced residues, but need benchmarks for checking the reliability. Moreover, the quality of calculations depends on the accurateness of the nuclear data to be used in the models. Especially the knowledge on cross sections for the production of long-lived isotopes need further improvement. We studied the proton-induced residue nuclide production of long-lived radionuclides like 10Be, 26Al, 36Cl, 129I and others from lead and bismuth in thin target irradiations with proton energies up to 2.6 GeV and derived the excitation functions for these isotopes [1,2]. Such radionuclides, with half-lives between 0.3 and 15.7 million years, cannot be measured by conventional decay counting techniques like gamma-spectroscopy, but have to be determined by accelerator mass spectrometry (AMS) after chemical separation of the elemental fractions from the matrix elements. Highly-sophisticated separation procedures, applied step-by-step, were developed to obtain samples suitable for AMS. We will present in this report a summary of these cross section measurements. Investigations on integral experiments, e.g. the determination of the radionuclide inventory both of the MEGAPIE target and a lead target from the SINQ are currently underway.
[1] D. Schumann et.al., AIP Conference Proceedings 769, Melville, New York, 2005,p. 1517 [2] D. Schumann et.al.,J.Phys.G: Nucl. Part. Phys. 38 (2011) 065103

DC 4 4:40 PM

Partial Cross Sections of Neutron-Induced Reactions on ^{nat}Cu at E_n = 6,8,10,12,14 and 16 MeV for $0\nu\beta\beta$ Background Studies

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Partial cross-section measurements of (n,xγ) reactions on ^{nat}Cu were carried out at TUNL using monoenergetic neutrons at six energies of E_n = 6, 8, 10, 12, 14, 16 MeV. These studies were performed to provide accurate cross-section data on materials abundant in experimental setups involving HPGe detectors used to search for rare events, like the neutrino-less double-beta decay of ^{76}Ge. Spallation and (α,n) neutrons are expected to cause the largest source of external background in the energy region of interest. Pulsed neutron beams were produced via the ^{2}H(d,n)^{3}He reaction and the deexcitation γ rays from the reaction ^{nat}Cu(n,xγ) were detected with clover HPGe detectors. Cross-section results for the strongest transitions in ^{63}Cu and ^{65}Cu will be reported, and will be compared to model calculations and to data recently obtained at LANL with a white neutron beam.

DC 5 5:00 PM

Measurement of Capture Gamma Rays from the Tc-99 Neutron Resonances at the J-PARC/ANNRI

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Tc-99 is one of the important nuclei among long-lived fission products contained in nuclear waste. To reduce its radioactive toxicity using a fast reactor or an accelerator driven system, accurate neutron-capture data are needed. Therefore, experiments of neutron-capture and total reactions have been performed, and resonance parameters have been derived by fitting the theoretical function on the spectra as a function of the neutron energy. On the other hand, radiative width, which is one of the resonance parameters, can be obtained by analyzing the capture gamma rays from the neutron resonances and calculating their intensities. We bombarded the pulsed neutron beam on a Tc-99 sample at the Accurate Neutron-Nucleus Reaction measurement Instrument (ANNRI) at the J-PARC and observed capture gamma rays by the 4-pi Ge spectrometer. The neutron energy was obtained by measuring the neutron flight time. The primary gamma-ray transition pattern from the 1st resonance was found to be similar to that from the capture reaction of thermal neutrons. On the other hand, transition patterns from the higher energy resonances were completely different. In this presentation, capture gamma rays from neutron resonances are reported and discussed. This work was supported by JSPS KAKENHI Grant Number 22226016.

DC 6 5:15 PM

Measuring Light-Ion Production and Fission Cross Sections Versus Elastic np-Scattering at the Upcoming NFS Facility

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The Medley setup has been used in many measurements at the Svedberg Laboratory (TSL) in Uppsala mainly with a quasi-mono-energetic neutron beam at 96 and 175 MeV [1,2]. Medley has eight detector telescopes each consisting of two silicon detectors and a CsI(Tl) detector at the back providing ΔE-ΔE-E data. The whole telescope setup is rotatable and can be made to cover any angle. Medley is now planned to be moved to and used at the new, currently under construction, neutron facility NFS [3] in Ganil where measurements of light-ion production as well as fission cross-sections are planned at 1-40 MeV. The light-ion production plays an important role in e.g. single-events effects in electronics. The ^{238}U fission is particularly important as a standard for high-energy neutron monitoring but also in nuclear power related areas and to understand the fission phenomena itself. At low and high neutron energies these cross-sections are fairly well known but at intermediate energies, especially above 20 MeV, there are large discrepancies among reported cross-sections. Our measurements will thus provide data in a much needed energy region. Our main goal is measuring U-238 and Th-232. However, we plan to extend the measurements also to other actinides. The fission cross-section is planned to be measured relative the standard np-cross-section by simultaneously measure protons in the forward angles and fission fragments in the backwards angles. The energy dependent anisotropy factor can also be measured. To be able to do these new measurements at NFS, which will have a high intensity white neutron beam coming from a full stop Be-target, Medley needs to detect the reaction products with a high temporal resolution providing the ToF of the primary neutron. In this paper we discuss the design of the Medley upgrade and experiments along with simulations of the setup. One option explored is to use PPAC's (Parallel Plate Avalanche Detectors) which works very well for detecting fission fragments but requires more consideration for detecting protons and other deeply penetrating particles.
[1] U. Tippawan et al., Phys. Rev. C 79, 064611 (2009). [2] R. Bevliacqua et al., Nucl. Instr. Meth. Phys. Res., A 646 100 (2011). [3] X. Ledoux et al., AIP Conf. Proc. 1412, 55 (2011).

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Dipole Strength in Xenon Isotopes

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The low-lying dipole strength in medium mass nuclei, which are known as typical fission products, was investigated in systematic studies using the photon-scattering facility at the electron accelerator of the Helmholtz-Zentrum Dresden-Rossendorf, Germany [1]. It has been shown, that the experimental strength found in (γ, γ) studies compared with phenomenological approximations used in statistical model calculations can have direct consequences for neutron capture cross sections [2] and the resulting deexcitation spectrum [3]. To investigate if the nuclear deformation has an influence on the dipole strength [4], especially in the energy region below the neutron-separation energy, we studied the photo-absorption cross sections of different isotopes in the xenon chain. Additional measurements at the HIγS facility at the Duke University, USA, allowed us to distinguish between electric and magnetic dipole strength. We will present experimental results from photon scattering experiments on the gaseous targets ^{124,128,134}Xe. These will be compared with results of experiments from other nuclei in the mass region around the closed neutron shell $N = 82$ [5,6,7]. The experiments are supported by Deutsche Forschungsgemeinschaft, Project No. SCHW883/1-1, the German BMBF project TRAKULA and the EURATOM FP7 project ERINDA.
[1] R. Schwengner NIM A 555 211-219 (2005) [2] M. Beard et al. PRC 85, 065808 (2012) [3] G. Schramm et al. PRC 85, 014311 (2012) [4] A.R. Junghans et al. PLB 670 200-204 (2008) [5] R. Massarczyk et al. PRC 86, 014319 (2012) [6] A. Makinaga et al. PRC 82, 024314 (2010) [7] A. Tonchev et al. PRL 104, 072501 (2010)

DC 8 5:45 PM

Absolute Cross Sections for Proton Induced Reactions on ^{147,149}Sm Below Coulomb Barrier

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The optical model parameters for charged particles (proton - alpha) are key ingredients in reaction cross sections evaluations widely used to calculate astrophysical reaction rates.These cross sections data may also be important to the extension of the nuclear data bases required by the development of the future generations of nuclear reactors. At incident energies below the Coulomb barrier, the predictions of different optical model parameterizations are tested against experimental cross sections for the (p,gamma) and (p,n) channels, the only open channels. Experimental data below the Coulomb barrier are difficult to measure and for this reason are scarce. In the rare earth region and particularly for the Samarium isotopes, there are insufficient experimental data. In this work, the cross sections of (p,gamma) and (p,n) processes on ^{147,149}Sm were measured by gamma ray spectroscopy using the activation method. Proton beams of energies between 3.5-8 MeV provided by the IFIN-HH Tandem accelerator, bombarded stacks of ^{147,149}Sm thin targets. The induced activity was measured with a pair of large volume HPGe detectors in close geometry in a special low background shielded area[1], thus allowing absolute cross section measurements down to tens of microbarns. The results are compared with the predictions of the Hauser-Feshbach statistical model calculations performed with the code EMPIRE 3.1 Rivoli. Different sets of optical model parameters were used in the calculations.
[1] D. Filipescu et al., "Cross sections for α-particle induced reactions on ^{115,116}Sn around the Coulomb barrier," Phys. Rev. C 83, 064609 (2011)

Session DD Nuclear Structure and Decay
Monday March 4, 2013
Room: Empire West at 3:30 PM
Chair: Kim Lister, University of Massachusets
DD 1 3:30 PM

Total Absorption Study of Beta Decays Relevant for Nuclear Applications and Nuclear Structure

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In this contribution we will present an overview of our recent studies of the beta decay of nuclei relevant for nuclear applications, as a continuation of our line of research related to nuclear data [1]. The measurements are performed using the best available technique to detect the beta feeding probability, the total absorption technique (TAS). In our studies we have combined the TAS technique with the use of a Penning Trap (JYFLTRAP, Univ. of Jyväskylä) as a high resolution isobaric separator in order to guarantee high purity of the sources. A brief summary of the latest results of the measurements using a new segmented

total absorption spectrometer, the faced challenges depending of the particular nuclei as well as new developments of the techniques of analysis will be discussed. The impact of the measurements on summation calculations of the decay heat in reactors and in nuclear structure will be addressed [2,3,4]. Future plans and the development of a new modular TAS detector (DTAS) for the DEcay SPECtroscopy (DESPEC) experiment at FAIR will also be presented.
[1] A. Algora et al., Phys. Rev. Letts. **105** (2010) 202501 [2] A. Petrovici private communication [3] K-L. Kratz, private communication [4] A. Sonzogni, private communication

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DD 2 4:00 PM

First Results from the Modular Total Absorption Spectrometer at the HRIBF (ORNL, Oak Ridge)*

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Total Absorption Spectrometers (TAS) capable of detecting most of the gamma transitions occurring during the decay process are perfect tools for establishing a true beta feeding pattern. TAS-aided experiments are particularly important for neutron-rich nuclei, where the beta strength is highly distributed over many final states. Knowledge of the correct beta feeding pattern is important for the analysis of the structure of parent and daughter activities as well as for the determination of the decay heat released by fission products during nuclear fuel cycle. The Modular Total Absorption Spectrometer (MTAS) has been recently constructed at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory. It consists of 19 NaI(Tl) hexagonal shape modules, with a full energy gamma ray efficiency approaching 90% around 300 keV [1]. The decays of over twenty ^{238}U fission products have been studied with MTAS during the first online experiment at the HRIBF. Already online data for some isotopes show significant discrepancy between the observed beta feeding and the corresponding database values. In this contribution the first results for nuclei with mass ranging from 86 to 90, including ^{86,87}Br, ^{89,90}Kr, will be presented. The impact of this new data on the decay heat calculation will be discussed as well. ∗ This work was supported by the U.S. Department of Energy Office of Nuclear Physics.
[1] M. Wolińska-Cichocka *et al.*, "Modular total Absorption Spectrometer at HRIBF", this conference

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DD 3 4:20 PM

Correlations Between Nuclear Charge Radii, E0 Transitions and Summed M1 Strengths

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A systematic study of energy spectra throughout the rare-earth region (even-even nuclei from 58Ce to 74W) is carried out in the framework of the interacting boson model (IBM), which gives a global description of the spherical-to-deformed shape transition in the different isotopic chains. The resulting IBM Hamiltonian is then used for the calculation of nuclear charge radii (including isotope and isomer shifts) and E0 transitions with consistent operators for the two observables [1,2]. Following ideas developed by Ginocchio [3], an additional correlation is pointed out between both of these properties (i.e., charge radii and E0 transitions) with the summed M1 strength from the ground state of even-even nuclei to the scissors mode. This leads to correlation plots between isotope shifts and summed M1 strength differences on the one hand, and between ρ^2(E0) values and summed M1 strengths on the other hand. Examples of such correlation plots are shown for rare-earth nuclei.

[1] S. Zerguine, P. Van Isacker, A. Bouldjedri, and S. Heinze, Phys. Rev. Lett. 101, 022502 (2008). [2] S. Zerguine, P. Van Isacker, and A. Bouldjedri, Phys. Rev. C 85, 034331 (2012). [3] J.N. Ginocchio, Phys. Lett. B 265, 6 (1991).

DD 4 4:40 PM

First Total Absorption Spectroscopy Measurement of the Beta Decay of ^{139}Xe

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The Modular Total Absorption Spectrometer (MTAS) has been recently constructed and commissioned at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory [1]. The main scientific goal of MTAS is to determine the true beta-decay feeding and following gamma radiation pattern for the decays of fission products. This is important not only for understanding of the relevant nuclear structure and beta decay processes, but also for the determination of the decay heat release during a nuclear fuel cycle. Existing theoretical simulations of decay heat show, in fact, significant deviations from experimental data [2-4]. These discrepancies are believed to be partially due to the incorrect or incomplete beta decay schemes. In this contribution we would like to present the results of the measurement of ^{139}Xe beta decay, which was identified among "most wanted" for the analysis of decay heat in nuclear reactors [2]. ^{139}Xe nuclei, among others [5], were produced at HRIBF in the proton-induced fission of ^{238}U, mass separated and implanted onto a moving tape, which periodically transported the activity to the centre of MTAS. The results and their impact on the decay heat calculations will be presented and discussed.

[1] M.Wolinska-Cichocka et al., contribution to this conference [2] "Assessment of fission product decay data for decay heat calculations" OECD 2007, NEA No 6284, vol. 25, ISBN 978-92-64-99034-0 [3] A. Algora et al., Phys. Rev. Lett., 105, 202501, 2010. [4] K. P. Rykaczewski, Physics 3, 94, 2010. [5] M. Karny et al., contribution to this conference.

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Further Test of Internal-Conversion Theory with a Measurement in ^{119}Sn^m

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Internal conversion is a general property of the atomic nucleus and its electronic shells, which has become of increased interest, particularly in the last decade. In order to balance decay schemes, one needs to know the internal conversion contribution to each transition as expressed by its internal conversion coefficients (ICC). For some transitions used in critical applications or basic nuclear science, very precise and accurate values of ICC's are crucial. However, ICC's are only rarely measured and are instead taken from calculations, so for decades people have relied on tabulated ICC's. Unfortunately the tabulated values can differ quite significantly from calculation to calculation so precision is hard to guarantee. Thus one must seek guidance from very precisely measured ICC's, which can distinguish among the various calculations. But in 2002, when a survey of measured ICC's was made [1], only about 20 out of hundreds of published measured values were found with a reported precision of 2% or better, so an extended set of 100 ICC values of precision not worse than 6% was finally adopted for comparison with theories. Of particular importance for calculations is the treatment of the electronic vacancy, which is known to survive long enough after the electronic conversion takes place that it should really be taken into account in determining the potential seen by the outgoing conversion electron. However the 2002 survey showed better agreement with calculations that ignored the electronic vacancy and, as a result, the most recent published tables [2] were deliberately calculated without the inclusion of the vacancy. This apparent contradiction prompted us 2003 to begin a series of ICC measurements aimed at high precision (1%) that focuses on transitions that are particularly sensitive to the theoretic treatment of the atomic vacancy. Our method consists of measuring α_K ICC's based on the ratio of the intensity of the K x rays produced as a result of internal conversion, and the corresponding gamma-ray intensity. This is possible using an HPGe detector whose high-precision calibration of the detection efficiency has been reported in [3]. The method is suitable for radioactive sources with a single transition that converts in the K shell. We use neutron activated sources, which introduces some impurities that need to be dealt with. For energies below 50 keV there are also important contributions from the scattered radiation that contribute to the K x-rays peaks, which we characterize specifically from case to case. We use redundancy checks and simulation calculations to address these issues. With this method we have measured [4] α_K's in ^{134}Cs, ^{137}Ba, ^{193}Ir, and ^{197}Pt. Here we report on a new ICC measurement, the 65.7-keV, M4 transition in ^{119}Sn for which we find $\alpha_K = 1604(30)$. This is in agreement with the calculated value that includes the vacancy (by the so-called "frozen-orbital" method), 1618, and differs from the calculated value that ignores the vacancy, 1544. The same conclusion resulted from all the cases we have measured previously, thus demonstrating that the calculations including the atomic vacancy should be used for tabulated values.

[1] S. Raman *et al.*, Phys. Rev. C bf 66 (2002) 044312. [2] I.M. Band *et al.*, At. Data Nucl. Data Tables, bf 81 (2002) 1. [3] R.G. Helmer *et al.*, Nucl. Instrum. Methods Phys. Res. A **511** (2003) 360. [4] N. Nica *et al.* Phys. Rev. C: **70** 2004 054305; **77** 2008 034306; **80** 2009 064314.

DD 6 5:15 PM

Gamma-ray Spectroscopy of ^{30}P

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Yasuyuki Abe, Shota Fukuoka, Yoko Ishibashi, Tetsuro Komatsubara, Daisuke Nagae, Akira Ozawa
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^{30}P is an N=Z=15 odd-odd nuclide whose level density is reasonably high (34 proton-bound excited states, S(p)=5594.5 keV). Also states with isospin T=0 and T=1 coexist from the ground state upwards. Therefore ^{30}P spectroscopy provides an experimental test of the effect of isospin symmetry breaking on level structure. Moreover, the proton-resonance structure of ^{30}P determines the ^{29}Si(p,γ)^{30}P reaction rate at a temperature characteristic of explosive hydrogen burning in supernovae type Ia. The ^{29}Si(p,γ)^{30}P reaction has recently [1] been identified as one of top ten proton-capture reactions important for supernova nucleosynthesis. We have studied ^{30}P levels up to 7.2 MeV via in-beam γ-ray spectroscopy using the ^{28}Si(^{3}He,pγ)^{30}P reaction at the University of Tsukuba Tandem Accelerator Complex in Japan. An energy level scheme was deduced from γ-γ coincidence measurements. Furthermore, spin assignments based on measurements of γ-ray angular distributions and γ-γ directional correlation of oriented nuclei (DCO ratios) were made for many of the observed levels of ^{30}P. This contribution presents results of γ-ray study of the ^{28}Si(^{3}He,pγ)^{30}P reaction using high-resolution HPGe detectors for this reaction for the first time.
Corresponding author: Balraj Singh

[1] E. Bravo and G. Martinez-Pinedo, Phys. Rev. C **85**,055805(2012)

Session DE Neutron Cross Section Measurements
Monday March 4, 2013
Room: Central Park East at 3:30 PM
Chair: Said Mughabghab, NNDC - BNL
DE 1 3:30 PM

Measurement and Analysis of Gamma-ray Cross Sections

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We have measured prompt and delayed thermal neutron-capture γ-ray cross sections on all stable elemental targets and selected enriched isotopic and radioactive targets with guided neutron beams from the Budapest and Munich Reactors. These data are maintained in the LBNL/IAEA Evaluated Gamma-ray Activation File (EGAF). The first version of EGAF data analysis is now complete and available at http://www-nds.iaea.org/pgaa/tecdoc.pdf. We have begun a new effort to expand EGAF and exploit the richness of this database for determining additional quantities important to both the nuclear data and physics communities. Total radiative thermal neutron cross sections, σ_γ, are determined from the neutron-capture γ-ray decay schemes supplemented with statistical model calculations of continuum contributions using the Monte Carlo code DICEBOX developed at Charles University in Prague. The calculations require reliable nuclear structure information, typically available in the Evaluated Nuclear Structure Data File (ENSDF). Our analysis improves the ENSDF file by using the EGAF data and detailed statistical model calculations. The newly evaluated nuclear structure data can then be included in both the ENSDF and Reaction Input Parameter Library (RIPL) files. The EGAF database also provides valuable model-independent information on the photon strength functions (PSFs) for primary gamma transitions and constraints on PSFs for low-energy transitions to-, from- and between nuclear levels in the quasicontinuum. The PSFs form an important ingredient of statistical model calculations. Nevertheless, reliable data on them in wide-enough energy region are still scarce. Both prompt and delayed γ-rays are measured simultaneously in our experiments, so we can determine the γ-ray transition probabilities $P_\gamma=\sigma_\gamma/\sigma_0$ necessary to normalize the decay schemes of activation products. New evaluations of activation decay data will be provided to the Decay Data Evaluation Project (DDEP). Our measurements also include precise determinations of primary γ-ray energies allowing us to provide precise neutron separation energies, Sn, to the Atomic Mass Data Center. In this paper we will discuss the recent progress that we have made measuring and evaluating EGAF data and our plans for disseminating this information to the nuclear science and engineering communities. *This work was performed under Contracts No. DE-AC02-05CH11231 and DE-AC52-07NA27344 with the U.S. Department of Energy, and supported by NAP VENEUS OMFB 00184/2006.*

DE 2 4:00 PM

Determination of (n,γ) Cross Sections of ^{241}Am by PGAA

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Accurate cross section data of actinides are crucial for criticality calculations of GEN IV reactors and transmutation but also for analytical purposes such as nuclear waste characterization, decommissioning of nuclear installations and safeguard applications. Tabulated data are inconsistent and sometimes associated with large uncertainties. In beam techniques, like prompt gamma activation analysis (PGAA) using external neutron beams from high flux reactors offer a chance for determination of absolute partial gamma ray production cross sections with a minimum of uncertainty to around 2 to 3%. Comparative experiments have been conducted at two independent research reactors to investigate the potential of PGAA for accurate cross section determination of actinides using well prepared ^{241}Am sources. Preparation of samples for irradiation at the Budapest Reactor and FRM II in Garching of the Am sources has been optimized together with PTB in Braunschweig. Samples were irradiated together and without flux monitors to extract the relevant nuclear data after appropriate corrections for self-absorption and attenuation of neutrons in the sample holder. Experimental parameters and results will be presented and discussed. This work was supported by the Federal Ministry for Education and Research, BMBF, Germany

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DE 3 4:20 PM

Impact of Prompt-Neutron Corrections on Final Fission-Fragment Distributions

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The determination of post-neutron fragment yields has a great impact on the reliable assessment of the nuclear waste inventory and on the correct prediction of delayed neutron pre-cursor yields. A large number of fission yields, included in evaluated nuclear data libraries, were measured without the knowledge on the neutron emission as a function of fragment mass $\bar{\nu}(A)$. Instead, $\bar{\nu}(A)$ had to be parametrized based on a few known reactions on e. g. ^{233,235}U and ^{239}Pu. The prompt neutron multiplicity is a crucial quantity in nuclear fission and is a function of mass, TKE and incident neutron energy, $\nu(A, TKE, E_n)$. Although it is well known that the total number of prompt fission neutrons, $\bar{\nu}_{tot}$, increases with incident neutron energy, the enthralling question has always been, how the additional excitation energy is shared between the fission fragments. Traditionally, the excess neutrons are assumed to be distributed equally across the mass distribution. But a few experiments have shown that the extra neutrons are exclusively emitted by the heavy fragments [1, 2]. Recently, several theoretical works tried to explain these observations [3-5]. For instance, in the "energy-sorting" process proposed in Ref. [4], the heavy fragment is assumed to have a lower nuclear temperature than the light one. As a result the excitation energy is transferred from the light to the heavy fragment, resulting in higher neutron emission. Up to date, the correct neutron emission model is still under debate. It is a crucial link in our understanding of the fission process as well as for established evaluated data files. Therefore, it is of importance to study the impact on fission observables, when applying either of the two neutron evaporation models. In this work we investigated the consequences of the two different models on the fission-fragment distributions from the reaction $^{234}U(n, f)$. The measurements were performed by means of a double Frisch-grid ionization-chamber at the MONNET neutron source of the Joint Research Centre IRMM. We found that the choice of neutron-emission correction has a strong impact on the mass and energy distributions. The effect of neutron correction seems to affect mainly the post-neutron distribution, therefore, motivating new experiments dedicated to the measurement of prompt-fission neutrons in coincidence with fragment properties.
[1] A.A. Naqvi, F. Käppeler, F. Dickmann and R. Müller, Phys. Rev. C 34 (1986) 218-225. [2] R. Müller, A.A. Naqvi, F. Käppeler, F. Dickmann, Phys. Rev. C 29 (1984) 885-905. [3] K.-H. Schmidt and B. Jurado, Phys. Rev. Lett. 104, 212501 (2010). [4] K.-H. Schmidt and B. Jurado, Phys. Rev. C 83:061601 (2011). [5] C. Manailescu, A. Tudora, F.-J. Hambsch, C. Morariu and S. Oberstedt. Nucl. Phys. A867 1 (2011) 12.

DE 4 4:40 PM

Neutron Irradiation Experiments: Automated Processing and Analysis of γ-Spectra

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The 14 MeV neutrons generated in the plasma of future fusion reactors will initiate nuclear reactions in the materials of the surrounding first wall and vacuum-vessel components, leading to compositional changes in the constituent materials. Accurate predictions of this transmutation and the resulting activation are vital to inform the engineering design and material choice for fusion reactors. Neutron transport simulations combined with inventory calculations, with codes such as MCNP and FISPACT, respectively, can produce the necessary quantitative predictions, but the reliability of these is largely dependent on the quality of the nuclear reaction cross section data. In many (most!) cases, the data for a particular reaction, in a database such as the European Activation File (EAF), is either largely or entirely based on theoretical calculations because little or no experimental data exists. In an effort to further improve the quality of data for fusion relevant materials, CCFE has undertaken a series of neutron irradiation experiments at the ASP experimental facility, which is hosted by AWE at their Aldermaston site in the UK. Here, a deuteron beam is directed onto a tritium target, leading to the DT fusion reaction and the production of 14 MeV neutrons. The γ-spectra emitted from sample-foils irradiated in this environment have been measured. To date around 160 irradiations have been performed, producing more than 8500 individual γ-spectra. The characteristic peaks from a single energy spectrum resulting from a foil experiment *can* be analysed by hand using proprietary software packages, but the processing of the complete data set has necessitated the creation of a set of automated processing tools. Apart from the ability to handle all of the data in consistent and well-understood manner, which may not always be the case with commercial software, the automated approach also has the advantage of allowing the data to be rapidly and easily reprocessed, as is often required as the quantification of the experimental conditions is refined. In this paper we discuss the various methods used to process and analyze the data, including peak separation, flux measurement using reference peaks, and decay-corrected activity and half-life measurement via data fitting. Additionally, we illustrate, with examples, how the automated processing gives a fuller picture of the variation in peak-count rate for a particular experiment, sometimes revealing extra information that may not have been evident in the analysis of a single spectrum. This work was funded by the RCUK Energy Programme under grant EP/I501045 and the European Communities under the contract of Association between EURATOM and CCFE. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

DE 5 5:00 PM

Determination of the ^{151}Eu(n,γ)^{152m1,g}Eu and ^{153}Eu(n,γ)^{154}Eu Reaction Cross Sections at Thermal Neutron Energy

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We have measured partial γ-ray cross sections following neutron capture in enriched targets of ^{151}Eu and ^{153}Eu at the cold neutron beam facility of the Budapest Neutron Center using a Compton-suppressed HPGe and a LEPS detector. These cross sections have been measured at thermal-neutron energy, corrected for the effective g-factor, and relative to the partial neutron-capture cross section of 2991 $\pm$ 60 barns for the 89.8-keV transition in ^{151}Eu. This partial cross section has been obtained by irradiating a europium oxide (Eu_2O_3) solution in 20% H_2SO_4 and relative to the cross section of 0.3326 $\pm$ 0.0007 barns for the 2223-keV transition from thermal neutron capture in ^{1}H. The total radiative capture cross sections of the ^{151}Eu(n,γ)^{152m1,g}Eu and ^{153}Eu(n,γ)^{154}Eu reactions were determined by combining experimental data with theoretical modeling of the γ-ray cascade: calculated intensities (using the DICEBOX Monte Carlo statistical code) for transitions from the continuum region were added to the measured transition intensities from known levels to the ground- or metastable-state. The individual ^{151}Eu(n,γ)^{152m1}Eu and ^{151}Eu(n,γ)^{152g}Eu reaction cross sections are found to be in disagreement with the recommended value by Mughabghab[1]. However, the total cross section of the ^{151}Eu(n,γ)$^{152m1+g}$Eu reaction is in good agreement. Also, our determined cross section for the ^{153}Eu(n,γ)^{154}Eu reaction is in good agreement with the recommended value. In the course of this work, the gamma decay schemes for the low-energy levels in ^{152}Eu and ^{154}Eu have been verified and evaluated. Another standardization measurement of the partial neutron capture cross section for the 89.8-keV transition using a stoichiometric compound of europium in solid form is in progress. This measurement will be useful for a better estimation of the effective g-factor and verification of the measured cross sections as well.

[1] S.F. Mughabghab - Atlas of Neutron Resonances, 5th edition, Resonance Parameters and Thermal

Cross Sections, Z = 1-100, Elsevier, Amsterdam (2006)
This work was performed under Contracts No. DE-AC02-05CH11231 and DE-AC52-07NA27344 with the U.S. Department of Energy, and supported by NAP VENEUS OMFB 00184/2006

DE 6 5:15 PM

New Measurement of the Thermal-Capture Cross Section for the Minor Isotope ^{180}W

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Tungsten occurs naturally in five isotopic forms; four of these isotopes, ^{182,183,184,186}W, contribute significantly to the overall elemental abundance (between 14 $\sim$ 30 %), while ^{180}W, occurring at the 0.12-% level, is only a minor isotope. Given its very low abundance, a precise measurement of the total radiative thermal neutron-capture cross section has, hitherto, proven extremely challenging. This work reports a new value of the thermal-capture cross section from a direct ^{180}W(n,γ) measurement using a guided-thermal beam at the Budapest Research Reactor, incident upon an 11.35-% enriched sample to induce prompt γ-ray activation within the sample. The thermal-capture cross section was then determined as the sum of experimentally observed partial neutron-capture γ-ray cross sections feeding the ground state directly, in addition to the modeled contribution from the (unobserved) quasi continuum feeding the ground state according to statistical-model predictions using the Monte Carlo program DICEBOX. A similar approach was also recently adopted in the analysis of enriched samples of the other major tungsten isotopes, leading to new structural insights, in addition to new independent thermal-capture cross sections for these isotopes. A summary of these findings will also be presented. This work was performed under the auspices of the University of California, supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U. S. Department of Energy at Lawrence Berkeley National Laboratory under Contract DE-AC02-05CH11231, the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, and by NAP VENEUS OMFB 00184/2006.

DE 7 5:30 PM

The Photon Strength Function at Low Energies

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Over the last decade several measurements in light- and medium-mass nuclei have reported an enhanced ability for the absorption and emission of gamma radiation (photon strength function PSF) at low energies. The impact of this effect may have profound implications on neutron capture reaction rates which are not only responsible for the formation of elements heavier than iron in stellar and supernova environments [1] but are also of central importance for advanced fuel cycles in nuclear reactors [2]. The results were received with significant skepticism by the community mainly due to the lack of any known mechanism responsible for such an effect but also because another established experimental technique failed to confirm the measurement. Now, a new experimental method which is free of model input and systematic uncertainties has been developed to determine the PSF. It is designed to study statistical feeding from the quasi-continuum (below the particle separation energies) to individual low-lying discrete levels. A key aspect to successfully study gamma decay from the region of high-level density is the detection and extraction of correlated high-resolution particle-gamma-gamma events which is accomplished using an array of Clover HPGe detectors and large area segmented silicon detectors. The excitation energy of the residual nucleus produced in the reaction is inferred from the detected proton energies in the silicon detectors. Gating on gamma-transitions originating from low-lying discrete levels specifies the states fed by statistical gamma-rays. Any particle-gamma-gamma event satisfying these and additional energy sum requirements ensures a clean and unambiguous determination of the initial and final states of the observed gamma rays. With these constraints the statistical feeding to discrete levels is extracted on an event-by-event basis. In this talk the latest results for 95Mo [3] are presented and compared to PSF data measured at the University of Oslo [4]. In particular, questions regarding the existence of the low-energy enhancement in the photon strength function will be addressed. This work is supported by the U.S. Department of Energy Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344, University of Richmond under DEFG52-06NA26206 and DE-FG02-05ER41379, Lawrence Berkeley National Laboratory under Contract No. DE-AC02-05CH11231, and by the National Research Foundation of South Africa.

[1] M. Arnould, S. Goriely and K. Takahashi, Physics Reports 450, 97213 (2007). [2] M.B. Chadwick et al., Data Nuclear Data Sheets 112, 2887 (2011). [3] M. Wiedeking et al., Phys. Rev. Lett. 108, 162503 (2012). [4] M. Guttormsen et al., Phys. Rev. C 71, 044307 (2005).

DE 8 5:45 PM

Recent Results on Studying Photon Strength Functions in Rare-Earth Nuclei

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Charles University in Prague

According to the statistical model of the nucleus the photon strength functions (PSFs) and nuclear level densities are the only entities that describe average properties of gamma-decay of highly or moderately excited levels in medium-weight and heavy nuclei. In this contribution recent results on PSFs in rare-earth nuclei are presented. The available experimental information come from various reactions. Our focus is on results from different (n,γ) experiments, specificaly resonance capture experiment performed at the LANSCE/DANCE neutron time-of-flight facility in Los Alamos (e.g. [1]), the average neutron capture experiment at Karlsruhe Van de Graaff facility (e.g. [2]) and TSC experiments performed at LVR-15 reactor in Řež (e.g. [3]). The emphasis is given to the following questions about dipole PSFs: What is the favored shape of low energy tail of GDER, i.e. behaviour of E1 PSF? Are there any resonances present in dipole PSFs around and below neutron separation energy and if so what are their properties? The results are confronted with those from nuclear resonance fluorescence[4] and ^{3}He induced gamma emission[5].

[1] Chyzh A., Baramsai B., Becker J. A. et al., PRC 84, 014306 (2011) [2] K. Wisshak et al., PRC 73, 045807 (2006) [3] Kroll J. et al., FRONTIERS IN NUCLEAR STRUCTURE, ASTROPHYSICS, AND

REACTIONS (FINUSTAR 3), AIP Conference Proceedings vol. 1377 p. 371 (2011) [4] U. Agvaanluvsan et al., Phys. Rev. C70, 054611 (2004) [5] U. Kneissl, H.H. Pitz, A. Zilges, Prog. Part. Nucl. Phys. 37, p. 349 (1996)

Session EA Plenary Tuesday
Tuesday March 5, 2013
Room: Met East at 8:30 AM
Chair: Andrej Trkov, Jozef Stefan Institute
EA 1 8:30 AM

WPEC SG33 on: Methods and Issues for the Combined Use of Integral Experiments and Covariance Data

M. Salvatores, G. Palmiotti, E. Dupont, M. Ishikawa, C. De Saint-Jean, R. D. McKnight, S. Pelloni, (on behalf of the members of the subgroup*)
CEA, INL, NEA, JAEA, ANL, PSI

The Working Party on International Nuclear Data Evaluation Cooperation (WPEC) of the OECD NEA Nuclear Science Committee has established a Subgroup (called "Subgroup 33") on "Methods and issues for the combined use of integral experiments and covariance data" in 2009. In its mandate "it is proposed for this WPEC subgroup to study methods and issues of the combined use of integral experiments and covariance data, with the objective of recommending a set of best and consistent practices in order to improve evaluated nuclear data files. Indication should be provided on how to best exploit existing integral experiments, define new ones if needed, provide trends and feedback to nuclear data evaluators and measurers." Based on major conclusions reached by the activity of the WPEC Subgroup 26 on "Uncertainty and Target Accuracy Assessment for Innovative Systems Using Recent Covariance Data Evaluations," this is the first international expert activity in this field. It reflects the growing interest for science-oriented methodologies in order to improve nuclear data for a wide range of applications and to meet more and more stringent requirements for safety and economic purposes, without necessarily deploying new resources for performing expensive and time consuming experiments. The first stage has been devoted for producing the description of different adjustment methodologies and assessing their merits. A detailed document related to this first stage has been issued. Eight leading organizations (often with a long and recognized expertise in the field) have contributed to the document: ANL, CEA, INL, IPPE, JAEA, JSI, NRG, and ORNL. Among the different information provided in the document we can list: identification of merit and drawbacks of existing methodologies, comparison of mathematical formulations and specific features (such as a-posteriori correlation matrices), criteria for assessing methodologies. In the second stage a practical exercise was defined in order to test the reliability of the nuclear data adjustment methodology. The goal of the exercise is:

- Assess if in a multigroup nuclear data adjustment one ends up with the same (or very close) set of isotope cross sections when a common shared set of integral experiments is used and different data adjustment methodologies are used.

- Assess the impact of using different starting evaluated libraries and/or different covariance matrices. The convergence of trends (e.g. cross section energy shapes) is investigated.

- Assess if the attained reduced uncertainties on a target design for a set of integral parameters of interest is consistent among the different solutions.

A set of 20 well defined integral parameters from 7 fast assembly experiments was used in the exercise to adjust the main nuclear data (major cross section reactions including capture fission elastic and inelastic scattering, but also relevant mu-bar, nu-bar and fission spectrum) of 11 major isotopes in a 33 group energy structure. Seven organizations have already provided their solution at different degrees of completeness. Three more plan to participate. In the final paper comparison of results and major lessons learned in the exercise will be provided. *Member Organizations: ANL, BNL, CEA, CIAE, INL, IPPE, IRSN, JAEA, JSI, KAERI, NRG, ORNL, PSI

EA 2 9:15 AM

Electron-Antineutrino Disappearance Seen by Daya Bay Reactor Neutrino Experiment

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The Daya Bay Reactor Neutrino Experiment has measured a nonzero value for the neutrino mixing angle with a significance of 7.7 standard deviations. Antineutrinos from six 2.9 GW reactors were detected by six 20-ton target-mass detectors of identical design, deployed in two near and one far underground experimental halls. With a 116.8 kton-GW-day live-time exposure in 139 days, 28909 and 205308 electron-antineutrino candidates were detected at the far hall and near halls respectively. The ratio of the observed to expected number of antineutrinos at the far hall is $R = 0.944 \pm 0.007(stat) \pm 0.003(syst)$. A rate-only analysis finds $\sin^2 2\theta_{13} = 0.089 \pm 0.010(stat) \pm 0.005(syst)$ in a three-neutrino framework. The experiments will continue for several years and more precise neutrino mixing angle θ_{13} will be given in the future.

Session FA Diseminations, New Formats and International Collaborations
Tuesday March 5, 2013
Room: Met East at 10:30 AM
Chair: Balraj Singh, McMaster U.
FA 1 10:30 AM

Developments of the EXFOR Database: Possible New Formats

R. A. Forrest, V. Zerkin, N. Otsuka, S. Simakov
IAEA Nuclear Data Section

The EXFOR database is a collection of experimental nuclear reaction data, maintained by the IAEA on behalf of the International Network of Nuclear Reaction Data Centres (NRDC). The format for the storage of such data was first described in 1969 and while there have been many incremental changes over the years so that the format is now capable of containing a very wide range of measurement results, there is a growing realisation that a major change is required. Consequently the IAEA NDS organised a Consultant's Meeting on "Further Development of EXFOR" in March 2012. This was an opportunity for a range of international experts to discuss ways of improving EXFOR and while this focussed on new formats there was also discussion on ways of storing new data, new output formats and software tools such as editors. This paper will discuss recent and proposed changes to enable new quantities to be stored (such as coincidence measurements and covariances), the range of output formats available (such as C4 and X4+) which make interaction with the data more user friendly and the possible use of XML to modernise the database.

FA 2 11:00 AM

Nuclear Structure Databases and Services at NNDC

Jagdish K. Tuli
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The primary mission of the National Nuclear Data Center (NNDC) at Brookhaven National Laboratory (BNL) is to compile, evaluate, and disseminate nuclear structure, radioactive decay, and nuclear reaction data. This presentation will confine to nuclear structure-related activities only at NNDC. The principal effort at NNDC in this regard is devoted to maintain, update, and disseminate the following databases: the Evaluated Nuclear Structure Data File (ENSDF), the Nuclear Science Reference (NSR) file, and the Experimental Nuclear Data List (XUNDL). NSR is a bibliographic database which includes most nuclear physics experimental as well as theoretical papers. The relevant articles are keyworded for easy search and assigned unique key numbers for easy reference. The references from the file can be retrieved by various criteria via user-friendly query program. The ENSDF is a collection of useful evaluated properties of all known nuclides with their supporting experimental data. The XUNDL provides unevaluated experimental data in ENSDF format as soon as the paper appears in literature. The retrievals from ENSDF and XUNDL are provided through NNDC web service in various different formats. Many of these databases are best accessed via NuDat, a state-of-art retrieval database using the latest data and technology. The evaluations in ENSDF are published in the Elsevier journal *Nuclear Data Sheets*. These together with compilations in XUNDL and bibliographic information in NSR are disseminated to the Nuclear Physics community worldwide via the web and other media including the derived publications, *e.g.*, the *Nuclear Wallet Cards*. This presentation will briefly review some of these databases, the publications based on these, and their dissemination online. This work is supported by the Office of Nuclear Physics, Office of Science, US Department of Energy under contract no. DE-AC02-98CH10886

FA 3 11:20 AM

A New Infrastructure for Handling Nuclear Data

C.M. Mattoon, B.R. Beck, G. Hedstrom
Lawrence Livermore National Laboratory

With the recent formation of WPEC subgroup 38, the nuclear data community has begun the process of defining a flexible new international standard for storing nuclear data that eliminates the limitations imposed by older formats. Lawrence Livermore National Laboratory (LLNL) has made an initial effort towards defining a new format, resulting in the 'Generalized Nuclear Data' (GND) structure for storing evaluated nuclear reaction data. By itself, a new format is of limited use. The nuclear data infrastructure must also be updated to support using, modifying, visualizing and processing data stored in the format. This talk focuses on the infrastructure that is being developed at LLNL for handling evaluated nuclear reaction data in GND. In particular, we discuss the LLNL code FUDGE, which was recently upgraded to support GND-formatted data. FUDGE is now capable of reading and writing GND files, as well as modifying and visualizing the data structures contained in those files. Many basic operations have also been implemented, including converting parameterized data types such as resonance parameters or Kalbach-Mann angular distributions into pointwise data. FUDGE also supports converting legacy formats both to and from GND, so that GND can be used along-side those legacy formats. Much work still remains towards building the new infrastructure for nuclear data. In particular, the ability to process the data for use by Monte Carlo and/or deterministic transport codes is not yet complete. After processing, the data must either be translated back into legacy processed formats, or a new API must be defined for using

processed data in GND. Progress towards all these goals will be discussed. This work has been supported by Department of Energy contract No. DE-AC52-07NA27344 (Lawrence Livermore National Laboratory).

FA 4 11:40 AM

Cloud Computing for Nuclear Data

M.S. Smith
Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA

The Nuclear Data Cloud Computing Consortium (NDC3) was established to explore the tremendous potential of online systems in the field of Nuclear Data. Running scientific, processing, and simulation codes online on remote servers - "in the cloud" - may provide the methodology breakthrough needed to enable data compilation, evaluation, processing, dissemination, and visualization activities to keep pace with the flood of new, more complex data in an era of decreasing manpower. There are many possibilities for significant productivity gains in nuclear data, including: running analysis and application codes remotely with no installation hassles; devising digital "assistants" to collect masses, level schemes, and references; enabling experts to upload supplemental information for evaluations; providing quick access to major databases; auto-filling of evaluation templates; designing custom dataset views; using "virtual experts" for evaluation guidance; sharing datasets too large for email; visually tracking the progress of evaluations; processing evaluated data in a "pipeline" for end-use applications; and running simulations with custom collections of nuclear data input. First-generation versions of many of these tools already exist online and will be discussed, along with an outlook for the future of cloud computing in this field and how you can contribute at ndc3.net. This work is supported by the US DOE Office of Nuclear Physics.

Session FB Benchmark and Testing
Tuesday March 5, 2013
Room: Met West at 10:30 AM
Chair: Oscar Cabellos, Madrid PU
FB 1 10:30 AM

Integral Data Testing of ENDF/B-VII.1 Files - Success Stories and Need to Improve Stories

A.C. Kahler, R.E. MacFarlane, M.B. Chadwick
Los Alamos National Laboratory

LA-UR-12-23712
The ENDF/B-VII.1 [1,2] nuclear data library was released in December, 2011 ... five years after the release of ENDF/B-VII.0 [3]. Integral data testing of the library has relied heavily upon Critical Safety benchmarks defined in the International Criticality Safety Benchmark Evaluation Project Handbook [4]. We have calculated the critical eigenvalue for hundreds of these benchmarks, spanning a range of fuel systems (^{233}U, HEU, LEU, ^{239}Pu) under various moderating and reflected conditions. The desired outcome of any critical eigenvalue calculation will be (i) accurate results obtained with previous evaluated cross sections should remain accurate, irrespective of any changes in the underlying evaluated cross section files; (ii) poor results should be improved if there are substantial changes in the underlying cross section evaluations, and (iii) poor results should not improve if there have not been any changes in the underlying nuclear data. We show examples of all three outcomes, with particular emphasis on benchmarks containing ^{233}U, ^{239}Pu, beryllium and lead. Benchmarks containing these materials were not calculated as accurately as desired with ENDF/B-VII.0 and they received limited attention during the development of ENDF/B-VII.1. We

now have a several year window were evaluators and data validators can iterate on potentially improved data sets that could become incorporated in the next generation evaluated data file. We also show comparisons between the latest ENDF/B-VII.1, JEFF-3.1.2 and JENDL-4.0 libraries. There remain significant differences in selected cross sections from the "Big 3" nuclides, ^{235,238}U and ^{239}Pu that the international community should work to resolve in the next several years. In some instances, the bare ^{239}Pu sphere commonly known as Jezebel for example, accurate eigenvalues are obtained with all three libraries. This suggests that at least one, and more likely all three, evaluated files is yielding an accurate eigenvalue for the wrong reason; an observation that casts doubt on the predictive capability of all three files.
[1] M.B.Chadwick *et al.*, "ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Yields and Decay Data," *Nuclear Data Sheets*, **112**, 2887 (2011). [2] A.C.Kahler *et al.*, "ENDF/B-VII.1 Neutron Cross Section Data Testing with Critical Assembly and Reactor Experiments," *Nuclear Data Sheets*, **112**, 2997 (2011). [3] M.B.Chadwick *et al.*, "ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology," *Nuclear Data Sheets*, **107**, 2931 (2006). [4] J.B.Briggs, editor, "International Handbook of Evaluated Criticality Safety Benchmark Experiments,"/ NEA/NSC/DOC(95)03, revised and updated annually.

FB 2 11:00 AM

Comparison of ENDF/B-VII.1 and ENDF/B-VII.0 Results for the Expanded Criticality Validation Suite for MCNP and for Selected Additional Criticality Benchmarks

Russell D. Mosteller
(retired)

Results obtained with the ENDF/B-VII.0 and ENDF/B-VII.1 nuclear data libraries are compared for a substantial number of criticality benchmarks. Results from the ENDF/B-VI nuclear data library also are included for historical perspective. The calculations were performed with the MCNP Monte Carlo code. The cases include the 119 benchmarks in the expanded criticality validation suite for MCNP and 23 additional benchmarks. Specifications for all of the benchmarks are taken from the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*. The full paper will contain the results for all 142 benchmarks. The 119 benchmarks in the expanded criticality validation suite are divided into five classes of fuel: ^{233}U, highly enriched uranium (HEU), intermediate enriched uranium (IEU), low enriched uranium (LEU), and plutonium. The ^{233}U, HEU, IEU, and plutonium benchmarks are subdivided farther according to spectrum – fast, intermediate, or thermal. The LEU category includes only thermal cases, since LEU can reach a critical condition only with a thermal spectrum. Succinct descriptions of each of the 119 cases are provided in *An Expanded Criticality Validation Suite for MCNP* (LA-UR-10-06230), which can be obtained from the NNDC. The suite includes three fast, one intermediate, and two thermal subcategories for ^{233}U, HEU, IEU, and plutonium systems and two thermal subcategories for LEU systems. The three subcategories for fast benchmarks are characterized by the type of reflection: unreflected, reflected by a heavy material, and reflected by a light material. The two subcategories for thermal benchmarks are lattices and solutions. The intermediate subcategory has a variety of configurations because only a relatively small number of critical experiments with intermediate spectra have been performed. The suite contains at least one benchmark in each of those subcategories for each fuel type. ENDF/B-VII.1 was found to produce improvements relative to ENDF/B-VII.0 for benchmarks that contain significant amounts of tungsten, zirconium, cadmium, or beryllium. The results for the benchmarks with beryllium suggest that further improvements still may be needed. A number of deficiencies previously identified for the ENDF/B-VII.0 library still remain in ENDF/B-VII.1. Those deficiencies include ^{235}U cross sections in the unresolved resonance region, thermal cross sections for ^{239}Pu, and fast cross sections for copper, ^{237}Np, and ^{232}Th.

Fast cross sections for graphite and nickel also may need to be reviewed. The ENDF/B-VII.1 results for the remaining benchmarks in the expanded criticality validation suite show only minor or negligible changes in k_{eff} relative to ENDF/B-VII.0.

FB 3 11:20 AM

A Feasibility and Optimization Study to Design a Nondestructive ATR Fuel Permanent Scaning System to Determine Cooling Time and Burnup

Jorge Navarro, Terry A. Ring, David W. Nigg
Idaho National Laboratory, P. O. Box 1625, Idaho Falls, ID 83415

The goal of this project was to develop the best available non-destructive technique process to determine burn-up and cooling time of the Advanced Test Reactor (ATR) fuels at the Idaho National Laboratory and to make a recommendation of the feasibility of implementing a permanent fuel scanning system at the ATR canal. This process led to the preliminary design of a permanent fuel scan system. The process started with determining if it was possible to obtain useful spectra from ATR fuel elements at the canal adjacent to the reactor [1]. Once it was established that good quality spectra can be obtained at the ATR canal, the next step was to determine which detector and which configuration was better suited to predict fuel burnup and cooling time. Three different detectors of High Purity Germanium (HPGe), Lanthanum Bromide (LaBr3), and High Pressure Xenon (HPXe) in two system configurations of above and below the water pool were used during the study [1]. Data was collected and analyzed in order to create burnup and cooling time calibration curves for ATR fuel. From spectra taken and the calibration curves obtained, it was determined that although the HPGe detector yielded better quality spectra alternatives were needed because of the in-situ nature of the measurements. The ATR fuel scanning system will be located at the canal adjacent to the reactor and has to be a rugged, low maintenance and an easy to control system. It was concluded that the LaBr3 and HPXe are better alternatives for canal in-situ measurements and that in order to enhance the quality of the spectra and burnup predictions obtained with these detectors a deconvolution process had to developed and applied before the final design of the ATR fuel scanning measurement system was completed. The deconvolution technique involved determining the response function of the two detectors using MCNPX. Once the response function of the detectors was determined and validated deconvolution algorithms were tested to determine which method was better suited for ATR fuel applications. The last step in the enhancement process will be testing the deconvolution technique against data generated from models, experimental data from calibration radiation sources and ultimately against high enriched uranium samples.

[1] J. Navarro, R. Aryaeinejad, D.W. Nigg, A, "Feasibility Study to Determine Cooling Time and Burnup of Advanced Test Reactor Fuel Using a Nondestructive Technique and Three Types of Gamma-ray Detectors", Journal of ASTM International, March 2012, Vol. 9, No. 6, March 2012.

FB 4 11:40 AM

Validation of Cross Sections with Criticality Experiment and Reaction Rates: The Neptunium Case

L.S. Leong, L. Tassan-Got, J.N. Wilson, C. Le Naour, C. Stéphan
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Critical experiments are valuable checks of nuclear data, in particular cross sections. We used such methods to check recently measured neutron-induced fission cross sections of 237Np. This isotope is abundantly produced in reactors and due to its long half-life, its high radiotoxicity and its large mobility in aquatic systems it could be a candidate for incineration, provided its neutron cross sections are known with a good accuracy. The neutron-induced fission cross section has recently been measured in a broad energy range (from eV to GeV) at the n_TOF facility at CERN and appears to be higher by 5-7% beyond the fission threshold, when compared to previous measurements. To check the reliability of the n_TOF data, we simulated a criticality experiment performed at Los Alamos with a 6 kg sphere of 237Np. This sphere was surrounded by enriched uranium 235U so as to approach criticality with fast neutrons. The simulation performed with MCNP5 predicts a multiplication factor keff in better agreement with the experiment (the deviation of -750 pcm is reduced to +250 pcm) when the ENDF-B7 evaluation is replaced by the n_TOF data. We also explored possible other effects which could be responsible for this underpediction like deficiencies of the inelastic cross section in 235U and the nubar of 237Np, but we show that the variation needed to cancel the keff deviation is hardly compatible with the measurements. These outcomes support the hypothesis of a higher fission cross section of 237Np. However ratios of fission rates 237Np/235U have been measured in different neutron energy spectra (GODIVA, COSMO, CGFR-Proteus). Those data are quasi-direct measurements of 237Np integrated fission cross section relative to 235U or 239Pu. The comparison of results C/E of fission rates indicates that the n_TOF data overestimate the fission cross section which turns out to be between those data and previous ones.

Session FC Nuclear Data Covariances
Tuesday March 5, 2013
Room: Empire East at 10:30 AM
Chair: Pavel Oblozinsky, Slovak Academy of Sciences
FC 1 10:30 AM

Full Bayesian Evaluation Technique for Angle-Differential Data

G. Schnabel, H. Leeb
Atominstitut, TU Wien, Wiedner Hautpstrasse 8-10, 1040 Vienna, Austria
D. Neudecker
T-2, Theoretical Division, Nuclear and Particle Physics, Astrophysics & Cosmology, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

The Full Bayesian Evaluation Technique [1] is a direct application of Bayesian statistics to nuclear data evaluation. It is characterized by a careful determination of the prior uncertainties related to modelling and is therefore well suited for evaluations strongly based on nuclear models. In its original version [1] the Full Bayesian Evaluation Technique was limited to angle-integrated cross sections. Thus information provided by angle-differential data has been ignored. In this contribution the evaluation method is extended to angle-differential data. The major problem is the large number of parameters involved. We present a proper parametrisation of the angular distributions with a reasonable number of parameters. Most important is the correlation of the parameters with the zero order Legendre coefficient which has a direct impact on angle-integrated cross sections. Thus the information contained in angle-differential data affects the angle-integrated cross sections and consequently also the complete evaluation. The formulation and the

properties of the method are discussed at different examples.
Corresponding author: H. Leeb
[1] H. Leeb, D. Neudecker, Th. Srdinko, Nucl. Data Sheets **109** (2008) 2762.

FC 2 11:00 AM

Advanced Uncertainty Quantification for Fission Observables

D. Neudecker, P. Talou, T. Kawano
Los Alamos National Laboratory, T-2, Theoretical Division, Nuclear and Particle Physics, Astrophysics & Cosmology
F. Tovesson
Los Alamos National Laboratory, LANSCE-NS

Advances in nuclear technologies, and in particular the next-generation of nuclear reactors, require an improved knowledge of different fission observables like e.g. prompt fission neutron spectra or fission cross sections. To meet these demands, sophisticated models are being developed, and high-precision measurements are undertaken at LANL such as the newly established time projection chamber at LANSCE. In this contribution recent advances in the related evaluation methodology are presented which aim at an improved quantification of uncertainties associated with experimental data as well as calculations. In the former case, more realistic covariance matrices are established in colloboration with experimentalists using detailed experimental information, see e.g. [1]. In the latter case, emphasis is put on the quantification of model deficiencies, see [2]. The impact of these advances is discussed by means of an evaluation of Np-237 and by prior data of Np-236.
[1] “Covariance matrix for a relative Np237 (n,f) cross section measurement,” F.Tovesson, T.S.Hill, K.M.Hanson, P.Talou, T.Kawano, R.C.Haight, and L.Bonneau, **LA-UR-06-7318** (2006) [2] “Consistent procedure for nuclear data evaluation based on modelling,” H. Leeb, D. Neudecker, Th. Srdinko. Nuclear Data Sheets 2762, **109** (2008)

FC 3 11:20 AM

Uncertainty Quantification of Prompt Fission Neutron Spectra using the Unified Monte Carlo Method

M.E. Rising, P. Talou
Theoretical Division, Los Alamos National Laboratory, USA
A.K. Prinja
Chemical and Nuclear Engineering Department, University of New Mexico, USA

In the ENDF/B-VII.1 nuclear data library [1], the existing covariance evaluations of the prompt fission neutron spectra (PFNS) were derived by combining experimental differential data where available with theoretical model calculations, relying on the use of a first-order linear Bayesian approach, the Kalman filter [2]. This approach requires in particular that the theoretical model response to changes in input parameters be linear about the prior central values. If the model response is nonlinear, the Kalman filter may lead to an inaccurate evaluation of the PFNS and associated uncertainties. One possible remedy to the issues associated with the first-order linear Kalman filter is the use of the so-called Unified Monte Carlo (UMC) approach [3]. The UMC method remains a Bayesian approach where the probability density functions (PDFs) of the *a priori* and the likelihood must be known to determine the PDF of the *a posteriori*. Similar to the Kalman filter approach, the Principle of Maximum Entropy is employed and the shape of

the *a priori* and likelihood PDFs are chosen to be multivariate Gaussian distributions. Now, before any assumptions are made, according to Bayes' theorem, the unnormalized *a posteriori* PDF is formed as the product of the *a priori* and likelihood PDFs. The UMC approach samples directly from the *a posteriori* PDF and as the number of samples increases, the statistical noise in the computed *a posteriori* moments converge to an appropriate solution which corresponds to the true mean of the underlying *a posteriori* PDF. Recently, the UMC approach has been studied in the context of comparing the convergence properties of differing Monte Carlo sampling techniques. We have implemented the UMC approach for the evaluations of the PFNS and its associated uncertainties and compared the results to the tradition first-order linear Kalman filter approach. The brute force Monte Carlo approach has been implemented with success but with an obvious computational disadvantage compared with the Kalman filter approach. Other methods that help improve the computational limitations of the UMC approach, including the stochastic collocation method (SCM), are studied in the framework of the UMC approach and these results will be presented. These results may help demonstrate what impact the UMC evaluation methodology can have on future evaluations of important nuclear data.
[1] M.B. CHADWICK, M. HERMAN, P. OBLOZINSKY *et al.*, "ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data," *Nuclear Data Sheets*, **112**, 2887 (2011). [2] R.E. KALMAN, "A New Approach to Linear Filtering and Prediction Problems", *J. Basic Eng.*, **82D**, 35-45 (1960). [3] R. CAPOTE and D.L. SMITH, "An Investigation of the Performance of the Unified Monte Carlo Method of Neutron Cross Section Data Evaluation", *Nucl. Data Sheets*, **109** (12), 2768 (2008).

FC 4 11:40 AM

Propagation of Nuclear Data Uncertainties in PWR Burnup Pin-Cell Deterministic Calculations using the Total Monte Carlo Approach

Francesco Ferragut, Pouya Sabouri, Adrien Bidaud
Laboratoire de Physique Subatomique et Cosmologie, CNRS/Université Joseph Fourrier, Institut Polytechnique de Grenoble

We present here the results of the PWR Burnup Pin-Cell Benchmark UAM I-1b based on the use of the TENDL library [1] with the deterministic transport code DRAGON [2]. The evaluation of the uncertainties uses the Total Monte Carlo method. Hundreds of TENDL evaluated files of of the most important nuclides for this benchmark (^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu) were processed with NJOY and other codes to produce hundreds of WIMS libraries that DRAGON can read. Then, hundreds of burnup calculation where done, whose spread is an image of the uncertainties in the evaluated files that is itself an image of the uncertainties in the model parameters of TALYS. Our methodology gives very similar results than the full stochastic Total Monte Carlo, where a Monte Carlo code such as SERPENT [3] is used for solving the Boltzmann equation. In our case, thanks to the deterministic approach, we do not have to subtract the statistical noise to calculate the uncertainty in the outputs such as keff or nuclide densities. Of course, our methodology would be limited to applications that are within the recommended domain of use of the transport code. When compared to methods based on the sampling of the deterministic XS [4],[5] the advantage of our method is the consistency of the handling of the nuclear data all along the process. We do not have to generate discontinuities in the cross sections to obtained our energy integrated libraries. Our sampled libraries are build exactly as any classical groupwise libraries. Our group constants are build from sampled but continuous cross sections themselves evaluated from sampled pre-evaluation parameters. Furthermore, our approach is more consistent with the evaluation as we do not sample the lumped cross sections (scattering, absorption, fission and total), but we lump sampled - probably more physical

- reactions such as elastic, inelastic scatterings and n,xn reaction for instance. Another advantage of the use of TENDL libraries in a deterministic code is that we can use perturbation theory at least at the first step of burn up so as to calculate not only the uncertainties but also the sensitivities as a function of energy of Keff or nuclide inventory changes. We can then better understand which reactions are more contributing to the uncertainties during fuel burnup. Furthermore, we have developed tools that can build the covariance matrices of the sampled groupwise nuclear data. The folding of the sensitivities obtained by Perturbation Theory with these calculated, self-shielded covariance matrices gives results very comparable to the observed uncertainties calculated with GPT. Thanks to this method, we can not only calculate the uncertainties but also track down the error down to the actual reactions described in the evaluation (and not on the lumped ND used in the deterministic code) and give the weight in the error of them and of the correlations between those reactions. Given the consistency of the method, our method not only complement the results of available other methods, but also allows for a more straightforward and more coherent link between the evaluation of the uncertainties given by the evaluator and their impacts calculated by the reactor physicist.

Corresponding author: Pouya Sabouri

[1] D. Rochman and A.J. Koning. TENDL-2011: TALYS-based Evaluated Nuclear Data Library, PHYSOR-2012 conference, Knoxville, Tenessee, USA, April 15-20, 2012. [2] G. Marleau, R. Roy and A. Hebert, DRAGON: A Collision Probability Transport Code for Cell and Supercell Calculations, Report IGE-157, Institut de genie nucleaire, ecole Polytechnique de Montreal, Montreal, Quebec (1994) [3] D. Rochman and A.J. Koning, Propagation of ^{235,236,238}U and ^{239}Pu nuclear data uncertainties for a typical PWR fuel element, accepted in Nucl. Technology, October 2011 [4] Artem Yankov, Makus Kleis, Marhew A. Jesse, WInfried Zwermann, Kiril Velkov, Andreas Pautz, Benjamin Collins, Thomas Downar, "Comparison of XSUSA and "TWO-STEP" aproaches for full-core uncertainty quantification", Physor 2012, Knoxville, Tenessee, USA, April 15-20, 2012 [5] Ball, Matthew R., "Uncertainty Analysis In Lattice Reactor Physics Calculations" (2012). Paper 6565 Open Access Dissertations and Theses, PhD Thesis, University of McMaster, Ontario, Canada

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Session FD Nuclear Reactor Antineutrinos
Tuesday March 5, 2013
Room: Empire West at 10:30 AM
Chair: Muriel Fallot, Subatech
FD 1 10:30 AM

Results of Reactor Neutrino Measurement from RENO

JeeSeung Jang, on behalf of the RENO collaboration
Gwangju Institute of Science and Technology, Korea

The Reactor Experiment for Neutrino Oscillation(RENO) started data-taking from August, 2011 and has observed the disappearance of reactor electron antineutrinos, consistent with neutrino oscillations. The experiment has performed a definitive measurement of the smallest neutrino mixing angle θ_{13} based on the disappearance. Antineutrinos from six reactors at Yonggwang Nuclear Power Plant in Korea, are detected and compared by two identical detectors located at 294 m and 1383 m, respectively, from the reactor array center. The detectors are located beneath hills that provide, respectively, 120 and 450 m of water-equivalent of rock overburden. The far (near) detector observes 73 (780) events per day electron antineutrino candidate events with a background fraction of 5.5% (2.7%), allowing an unprecedentedly accurate measurement of reactor neutrino flux. In this talk, a new result from RENO will be presented based on the further reduction of backgrounds and a spectral shape analysis. A precise measurement of reactor neutrino flux and spectrum will be also presented in comparison with expectations.

FD 2 11:00 AM

Nuclear Data in the θ_{13} measurement by the Daya Bay Reactor Experiment

Patrick Huber, the Daya Bay collaboration
Virginia Tech

In this talk I will explain how reactor antineutrino fluxes are inferred from existing integral beta spectra of fission fragments and how information from nuclear data bases enters crucially in the process. I also will explain how our theoretical understanding of corrections to the simple, statistical beta decay spectra enters this conversion and how missing data from nuclear data bases limits our ability to account for induced currents. It turns out that for the θ_{13} measurement at the Daya Bay reactor experiment the flux uncertainties and complexities of the flux computation have no discernible effects thanks to the careful layout of near and far detectors.

FD 3 11:20 AM

Reactor Neutrino Spectrum Modeling from the Latest ENDF Nuclear Data Library

T.D. Johnson, A.A. Sonzogni, E.A. McCutchan
Brookhaven National Laboratory

There has been considerable effort in recent years in the investigation of neutrino physics. For example, understanding neutrino oscillations is an important aspect of fundamental physics. Controlled sources of the large number of neutrinos needed to be able to detect them are nuclear reactors, and, in fact, acquiring neutrino spectra is rapidly becoming an important tool for reactor monitoring [1]. A complete understanding of the spectra is essential to be able to correctly interpret results in any case. A neutrino spectrum for a single beta decay may be obtained through an inversion of the beta decay spectrum. The total neutrino spectrum is obtained by following the decay branches of the fission products. The nuclear decay sub-libraries were recently updated at the NNDC and among the over 3800 datasets are around 700 fission products including isomers. Included in the update are the latest Q values (for which the neutrino spectra is sensitive), the latest experimental data from ENSDF, and in some cases, TAGS (total absorption) data . Based on the sub-libraries, the decay network following fission was followed to develop full neutrino spectra in several important cases. Presented are results for ^{235}U, ^{238}U, and ^{239}Pu. These results are compared against recent experimental data from the reactors at Daya Bay [2]. Key contributors to the spectra were identified, and sensitivity studies were carried out.

[1] D.Lhuiller, Nuclear Physics B. (Proc. Supp.) 188 (2009) 112-114 [2] F.P. An, et al. arXiv:1203.1669v1 [hep-ex] 8 Mar 2012

FD 4 11:40 AM

Reactor and Antineutrino Spectrum Calculations for the Double Chooz First Phase Results

Anthony Onillon, on behalf of the Double Chooz collaboration
Laboratoire Subatech, FRANCE

The Double Chooz experiment is designed to measure the θ_{13} mixing angle through antineutrinos disappearance. In this view, two identical liquid detectors located at two different baselines of the two 4.25MW

Pressurized Water Reactor (PWR) cores of the Chooz power plant in the French Ardennes will be installed. The value of θ_{13} can be investigated by searching for a disappearance of electron antineutrinos in the far detector with respect to the antineutrinos measured in the near detector. The Double Chooz experiment has started taking data from April 2011. From the results of this first experimental phase, we have obtained an indication for a reactor electron antineutrino disappearance consistent with neutrino oscillations. During this, only the far detector is operational. A full core simulation of the two PWRs with a follow-up of the core operating parameters has thus been developed with the MURE code (MCNP Utility for Reactor Evolution) to compute the reactor fission rates. The reactor antineutrino flux is then deduced by coupling the fission rates with the recently computed reference antineutrino spectra by P. Huber and using the normalisation of the Bugey4 antineutrino flux measurement after correction for differences in the core composition. We propose at this conference, to present the latest results of the Double Chooz experiment and detail the ingredients that led to the antineutrino spectrum prediction that was compared with the experimental data.

Session FE Cross Section Measurements
Tuesday March 5, 2013
Room: Central Park East at 10:30 AM
Chair: S. Basunia, LBNL
FE 1 10:30 AM

Target Mass Dependency of Light Mass Fragment Energy Spectra for Intermediate Energy Proton Induced Reaction

Toshiya Sanami, Masayuki Hagiwara
High energy accelerator research organization

Estimation on detail distribution of energy deposition due to single nucleon incidence with intermediate energy is required to evaluate irradiation effects depending on linear energy transfer. To estimate the energy deposition, several kinds of fragment production models have been used as a part of multi particle transport codes. The model itself, their combination and parameters should be examined through the comparison with experimental data. Systematic experimental data covering variety of incident energies, targets and production fragments have been desired to establish a theoretical model describing their production, properly. We have been developed a Bragg Curve Counter (BCC) that has capability of particle identification with large solid angle to provide the systematic data. The BCC has a data taking electronics to achieve lower particle identification threshold than a conventional BCC has, by measuring fragment range [1]. The data taken by the BCC are analyzed with compensation of missing energy due to penetration, to enhance it's measurable energy range [2]. Experimental data of double differential cross section (DDX) for Li, Be, B and C production at 30, 45, 60, 90 and 135 degree emission angles for 40, 50, 70, 80, 140, 200 and 300 MeV proton on C, N, O, Al, Ti and Cu targets have been measured using four BCCs at same time using cyclotron facility in National Institute of Radiological Science (NIRS) and Ring Cyclotron of Research Center of Nuclear Physics at Osaka University (RCNP), Japan. For 200 MeV, the data with combining one taken by another group [3,4] provides fragment emission DDXs for C to Au target that enable us to obtain target dependency. Suppression of fragment emission was observed for energy spectrum of fragment with increasing target mass due to varying coulomb barrier of residual nuclei.

[1] T.Sanami et al., Nucl. Instrm. Meth. **A Vol 589** 193 (2008) [2] M. Hagiwara et al., Nucl. Instrm. Meth. **A Vol 592** 73 (2008) [3] H.Machner et al., Phys.Rev.**C73**, 044606(2006) [4] R.Green et al., Phys.Rev.**C22** 1594(1980)

FE 2 11:00 AM

Spin Measurements of Neutron Resonances of ^{87}Sr for Level Density Studies

F. Gunsing, *et al.* (the n_TOF Collaboration)
CEA Saclay, Irfu, F-91191 Gif-sur-Yvette, France

Neutron resonances reveal nuclear levels in the highly excited region of the nucleus around the neutron binding energy. Nuclear level density models are therefore usually calibrated to the number of observed levels in neutron-induced reactions. The energy position of nuclear levels above the neutron binding energy can be accurately determined for resolved resonances using neutron time-of-flight experiments. To a certain extent, spin and parity distributions are in general much less straightforward to obtain. The gamma-ray cascade from the decay of highly excited compound nucleus states like neutron resonances show differences dependent on the initial spin. This results in a difference in the multiplicity distribution which can be exploited. We have used the 4π total absorption calorimeter (TAC) at the neutron time-of-flight facility n_TOF at CERN to determine the spins of resonances formed by neutrons incident on a metallic ^{87}Sr sample by measuring the gamma multiplicity distributions for the resolved resonances. The first results will be presented here.

FE 3 11:20 AM

Measurements of Partial γ-ray Cross Sections in ^{60}Ni$(n, xnypz\alpha\gamma)$ Reactions

N. Fotiades, M. Devlin, R. C. Haight, T. Kawano, S. Kunieda*, R. O. Nelson.
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA.

Absolute partial cross sections for production of discrete γ-rays using ^{60}Ni$(n, xnypz\alpha\gamma)$ reactions with $x \leq 3$, $y \leq 2$ and $z \leq 4$ in a total of 20 reaction channels were measured. The data were taken using the GEANIE spectrometer comprised of 20 high-purity Ge detectors with BGO escape-suppression shields. The broad-spectrum pulsed neutron beam of the Los Alamos Neutron Science Center's (LANSCE) WNR facility provided neutrons in the energy range from 0.2 to 300 MeV. The time-of-flight technique was used to determine the incident neutron energies. Partial γ-ray cross sections have been measured for a total of 57 transitions and for neutron energies 1 MeV$< E_n <$300 MeV. Hauser-Feshbach theoretical calculations with an improved cluster emission model in the pre-equilibrium process were performed up to $E_n = 150$ MeV and are compared to the experimental results. Comparison of the present results for the (n, α) and $(n, 2p2n)$ channels to previous experimental data obtained at LANSCE establishes a trend of decreasing transmission for the α particle inside the increasing mass of a compound nucleus formed in fast neutron-induced reactions on stable isotopes. * Present address: Nuclear Data Center, Japan Atomic Energy Agency, Tokai-mura Naka-gun, Ibaraki 319-1195, Japan

Presenting author: Matt Devlin

FE 4 11:40 AM

Measurements of Neutron-Capture Cross-Sections of ^{118}Sn with J-PARC/MLF/ANNRI

Atsushi Kimura, Kentaro Hirose, Shoji Nakamura, Hideo Harada, Kaoru Y. Hara, Fumito Kitatani, Mitsuo Koizumi, Masumi Oshima, Yosuke Toh
Nuclear Science and Engineering Directorate, Japan Atomic Energy Agency
Masayuki Igashira, Tatsuya Kstabuchi, Motoharu Mizumoto
Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology

Takashi Kamiyama, Koichi Kino, Yoshiaki Kiyanagi
Hokkaido University
Jun-ichi Hori
Research Reactor Institute, Kyoto University

Accurate data of the neutron-capture cross section for ^{126}Sn are required in the study of nuclear transmutation. However, an ordinary ^{126}Sn sample for a nuclear data experiment contains large amount of its stable isotopes because the stables isotopes also have fission yields and the sample normally prepared only through a chemical process from spent fuel. The stable isotopes have large effects on the experiment. To obtain accurate neutron-capture cross section data for ^{126}Sn, those for the stable isotopes are also required. Therefore, a series of neutron-capture cross section measurements for the tin stable isotopes have been started with Accurate Neutron-Nucleus Reaction measurement Instrument (ANNRI) at J-PARC. In this presentation, preliminary neutron-capture cross section for ^{118}Sn is reported in the neutron energy range from thermal energy up to 1 keV. This work is supported by JSPS KAKENHI (22226016).

Session GA Evaluated Nuclear Data Libraries
Tuesday March 5, 2013
Room: Met East at 1:30 PM
Chair: Tokio Fukahori, Subatech
GA 1 1:30 PM

Status of the ENDF/B Nuclear Data Library

Dave Brown
BNL

In December 2011, The Cross Section Evaluation Working Group (CSEWG) released its latest recommended evaluated nuclear data file, the ENDF/B-VII.1 library. This library incorporated many advances made in the five years after the release of ENDF/B-VII.0. That said, CSEWG is now preparing another release: ENDF/B-VII.2. In this talk, I will outline some of the new or improved evaluations already prepared for ENDF/B-VII.2 including new zirconium evaluations, new charged particle evaluations including a new alpha-projectile sublibrary, and recent results from several NEA Working Party on Evaluation Cooperation subgroups and IAEA Cooperative Research Projects. I will also discuss CSEWG's expanded and automated testing regime using the ADVANCE continuous integration system. In ADVANCE, every change or addition to ENDF/B-VII.2 is tested automatically with NNDC's checking codes and the PREPRO, fudge and NJOY processing codes. As a side-effect of ADVANCE, we automatically produce usable ACE, GENDF and PREPRO files for neutronics codes. Finally, in this talk I present some emerging initiatives that impact the ENDF/B library, namely the move to a new nuclear data format (the Generalized Nuclear Data format) and the possibility of a world-wide nuclear data library.

GA 2 2:00 PM

n+^{12}C Cross Sections from an R-Matrix Analysis of Reactions in the ^{13}C System

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Group T-2, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

We have performed an R-matrix analysis of reactions in the ^{13}C system, resulting in a new evaluation of the neutron cross sections for ^{12}C at energies below about 6.5 MeV. This is the first new evaluation work that has been done for carbon in many years, and it is part of an effort to separate the evaluation done by C. Y. Fu *et al.* for natural carbon into isotopic evaluations for ^{12}C and ^{13}C. Carbon is, of course, an important element in many technology applications, including nuclear power reactors, and its elastic scattering cross section is a neutron standard at energies below 1 MeV. The analysis included the two channels n+^{12}C(0^+) and n+^{12}C*(2^+), having $l_{\rm max} = 4$ in the ground-state channel and $l_{\rm max} = 1$ in the excited-state one. Experimental data, including total cross sections, differential cross sections, and neutron analyzing powers, were fitted for the reactions ^{12}C$(n,n)^{12}$C and ^{12}C$(n,n')^{12}$C* at neutron lab energies below 6.5 MeV. Quite a good fit ($\chi^2/\nu = 1.36$) was obtained to the more than 6300 data points in the experimental data set with 37 free parameters. The R-matrix parameterization included levels for a dozen bound states and resonances at excitation energies up to 10.75 MeV, as well as fixed background levels in all J^π submatrices. Representative fits to the experimental data and comparisons to the previous evaluation will be shown. Changes in the integrated and total cross sections are much less than those in the Legendre coefficients representing the elastic and inelastic angular distributions. We will also discuss the implications of the analysis for the level structure of ^{13}C at excitation energies below 10.75 MeV, and present covariance information for the cross sections.

GA 3 2:20 PM

New Version of Chinese Evaluated Nuclear Data Library CENDL-3.2 and the Development Methodology of Nuclear Data Evaluation in China

Ge Zhigang, Wu Haicheng, Cheng Guochang, Xu Ruirui, Huang Xiaolong, Shu Nengchuan, Qian Jing, Liu Ping

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The CENDL-3.2 is general purpose evaluated nuclear data file which consists of the neutron reactions sub-library, the activation sub-library, decay data sub-library and fission yields sub-library. CENDL-3.2 can be used for the nuclear engineering, nuclear medicine and nuclear science etc. fields. The CENDL-3.2 is based on the previous version of CENDL and other special purpose libraries established by China Nuclear Data Center(CNDC), the updated experimental information and new nuclear data evaluation methodologies. The mainly contribution of CENDL-3.2 are being carried out at CNDC, China Institute of Atomic Energy and China Nuclear Data Coordination Network(CNDCN). The nuclei region of the new neutron reactions sub-library will be extend comparison with the CENDL-3.1 and the materials number will up to 300, which can be covered almost needs for the nuclear engineering, nuclear power and related fields. The high fidelity covariance files for some important structural materials, actinide and low fidelity covariance files for other nuclei will be included in the sub-library. All the covariance files will be evaluated through a covariance evaluation system COVAC developed by CNDC. The benchmark testing and validation for the CENDL-3.2 will be performed through the updated Evaluated Nuclear Data Integra Test System (ENDIST) established at CNDC. Activation sub-library will contain the most important excitation functions for more than 600 nuclei which can be used for nuclear reactor design, operation and nuclear safety etc. Some of the evaluated data will be obtained based on the updated measurements and mode calculations. Decay data sub-library contains the updated decay information for more than 2000 nuclei, and more than 200 new evaluations will be carried out by Chinese evaluators, other the data come from the new results of the NSDD. Fission product yield sub-library will provide the evaluated fission yields by various methods for the neutron introduced fissions for the U, Pu and Th etc. The progress of the evaluation methodologies during recent years at CNDC and CNDCN will be introduced in this presentation.

GA 4 2:40 PM

Overview of the 2011 Release of the Evaluated Nuclear Data Library (ENDL2011)

N. C. Summers, D. A. Brown, B. Beck, M.-A. Descalle, J. E. Escher, R. Hoffman, T. Luu, C. M. Mattoon, P. Navratil, G. P. A. Nobre, W. E. Ormand, S. Quaglioni, I. J. Thompson, and R. Vogt
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R. Barnowski
University of Michigan, Ann Arbor, MI, USA

The Lawrence Livermore National Laboratory (LLNL) Physics Division has produced the next iteration of LLNL's evaluated nuclear database, ENDL2011. ENDL2011 is designed to support LLNL's current and future nuclear data needs. This library includes 918 distinct transport-ready evaluations in the neutron sub-library and many physics improvements for energy, nuclear security and stockpile stewardship. In building this library, we adopted the best of the international nuclear data efforts including the ENDF/B-VII.0, JENDL, JEFF, and other libraries. This library contains many new evaluations for radiochemical diagnostics, structural materials, and thermonuclear reactions. We have made an effort to eliminate all holes in reaction networks, allowing in-line isotopic creation and depletion calculations. We have striven to keep ENDL2011 at the leading edge of nuclear data library development by reviewing and incorporating new evaluations as they are made available to the nuclear data community. This release is our most highly tested release as we have strengthened our already rigorous testing regime by adding tests against IPPE Activation Ratio Measurements and many more critical assemblies. ENDL2011 is currently being updated to include the latest ENDF/B-VII.1 release and converted to the new Generalized Nuclear Data (GND) structure for the next generation of nuclear data formats. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, and was also supported in part by the National Science Foundation Grant NSF PHY-0555660.

Session GB Nuclear Structure and Decay
Tuesday March 5, 2013
Room: Met West at 1:30 PM
Chair: Alan Nichols, University of Surrey
GB 1 1:30 PM

Gamma-ray Spectroscopy using Rare Isotope Sources*

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Rare isotope sources can be used to populate excited structures in nuclei near and away from the line of stability which are not easily accessible with reactions involving stable heavy-ion beams and targets. Results will be presented from recent studies with Gammasphere as well as with several germanium clover and $LaBr_3$(Ce) scintillation detectors. These investigations involve sources with the long-lived, high-K isomers in ^{177}Lu (K^π=23/2$^-$, $T_{1/2}$=160.44 d) and ^{178}Hf (K^π=16$^+$, $T_{1/2}$=31 y). In the case of ^{177}Lu, unusually retarded $M3$ and $E4$ transitions depopulating the K^π=23/2$^-$ isomer were discovered. The large hindrance factors deduced from the data provide evidence for significant configuration changes associated with this isomeric decay. The lifetime of the (K^π,I^π)=(8$^-$,9$^-$) collective level in ^{178}Hf, populated in the decay of the K^π=16$^+$ isomer, was measured for the first time with two $LaBr_3$(Ce) detectors using the direct

gamma-gamma-time (electronic) technique. The $B(M1)$ value deduced for the $9^- \rightarrow 8^-$ in-band transition was compared with theoretical predictions for competing 2-quasiproton and 2-quasineutron configurations, and allowed to determine the amplitude of configuration mixing due to the effect of residual proton-neutron interactions. Future studies at the CARIBU facility of the ATLAS accelerator, where a ^{252}Cf source ($T_{1/2}$=2.645 y) is used to produce and separate neutron-rich fission products, will also be discussed.
*This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

GB 2 2:00 PM

New Half-Life Measurements for Millisecond Isomers at LANSCE

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The unique time structure of the pulsed neutron beam at the Weapons Neutron Facility (WNR) at the Los Alamos Neutron Science Center (LANSCE) allows for lifetime measurements of isomeric states populated in neutron-induced reactions, for isomers in the range from tens of microseconds to tens of milliseconds. This feature has been used in the past for half-life measurements of isomers in Tl nuclei [1,2], using the GEANIE array of HPGe detectors to identify their decay between the pulses of neutrons from WNR. We report here on a set of new half-life measurements for various isomeric states in the millisecond range, again using the GEANIE array: ^{114m}In, ^{205m}Pb, ^{75m}As, ^{71m}Ge, ^{171m}Yb, ^{208m}Bi, and ^{206m}Bi, as well as others. For some of these measurements, the repetition rate of the LANSCE accelerator was modified, in order to better measure longer half-lives. The new measurements will be presented and compared to prior measurements, with attention to the systematic errors involved in these measurements.
[1] N Fotiades, RO Nelson, M Devlin, and JA Becker, Phys Rev C76, 014302 (2007) [2] N Fotiades, RO Nelson, M Devlin, and JA Becker, Phys Rev C77, 024306 (2008)

GB 3 2:20 PM

Using LaBr3 Gamma-ray Detectors for Precision Measurements of Nuclear Excited State Lifetimes in the 100ps - 10ns Regime

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N. Marginean, D. Filipescu, D. Deleanu, T. Glodariu, D. Ghita, R. Marginean, C. Mihai, D. Bucurescu, A. Negret, L. Stroe, T. Sava
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Precision measurements of electromagnetic transition rates provide accurate inputs into generic nuclear data evaluations and are also used to test and validate predictions of state of the art nuclear structure models. Measurements of transition rates can be used to ascertain or rule out multipolarity assignments for the measured EM decay, thus providing (in some cases) firm spins and parities for states between which the transition takes place. We report on a variety of precision measurements of electromagnetic

transition rates between excited nuclear states using 'fast-timing' gamma-ray coincidence spectroscopy using cerium-doped lanthanum-tribormide ($LaBr_3$(Ce)) detectors which couple high light output with good timing characteristics.Examples of recent precision measurements using a combined $LaBr_3$-HpGe array based at the tandem van de Graaff accelerator, Bucharest, Romania will be presented [1,2]. The presentation will also discuss the development of a multidetector array based on $LaBr_3$ detectors for future studies of very exotic nuclei produced at the upcoming Facility for Anti-Proton and Ion Research (FAIR) [3]. *This work is supported by grants from the Engineering and Physical Sciences Research Council (EPSRC-UK) and the Science and Technology Facilities Council (STFC-UK).
[1] P.J.Mason et al., Phys. Rev. C **85**, 064303 (2012) [2]T.Alharbi et al., App. Rad. Isotopes **70**, 1337 (2012) [3] P.H. Regan App. Rad. Isotopes **70**, 1125 (2012)

GB 4 2:40 PM

Scissors Mode Strength in Rare Earth Nuclei Studied from (n,γ) reaction

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The existence of the scissors M1 vibrational mode built on ground states of even-even deformed nuclei, predicted by the theory [1], has already been firmly established from extensive nuclear resonance fluorescence (NRF) studies [2]. Later, the measurements of gamma-ray spectra of two-step cascades (TSCs) following the thermal neutron capture in ^{162}Dy strongly indicated that, in line with Brink hypothesis, this mode is built not only on the ground state, but also on each excited level of deformed nuclei [3]. Results of later studies of the scissors mode of excited nuclear levels will be reported with emphasis on data from three different kinds of neutron capture experiments: (i) TSC experiments performed at LVR-15 reactor in Rez on targets ^{155,157}Gd, ^{159}Tb, ^{161}Dy and ^{176}Lu, (ii) the experiments at the LANSCE/DANCE neutron time-of-flight facility in Los Alamos which made it possible to retrieve gamma-ray spectra of multi-step cascades (MSCs) accompanying the neutron capture at isolated resonances of $^{152,154-158}$Gd, and (iii) the experiments undertaken at Karlsruhe Van de Graaff facility using pulsed neutrons produced via the ^{7}Li(p,n)^{7}Be reaction – in this case the spectra of MSCs following the neutron capture in $^{155-158}$Gd in the energy region of unresolved resonances were analyzed. These classes of experiments are, to a large extent, complementary. Their noteworthy feature is that they also provide information on scissors mode of odd and odd-odd nuclei, for which the present state-of-the-art of the NRF technique meets with difficulties. Systematic trends in the energy, damping width and B(M1) reduced strength of the observed scissors mode built on excited levels will be discussed and compared with what has been deduced from the NRF data for the ground-state scissors mode and from the data on ^{3}He-induced γ emission. The impact of knowledge of the scissors mode on understanding the systematic behaviour of total radiation width of neutron resonances will be highlighted.
[1] N. Lo Iudice and F. Palumbo, Phys. Rev. Lett. **41**, 1532 (1978). [2] U. Kneissl, H. H. Pitz and A. Zilges, Prog. Part. Nucl. Phys. **37**, 349 (1996). [3] M. Krticka *at al.*, Phys. Rev. Lett. **92**, 172501 (2004).

Session GC Accelerator Applications
Tuesday March 5, 2013
Room: Empire East at 1:30 PM
Chair: Alfredo Ferrari, CERN
GC 1 1:30 PM

Recent Developments of the Liège Intra Nuclear Cascade Model in View of its Use into High-Energy Transport Codes

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J. Cugnon,
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The Liège Intranuclear Cascade model, INCL, has been originally developed to describe spallation reactions, i.e. nucleon induced collisions in the 100 MeV - 3 GeV energy range. Extensive comparisons with experimental data covering all possible reaction channels have shown that its last version, INCL4, coupled to the ABLA07 de-excitation code from GSI, is presently one of the most reliable models in its domain. The model has been implemented into several high-energy transport codes allowing simulations in a wide domain of applications. Recently, efforts have been devoted to extending the model beyond its strict limits of validity, i.e. at energies below 100 MeV and above 3 GeV and for light-ion (up to oxygen) induced reactions. In this paper, these extensions will be presented, comparisons with experimental data will be shown and impact on applications will be discussed. Examples of simulations performed for spallation targets (ESS and ISOLDE) with the model implemented into MCNPX and in the domain of medical applications with GEANT4 will be shown.

GC 2 2:00 PM

Beam-machine Interaction at the CERN LHC

F. Cerutti, on behalf of the FLUKA collaboration
CERN, Geneva, Switzerland

The radiation field generated by a high energy and intensity accelerator is of concern in terms of element functionality threat, component damage, electronics reliability, and material activation, but provides also signatures allowing to monitor the actual operation conditions. The shower initiated by an energetic hadron involves many different physical processes, down to slow neutron interactions and fragment de-excitation, which need to be accurately described for design purposes as well as to interpret operation events. The experience with the transport and interaction Monte Carlo code FLUKA at the Large Hadron Collider (LHC), operating at CERN with 4 TeV proton beams (and equivalent magnetic rigidity Pb beams) and approaching nominal luminosity and energy, is presented. Design, operation and upgrade challenges are reviewed in the context of beam-machine interaction account and relevant benchmarking examples based on radiation monitor measurements are shown.

GC 3 2:20 PM

Simulation of Radiation Quantities for Accelerator-Based Experiments

V.S. Pronskikh, N.V. Mokhov
Fermi National Accelerator Laboratory

Simulations of secondary particle fluxes, energy deposition, radiation damage, doses and other radiation quantities are necessary means of apparatus designing and understanding results of accelerator-based experiments. Among modern and developed Monte-Carlo codes, MARS15 is extensively used for those purposes. Taking as an example two experiments a fundamental physics muon-to-electron conversion experiment Mu2e and the prospective multi-purpose ProjectX Energy Station at Fermilab results of MARS15 application to design of the target stations are presented.
In the Mu2e experiment, the 8 GeV proton beam will deliver 6E12 protons per second to the tungsten target, placed at the center of the Production Solenoid (PS) bore during the lifetime of the apparatus (5 years). Being in the vicinity of the target, PS magnets are most subjected to the radiation damage. In order for the PS superconducting magnet to operate reliably, the peak neutron flux in the PS coils must be reduced by 3 orders of magnitude by means of a sophisticated absorber, optimized for the performance and cost. An issue with radiation damage is related to large residual electrical resistivity degradation in the superconducting coils, especially its Al stabilizer. Detailed MARS15 analysis has been carried out to optimize the heat and radiation shield, focusing on the most important radiation quantities such as displacements per atom, peak temperature and power density in the coils, absorbed dose in the insulation, and dynamic heat load.
A ProjectX Energy Station is proposed at Fermilab to carry out studies on radiation damage and other aspects of material science, as well as ADS-related research, using a spallation target irradiated by a GeV-range 1 MW proton beam. MARS15 calculations are performed to estimate energy deposition and radiation damage in the target. The MARS15 code is benchmarked against available data for spallation targets including Energy plus Transmutation experiments at JINR, Dubna. In those integral experiments with an extended natural uranium target at 1-8 GeV deuterons (Fermilabs ProjectX energy range) neutron yield, transmutation, fission rates as well as isotope production in the target are measured. Calculated dependences are benchmarked with experimental ones, to explain regularities observed and suggest directions of further studies. Benchmark results can contribute to the estimate of modern code readiness for nuclear energy application and suggest directions for further code developments.

GC 4 2:40 PM

Material Activation Benchmark Experiments at the NuMI Hadron Absorber Hall in Fermilab

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The NuMI hadron absorber, which consists of aluminum core plates and large iron and concrete blocks, is located in the NuMI absorber hall at the Fermi National Accelerator Laboratory (Fermilab). Hadrons that are produced by the bombardment of a graphite target with 120-GeV protons pass through a 675-meter pion decay pipe and are stopped in the hadron absorber. In our previous study, distributions of radiation fluxes behind the hadron absorber were indirectly measured by using metal foil activation method [1]. Radiation distribution contours on the back of the absorber showed two large radiation peaks. Those were unexpected in the original radiation simulations of the absorber design. Voids between blocks and/or the cooling-water pipes gaps are expected to be the cause of these two peaks. In this study, the distribution of activation was calculated by using the latest version of MARS15 in order to explain the production the two peaks. Furthermore, recoil radionuclides in the activation reactions were analyzed by gamma-ray spectrometry and the results were compared with the MARS results.

[1] N. Matsuda *et al.*, "Beam dump experiment using activation detectors at the NuMI hadron absorber in the Fermilab," abstract of 12th International Conference on Radiation Shielding (2012).

Session GD Nuclear Reactor Antineutrinos
Tuesday March 5, 2013
Room: Empire West at 1:30 PM
Chair: Elizabeth McCutchan, NNDC - BNL
GD 1 1:30 PM

The Detection of Reactor Antineutrinos for Reactor Core Monitoring: an Overview

M. Fallot
SUBATECH, CNRS/IN2P3 - Univ. of Nantes - Ecole des Mines de Nantes, Nantes, FRANCE

The field of applied neutrino physics has shown new developments in the last decade. The International Atomic Energy Agency (IAEA) has expressed its interest in the potentialities of antineutrino detection as a new tool for reactor monitoring and has created a dedicated ad-hoc Working Group in late 2010 to follow the associated Research and Development. Several research projects are on-going over the world either to build antineutrino detectors dedicated to reactor monitoring, either to search for and develop innovative detection techniques, or to simulate and study the characteristics of the antineutrino emission of actual and innovative nuclear reactor designs. The European Safeguards Research and Development Association, ESARDA [1], has created in late 2010 a group devoted to Novel Approaches and Novel Technologies (NA/NT) [2] in order to create contacts between the research community and agencies. The ESARDA NA/NT working group has decided one year ago to create a sub-WG dedicated to the detection of antineutrinos. At this conference, we propose to give an overview of the relevant properties of antineutrinos, the possibilities and limitations of their detection and the status of various developments towards compact antineutrino detectors for reactor monitoring considered in perspective of the antineutrino emission from various reactor designs. We will then present the ESARDA sub-WG devoted to the antineutrino probe and its objectives.

[1] European Safeguards Research and Development Association, http://esarda2.jrc.it/about/index.html
[2] ESARDA NA/NT: http://esarda2.jrc.it/internal_activities/WG-NT-NA/index.html

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GD 2 2:00 PM

Development of a High Precision Beta Spectra Generator Using the Latest Nuclear Databases

Gregory Keefer, Timothy Classen
Lawrence Livermore National Laboratory

We describe an effort at LLNL, aimed to produce a well-validated and public code base for the nuclear physics community to model the dN/dE spectra for electron and positron decay from the theory of beta decay. A detailed generator for producing these spectra is something that is absent from widely used Monte Carlo codes like Geant4. The ability to precisely model these decays is vital to low background experimental searches such as dark matter or neutrino-less double beta decay. Furthermore, high precision beta spectra (HPBeta) have recently been found to be critical input to the composite fission beta

spectrum flux predictions. The last 30 years of reactor antineutrino experiments, and the recent interpretation of a possible 1 eV sterile neutrino, rely on our ability to precisely model and interpret these composite fission beta spectra. We present our efforts to extract and apply the relevant parameters from the JENDL4.0, ENDF-VII and ENSDF nuclear databases to the composite fission beta spectra of ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu. The individual beta spectra calculations for each fission product are constructed and a subset of these are being validated against measured beta data. Additionally we will present an update in the ongoing effort to apply the fission yield information extracted from these same databases to the calculation of a typical PWR antineutrino spectrum weighted by the production and depletion of the various fission isotopes. We will further present an outline of the theory used to model beta decay, specifically highlighting the important parameters we must obtain from the nuclear databases. Finally, we will present the problems we have encountered in using nuclear databases and provide our solution to the issues if one was obtained. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and DOE-NP ANS & T Grant LLNL SCW1234.

GD 3 2:20 PM

The Nucifer Experiment

L. Bouvet, P. Contrepois, G. Coulloux, M. Cribier, V. Fischer, J. Gaffiot, R. Granelli, T. Lasserre, L. Latron, A. Letourneau, D. Lhuillier, A. Marchix, G. Mention, N. Pedrol-Margaley, Y. Piret, A. Porta, G. Prono, L. Scola, P. Starzynski, M. Vivier
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Coupled with an accurate reactor simulation, the detection of reactor antineutrinos could allow the survey of the isotopic composition of the core, given for instance a declared reactor power history. These features may be of interest for electricity companies running reactor cores, but also attracted the attention of the International Atomic Energy Agency (IAEA), which asked to its member states a sensitivity study about the antineutrino probe. The IAEA is the UNO agency responsible for the application of the non-proliferation treaty (NPT). The recalculation of antineutrino energy spectra presented in Ref.[1] led to a generic shift in normalization of the reactor antineutrino flux reference w.r.t. 80's and 90's neutrino experiments. In consequence, these measurements are not compatible with the non-oscillation hypothesis previously assumed, and, as suggested in Ref.[2], could be explained by an oscillation of the electron-antineutrinos into a sterile flavour. Focused on these two physics goals, the Nucifer detector is currently taking data at CEA-OSIRIS research reactor. The particularities of this site (compactness of the reactor core, very short distance source-detector of only 7m) have the potential to improve the sensitivity of the experiment to a test of the sterile neutrino oscillation hypothesis once backgrounds will be carefully understood. Presently, the ongoing analyses are considering the main sources of background for the antineutrino detection.
Corresponding author: Andi S. Cucoanes
[1] Th. A. Mueller et al., Phys. Rev. C 83, **054615** (2011) [2] G. Mention et al., Phys. Rev. D 83, **073006** (2011)

GD 4 2:40 PM

Contribution of Recently Measured Nuclear Data to Reactor Antineutrino Energy Spectra Predictions

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The aim of this work is to study the impact of the inclusion of the recently measured beta decay properties of the $^{102;104;105;106;107}$Tc, ^{105}Mo, and ^{101}Nb nuclei in the calculation of the antineutrino energy spectra arising after the fissions of the four fissible isotopes $^{235;238}$U, and $^{239;241}$Pu, the main contributors to the fissions in PWRs. These beta feeding probabilities have been found to play a major role in the gamma component of the decay heat for ^{239}Pu in the 4-3000 s range [1]. They have been measured using the Total Absorption Technique (TAS), coupling for the first time a total absorption spectrometer to a double Penning trap at the JYFL facility of the University of Jyväskylä. Following the fission product summation method presented in the reference [2], the calculation was performed using the MCNP Utility for Reactor Evolution code coupled to the experimental spectra built from beta decay properties of the fission products taken in evaluated databases JEFF3.1, JENDL (experimental data supplemented by Gross theory spectra), supplemented by ENSDF data, the data measured by Tengblad *et al.* and the TAS data measured by Greenwood *et al.* in the nineties. For the remaining unknown nuclei, a rough approximation assuming 3 equiprobable decay branches is used. The antineutrino energy spectra are computed after the formulae adopted by P. Huber [3]. The latest TAS data quoted above are found to have a significant effect on the Pu isotope energy spectra and on the energy spectrum of ^{238}U. These results show the importance of the measurement of new TAS data for a better assessment of the reactor antineutrino energy spectrum, of importance for fundamental neutrino physics experiments as well as neutrino applied physics.
Corresponding author: M. Estienne
[1] A. Algora *et al.*, Phys. Rev. Lett. **105**, 202501 (2010). [2] Th. Mueller *et al.*, Phys. Rev. C 83, 054615 (2011). [3] P. Huber, Phys. Rev. C 84, 024617 (2011).

Session GE Neutron Cross Section Measurements
Tuesday March 5, 2013
Room: Central Park East at 1:30 PM
Chair: Stanislav Hlavac, Slovak Academy of Sciences
GE 1 1:30 PM

Measurement of Fission Neutron Spectrum and Multiplicity using a Double Time-of-Flight Setup

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Recent efforts have been made to improve the prompt fission neutron spectrum and nu-bar measurements for Uranium and Plutonium isotopes particularly in the keV region. A system has been designed at Rensselaer Polytechnic Institute (RPI) utilizing an array of EJ301 liquid scintillators as well as lithium glass and plastic scintillators to experimentally determine these values. An array of BaF_2 detectors was recently obtained from Oak Ridge National Laboratory to be used in conjunction with the neutron detectors. The

system uses a novel gamma tagging method for fission which can offer an improvement over conventional fission chambers due to increased sample mass. A coincidence requirement on the gamma detectors from prompt fission gammas is used as the fission tag for the system as opposed to fission fragments in a conventional fission chamber. The system utilizes pulse digitization using Acqiris 8 bit digitizer boards which allow for gamma/neutron pulse height discrimination on the liquid scintillators during post processing. Additionally, a ^{252}Cf fission chamber was designed and constructed at RPI which allowed for optimization and testing of the system without the need for an external neutron source. The characteristics of the gamma tagging method such as false detection rate and detection efficiency were determined using this fission chamber and verified using MCNP Polimi modeling. Prompt fission neutron spectrum data has been taken using the fission chamber focusing on the minimum detectable neutron energy for each of the various detectors. Plastic scintillators were found to offer a significant improvement over traditional liquid scintillators allowing energy measurements down to $\sim$100 keV. Background was also studied and characterized for all detectors and will be discussed.

GE 2 2:00 PM

Prompt Fission γ Rays Measured Using Liquid Scintillators

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Accurate data on fission products and their distributions as a function of neutron energy are needed for radiation transport calculations used in a wide range of applied programs. Knowledge on the energy distribution of the emitted neutrons and γ rays is essential to design proper shielding and cooling systems used in reactors. Although there have been significant work measuring the neutron-induced fission yields and neutron multiplicity, information about the prompt neutron and γ-ray distributions as a function of incident neutron energy is limited. Only a handful of data is available, mostly at thermal energies, on the prompt γ-ray distributions. The prompt γ-ray and neutron distributions for the spontaneous fission of ^{252}Cf and neutron-induced fission of ^{235}U at incident energies of 1-20 MeV were measured simultaneously [1] using an EJ301 liquid scintillator detector array [2] at the WNR/LANSCE facility. The feasibility of exacting information about the prompt neutron and γ-ray distributions by using the same detector opens up the opportunity to study γ-neutron correlations while simultaneously reducing amount of scattering material. The first step in achieving this goal was to determine whether we could unfold the γ-ray and neutron spectra. The prompt γ-ray spectra were unfolded using a simulated detector response matrix validated using standard calibration sources. The γ-ray distributions obtained using the iterative Bayesian and singular value decomposition unfolding techniques and comparisons to previous measurements will be presented. This work benefited from the use of the LANSCE accelerator facility and was performed under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344 and LANL under Contract DE-AC52-06NA25396.
[1] E. Kwan *et al.*, Nucl. Instrum. Methods Phys. Res. A **688**, 555 (2012). [2] D. Rochman *et al.*, Nucl. Instrum. Methods Phys. Res. A **523**, 102 (2004).

GE 3 2:20 PM

Cross Section Measurements of the Radioactive ^{107}Pd and Stable ^{105,108}Pd nuclei

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Neutron-capture cross sections of Long-Lived Fission Products (LLFPs) are of great importance for predicting long-term characteristics of nuclear reactors. Palladium-107 is one of the important LLFPs because of its extremely long half-life (6.5x10^6 year) and fission yield (3% for ^{239}Pu). Some Pd isotopes among LLFPs, *e.g.*^{105,108}Pd, are also listed as important absorbers for thermal and fast reactors. From these points of view, we have started the measurements of the neutron-capture cross sections for stable ^{105,108}Pd nuclei as well as the radioactive ^{107}Pd. The neutron-capture cross-section measurements by the time-of-flight method were performed using an apparatus called "Accurate Neutron-Nucleus Reaction measurement Instrument (ANNRI)" installed at the neutron Beam Line No.4 of the Materials and Life science experimental Facility (MLF) in the J-PARC. The neutron-capture cross sections of ^{107}Pd and ^{105,108}Pd have been measured in the neutron energy range from thermal to 300 eV. Some new information was obtained for resonances of these Pd nuclei. In this talk, we will present results of these measurements at J-PARC/MLF/ANNRI.
Present study is the result of "Study on nuclear data by using a high intensity pulsed neutron source for advanced nuclear system" entrusted to Hokkaido University by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT). This work was supported by JSPS KAKENHI Grant Number 22226016.

GE 4 2:40 PM

The Limits of the GAINS Spectrometer

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The Gamma Array for Neutron Inelastic Scattering (GAINS) [1] is currently operating at the GELINA neutron source producing highly precise neutron data. The setup was used during the last years to determine the neutron inelastic cross sections on ^{28}Si, ^{24}Mg, ^{23}Na, ^{90}Zr and other isotopes of importance for the development of the next generation of nuclear reactors. Some of these data are still under analysis while other were already published [2,3]. More recently we performed several experiments pushing the technical capabilities of the experimental setup to the limits. We will present the preliminary results obtained for ^{12}C and ^{57}Fe. The first case is the lightest nucleus ever studied with the present setup. We aimed the determination of the cross section for the 4438 keV gamma ray produced in the inelastic excitation of ^{12}C using large volume HPGe detectors. On the contrary, in case of the ^{57}Fe isotope, the measurement attempted the determination of a gamma ray of the energy as small as 14 keV using the

same array of detectors. The second part of the presentation will focus on the recent development of an analysis technique meant to produce covariance matrices for the inelastic cross section data from GAINS. During this effort we also explore the uncertainty limits and the technical capabilities of the setup. We will show the main steps of our analysis technique together with the first covariance matrices produced for the test case of ^{28}Si.

[1] D. Deleanu, C. Borcea, Ph. Dessagne, M. Kerveno, A. Negret, A.J.M. Plompen and J.C. Thiry, Nucl. Instrum. and Meth. in Phys. Res. A624, 130 (2010) [2] A. Negret, C. Borcea and A.J.M. Plompen, J. Korean Phys. Soc. 59, 1765 (2011) [3] C. Rouki, P. Archier, C. Borcea, *et al.*, Nucl. Instrum. and Meth. in Phys. Res. A672, 82 (2012)

Session HA Neutron Cross Section Measurements
Tuesday March 5, 2013
Room: Met East at 3:30 PM
Chair: Yaron Danon, RPI
HA 1 3:30 PM

The CERN n_TOF facility: Neutron Beams Performances for Cross Section Measurements

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CERN

The existing CERN n_TOF neutron beam is characterized by a very high instantaneous neutron flux, excellent TOF resolution at the 185 m long flight path, low intrinsic backgrounds and coverage of a wide range of neutron energies, from thermal to a few GeV. These characteristics provide a unique possibility to perform neutron-induced cross-section and angular distribution measurements for applications such as nuclear astrophysics, nuclear reactor technology and basic nuclear physics. This paper presents in detail all the characteristics of the present neutron beam in the different available configurations, which correspond to two different collimation systems and two choices of neutron moderator. The features include shape and intensity of the neutron flux, beam spatial profile, in-beam background components and the energy resolution broadening. The description of these features is based upon both dedicated measurements as well as Monte Carlo simulations, and includes an estimation of the systematic uncertainties in the mentioned quantities. The overall efficiency of the experimental program and the range of possible measurements will be expanded in the near future with the construction of a second experimental area (EAR-2), vertically located 20 m on top of the present n_TOF spallation target. This upgrade, which will benefit from a neutron flux 25 times higher than the existing one, will provide a substantial improvement in measurement sensitivities and will open the possibility to measure neutron cross-section of isotopes with very short half-lives or available in very small quantities. The technical study for the construction of this new neutron beam will be presented, highlighting the main advantages compared to the presently existing Experimental Area (EAR-1).

HA 2 4:00 PM

Measurement of the Neutron Capture Cross Section of the Fissile Isotope ^{235}U with the CERN n_TOF Total Absorption Calorimeter and a Fission Tagging Based on Micromegas Detectors

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and the
n_TOF collaboration

Actual and future nuclear technologies require more accurate nuclear data on the (n,γ) cross sections and α-ratios of fissile isotopes [1,2]. Their measurement presents several difficulties, mainly related to the strong fission γ-ray background competing with the weaker γ-ray cascades used as the experimental signature of the (n,γ) process. A specific setup [3] has been used at the CERN n_TOF facility in 2012 for the measurement of the (n,γ) cross section and α-ratios of fissile isotopes and used for the case of the ^{235}U isotope. The setup consists in a set of micromegas fission detectors [4] surrounding the ^{235}U samples and placed inside the segmented BaF_2 Total Absorption Calorimeter [5]. At the time of the conference we will present the details of the measurement, the methodology used for the data analysis, based both on experimental corrections and GEANT4 Monte Carlo simulations, and preliminary results on the (n,γ) cross section and the α-ratios. As a side product of the analysis, the experimental data will serve to test the validity of several models for predicting the γ-ray emission in the (n,γ) and (n,f) reactions.
[1] M. Salvatores and R. Jacqmin, Uncertainty and target accuracy assessment for innovative system using recent covariance data evaluations, ISBN 978-92-64-99053-1, NEA/WPEC-26 (2008) [2] NEA High Priority Request List www.nea.fr/dbdata/hprl/ [3] C. Guerrero et al., Simultaneous measurement of neutron-induced capture and fission reactions at CERN, Eur. Phys. J. A 48, 3 (2012) 29 [4] S. Andriamonje et al., A transparent detector for n_TOF neutron beam monitoring, Journal of the Korean Physical Society 59, (2011) 1597-1600 [5] C. Guerrero et al., The n_TOF Total Absorption Calorimeter for neutron capture measurements at CERN, Nucl. Instr. and Meth. A 608 (2009) 424-433.

HA 3 4:20 PM

Measurement of the ^{238}U Radiative Capture Cross Section with C_6D_6 at the n_TOF CERN Facility

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The measurement of the ^{238}U radiative capture cross section falls within the NEA High Priority Request List [1] for the most relevant isotopes to be investigated in more detail for improving the design of different advanced nuclear systems [2] and nuclear fuel cycles [3]. According to the European Strategic Energy Technology Plan, in fact, nuclear energy appears as an unavoidable source of energy for the future, and to achieve a long term sustainability of nuclear energy an improvement in the accuracy and precision of the present basic nuclear data is crucial. Although there are lots of ^{238}U(n, γ) measurements, inconsistencies are still present in the cross section. Therefore there is a proposal for a series of joined measurement of this reaction cross section in order to reach an uncertainty below 2% in the range from a few eV to hundreds of keV, both at the EC-JRC-IRMM facility GELINA and at the n_TOF facility at CERN. The preliminary results of the ^{238}U capture cross section measurement using C_6D_6 detectors are presented. This measurement has been performed in April 2012 at the n_TOF facility, in an energy range from the thermal point to about 500 keV. The very high instantaneous neutron flux, the excellent energy resolution and the low repetition rate characteristic of the facility allowed us to reach the desired precision.
[1] http://www.nea.fr/html/dbdata/hprl/. [2] OECD/NEA WPEC Subgroup 26 Final Report: "Uncertainty and Target Accuracy Assessment for Innovative Systems Using Recent Covariance Data Evalua-

tions", http://www.nea.fr/html/science/wpec/volume26/volume26.pdf. [3] Report of the Numerical results from the Evaluation of the nuclear data sensitivities, Priority list and table of required accuracies for nuclear data. FP-7 IP-EUROTRANS.

HA 4 4:40 PM

Measurement of the ^{240,242}Pu(n,f) Cross Section at the CERN n_TOF Facility

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The sustainable use of nuclear energy as a means of reducing reliance on fossil-fuel for energy production has motivated the development of nuclear systems characterised by a more efficient use of nuclear fuels, a lower production of nuclear waste, economic viability and competitiveness and minimal risk of proliferation of nuclear material is being pursued by international collaborations [1]. The accurate knowledge of relevant nuclear data is crucial for feasibility and performance studies of advanced nuclear systems, including Accelerator Driven Systems (ADS). These data include neutron cross sections of a variety of plutonium isotopes and other minor actinides, such as neptunium, americium and curium. In this context, the ^{240,242}Pu(n,f) cross sections were measured relative to the well-known ^{235}U(n,f) cross section. These isotopes are included in the Nuclear Energy Agency (NEA) High Priority List [2] and the NEA WPEC Subgroup 26 Report on the accuracy of nuclear data for advanced reactor design [3]. The measurements were performed at the CERN n_TOF facility [4], taking advantage of the wide energy range (from thermal to GeV) and the high instantaneous flux of the n_TOF neutron beam. These characteristics mitigate the adverse effects of the strong α-particle background produced by the samples and the low fission cross section below the fission threshold. The measurements were carried out with the innovative Micromegas (Micro-MEsh GAseous Structure) gas detector [5]. The gas volume of the Micromegas is separated into a charge collection region (several mm) and an amplification region (tens of μm) by a thin "micromesh" with 35 μm diameter holes on its surface. The amplification that takes place in the amplification region significantly improves the signal-to-noise ratio of the detector. A chamber capable of holding up to 10 sample-detector modules was constructed and used to house the plutonium samples ($4\times^{240}PuO_2$, $4\times^{242}PuO_2$, with a total mass of 3.1 and 3.6 mg respectively for each isotope) and a reference ^{235}U sample (3.3 mg). The detector was operated with an $Ar:CF_4:isoC_4H_{10}$ gas mixture. The behaviour of the detectors was studied in detail by means of Monte Carlo simulations performed with the FLUKA code [6], focusing particularly on the reproduction of the pulse height spectra for α-particles and fission fragments for the evaluation of the detector efficiency and the quality of the peak-search routine.

[1] Generation-IV International Forum, http://www.gen-4.org, International Framework for Nuclear Energy Cooperation (IFNEC), http://www.ifnec.org [2] NEA Nuclear Data High Priority Request List, http://www.nea.fr/html/dbdata/hprl [3] OECD/NEA Working Party on Evaluation and Co-operation (WPEC) Subgroup 26 Final Report: Uncertainty and Target Accuracy Assessment for Innovative Systems Using Recent Covariance Data Evaluations, http://www.nea.fr/html/science/wpec/volume26/volume26.pdf [4] U. Abbondanno *et al.*, *CERN n_TOF Facility: Performance Report*, CERN-SL-2002-053 ECT. [5] Y. Giomataris, Ph. Rebourgeard, J.P. Robert, G. Charpak, *MICROMEGAS: a high-granularity position-sensitive gaseous detector for high particle-flux environments*, Nucl. Instr. Meth. A, **376** 29-35, 1996 [6] G. Battistoni et al., *The FLUKA code: Description and benchmarking*, Proceedings of the Hadronic

Shower Simulation Workshop 2006, FERMILAB 6–8 September 2006, AIP Conf. Proc. 896, pages 31–49 and A. Fasso, A. Ferrari, J. Ranft, and P.R. Sala, *FLUKA: A multi-particle transport code*, Tech. Rep. CERN-2005-10, INFN/TC_05/11, SLAC-R-73, 2005.

HA 5 5:00 PM

A Micromegas Detector for Neutron Beam Imaging at the n_TOF Facility at CERN

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Micromegas (Micro-MEsh Gaseous Structure) detectors are gas detectors consisting of a stack of one ionization and one proportional chamber. A micromesh separates the two communicating regions, where two different electric fields establish respectively a charge drift and a charge multiplication regime. The n_TOF facility at CERN provides a white neutron beam (from thermal up to GeV neutrons) for neutron induced cross section measurements. These measurements need a perfect knowlodge of the incident neutron beam, in particular regarding its spatial profile. A position sensitive micromegas detector equipped with a ^{10}B based neutron/charged particle converter has been extensively used at the n_TOF facility for characterizing the neutron beam profile and extracting the beam interception factor for samples of different size. The boron converter allowed to scan the energy region of interest for neutron induced capture reactions as a function of the neutron energy, determined by the time of flight. Experimental results will be presented and compared to simulations, performed by means of the FLUKA code.

HA 6 5:15 PM

Measurement of the ^{241}Am and the ^{243}Am Neutron Capture Cross Sections at the n_TOF Facility at CERN

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CIEMAT
C. Guerrero and the n_TOF collaboration
CERN

There is a great interest in performing new neutron cross section measurements of minor actinides for reducing the sometimes unacceptably large uncertainties in the evaluated data. Such data are of great importance for evaluating the design of advanced nuclear reactors and, in particular, for determining their performance in the transmutation of the nuclear waste. The capture cross sections of ^{241}Am and ^{243}Am were measured at the n_TOF facility at CERN with a BaF_2 Total Absorption Calorimeter [1], in the energy range from 1 eV up to a few keV. A preliminary analysis of the ^{241}Am and a complete analysis of the ^{243}Am measurement, including the data reduction and the resonance analysis, will be presented. For the case of the ^{243}Am, there are no capture data below 250 eV available in the EXFOR database. There are three measurements reported [2,3], but their analysis results haven't been published yet. All the existing evaluations of the elastic and capture cross sections are based essentially in one single transmission measurement by Simpson et al. [4]. Above 250 eV, there are only two incompatible capture measurements available [5,6]. Such a lack of experimental data causes the significant differences existing between the ENDF/B-VII.0, JEFF-3.1, and JENDL-4.0 evaluated data libraries. The measurement performed at n_TOF will contribute to the reduction of the uncertainty in the ^{243}Am (n, γ) cross section

in the resolved resonance region, and indicates that the capture cross section in the existing libraries is underestimated in the energy range between 250 eV and 2 keV. The ^{241}Am is part of the experimental program of the ANDES project, and preliminary results will be presented.

[1] C. Guerrero et al., Nucl. Instr. Methods A 608, 424 (2009). [2] M. Jandel et al., AIP Conf. Proc. 1090, 220 (2009). [3] J. Hori et al., JAEA-Conf 2009-004, 123-128 (2009). [4] O. D. Simpson et al., Nucl. Sci. Eng. 55, 273 (1974). [5] L.W.Weston and J.H.Todd, Nucl.Sci.Eng. 91, 444 (1985). [6] K. Wisshak and G. Käppeler, Nucl. Sci. Eng., 85, 251-260 (1983).

HA 7 5:30 PM

Fission Fragment Angular Distribution for Th-232(n,f) at the CERN n_TOF Facility

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In the development of new nuclear reactors, Th/U cycle is an alternative to the most widely used U/Pu cycle, producing a smaller quantity of transuranic elements. A good knowledge of the involved reactions is required and, in particular, the neutron-induced fission of Th-232, that plays an important role in this fuel cycle. The n_TOF facility at CERN is carrying out an extensive program on neutron-induced reactions. The high-intensity neutron beam covers an unprecedented neutron energy range, from less than 1 eV up to 1 GeV. In order to study fission reactions, a chamber with up to ten Parallel Plate Avalanche Counters (PPAC) is used to identify, in time coincidence [1,2], both fission fragments emitted in the targets placed in between. The stripped cathodes used in the PPAC allow us to know the fragment position in each detector and, therefore, to determine their trajectory. However, in former experiments, the measured fission cross sections had to be corrected by means of the limited geometrical acceptance affecting the detector efficiency, being particularly important for neutron energies close to the multiple-chance thresholds. An improved geometrical configuration where both detectors and targets are tilted 45° with respect to the neutron beam direction was recently used at n_TOF. This new configuration makes possible to detect fission fragments at any angle between 0° and 90° so that the full angular distribution can be measured. Apart from the interest on a precise knowledge of the angular distributions for developing nuclear models, this method will make possible to properly correct the detection efficiency in the cross section measurements. The first measurement with this experimental setup has been done at n_TOF to measure the angular distribution of fragments emitted in Th-232(n,f) reaction. These results represent the first measurement of the angular distribution in neutron-induced fission covering such a wide neutron energy range, from fission threshold up to 1 GeV. In addition, our results also confirm the anisotropic behaviour observed recently by Ryzhov et al. [3] for Th-232, that was the unique measurement of the angular distribution of the fragments in fission induced by neutrons in the range 20-100 MeV.

Corresponding author: D. Tarrío

[1] C. Paradela et al., Phys. Rev. C 82, **034601** (2010) [2] D. Tarrío et al., Phys. Rev. C 83, **044620** (2011) [3] I. V. Ryzhov et al., Nucl. Phys. A 760 **19** (2005)

HA 8 5:45 PM

Measurement of the 233U(n,g) and 233U(n,f) Cross Sections in the Resonance Region

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The ^{232}Th/^{233}U cycle is an alternative to the classical ^{238}U/^{239}Pu cycle, with the advantage of a lower production of highly radiotoxic nuclear wastes. But as ^{233}U does not exist, it has to be produced in nuclear plants. A reliable development of thorium-based implies a good knowledge of the breeding ratio of such reactor. It puts severe requests to the accuracy of the capture cross section of ^{233}U, especially in the resonance region. Since the available experimental data are scarce and sometimes contradictory, new experimental studies are required. A new simultaneous measurement of σ(n,f) and σ(n,γ) will shortly be performed at the neutron time-of-flight facility GELINA at Geel (Belgium). The fission events are detected by a multi-targets high efficiency ionization chamber (IC). An efficient array of C_6D_6 scintillators is used for the detection of gamma-rays and neutrons produced in capture and fission reactions. The disentanglement between fission and capture gamma-rays can be achieved by the demand of anticoincidence between events in the IC and the C_6D_6 detectors, whereas the pulse-shape analysis technique allows for the gamma/neutron discrimination. Seen the difference in the fission and capture cross sections, the assignment of a gamma-ray to one or the other reaction type has to be very effective and reliable. With the IC efficiency not absolute, a correction should be applied to take into account the undetected fission events. To keep this correction factor low and reliable, the efficiency parameter of the IC should be high and known with a high degree of accuracy. The IC efficiency towards fission can be defined as a ratio between numbers of detected neutrons with and without coincidence with fission fragments. It is therefore a value directly extractable from the experimental data. MCNPX simulations will be presented and discussed, along with the results from test experiments of the IC.

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Session HB Nuclear Power Applications
Tuesday March 5, 2013
Room: Met West at 3:30 PM
Chair: Andrei Trkov, Jozef Stefan Institute
HB 1 3:30 PM

Improvement of ^{238}U Inelastic Scattering Cross-Section for an Accurate Calculation of Large Commercial Reactors

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Sensitivity/Uncertainty studies are more and more used in Reactor Physics [1] and Safety-Criticality [2] [3]. There are currently utilized to assess the calculation uncertainty of design parameters for GEN-3 and GEN-4. However, these S/U studies require realistic variance/covariance matrices associated with the Nuclear Data evaluation implemented in the ND working library. Therefore, it is recommended to derive reliable covariances from targeted integral experiments using a re-estimation method [4][5]. Commercial Reactors are characterized by large sizes and consequently a strong "Eigen Value Separation"

factor (EVS>20). Consequently, the radial power map calculation is very sensitive to ND perturbations. The main uncertainty component is linked to ^{238}U inelastic scattering cross-section. Moreover, in GEN-4 Fast Reactors the ^{238}U(n,n') contribution to Keff uncertainty (1400 pcm in 1sigma for GFR) amounts to 4 times the target-accuracy. To meet the target-accuracy required by GEN-3 and GEN-4 designs, the ^{238}U(n,n') uncertainty has to be reduced from 20% (current standard deviation) to 5%. The improvement of ^{238}U inelastic scattering data, and the reduction of the associated uncertainty, were obtained through the use of targeted integral measurements. We selected experiments which show a strong sensitivity to ^{238}U(n,n') : - Critical Pu spheres reflected by Unat (PMF-001, PMF-006, PMF-022 from ICSBE Handbook [6]), compared to Pu bare spheres - Critical Uenriched sphere/cylinder/parallelepipeds reflected by Unat (TOPSY experiments), compared to Uenriched GODIVA bare sphere - Fast Reactor lattices with Uranium fuel at Kinf = 1 (SCHERZO experiments in MINERVE and SNEAK [7]) - 3D fission rate distribution from start-up measurements of the French N4 PWR-1500MWe [8]. Owing to the large size of this fresh core, the radial power map is very sensitive to 238U(n,n') data. C/E biases were obtained from TRIPOLI4 Monte Carlo reference calculations [9] using the latest European library JEFF-3.1.1 [10]. C/E comparison showed satisfactory results, with a small tendency to overestimate Keff when the spheres are reflected by Unat. Sensitivity coefficients of these measured Keff (and P) to ^{238}U(n,n') multigroup cross-sections were also obtained from TRIPOLI4. The re-estimation of ^{238}U inelastic cross-sections, performed by our RDN code based on a non-linear regression technique, enhanced a trend for a slight reduction of JEFF3.1.1 ^{238}U(n,n') above 800 keV. This method allowed the determination of the actual JEFF3 covariance matrix. This reliable ^{238}U(n,n') covariance will enable, through propagation technique, the calculation uncertainty due to nuclear data for GEN-3 and GEN-4 neutronic parameters.

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HB 2 4:00 PM

Investigation of Nuclear Data Libraries with TRIPOLI-4 Monte Carlo Code for Sodium-Cooled Fast Reactors

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Sodium-cooled fast neutron reactor ASTRID is currently under design and development in France. Traditional ECCO/ERANOS fast reactor code system using for ASTRID core design calculations lies only on multi-group JEFF-3.1.1 data library. To gauge the use of ENDF/B-VII.0 and JEFF-3.1.1 nuclear data libraries in the fast reactor applications, in this study two recent OECD/NEA computational benchmarks specified by Argonne National Laboratory have been calculated. Using the continuous-energy TRIPOLI-4 Monte Carlo transport code, both ABR-1000 MWth oxyde (MOX) core and metallic (U-Pu) core have been investigated. Under two different fast neutron spectra and two data libraries, ENDF/B-VII.0 and JEFF-3.1.1, the reactivity impact studies have been performed. With the JEFF-3.1.1 data library under the BOEC (Beginning of equilibrium cycle) condition, higher reactivity effects of 750 pcm and 1080 pcm have been observed for ABR-1000 MOX core and metallic core respectively. To study the causes of these differences in reactivity, several TRIPOLI-4 runs using mixed data libraries feature allow us to identify the nuclides and the nuclear data accounting for the major part of the observed reactivity differences. This work was supported by EDF and AREVA.
[1] T. K. Kim, W. S. Yang, C. Grandy and R. N. Hill, Core Design Studies for a 1000 MWth Advanced Burner Reactor, Annals of Nuclear Energy 36, p. 331 (2009). [2] Y. K. Lee, TRIPOLI-4 Criticality Calculations for MOX Fulled SNEAK 7A and 7B Fast Critical Assemblies, Physor 2012, Knoxville, TN. USA, April 15-20, 2012.

HB 3 4:20 PM

Nuclear Data and the Oklo Natural Nuclear Reactors

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Recent years have seen a renewed interest in the Oklo phenomenon, particularly in relation to the study of time variation of the fine structure constant α where Oklo data lead at present to the most precise terrestrial bounds. Nuclear data are essential to these analyses, but not all are known to the required precision. We summarize our recent work on Oklo and time variation of fundamental constants, and highlight ^{175}Lu neutron capture as one area where improved cross section measurements could lead to more precise bounds on the operating temperatures of the Oklo reactors. We also comment on γ-ray fluxes in Oklo, and on ^{138}La as an independent measure of neutron fluences in the reactors. This work was supported by the US Department of Energy, Office of Nuclear Physics, under Grant No. DE-FG02-97ER41041 (NC State University), and under contract No. DE-AC02-98CH10886 with Brookhaven Science Associates (NNDC).

HB 4 4:40 PM

Identification of Energy Regions for Maximising the Fertile-To-Fissile Conversion in Thorium Fuel Cycles Using Point-Wise Energy Cross Sections in an Actinide Depletion Code

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Concerns about the limits of worldwide uranium resources motivated initial interest in the thorium fuel cycle. It was envisioned that as uranium reserves were depleted, thorium would supplement uranium as a fuel in nuclear reactors. In thorium fuel cycle, Th-232 is the well known fertile nuclide. It is seen from the detailed energy dependent neutron-induced cross-section behaviour of this isotope that it supports fission only with very fast neutrons, i.e. beyond about 1 MeV. At lower energy it has high potential of absorption of neutrons, and consequently converting to fissile nuclides. In that way, even though Th-232 itself is not fissile, it transforms into fissile isotope U-233 upon absorption of a neutron. Conversion of fertile to fissile is possible over a wide energy range, but significant conversion is possible only in an appropriate range. In a nuclear reactor, the conversion depends on available neutrons over and above what is required to sustain the fission chain and the inevitable losses due to leakage and parasitic absorption. It must be noted that the newly generated nuclei undergo all probable interactions and decays, so that they have both production and destruction routes. It is a challenge to obtain an adequate conversion through a proper combination of fissile, fertile and other materials arranged in a carefully worked out geometry in the design. Even before trying with different combination of these factors for achieving better conversion, one should have a proper and quantified idea about the energy range in which a pure Th-232 isotope have better conversion in U-233. Since all the parameters such as production and depletion cross sections involved in the conversion vary with neutron energy due to resonance characteristics which show marked variation with energy, it becomes very difficult to quantify and select the specific energy range/s in which the conversion from pure Th-232 sample to U-233 is more favorable. The burnup and depletion codes such as ORIGEN 2.1 [1] which solve the transmutation and decay equation uses a one group effective cross section are incapable of generating the behavior of conversion from Th-232 to U-233 with energy. In the world, none of depletion and radioactive decay computer codes use the point cross section of nuclide directly. We have developed a computer code which solves the nuclide chain originating with Th-232 with point cross section. This code is used to estimate the variation of conversion of pure Th-232 sample into fissile U-233 as a function of neutron energy. In this code, Bateman equations which represent the time rate of change in the concentration of a specific isotope are solved at every energy point of neutron energy spectrum. The energy interval is obtained after the proper energy grid unionization process of energy interval used in each isotope. We have taken point-wise cross section data from the basic evaluated nuclear data file (ENDF/B-VII.0) for each isotope presented in nuclide chain originating with Th-232. Behaviour of conversion ratio with energy and with exposure time of pure Th-232 sample is studied in our study with the help of developed code. The results are also compared using different nuclear data libraries such as JENDL-3.3.

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HB 5 5:00 PM

Remarks on KERMA Factors in ACE files

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KERMA (Kinematic Energy Release in Material) factors are used as response data in order to obtain nuclear heating in nuclear analyses. These data are not directly included in nuclear data libraries and they in ACE (A Compact ENDF) files for the Monte Carlo radiation transport code MCNP are deduced from cross section data for all the reactions in nuclear data libraries with the NJOY code. Many peoples often use these data, but little is known concerning fact that most of these data are not always correct. We will present this issue here. As well known, there are two methods to compute KERMA factors; one

is "energy-balance method" and the other is "kinematic method". The energy-balance method is the best method if the nuclear data libraries keep energy balance, but this method produces negative or extremely large KERMA factors if the nuclear data libraries do not keep energy balance, e.g. in the case of no gamma production data. The kinematic method produces only minimum and maximum KERMA factors, but the calculated KERMA factors are not negative and extremely large. The maximum KERMA factors are close to ones adequately calculated with the energy-balance method. NJOY outputs only KERMA factors calculated with the energy-balance method to ACE files. Thus the KERMA factors in ACE files are not correct if the nuclear data libraries do not keep energy balance. We examined KERMA factors in the latest official ACE files; those of JENDL-4.0, ENDF/B-VII.1, JEFF-3.1.1, etc. We also checked DPA cross section data because they are related to KERMA factors. Moreover we investigated KERMA factors and DPA cross section data in MATXS files if they are released. We will present these results in the conference.
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HB 6 5:15 PM

Nuclear Data Uncertainty Propagation to Reactivity Coefficients of Sodium Fast Reactor

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Engineering of new reactor models requires computational tools capable of producing results with the adequate level of accuracy. One source of uncertainty in the modeling arises from the employed nuclear data. Here, sensitivity analysis of the quantities important for safety and design to the input parameters, and posterior uncertainty propagation from the parameters to the results is a main tool to point out which nuclear data should be improved. One such new reactor models is the European Sodium Fast Reactor (ESFR), and a one of such design quantities is the group of reactivity coefficients due to heating and voiding effects. Here we present uncertainty quantification from nuclear cross sections data to the mentioned reactivity coefficients of the ESFR core model, with the objective of identifying the nuclear reaction data where an improvement will certainly benefit the design accuracy. The ESFR full core has been modeled for SCALE6.1, and a series of steady states have been computed with KENO-VI Monte Carlo code using the available 238 energy groups cross sections library based on ENDF/B-VII.0 evaluation. An adjoint calculation is also performed to apply Adjoint Sensitivity Analysis Procedure (ASAP) to obtain sensitivities, first for each steady state k-eff, then for the reactivity coefficients between the reference and perturbed states using SCALE6.1 tools. Propagated uncertainty data comes from the 44 energy groups evaluation included with SCALE6.1. The research leading to these results has received funding from the European Atomic Energy Community's 7th Framework Programe in the ANDES project under grant agreement No. 249671. It has also been funded by the specific collaborative agreement between CIEMAT and UNED/UPM in the area of "High level waste transmutation."

HB 7 5:30 PM

Assessing the Impact of Pb and Pu Cross Section Data Uncertainties on Safety Parameters of a Low Power Lead Cooled Reactor

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Accurate and reliable nuclear data and their uncertainties are important in the design, modeling and development of GEN-IV reactors. As part of GEN-IV research in the Universities in Sweden, the design and development of a plutonium-fueled European Lead-Cooled Training Reactor (ELECTRA) [1] was proposed and it is envisaged that it will provide practical experience and experimental data for research and development of GEN-IV reactors. In this paper, the global effect of Pb-208 and Pu-239 cross section data uncertainties on the k-eff, Doppler constant, coolant temperature coefficient, void coefficient and the effective delayed neutron fraction are investigated and analyzed. The analyses were carried out for the ELECTRA reactor using the Total Monte Carlo method proposed in Ref [2]. A large number of Pb-208 and Pu-239 random ENDF-format libraries, generated using the Talys based system [3] and processed into ACE format using Njoy99.336, are used as input into the Serpent Monte Carlo code to obtain the reactor safety parameters. Parameter distributions for the different isotopes are compared with the latest major nuclear data libraries; JEFF-3.1.2, ENDFB/VII.1 and JENDL-4.0. Finally, based on obtained values of chi squared from Ref [3], we investigated if an accept/reject criteria can reduce the uncertainty in reactor parameters.
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HB 8 5:45 PM

Neutronic Study of Burnup, Radiotoxicity, Decay Heat and Basic Safety Parameters of Mono-reycling of Americium in French PWR

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The MURE code is based on the coupling of a Monte Carlo static code and the calculation of the evolution of the fuel during irradiation and cooling periods. The MURE code has been used to analyse two different questions, concerning the mono-recycling of Am in present French Pressurized Water Reactor. The UOX fuel assembly, as in the open cycle system, was designed to reach a burn-up of 46GWd/T and 68GWd/T. The spent UOX was reprocessed to fabricate MOX assemblies, by the extraction of Plutonium and addition of depleted Uranium to reach burn-ups of 46GWd/T and 68GWd/T, taking into account various cooling times of the spent UOX assembly in the repository. The effect of cooling time on burnup and radiotoxicity was then ascertained. Spent UOX fuel, after 30 years of cooling in the repository required higher concentration of Pu to be reprocessed into a MOX fuel due to the decay of Pu-241. Americium, with a mean half-life of 432 years, has high radiotoxic level, high mid-term residual heat and a precursor for other long lived isotope. An innovative strategy consists of reprocessing not only the plutonium from the UOX spent fuel but also the americium isotopes which dominate the radiotoxicity of present waste. The mono-recycling of Am is not a definitive solution because the once-through MOX cycle transmutation of Am in a PWR is not enough to destroy all the Am. The main objective is to propose a “waiting strategy” for both Am and Pu in the spent fuel so that they can be made available for further transmutation strategies. The MOXAm (MOX and Americium isotopes) fuel was fabricated to see the effect of americium in MOX fuel on the burn-up, neutronic behavior and on radiotoxicity. The MOXAm fuel showed relatively good

indicators both on burnup and on radiotoxicity. A 68GWd/T MOX assembly produced from a reprocessed spent 46GWd/T UOX assembly showed a decrease in radiotoxicity as compared to the open cycle. All fuel types understudy in the PWR cycle showed good safety inherent feature with the exception of the some MOXAm assemblies which have a positive void coefficient in specific configurations, which could not be consistent with safety features.

Session HC Nuclear Reaction Models
Tuesday March 5, 2013
Room: Empire East at 3:30 PM
Chair: Brett Carlson, Instituto Tecnologico de Aeronautica
HC 1 3:30 PM

New Approach for Nuclear Reaction Model in Combination of Intra-Nuclear Cascade and DWBA

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Monte Carlo simulation codes such as PHITS, MCNP, FLUKA and MARS play an important role in prediction of radiation damage to materials and human bodies under irradiation. As these codes can describe the transport of many particles, e.g. photons, electrons, nucleons, and heavy ions, using various physical processes, we can obtain deposit energies and particle fluxes in materials for many purposes. In particular, nuclear reaction processes are essential parts for the production of secondary particles in a high energy region. Recently, there are plans to utilize accelerator-based neutron sources using the reaction between proton or deuteron beams and Li, Be or C target for Boron Neutron Capture Therapy (BNCT) or the material test under irradiation at the International Fusion Materials Irradiation Facility (IFMIF) project. For neutron source design, evaluation of neutron yields created by nuclear reactions at incident energies from 10 to 100 MeV is indispensable. However, as nuclear reaction models of the Intra-Nuclear Cascade type used in most of the simulation codes cannot describe quantum mechanical effects, discrete neutron peaks in the neutron energy spectrum are neglected. Although the use of the evaluated nuclear data can give detailed and complex spectra, the energy of the incident particle has been generally limited, e.g. less than 20 MeV. In this study, we obtain cross sections of the discrete states using the Distorted Wave Born Approximation (DWBA) method, which is a theoretical model based on quantum mechanics, and combine the cascade type calculation with the event generator using the DWBA results. This combined model gives not only a broad peak but also discrete peaks of the neutron spectrum for deuteron induced reactions on Li, Be, and C targets. We will show results for proton induced reactions on the targets, and discuss effects of neutron spectra by different nuclear reaction models on the dose estimation.

HC 2 4:00 PM

Calculations of Compound Nucleus Spin-Parity Distributions Populated via the (p,t) Reaction in Support of Surrogate Reaction Measurements

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The surrogate reaction method may be used to determine the cross section for neutron induced reactions not accessible through standard experimental techniques. This is achieved by creating the same compound nucleus as would be expected in the desired reaction, but through a different incident channel, generally a direct transfer reaction. So far, the surrogate technique has been applied with reasonable success to determine the fission cross section for a number of actinides [1], but has been less successful when applied to other reactions, e.g. (n,γ), due to a "spin-parity mismatch" [2]. This mismatch, between the distributions of the excited levels of the compound nucleus populated in the desired and surrogate channels, leads to differing decay probabilities and hence reduces the validity of using the surrogate method to infer the cross section in the desired channel. A greater theoretical understanding of the expected distribution of levels excited in both the desired and surrogate channels is therefore required in order to attempt to address this mismatch and allow the method to be utilised with greater confidence. Two neutron transfer reactions, e.g. (p,t), which allow the technique to be utilised for isotopes further removed from the line of stability, are the subject of this study. Preliminary results will be presented for calculations of the distribution of compound nucleus states populated, via the (p,t) reaction, at excitation energies consistent with those expected via an (n,γ) reaction. Preliminary calculations for the even Zr isotopes will be presented, which will complement US measurements currently being conducted [3].
[1] J.T. Burke et al, "Deducing the ^{237}U(n,f) cross section using the surrogate ratio method", Phys. Rev. C 73 054604 (2006) [2] N.D. Scielzo et al, "Measurement of γ-emission branching ratios for ^{154,156,158}Gd compound nuclei: Tests of surrogate nuclear reaction approximations for (n,γ) cross sections", Phys. Rev. C 81 034608 (2010) [3] J.T. Burke et al, personal communication, Lawrence Livermore National Laboratory, June 2012

HC 3 4:20 PM

Evaluation of Non-Rutherford Alpha Elastic Scattering Cross-Section for Silicon

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The analysis of silicon samples by Ion Beam Analysis (IBA) methods is widely used in numerous laboratories. IBA exploits the interactions of rapid charged particles with matter to determine the composition and structure of the surface regions of solids, the differential cross-section data being needed to derive element concentrations through computer simulation of measured spectra. There are a number of benefits in use for IBA of ^{4}He elastic backscattering at elevated energies where the elastic scattering cross-section is non-Rutherford and consequently has to be determined through measurements and evaluation. A procedure applied in order to obtain an evaluated differential Si(^{4}He,^{4}He)Si cross-section resembled a standard approach in all respects save one. Generally established steps starting from a compilation of relevant experimental data followed by their examination and critical selection were made. The R-matrix theory was employed in order to calculate the Si(^{4}He,^{4}He)Si cross sections. In the calculations the phases obtained in the frameworks of the optical model with Saxon-Woods real potential well and a surface absorption were taken instead of hard sphere ones in order to take into account broad single particle resonances. The specific feature of the procedure employed was adjusting of free model parameters to fit both the available differential cross-section data and thick target yields measured with a thick uniform silicon target. The measurements were performed using the Tandetron accelerator of Surrey University Ion Beam Centre. Such an approach made it possible to adjust resonance widths for narrow resonances in the cases when the cross-section structure was measured with insufficient energy resolution. The evaluated differential

$Si(^4He,^4He)Si$ cross-section in the energy range up to 8 MeV will be made available to the community through the on-line SigmaCalc calculator at http://www-nds.iaea.org/sigmacalc/.
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HC 4 4:40 PM

Modern Techniques for Inelastic Thermal Neutron Scattering Analysis

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Thermal inelastic scattering is the process by which low energy neutrons exchange energy with a surrounding atomic system. During this process the neutron energy distribution attains a quasi-equilibrium state with an average energy that is defined by the temperature and structure of the medium. This coupling between the neutron and the atomic system is quantified using interaction cross sections that are developed based on Born scattering theory combined with Fermi's Golden rule and the assumption of an extremely short range (delta function) nuclear potential. Consequently, the resulting inelastic thermal scattering cross sections reflect both the nuclear interaction process and the atomic structure of the medium. In this case, the atomic system information are represented by the dynamic structure factor, which is also known as the scattering law, i.e., $S(\alpha,\beta)$. The scattering law is interpreted as the Fourier transform (in space and time) of the probability distribution functions that describe the correlated time dependent locations of the atoms. Previously, significant assumptions were used to allow the calculation of such correlation functions and subsequently $S(\alpha,\beta)$ for various atomic systems. More recently, a predictive approach based on ab initio quantum mechanics or classical molecular dynamics has been formulated to estimate $S(\alpha,\beta)$. In principle, these modern atomistic simulation methods make it possible to generate the inelastic thermal neutron scattering cross sections of any material and to accurately reflect the physical conditions of the medium (i.e, temperature, pressure, etc.). In addition, the generated cross sections are free from assumptions such as the incoherent approximation of scattering theory and, in the case of solids, crystalline perfection. As a result, new and improved thermal neutron scattering data libraries have been generated for a variety of materials. Among these are reactor moderators and reflectors such as reactor-grade graphite and beryllium (with coherent inelastic scattering), beryllium carbide, silicon dioxide, cold and ultracold neutron media such as solid methane and solid deuterium, and neutron beam filters such as sapphire and bismuth. Consequently, it is anticipated that the above approach will play a major role in providing the nuclear science and engineering community with its needs of thermal neutron scattering data especially when considering new materials where experimental information may be scarce or nonexistent.

HC 5 5:00 PM

Level Density Options for Hauser-Feshbach Model Calculations from an Experimental Point of View

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The current generation of nuclear reaction codes uses many options for level density inputs which affect cross section calculations to a large extent. Level density parameters determined on the basis of the neutron resonance data obviously experience problems related to both unknown spin and parity distributions at neutron resonance energies and way the level density is extrapolated towards the discrete level region.

Therefore, the extensive tests of available input level density options in modern reaction codes are needed. Particle spectra from compound nuclear reactions are very sensitive to level densities of residual nuclei. We have measured neutron, proton and alpha spectra from reactions induced by deuterons, ^{3}He, alpha particles and ^{6,7}Li beams from the tandem accelerator of the Edwards Laboratory. It is seen that at beam energies around 2-4 MeV/A spectra measured at backward angles do not significantly depend on the type of incoming species indicating that the compound reaction mechanism is dominant. Experimental particle spectra have been compared to calculations from the Empire nuclear reaction code [1] employing different input options for the level density model. It is shown that calculations are sensitive to input level densities and it is possible to rule out some of the models. Particularly, we found that for the mass range 50-60, the level density model must include the constant temperature formula. The model based on Gilbert and Cameron formulation [2] is the best to describe compound nuclear reactions in this mass range. Empire calculations against experimental data are presented.
[1] M. Herman, R. Capote, B. Carlson, P. Oblozinsky, M. Sin, A.Trkov, H. Wienke and V. Zerkin, Nucl. Data Sheets 108, (2007) 2655. [2] A. Gilbert, F. S.Chen and A. G. W. Cameron, Can. J. Phys 43, (1965) 1248.

HC 6 5:15 PM

Statistical Model Analysis of (n,α) and (n,p) Cross Sections Averaged Over the Fission Neutron Spectrum

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Investigation of (n,α) and (n,p) cross sections averaged over the fission neutron spectrum is important to estimate radiation damage due to helium and hydrogen production, nuclear heating and transmutations in the reactor structural materials. On the other hand, systematical analysis of neutron cross sections is of interest to study nuclear reaction mechanisms. In addition, it is often necessary in practice to evaluate the neutron cross sections of the nuclides, for which no experimental data are available, using the systematics. Analysis of the experimental (n,α) and (n,p) cross sections in the energy range of 14-15 MeV was carried out by Levkovsky [1,2] and a certain systematical dependence of the cross sections on the asymmetry parameter of neutron and proton numbers (N-Z)/A was observed which in literature is termed as the isotopic effect. We also have obtained a similar dependence for the (n,α) and (n,p) cross sections of 6 to 20 MeV [3] and for wide energy range suggested the statistical model [4-6] to explain the dependence of the (n,α) and (n,p) cross sections on the parameter (N-Z+0.5)/A and (N-Z+1)/A, respectively. In this paper the statistical model based on the Weisskopf-Ewing theory is used for systematics of known experimental (n,α) and (n,p) cross sections averaged over the fission neutron spectrum. A regular behaviour in the fission neutron spectrum averaged (n,α) and (n,p) cross sections was observed. It was shown that the experimental data is satisfactorily described by the statistical model. In addition, the average effective neutron energy for (n,α) and (n,p) reactions induced by fission neutrons was found to be around 5 MeV.
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Session HD Cross Section Measurements
Tuesday March 5, 2013
Room: Empire West at 3:30 PM
Chair: Mike Herman, NNDC - BNL
HD 1 3:30 PM

Investigation of d- and Alpha-Induced Nuclear Reactions for the Production of Radioisotopes of Bromine and Iodine for Medical Application

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Reaction cross section data are of fundamental importance for accelerator based production of radionuclides. They are mandatory for the assessment and optimization of production yields to be expected as well as for selecting a suitable energy range with respect to undesired side-products. Whereas proton induced nuclear reactions are most often used for production, the utilization of deuterons or alpha-particles offers promising alternatives. In this work excitation functions for the formation of the radionuclides $^{75-78,82}$Br and ^{124}I were investigated. Although the radionuclide ^{124}I ($T_{1/2}$=4.18 d; $E_{\beta+}$=2.13 MeV; $I_{\beta+}$=22%) is an often applied non-standard positron emitter with potent utilization also in theragnostics, some discrepancy was found between the existing experimental data as well as between experimental data and nuclear model calculations, especially for the formation of radioiodine in α-particle induced reactions [1,2]. Excitation functions of (α,xn)-reactions on 98.28% enriched ^{123}Sb and on ^{nat}Sb were measured from 40 to 9 MeV and compared with the calculations done using the computer code TALYS. The discrepancies in literature data for the formation of ^{124}I, ^{125}I and ^{126}I were thereby solved. The nuclear reaction ^{123}Sb(α,3n)^{124}I using an enriched target appears to be interesting for production over the energy range of 42 to 32 MeV; its yield being 11.7 MBq/μAh. Concerning the production of radiobromines which are attractive radionuclides for medical application due to their advantageous chemical behavior, deuteron induced processes on selenium may represent good alternatives to proton induced reactions. As currently very few are data available in the literature, the corresponding cross sections for the nuclear reactions ^{nat}Se(d,xn)$^{75-78,82}$Br were measured in the energy range of 41 to 17 MeV using targets of elemental selenium. The produced radioactivity was analysed non-destructively. The measurement of the short-lived ^{78}Br ($T_{1/2}$=6.45 min) demanded a careful decay curve analysis due to interference from co-produced ^{78}As. The yields of the various products were estimated.
[1] M.N. Aslam, S. Sudar, M. Hussain, A.A. Malik, S.M. Qaim, Appl. Radiat. Isot. **69**, p. 94 (2011). [2] F. Tarkanyi, S.Takacs, B. Kiraly, F. Szelecsenyi, l. Ando, J. Bergman, S.-J. Heselius, O. Solin, A. Hermanne, Yu.N. Shubin, A.V. Ignatyuk, Appl. Radiat. Isot. **67**, p. 1001 (2009).

HD 2 4:00 PM

Nuclear Data for ^{227}Ac Production Below 200 MeV by Proton Bombardment of Thorium

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Nuclear cross section data for the production of ^{227}Ac were measured at Los Alamos National Laboratory by bombarding thin, stacked thorium foils with protons at 12 energies below 200 MeV. The thorium targets were chemically separated and the ^{227}Ac was quantified using alpha spectroscopy. These results, along with previously published data and theoretical values, outline accelerator production pathways for ^{227}Ac, which can be used as a ^{223}Ra generator, and for ^{225}Ac with a minimized level of ^{227}Ac impurity.

HD 3 4:20 PM

Cross Sections for Proton Induced Reactions on Thorium at 800 MeV

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Cross sections were measured for the formation of 69 nuclei from natural thorium targets irradiated with 800 MeV protons in the Blue Room of the Los Alamos National Laboratory (LANL) Neutron Science Center. Irradiated thorium foils were assayed by gamma spectroscopy to quantify produced radionuclides. The formation of non-actinide isotopes by fission and spallation processes during irradiations of thick thorium targets is germane to the development of radiochemical separations and routine irradiation procedures necessary to produce ^{225}Ac for use in clinical trials. Predictions by the recent LANL Monte Carlo MCNP6 transport code using different models considered by its several event generators are compared with measured data in order to Verify and Validate (V&V) MCNP6.

HD 4 4:40 PM

Nuclear Fragmentation Measurements for Hadrontherapy: 95MeV/u ^{12}C Reactions on H, C, Al, O and ^{nat}Ti Targets

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The interest for hadrontherapy, the use of ion beams for the treatments of cancerous tumors, is increasing. This can be attributed to the great accuracy of ion beams to target the tumor while sparing the surrounding healthy tissues (due to the high dose deposition in the Bragg peak and the small angular scattering of ions) as well as the potential biological advantage of ions for some tumor types compared to photons. To keep the benefits of carbon ions in radiotherapy, a very high accuracy on the dose location is required. The dose deposition is affected by the fragmentation of the incident ion that leads to a consumption of the projectiles with their penetration depth in the tissues (up to 70% for 400MeV/u ^{12}C in water), to the creation of lighter fragments having different biological effectiveness (RBE) and to the apparition of a fragmentation tail behind the tumor. The constraints on nuclear models and fragmentation cross sections in

the energy range used in hadrontherapy (80 to 400MeV/u) are not yet sufficient to reproduce the fragmentation processes with the required accuracy for clinical treatments. A first integral experiment, on thick water equivalent targets has been performed by our collaboration on May 2008 at GANIL (France) [1]. The goals were the measurements of energy and angular distributions of the fragments due to nuclear reactions of 95MeV/u ^{12}C with thick PMMA targets. Comparisons between experimental data and Geant4 simulations using different physics processes show discrepancies up to one order of magnitude for the production rates of fragments. The shapes of the angular and energy distributions are also not well reproduced. To improve the models and reach the accuracy required for a reference simulation code for hadrontherapy, a second experiment has been performed on thin targets on May 2011 at GANIL. The experimental set-up was made of five three stages δE-E telescopes, each composed of two Si detectors and one CsI scintillator mounted on rotating stages to cover angles from 4° to 45°. The energy calibration of the detector and the identification of the fragments have been achieved. The double differential cross sections $\delta^2\sigma/(\delta E\delta\Omega)$ have been obtained for all fragment isotopes from p to ^{12}C for nuclear reactions of ^{12}C with H, C. Al, O and ^{nat}Ti. Simulations are under completion to evaluate the systematic uncertainties (first estimations lead to an accuracy of 10% for Z>2 fragments and up to 20-30% for protons at forward angles). The cross sections increase with the mass of the target. The results also show a more forward-focused angular distributions for heavier fragments and a predominance of Z=2 fragments at forward angles ($< 10°$), compatible with the three alpha structure of the ^{12}C. The energy distributions of the fragments at forward angles are peaked close to the beam energy showing an emission dominated by the quasiprojectile. The angular and energy cross sections obtained with a thin PMMA target have been reproduced with a 10% accuracy thanks to the elemental cross sections obtained on C, H and O targets. The experimental setup and the results for the different targets will be presented.
Corresponding author: Labalme Marc
[1] B. Braunn et al., "Nuclear reaction measurements of 95MeV/u ^{12}C interactions on PMMA for hadrontherapy", Nucl. Inst. Meth. B 269 (2011), 2676.

HD 5 5:00 PM

Strontium-82 Production at ARRONAX

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There has been a strong increase of the use of rubidiulm-82 in the USA over the last years. As an analogue of potassium, rubidium-82 is used for PET cardiac imaging. It has been shown [1], that Rubidium-82 present better performances than Technicium-99m and Thallium-201 for overweight patients or women. Rubidium is made available through a generator system, the Strontium-82/Rubidium-82 generator. Strontium is produced using high energy accelerator in only few places in the world. Targets can be of two types: Rubidium chloride (RbCl) or Rubidium metal. The latter is offering higher production yield and better thermal conductivity with higher constraints in its handling. Rubidium as an alkaline can highly react with water and air. The aim of this paper is to present the work done at our facility, ARRONAX, to develop such production. ARRONAX, acronym for "Accelerator for Research in Radiochemistry and Oncology at Nantes Atlantique," is a high energy (70 MeV) and high intensity (2*375 A) multi-particle cyclotron located in Nantes (France). Two proton beams can be extracted at the same time (dual beam mode) and experimental vaults are equipped with irradiation stations connected to hot cells via a pneumatic transport system. For strontium production, we have developed a new targettry system which allows irradiating several pressed pellets of RbCl (dual target mode). We have also set three hot cells to perform the extraction and purification process. Laboratories are present on site to perform radioactive assays (germanium detectors and liquid scintillation) and non radioactive assays (ICP-AES). Several production runs have been made since 2011 using dual target mode and dual beam modes (up to 2*100 A on target) to qualify the production. Routine productions have started in June 2012. The produced strontium-82 is fully in accordance to the FDA specifications for the radionuclidic purity, the specific activity, the activity concentration: as well as the non radioactives species. Developments are being made to improve the production yield by moving from RbCl target to Rb metal target. This is being done in collaboration with INR Troitsk (Russia). Another development is connected to the production of Ge-68 which can be done simultaneously by using the 40 MeV coming out of the target. The cyclotron ARRONAX is supported by the Regional Council of Pays de la Loire, local authorities, the French government and the European Union

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[1] Le Guludec D. et al, Eur J Nucl Med Mol Imaging 2008; 35: 1709-24

HD 6 5:15 PM

Electrodeplating of Gallium 69 for the Production of Gallium 68 for the Nuclear Medicine at ARRONAX

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One of the ARRONAX's objectives is to produce innovative radioisotopes for research in nuclear medicine. The main applications are the diagnostic imaging (Positron Emission Tomography) and therapeutic (radiotherapy) in oncology. Another application is medical imaging PET in cardiology. For that purposes, a particular focus is done on the production of the following radioisotopes: the Sr 82, At 211, Cu 67, Sc 47 and Ga 68. The aim of this work is to study and produce targets for the production of germanium 68. Germanium 68, mother of gallium 68, will be used to make generators of gallium 68. The manufacturing of targets should be in accordance with quality criteria. The thickness of the deposit must be uniform to ±5% over the entire surface and must adhere perfectly to the substrate. Its composition must be accurately known [1]. The production of Ga68 is in most case made using ^{69}Ga + p → ^{68}Ge + 2n. It is obtained from natural gallium or enriched gallium 69. Gallium has a low melting temperature at 29.7 C [2-4]. During irradiation, it is in liquid form. This highly corrosive liquid [2,3] is usually encapsulated. However, he attacked the container whatever materials used sometimes resulting in breaks. To circumvent this problem, a gallium based alloy can be used whose melting temperature is higher. These alloys are produced by electroplating. The search for the metal alloyed with gallium is made by studying the phase diagrams of gallium based alloys. They provide information about existing phases and corresponding melting temperatures. The electrochemical potentials standards are also taken into account: the ideal is that the potentials of the two metals are close in order to be simultaneously deposited [5]. One of the chosen metal could be nickel. According to the phase diagram (Ni/Ga), the maximum atomic proportion of gallium for an homogeneous compound with a melting temperature above 500 C, is between 60% and 80% gallium. The three possibly phases are Ga_4Ni, Ga_3Ni_2 and Ga_4Ni_3. However, the electrochemical standard potentials of gallium (-0.52 V/ENH) and nickel (-0.25 V/ENH) are quite distant. So, nickel reduction is promoted. It is possible to minimize its amount in the deposit by varying the nickel concentration [6]. The concentrations of nickel and gallium will have to be maintained at a certain level to succeed in reaching enough thicknesses. The chosen support, which is the work electrode, is made of gold because it provides a good deposit quality and has a good thermal conductivity. But the chemical separations risks to be complicated with the presence the big abundances of 3 metals: gallium, nickel and gold. To avoid this complication, tests were also made with a nickel support giving good results. A series of experiments have been conducted with different nickel and gallium ratio varying the speed stirring (from 300 rpm to 1300 rpm), the addition of chloride ions (0.1 M to 1 M), the voltage and the duration. On both type, the optimized parameters are -1.6 V, 1300 rpm with concentrations of 0.2 M of $Ga_2(SO_4)_3$ and 0.2 M of $NiCl_2$. The phase obtained has been characterized by DRX, ICP-AES and SEM. It corresponds to a homogeneous phase of Ga4Ni3. For the duration of 2 hours, the thickness reached is 45 μm . Our objectives are now to reach for this phase the thickness between 230 μm and 280 μm which corresponds to the minimal value necessary to implement germanium production on ARRONAX. This production will be made together with the Strontium 82 production, using the 40 MeV coming out of the Rubidium target.

[1] IAEA, technical reports series no 465, p 135 [2] a new production method for germanium 68, N.R. Stevenson, M. Cackette and T.J Ruth, The Synthesis and Applications of Isotopes and Isotopically Labelled Compounds, Strasbourg, France, June 20-24 [3] a new preparation of germanium 68, C. Loch'H, B. Maziere, D. Comar and Knipper, Int. J. Appl, isto. Vol. 33. pp. 267 to 270, 1982 [4] preparation of Ge68/Ga68 generator with a binary Ga/Ag electrodepositions as solid target, Wu-Long Cheng, Yun Jao, Chung-Shin Lee, Ai-Ren Lo, Journal of radioanalytical and Nuclear Chemistry, Vol. 245, No. 1 (2000) 25-30 [5] E. Chassaing, technique de l'ingénieur, alliages électrodéposés, [M 1620] (2006) [6] H. F. Ayedi et M. Depetris-Wery, technique de l'ingénieur, Electrodéposition de zincs alliés, [M 1602] (2012)

HD 7 5:30 PM

Th-232 (d, 4n) Pa-230 Cross-Section Measurements at ARRONAX Facility

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The ARRONAX cyclotron [1], acronym for “Accelerator for Research in Radiochemistry and Oncology at Nantes Atlantique” is a new facility installed in Nantes, France. It is a high intensity - up to twice 375 μA for protons - and high energy - up to 68.7 MeV - multiple projectiles - protons, deuterons, α particles - cyclotron. Two beams can be extracted at the same time for protons and deuterons in dual beam mode. ARRONAX has 6 experimental vaults among which four are connected to hot cells through a rabbit system and are devoted to radionuclide production. Its main objective is the production of radionuclides for medical use. Other developed activities are radiolysis and radiobiology using a pulsed α beam and physics. On ARRONAX, a dedicated program has been launched on production of radionuclides for α targeted radiotherapy. A great effort is put on production of At-211. At the same time, we have looked for other α emitters that can be produced by cyclotron. Among them, Th-226 is of great interest since it has been found to be a more potent α particle emitter for leukemia therapies than Bi-213 [2]. It can be obtained via production of its mother nuclide U-230. Different reaction routes are possible for U-230 generation: Th-232 (p, 3n) Pa-230 → U-230, Th-232 (d, 4n) Pa-230 → U-230 or via direct production, Pa-231 (p, 2n) U-230. In this study, we focus on the use of deuteron as projectile. In the literature, only one set of data

[3] has been found. As optimization of isotope productions required a good knowledge of cross-sections for the isotope of interest but also for all the contaminants created during irradiation, it deserves a new set of data. We start on ARRONAX to measure deuteron induced production cross-sections from 15 MeV up to 35 MeV using the well-known Stacked-Foils technique [4]. An originality of our work is the use of monitor foils behind each target foil in order to record efficiently the incident particle flux and its energy all over the stack. For Pa-230 production, our stack is composed of 40 microns Th-232 foils. Each of them is followed by a monitor, 20 microns of natural Nickel, Aluminum or Titanium. Energy degradation is obtained by the intercalation of a 500 microns Aluminum foil. Typical irradiation uses a beam intensity of 100 nA during 30 min. Activity measurements are made using gamma spectrometry. Our new set of data will be compared with the existing data [3] and with TALYS code calculations [5]. The production yield of the different production routes will be presented allowing the choice of the best one.
[1] F. Haddad *et al.*, ARRONAX, a high energy and high intensity cyclotron for nuclear medicine, Eur. J. Med. Mol. Imaging (2008) 35:1377-1387. [2] C. Friesen *et al.*, Radioimmunotherapy using anti-CD33 antibodies radiolabeled with Thorium-226 or Bismuth-213 overcome chemo- and radioresistance in myeloid leukemia cells, Haematologica 2009; 94[suppl.2]:329 [3] J. Rama Rao, J. Ernst, H. Machner Comparative study of d- and 6Li-induced reactions on 232Th in terms of breakup and preequilibrium processes, Nuclear Physics A448 (1986) 365-380 [4] E. Garrido, Production de radio-isotopes : de la mesure de la section efficace à la production, PhD thesis, November 2011 [5] A.J. Koning, S. Hilaire and M. Duijvestijn, "TALYS-1.0", proceedings of the international conference on nuclear data for science and technology, ND2007 (2007).

Session HE Experimental Facilities and Techniques
Tuesday March 5, 2013
Room: Central Park East at 3:30 PM
Chair: Robert Haight, LANL
HE 1 3:30 PM

Verification of the Thermodynamic Model in Nuclear Fission: the New Spectrometer FIPPS

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The thermodynamic model provides the entry state population in fission fragments in defining excitation energy and spin distributions as function of fragment mass and charge. In the same way the distribution functions for the decay products of excited fragments are provided (in particular prompt gamma and neutron decay). The parameters relevant to the thermodynamic descriptions are the level density, which is taken from low energy nuclear physics data, and a nuclear temperature, which can be derived from a single fragment kinetic energy measurement. In the presentation we will review the statistical model for excitation and spin distributions of fragments, and the distributions for decay particles as function of mass, charge and fragment kinetic energy. We will present a new spectromenter which aims to provide the observables Y(A,Z,E*,J), which characterize fully a fission event. The new spectrometer will consist of a gamma array of HP germanium detectors, and a gas filled magnet for the determination of Y(A,Z,Ekin), from which the various distribution functions and the decay characteristics are derived. First experiments on a gas filled magnet device will be presented, and the the approach for the calculation of the ion tracks in the magnet will be given.

HE 2 4:00 PM

Modular Total Absorption Spectrometer at the HRIBF

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The Modular Total Absorption Spectrometer (MTAS) array will be presented. MTAS has been designed, constructed and applied to the decay studies of ^{238}U fission products at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory. Total absorption spectroscopy of fission products is important for the verification and development of nuclear structure models, as well as for the determination of decay heat released by radioactive nuclei during nuclear fuel cycle. The MTAS detector array consists of 19 NaI(Tl) hexagonal shape detectors, each one is 21 inches long and about 8 inches maximum diameter. MTAS is mounted on a movable cart allowing to adjust the height. The entire MTAS array is surrounded by over 12,000 pounds of lead and paraffin shielding. This heavy shielding consists of three individual movable segments. MTAS efficiency for full energy deposition of a single gamma ray approaches nearly 93% around 300 keV and it is about 68% for a 5 MeV gamma-transition. The energy resolution of individual MTAS modules is below 6% at 1.33 MeV and about 7% to 8% at 0.66 MeV. Auxiliary detectors include two segmented 1-mm-thick silicon strip detectors placed inside the MTAS array around the tape transporting collected activities. These Si-counters cover over 80% of the solid angle for beta-energy loss detection and help to center the radioactive samples inside MTAS. The energy resolution for 976 keV electrons is about 2.5% (∼25 keV) and the low energy threshold for electrons is less then 50 keV. The on-line MTAS commissioning run was performed in January 2012 at the mass separator on-line to the HRIBF Tandem accelerator. Over twenty decays of fission products have been studied using MTAS including seven decays defined as having the highest priority for decay heat analysis in nuclear reactor by the assessment of OECD Nuclear Energy Agency. Selected results will be presented at this meeting [1].

This work was supported by the U.S. Department of Energy Office of Nuclear Physics.

[1] M. Karny *et al.*, "First results from the Modular Total Absorption Spectrometer at the HRIBF (ORNL, Oak Ridge)," ND2013 Proceedings.

HE 3 4:20 PM

Measurements of the $(n,2n)$ Reaction Cross Section of ^{181}Ta from 8 MeV to 14.5 MeV

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Nuclear data are the backbone of nuclear technology. They are useful in many areas such as design and modeling of nuclear energy systems,radiation safety, activation techniques, and interdisciplinary areas like

production of radioisotopes for medical and industrial applications, space applications, radiation damage studies, environmental monitoring, etc. In addition, precise nuclear data, particularly cross-section measurements are playing an important role in fundamental research, to test different statistical-model codes and to provide insight into the reaction mechanisms in different energy regimes. ^{180}Ta is a subject of extensive study in nuclear physics. It is a natural isomeric target, and therefore of great interest for nuclear astrophysics as well. Furthermore, the $^{181}\mathrm{Ta}(n,2n)^{180}\mathrm{Ta}$ reaction was used as witness foils (chemical tracers) in underground tests of nuclear devices to assess their performance and very recently, also for diagnostic purposes at NIF (National Ignition Facility). The cross section of the reactions $^{181}\mathrm{Ta}(n,2n)^{180}\mathrm{Ta}$ was measured from 8 to 14.5 MeV in small energy steps to resolve inconsistencies in the existing database. For the first time the cross section of the $(n,2n)$ reaction on ^{181}Ta was measured for neutron energies near threshold. Mono-energetic neutron beams were produced via the $^{2}\mathrm{H}(d,n)^{3}\mathrm{He}$ reaction, known for its high neutron yield in the energy region of the present measurements. The induced γ-ray activity of ^{180}Ta was measured with high-resolution HPGe detectors. The acquired γ-ray spectra, from the off-line measurements of the activated samples, were analyzed to identify the reaction products and to determine the respective peak areas. The cross section was determined relative to Al and Au neutron activation monitor foils, measured in the same geometry. Results for the cross-section data obtained from 8 to 14.5 MeV are reported.
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HE 4 4:40 PM

Development of Anti-Compton $LaBr_3$(Ce) Spectrometer for Measurement of Surrogate Reaction

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Anti-Compton $LaBr_3$(Ce) spectrometers have been installed at JAEA-Tokai tandem accelerator facility in order to measure the γ rays from the highly excited states produced by surrogate reactions. Each spectrometer consists of a central $LaBr_3$(Ce) detector with a diameter of 10.2 cm and a length of 12.7 cm, and an annular BGO detector with a thickness of 2.5 cm and a length of 25.4 cm. In this contribution, we will present the results of performance test using the standard γ ray source and high-energy γ rays from the ^{27}Al(p,γ)^{28}Si reaction, and a measurement plan for (n,γ) cross sections using a surrogate reaction at JAEA-Tokai tandem accelerator facility.

HE 5 5:00 PM

Development of an Ionization Chamber for the Spider Fission Fragment Detector

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The ionization chamber component of the SPIDER detector has been designed to measure energy loss and kinetic energy of fragments produced through neutron-induced fission with energy resolutions <1% and time-dependent signal collection. Important design elements implemented are an axial configuration of the electrodes for improved energy loss measurement and a thin silicon-nitride entrance window to minimize both energy loss and energy straggling of the incoming fragments. High energy resolution and improved charge resolution from the ionization chamber are combined with the high precision of the upstream time-of-flight component of SPIDER to achieve resolutions in mass and nuclear charge of 1 amu and Z=1. A discussion of the present resolution capabilities of the ionization chamber and characterization using a ^{252}Cf source will be presented. Work supported by grants for LDRD Project 20110037DR. LA-UR-12-23722.

HE 6 5:15 PM

CALIFA, a Calorimeter for the R3B/FAIR experiment

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The R3B experiment (Reactions with Relativistic Radioactive Beams) at FAIR (Facility for Antiproton and Ion Research) is a versatile setup dedicated to the study of reactions induced by high-energy radioactive beams. It will provide kinematically complete measurements with high efficiency, acceptance and resolution, making possible a broad physics program with rare-isotopes that addreses very relevant questions such as the structure of the atomic nucleus at the extreme of nuclear stability or reactions of astrophysics interest. CALIFA (CALorimeter for In-Fligth emitted pArticles), is a complex detector based on scintillation crystals, that will surround the target of the R3B experiment. CALIFA will act as total absorption gamma-calorimeter and spectrometer, as well as identifier of charged particles from target residues. This versatility is its most challenging requirement, demanding a huge dynamic range, to cover from low energy gamma-rays up to 300 MeV protons. This fact, along with the high-energy of the beams determine the conceptual design of the detector that will be presented in this paper together with the technical solutions proposed for its construction.

HE 7 5:30 PM

Atomic Number Determination of Fission Products by Digital Techniques

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Determination of atomic numbers of non-accelerated fission products by non-radiative methods is a long-standing experimental problem. Correct fragment identification (i.e., by mass and atomic number) is relevant to the production probability (yield) of nuclei in low-energy fission reactions and is of interest to different domains of research incuding nuclear data for industry and spectroscopic studies of exotic nuclei. The difficulty in atomic number assignment is determined by the difference in the energy lost in a detector by fragments with adjacent nuclear charges. This difference is small and comparable to the detector

energy resolution, whereas the range of nuclei to identify is relatively wide. An additional complication comes also from the fact that these subtle changes in the loss of energy between nuclei do not remain the same over the range of kinetic energies with which nuclei are produced in fission. Therefore assignment of atomic numbers to fission products is possible only if thorough care is given to the collection of the ionisation produced in the detector and to the consequent electronic treatment of signals. This approach is implemented in the design of the two-arm spectrometer of fission products (STEFF) recently built at the Manchester University. In addition to the identification of masses, by the double energy / double velocity measurement, the spectrometer is capable of delivering information on nuclear charges of fission products, on the event-by-event basis. This is achieved from the analysis of the fragments' pulse shapes and ranges in gaseous detectors, both obtained using digital electronics in conjunction with specially developped algorithms. The technique has been optimised with beams of fission products with known kinetic energy and isobaric composition, as well as tested in the $^{235}U(n_{th}, f)$ experiment at the ILL in France. The details of the method will be presented and explained, results on the identification of atomic numbers in the light group of fission products will be demonstrated and the perspectives discussed.

HE 8 5:45 PM

Fast Neutron Laboratory of the NPI Řež: Neutron Measurement Techniques

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Nuclear reaction department of the NPI Řež operates three different fast neutron sources: p+D_2O and p+Be with continuous neutron spectrum with energies up to 37 MeV, and p+Li quasi-monoenergetic neutrons with energies up to 37 MeV. Isochronous cyclotron U-120M provides protons in the energy range 20-38 MeV and currents up to 20 μA. Several neutron detection techniques were developed next to the neutron sources. Primarily the spectra were deconvoluted from the reaction rates of irradiated activation foils. Later a proton recoil telescope was constructed and the spectra from p+Li target were successfully validated against MCNPX simulations (agreement within 10%) [1]. Recently, we started to use NE213 scintillation detector together with 500 MHz digitizer card and have succeded to obtain neutron spectra from the scintillator response and also to record a limited Time-Of-Flight spectra from our neutron sources on cylotron without axial injection and with complicated micro- and macro-structure of the beam. Obtained neutron spectra from all methods are compared and show good agreement.
[1] S.P. Simakov et al., Analysis of the Dosimetry Cross Sections Measurements up to 35 MeV with a ^{7}Li(p,xn) Quasi-monoenergetic Neutron Source, **ND-1450**, DOI: 10.3938/jkps.59.1856

Session IA Plenary Wednesday
Wednesday March 6, 2013
Room: Met East at 8:30 AM
Chair: Pavel Oblozinsky, Slovak Academy of Sciences
IA 1 8:30 AM

Physics of Neutron Interaction with U-238 Nucleus: New Developments and Challenges

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The latest release of the EMPIRE-3.1 system (codename Rivoli) is being used in the advanced modeling of neutron induced reactions on U-238 nucleus aimed at improving our knowledge of the neutron scattering and prompt fission neutron emission. The reaction model includes - a new rotational-vibrational dispersive optical model potential couplings the low-lying collective bands of vibrational character observed in even-even actinides; - the Engelbretch-Weidenmuller transformation allowing for inclusion of compound-direct interference effects enhanced by a dispersive treatment of the optical model potential; - a multi-humped fission barrier with absorption in the secondary well described within the optical model for fission; - a modified Lorentzian model (MLO) of the radiative strenght function; and integrated prompt fission neutron spectra modeling that may include emissive contributions from (n,xnf) reactions, and neutron emission from fission fragments calculated by Los Alamos or Kornilov models. Impact of the advanced modeling on inelastic scattering cross section and corresponding uncertainties is being assessed both by comparison with selected microscopic experimental data and integral criticality benchmarks including measured reaction rates (e.g. FLAPTOP and BIG TEN). Benchmark calculations provide feedback to improve the reaction modeling and reduce both model and model-parameters uncertainties. Improvement of existing libraries will be discussed.

IA 2 9:15 AM

Plasma Nuclear Science: Nuclear Science in Hot, Dense, and Dynamic Laboratory Plasmas

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The plasma environments created using laser-driven inertial confinement fusion implosion at the National Ignition Facility [1] and OMEGA Laser Facility [2] probe new degrees of freedom in nuclear reactions and nuclear-atomic interactions. These thermal plasma environments closely resemble the burning core of a star where the reactants are ionized and the electrons are in continuum states. The fusion reactions in these plasmas can also lead to an extremely high neutron brightness, 10 orders of magnitude higher than produced in conventional accelerator and reactor facilities. However, these facilities also present challenges for nuclear astrophysics measurements because the plasma environment is a complex and dynamic system that is difficult to model. Results from three studies are presented: (1) the n-T differential elastic scattering cross section at $E_n = 14$ MeV [3], (2) the stellar ^{3}He(^{3}He,2p)^{4}He (or 3He3He) reaction, the dominant energy-producing step in the solar proton-proton chain, and (3) its charge conjugate reaction, the T(t,2n)^{4}He (or tt) reaction [4]. These measurements were carried out at OMEGA, where gas-filled spherical capsules were spherically irradiated with powerful lasers to compress and heat the fuel to high enough temperatures and densities for significant nuclear reactions to occur. Reactant products are measured with particle spectrometers designed to work in this special environment [5]. While the n-T differential scattering results were consistent with expectations, the results from the tt measurements are puzzling on two fronts. First, the tt rate is higher than expected based on accelerator measurements [6]. Second, in contrast to accelerator experiments conducted at CM energies above 100 keV [4], the tt neutron spectrum shows a smaller n+^{5}He reaction channel at a CM energy of 23 keV [4]. This suggests that the reaction mechanism is changing at lower energies. These results, implications and possibilities for future nuclear astrophysics measurements will be discussed. * Prepared by LLNL under Contract DE-AC52-07NA27344 and supported in part by NLUF (DOE), FSC (UR), US DOE, LLE, LLNL, and GA under DOE.

1. G. H. Miller et al., Nucl. Fusion **44**, S228 (2004). 2. T.R. Boehly et al., Optics Communications **133**, 495 (1997). 3. J.A. Frenje et al., Physical Review Letters **107**, 122502 (2011). 4. D.T. Casey et al., Physical Review Letters **108**, 075002 (2012); D.T. Casey et al., Physical Review Letters, **109**, 025003 (2012). 5. F.H. Séguin et al., Review of Scientific Instruments **74**, 975 (2003). 6. N. Jarmie and R. E. Brown, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **10-11** (Part 1), 405-410 (1985).

Session JA Atomic Masses
Wednesday March 6, 2013
Room: Met East at 10:30 AM
Chair: Jose Luis Tain, IFIC - Valencia
JA 1 10:30 AM

The 2012 Atomic Mass Evaluation and the Mass Tables

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As announced at the ND2010, the new Atomic Mass Tables will soon be released. The publication is due for December 2012 in the "Chinese Physics C" journal. This new publication will include all material that is available to us. The Atomic Mass Tables are the fruit of the evaluation of all valid experimental data aiming at mass measurements, or in which relevant energy measurements are given. Among the various projects that originated in the 1950's, the concept developed by Aaldert H. Wapstra, proved to be able to face the otherwise insolvable difficulties due to the strong interconnections among the measurements. This concept is the one that is referred to as the Atomic Mass Evaluation (Ame)ö. It was the only one which survived and produced a series of Mass Tables over the years, the most recent of those, in 1983, 1993, and 2003. At the conference we will present the new policies and procedures used and also some of the most important features of our knowledge of the nuclear properties stemming from the surface of masses as it appears nowadays. Among the co-authors of the coming AME2012 tables is the name of Aaldert H. Wapstra, the founder of the AME, who passed away at the end of 2006. He made essential contributions to the AME2012 during the two years following the publication of AME2003. And more than those two years, this work is filled with his spirit. *Deceased, December 2006.

[1] G. Audi, A.H. Wapstra, and C. Thibault Nucl. Phys. A 729, 337 (2003) and reference therein. [2] Bulletins of the Amdc: http://amdc.in2p3.fr/bulletins/filel.html.

JA 2 11:00 AM

Precision Atomic Mass Measurements for Nuclear Data Applications

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Mass of the atomic nucleus is a basic observable which contains information of its constituents and forces acting between them. If atomic masses are known precisely enough, differences of atomic masses give insight for the underlying nuclear structure. A unique combination of IGISOL technique and JYFLTRAP has allowed systematic studies of atomic masses over large range of fission products, as reviewed in [1]. Roughly 200 atomic masses of neutron-rich fission products have been measured at JYFLTRAP with the typical precision in 1-10 keV regime. When combined with the data from other Penning trap facilities, the systematic data spans more than 300 neutron-rich isotopes. Such data sets provide an important benchmark for existing atomic mass predictions but affect also our understanding of some key phenomena in nuclear technology. In this presentation a global picture on improved mass surface of neutron-rich nuclei will be presented and discussed in the light of selected mass models and nuclear theories representing different approached from simple extrapolations schemes to more sophisticated microscopic approaches. A closer look on closed shell regions studied at JYFLTRAP will also be discussed as well as their connections to nuclear data applications.

[1] A. Kankainen, J. Aysto, A. Jokinen, J. Phys. G: Nucl. Part. Phys. **39** (2012) 093101

JA 3 11:20 AM

Mass Measurements of Short-lived Nuclei at HIRFL-CSR

M. Wang, H.S. Xu, Y.H. Zhang, X.L. Tu, X.H. Zhou, Y.J. Yuan, J.W. Xia, X.C. Chen, C.M. Du, P. Geng, Z.G. Hu, W.X. Huang, S.L. Jin, L.X. Liu, Y. Liu, X. Ma, R.S. Mao, B. Mei, P. Shuai, Z.Y. Sun, S.W. Tang, J.S. Wang, S.T. Wang, G.Q. Xiao, X. Xu, X.L. Yan, J.C. Yang, R.P. Ye, Y.D. Zang, H.W. Zhao, T.C. Zhao, W. Zhang, X.Y. Zhang, W.L. Zhan, *Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, People's Republic of China.* Y. Sun, *Department of Physics, Shanghai Jiao Tong University, Shanghai 200240, People's Republic of China.* Yu.A. Litvinov, S. Typel, *GSI Helmholtzzentrum für Schwerionenforschung, Planckstrasse 1, 64291 Darmstadt, Germany.* K. Blaum, *Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany.* G. Audi, *CSNSM-IN2P3-CNRS, Université de Paris Sud, F-91405 Orsay, France.* H. Schatz, B.A. Brown, *Department of Physics and Astronomy, National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA.* T. Yamaguchi, *Department of Physics, Saitama University, Saitama 338-8570, Japan.* Y. Yamaguchi, *RIKEN Nishina Center, RIKEN, Saitama 351-0198, Japan.* H. Suzuki, *Institute of Physics, University of Tsukuba, Ibaraki 305-8571, Japan.*

Since commissioning in 2007, four campaigns of mass measurements for short-lived nuclei have been carried out at the HIRFL-CSR (Cooler Storage Ring at the Heavy Ion Research Facility). The radioactive nuclei were produced by projectile fragmentation and injected into the experimental storage ring CSRe, which was set as an isochronous mass spectrometry. The revolution times of various ions stored in the CSRe were measured, and masses of nuclei of interest deduced. Masses of fragments of 78Kr[1], 58Ni[2] and 86Kr have been measured, for some of them for the first time. The resolving power of 170000-180000 has been achieved in the experiments. The experimental results will be presented. Their impact on nucleosynthesis in the rp process and nuclear structure will be discussed.

[1] X.L.Tu et al., Phys.Rev.Lett. 106, 112501 (2011) [2] Y.H.Zhang et al., Phys.Rev.Lett. 109, in press (2012)

JA 4 11:40 AM

Precision Mass Measurements for Nuclear Physics Application and Metrology

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The understanding of the strong force and the nuclear interaction is on the forefront of today's nuclear research. More and more detailed theories are successfully used to describe an every increasing set of nuclei on the Segre chart. To further refine the theoretical approaches, such as ab-initio or density functional theories, one needs accurate and precise data to compare predictions to. One of the key quantities of an atom is its mass. The mass of an atom is a fundamental quantity, and provides a wealth of data for related fields, including basic and applied research. However, many of the relevant isotopes are short-lived and need to be produced on-line. To overcome the obstacles given by the nature of rare isotopes, we have developed very sensitive and fast methods using ion trap techniques at TITAN (TRIUMF's Ion Trap of Atomic and Nuclear science). Ion traps are typically used in analytical chemistry and atomic physics for stable molecules or isotopes. We have adapted the technique to the challenging conditions and at TITAN we are able to measure masses, using one single ion in as short as 8ms with 10ppb precision. This is breaking a new world-record for precision mass spectroscopy. Using this appraoch we are able to probe a wide range of isotopes, where masses are needed. Fields of interest include fundamental nuclear physics, tests of symmetry concepts in the Universe, nuclear astrophysics, and metrology. In this talk I will report on such measurements and show how and where they are applied in the various fields.

Session JB Fusion Applications
Wednesday March 6, 2013
Room: Met West at 10:30 AM
Chair: Jean-Christophe Sublet, UK AEA
JB 1 10:30 AM

The Activities of the European Consortium on Nuclear Data Development and Analysis for Fusion

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The European Fusion Programme builds on the availability of qualified computational tools and data as pre-requisites for reliable neutronic design calculations of any kind of fusion devices like ITER, irradiation facilities or future power plants. To serve this end, the European Consortium on Nuclear Data Development and Analysis was formed combining the available European expertise on nuclear data evaluation, processing, validation and benchmarking. The Consortium, consisting of the research institutions of KIT (Germany), CCFE (UK), NRG (The Netherlands), JSI (Slovenia), TUW (Austria), CIEMAT (Spain) and IFIN-HH (Romania), provides the services requested by Fusion for Energy (F4E), Barcelona, for the generation, maintenance, and validation of nuclear data evaluations and data files relevant for ITER, IFMIF and DEMO, as well as codes and software tools required for related nuclear calculations. Activities of the current F4E work programme include nuclear data evaluations for neutron induced reactions on Mn-55, Cu-63, -65, and Ta-181, benchmark analyses for neutron (Fe, Pb) and deuteron (Cu, Al) induced reactions, the evaluation/generation of damage energy/displacement cross-section data, the evaluation of deuteron induced activation cross-section data, the development of optical model potentials for the emission of alpha-particles over a wide target nuclide mass range, the development of consistent TALYS model based activation/transmutation and transport neutron sub-libraries as well as the processing of photo-nuclear data libraries and thermal scattering data tables for Monte Carlo applications. Codes and software tools related activities focus on the further development of the stochastic and deterministic sensitivity/uncertainty approaches (MCsen and SUSD3D codes), associated pre- and post-processing tools, and the MCUNED extension of MCNPX for the use of deuteron cross-section data in Monte Carlo transport calculations. The paper presents an overview of these activities, reviews the current status in some detail, and provides an outlook of the programme planned for the further development and analysis of fusion nuclear data in the EU.

JB 2 11:00 AM

Consistent Account of Fast Neutron Induced α-particle Emission

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The high precision of recent measurements for low-energy α-particle elastic-scattering as well as induced-reaction data makes possible the understanding of actual limits [1,2] and possible improvement [3] of the global optical model potentials parameters. Involvement of these potentials for further description of also the α-particle emission in fast-neutron induced reaction at low energies, at the same time with the α-particle elastic-scattering and induced reaction data is moreover discussed in the present work, of equal interest not only for nuclear astrophysics but for nuclear technology of fusion devices too. However, the approach of the former issue should take into account the need for new physics in nuclear potentials in order to describe nuclear de-excitation within the statistical model calculations [4]. In particular, effects due to changes of the nuclear density at a finite temperature have been considered within the double folding (DF) formalism [5] of the α-nucleus real part of the optical potential. Finally, it is shown that a better knowledge of this issue would be also very convenient for additional insight on basic nuclear properties as the moment of inertia [6] that determines the spin distribution of the nuclear level density.
[1] M. Avrigeanu *et al.*, At. Data Nucl. Data Tables **95**, 501 (2009). [2] M .Avrigeanu and V. Avrigeanu, Phys. Rev. C **82**, 014606 (2010). [3] V. Avrigeanu and M. Avrigeanu, in *Exotic Nuclei and Nuclear/Particle Astrophysics (IV). Proc. of the Carpathian Summer School of Physics, Sinaia, Romania, 24 June - 7 July 2012*, edited by L. Trache, AIP Conf. Proc. (American Institute of Physics, New York, 2012) (in press). [4] G. La Rana *et al.*, Phys. Rev. C **35**, 373 (1987); G. D. J. Moses *et al.*, Phys. Rev. C **36**, 422 (1987). [5] M .Avrigeanu, W. von Oertzen, and V. Avrigeanu, Nucl. Phys. **A764**, 246 (2006). [6] M. Avrigeanu, V. Avrigeanu, M. Diakaki, and R. Vlastou, Phys. Rev. C **85**, 044618 (2012).

JB 3 11:20 AM

Benchmarking of the FENDL-3 Neutron Cross-Section Data Starter Library for Fusion Applications

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The Fusion Evaluated Nuclear Data Library FENDL has been developed under the auspices of the IAEA/NDS with the objective to provide a dedicated nuclear data library which satisfies the needs of fusion technology applications. Version FENDL-2.1, assembled in 2003, serves as current reference data library for ITER nuclear design analyses. A recent Co-ordinated Research Project (CRP) of the IAEA/NDS was dedicated to the creation of FENDL-3 as a major update and extension to FENDL-2.1. The related development step includes the updating of nuclear data evaluations from the major nuclear data projects such as ENDF/B, JEFF, JENDL and RUSFOND, the extension of the energy range of incident particles up to 150 MeV to comply with the requirements for design calculations of the accelerator based IFMIF neutron source, and the inclusion of full co-variance data to enable uncertainty assessments in design analyses. The CRP has resulted in a starter library, called FENDL-3/SLIB, consisting of general purpose and activation sub-libraries with cross-section data for neutron, proton and deuteron induced reactions, as well as a neutron shadow library with full co-variance data. FENDL-3/SLIB, release 4, is considered as final version of the library assuming its successful qualification by means of benchmark analyses. This paper summarises the benchmark analyses performed in a joint effort of ENEA (Italy), JAEA (Japan), KIT (Germany), and the University of Wisconsin (USA) to qualify the neutron induced general purpose FENDL-3 data library for fusion applications. The benchmark approach consists of two major steps including the analysis of a simple ITER-like computational benchmark, and a series of analyses of benchmark experiments conducted previously at the 14 MeV neutron generator facilities at Frascati, Italy (FNG) and Tokai-mura, Japan (FNS). The computational benchmark enables to evaluate the effect of the updated FENDL data evaluations on the nuclear responses for ITER, while the data validation is achieved with the analyses of the experimental benchmarks. Both steps include comparative analyses using FENDL-2.1 data and state-of-the art JEFF, JENDL, or ENDF/B data. Major results of the FENDL-3 benchmarking are reported in this overview paper, existing deficiencies and shortcomings are discussed, and recommendations are given to turn FENDL-3/SLIB, release 4, into the final library version.
Corresponding author: M. Sawan

Session JC Nuclear Reaction Models
Wednesday March 6, 2013
Room: Empire East at 10:30 AM
Chair: Patrick Talou, LANL
JC 1 10:30 AM

A Modern Code System for Hauser-Feshbach Modeling Based on a Monte Carlo Framework

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A new system of computer programs to perform Hauser-Feshbach modeling of nuclear reactions, specifically those induced by neutrons, protons, deuterons, tritons, He, and alphas is presented. A principal feature of the program is that the decay of the nuclear system is tracked via Monte Carlo methods. This easily permits: 1) distinguishing between similar channels to the same product nucleus, such as (n,np) and (n,pn) reactions, 2) explicit tracking of the spectra for all emitted particles in each channel, such as first and second neutron, etc., 3) explicit treatment of the angular distributions for each emitted particle, and 3) analysis of correlations between the emitted particles. The code system is written in FORTRAN 95, and makes use of derived types and dynamic memory allocation to both simplify the Hauser-Feshbach bookkeeping and to minimize memory usage. The code system is driven with simple input commands, and is designed with system defaults to permit a "push-button mode" for many reactions. Many physics models are included and are modularized for flexibility, interchangeability, and user control over all input parameters, including the resolution of the calculation. The framework of the code system will be described and various applications will be demonstrated. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

JC 2 11:00 AM

The Impact of Intermediate Structure on the Average Fission Cross Section Calculations

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A significant breakthrough in our theoretical understanding of the fission process was made in 1956 when A.Bohr introduced the concept of "fission channels" that determine the outcome of many fission observables [1]. A decade later, a new picture of the fission barrier was achieved by Strutinsky [2] who superimposed the oscillatory frame of the shell correction term onto the liquid drop energy term. On both the experimental and theoretical evidence of the existence of class-II compound states (so called λ_{II}), Lynn used a formal R-matrix formalism for interactions in the deformation channels [3] to reproduce physically and more accurately the magnitude of the average sub-threshold fission cross sections. In particular, Lynn stated several possible coupling modes of class-I and class-II states and derived the corresponding class-II width fluctuation factor, W_{II}, expressions superimposed on the classic class-I reaction width fluctuation factor, W_{nr}, of standard Hauser-Fesbach theory. Ruled by Porter-Thomas statistics as other reaction channel widths, fluctuations of class-II fission, $\Gamma_{\lambda_{II}\uparrow}$, and coupling, $\Gamma_{\lambda_{II}\downarrow}$, widths can be handled similarly to other width fluctuations such that $W_{II} = Gamma_{\lambda_{II}\downarrow}\Gamma_{\lambda_{II}\uparrow}/\Gamma_{\lambda_{II}\lambda_{II}}$. One purpose of this presentation will be to emphasize the existence of this W_{II} fluctuation factor, which is commonly disregarded in standard Hauser-Feshbach reaction codes. An additional consequence of the existence of an intermediate structure is the reduction of the number of degrees of freedom, ν_{eff}, of the classic class-I overall fission width fluctuation factor, W_{nf}, traditionally assumed to be equal to 1 per each fully open outer barrier Bohr channel. The right assessment of ν_{eff} is dependent of the underlying intermediate structure coupling strength and selected mode, and of the fissioning system. This presentation will show how the intermediates structures and the additional impact of the WII factor affect the average cross-sections. We use, as illustration, our full calculations for the fissile and fertile isotopes of the plutonium series [4]. These are based on Monte Carlo averaging over the intermediate and fine structure calculated with formal R-matrix theory.

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JC 3 11:20 AM

Unitary Account of Nuclear Reaction Mechanisms for Deuteron-Induced Activation at Low and Medium Energies

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An extended analysis of the reaction mechanisms involved within deuteron interaction with target nuclei from ^{27}Al to ^{231}Pa, *i.e.* the breakup (BU), stripping, pick-up, pre-equilibrium emission (PE) and evaporation from fully equilibrated compound nucleus (CN), is presented. An increased attention is given to the BU mechanism [1-3] including all its components, namely the elastic (BE), inelastic (fusion) (BF), and total breakup (BU). An extension of the empirical parameterization of the BE cross sections beyond the energies considered in this respect, checked by microscopical calculations in the frame of Continuum-Discretized Coupled-Channels (CDCC) formalism [4], should be completed. Concerning the deuteron BU importance, regardless the differences between various parametrizations [1,5], both of them predicts its enhanced role with the target-nucleus mass/charge increase, as well as the BU dominance around the Coulomb barrier for heavy nuclei as, *e.g.*, ^{231}Pa. Furthermore, the consideration of the deuteron BU contribution to the activation cross section has to take into account two opposite effects, namely the important BU leakage of initial flux as well as the BF enhancement brought by the BU–nucleon interactions with the target nucleus [1-3]. On the other hand, the stripping (d,p) and (d,n), as well as the pick-up (d,t) reactions, usually neglected or very poorly taken into account, that have been proved to be important at low incident energies [2], are appropriately analyzed through the Coupled-Reaction Channels formalism using the FRESCO code[6]. A particular note should concern the (d,t) pick-up contribution to the total (d,t) activation cross section at low energies, between its threshold and the (d,dn) and (d,p2n) reaction thresholds leading to the same residual nucleus. All these BU and direct processes are also taken into account above the Coulomb barrier, where the PE and CN reaction mechanisms become important and are accounted for codes TALYS [7] and STAPRE-H [8]. Particularly, a consistent local parameter set was involved within the detailed analysis carried out using the code STAPRE-H. The overall agreement between the measured data and model calculations validates the theoretical approach of the various deuteron interactions while the comparison to the global predictions [9] underlines the effects of overlooking the BF enhancement as well as the stripping and pick-up processes. However, while the theoretical framework is already settled for stripping, pick-up, PE, and CN, an increased attention should be paid to BU description, and especially to its inelastic component. The complementary experimental studies requested by the improvement of this status are pointed out too.

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JC 4 11:40 AM

Application of the Continuum Discretized Coupled Channels Method to Nucleon-Induced Reactions on ^{6,7}Li for Energies up to 150 MeV

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In fusion technology, lithium is an important element relevant to not only a tritium breeding material in DT fusion reactors but also a target material in the intense neutron source of IFMIF. The accurate nuclear data of nucleon induced reactions on ^{6,7}Li are currently required for incident energies up to 150 MeV. Since ^{6}Li and ^{7}Li can easily break up like $^{6}\mathrm{Li} \rightarrow \mathrm{d} + \alpha$ and $^{7}\mathrm{Li} \rightarrow \mathrm{t} + \alpha$, systematic understanding of the breakup reaction mechanism is also an interesting and meaningful subject from the viewpoint of nuclear physics. Therefore, the study of nucleon induced reactions on ^{6,7}Li is not only of practical value but also of theoretical significance. The nucleon induced reactions on ^{6,7}Li are analyzed systematically with the Continuum Discretized Coupled Channels (CDCC) method [1,2]. ^{6}Li and ^{7}Li are considered as d+α and t+α cluster, respectively. Their discretized internal wave functions are obtained by the pseudostate method [3,4] with the interactions as Gaussian forms [5]. The diagonal and coupling potentials between nucleon and ^{6,7}Li are obtained by folding complex Jeukenne-Lejeune-Mahaux (JLM) effective nucleon-nucleon interaction with the transition density of the corresponding discretized coupled states. The parameters of JLM interaction are determined finally so as to reproduce experimental data well. The neutron total cross sections, the proton reaction cross sections, the neutron and proton elastic and inelastic scattering angular distributions, and the neutron and proton emission spectra for incident energies up to 150 MeV are calculated with the above-mentioned method. The theoretical results are compared with the existing data. For the cross sections and angular distributions, the calculated results are in good agreement with the experimental data. For the emission spectra, the calculated results can reproduce the experimental data well for higher emission energies, while they underestimate the experimental data for lower emission energies. The reason of the discrepancy is that some other reaction channels except the breakup channel may contribute to this energy region.

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Session JD Space and Medical Applications

Wednesday March 6, 2013

Room: Empire West at 10:30 AM
Chair: Francesco Cerutti, CERN

JD 1 10:30 AM

Accelerator Testing for Neutron-Induced Failures in Semiconductor Devices

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Neutron-induced failures in semiconductor devices are an increasing concern in the semiconductor industry. Understanding these failures involves several areas of nuclear science including reaction rate measurements, modeling and simulations. Neutrons are produced in the upper atmosphere by cosmic-ray bombardment of nuclei in the air. Because the neutrons are uncharged, they have long mean-free paths and can reach aircraft altitudes and below. Neutron interactions in semiconductor devices produce ionized recoils or reaction products that deposit charge in the vicinity of nodes and cause the devices to fail. These types of failures include bit flips, latchups, burnout etc. Predicting the failure rate depends on knowing the neutron flux in the environment of the semiconductor device and the response of the device to neutrons. To acurately model the device response, neutron induced cross sections are needed for the materials in the semiconductor devices. Many semiconductor companies have measured the system response at an accelerated rate by using the high-energy Los Alamos Neutron Science Center (LANSCE) spallation neutron source. The LANSCE source produces a neutron spectrum that is very similar in shape to the neutron spectrum produced by cosmic rays in the earth's atmosphere but is approximately 108 times more intense than the sea-level neutron flux. This acceleration factor allows testing of semiconductor devices to measure their response, and to develop and test failure models and mitigation approaches.

JD 2 11:00 AM

Nuclear Reaction Models Responsible for Simulation of Neutron-Induced Soft Errors in Microelectronics

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In recent years, radiation effects have been recognized as one of serious reliability issues for modern microelectronic devices operating under various cosmic-ray environments. In the terrestrial environment, secondary cosmic-ray neutrons are known to cause soft errors due to single-event effects. Physics-based simulation of the soft error phenomena is an essential tool in understanding the phenomena as well as designing radiation-tolerant devices. To simulate the soft error phenomenon accurately, it is necessary to employ highly reliable models describing various physical processes involved in the soft errors. In particular, the modeling of nuclear reactions is of great importance in terrestrial neutron induced soft errors initiated by nuclear interaction with constituent materials. Prediction of generated secondary ions has an impact on simulation of the subsequent physical processes, i.e., charge deposition and collection processes. Recently, we have developed a multi-scale Monte Carlo simulation framework for neutron induced soft errors by linking a particle transport code PHITS and a 3-D TCAD simulator HyENEXSS[1,2], and have applied it to the analyses of terrestrial neutron-induced soft errors in MOSFETs from a 65 nm to a 25 nm design rule. From the validation of nuclear reaction models used in PHITS[1,3], we have recommended the combined use of the "event generator mode(e-mode)" with JENDL-3.3 or JENDL-4.0 below 20 MeV and the modified Quantum Molecular Dynamics(MQMD) model[4] plus Generalized Evaporation Model(GEM) above 20 MeV in the soft error simulation with PHITS. Using the simulation code system with PHITS and HyENEXS, we have investigated major secondary ions causing terrestrial neutron induced soft errors and the dependence on incident energy. The result has clarified that the secondary H and He ions generated by neutrons up to several hundreds of MeV play a crucial role in terrestrial neutron-induced soft error simulation. In addition, our recent study of multi-cell upsets (MCUs) has revealed that its dependence on incident angle is caused by forward angular distribution of heavy recoils generated by nuclear fragmentation. This will stimulate further improvement in the modeling of nuclear fragmentation in the future.
[1] S. Abe, Y. Watanabe, N. Shibano, N. Sano, H. Furuta, M. Tsutsui, T. Uemura and T. Arakawa, "Multi-Scale Monte Carlo Simulation of Soft Errors using PHITS-HyENEXSS code system", IEEE Trans.

on Nucl. Sci., vol.59, no.4 (2012) in press. [2] S. Abe, Y. Watanabe, N. Shibano, N. Sano, H. Furuta, M. Tsutsui, T. Uemura and T. Arakawa, "Neutron-Induced Soft Error Analysis in MOSFETs from a 65nm to a 25nm Design Rule using Multi-Scale Monte Carlo Simulation Method", Proc. of 2012 IEEE Int. Rel. Phys. Symp., April 15-19, 2012, Anaheim CA USA. [3] S. Abe, S. Hirayama, Y. Watanabe, N. Sano, Y. Tosaka, M. Tsutsui, H. Furuta and T. Imamura, "Applicability of nuclear reaction models implemented in PHITS to simulations on single-event effects", J. of Korean Phys. Soc., **59**, 1443-1446 (2011). [4] Y. Watanabe and D.N. Kadrev, "Extension of quantum molecular dynamics for production of light complex particles in nucleon-induced reactions", Proc. of the Int. Conf. on Nuclear Data for Sci. and Technol., April 22-27, 2007, Niece, France, EDP Sciences, 1121-1124 (2008).

JD 3 11:20 AM

Benchmark Experiment of Dose Rate Distribution Around Gamma Knife Medical Apparatus

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Gamma Knife is one of the most popular radiation oncology apparatus by using Cobalt 60 radioisotopes. Since the inventory of Cobalt 60 is very high and the shielding is very complicated, the shielding calculation for the apparatus is not easy by simple calculation methods. In this study, the detailed shielding calculation by using three-dimensional calculation method was performed and verified by the measurements. The dose rate measurements were performed by using the passive detectors and ionization chamber as an active detector. The measured positions were varied around the Gamma Knife apparatus. For the horizontal plane, the measured positions were each 500mm mesh. The plane was as the same that of focus point. The measurements along the vertical plane were also performed. Two cases were applied when the shutter was opened and closed. Analyses have been performed by using Monte-Carlo calculation code MCNP-5. The nuclear libraries used for the dose rate distribution of Cobalt 60 were MCPLIB04. The calculation model was prepared with a high degree of fidelity, such as the position of each Cobalt source and shielding materials. Comparisons between measured results and calculated ones were performed. Very good agreements between measured and calculated results were obtained. It is concluded that the Monte Carlo calculation method is very effective for such a complicated radiation oncology apparatus.

JD 4 11:40 AM

Nuclear Data Requirements for Medical Applications - Recent Contributions and Future Requirements as Formulated Under the Auspices of the International Atomic Energy Agency

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Cancer treatment represents a major economic and medical issue because of the extensive incidence of the disease worldwide, with a particularly large rate of increase to be found in developing countries - under such unfortunate circumstances, up to half of all cancer patients receive some form of radiation therapy in the course of their treatment. The suitability of specific radioisotopes for medical applications is well established in relation to cancer diagnosis and therapy. Nuclear reactors and particle accelerators, coupled with powerful chemical separation techniques, provide the means of producing suitable high-purity radioisotopes in an efficient and efficacious manner. Medical applications of radiation are of considerable

interest to member states of the International Atomic Energy Agency (IAEA). Therefore, over the previous twenty years, the IAEA has dedicated a series of well-directed investigations towards identifying and quantifying the production routes and decay characteristics of an extensive number of radioisotopes judged to be of existing and emerging importance in nuclear medicine. Both the recommendations formulated during the course of a series of technical debates and the results of recently completed and on-going coordinated research projects are described which embrace the following IAEA initiatives: (a) charged-particle cross sections for diagnostic radioisotopes and monitor reactions (coordinated research project undertaken from 1995 to 2001, and a new coordinated research project starting in 2012); (b) nuclear data for the production of therapeutic radionuclides (coordinated research project undertaken from 2003 to 2011); (c) high-precision beta-intensity measurements and evaluations for specific PET radioisotopes (extensive discussion in 2008); (d) intermediate-term nuclear data requirements for medical applications: cross sections and decay data (extensive discussion in 2011). Existing recommendations identified with items (a), (b) and (d) focus on cross sections for a reasonably wide range of targets and projectiles, along with highly-specific requirements for further decay data measurements. Item (c) is more clearly related to inadequacies in the measured positron and X-ray emission probabilities of a relatively modest number of existing and potential PET radioisotopes. Nuclear data requirements will be described with respect to their importance in ensuring the continued successful evolution of improvements in nuclear medicine throughout the early 21st century. ALN is affiliated to Department of Physics, Faculty of Engineering and Physical Sciences, University of Surrey, Guildford, GU2 7XH, UK; and Manipal University, Madhav Nagar, Manipal 576104, Karnataka, India.
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Session JE Surrogate Reactions
Wednesday March 6, 2013
Room: Central Park East at 10:30 AM
Chair: Jolie Cizewski, Rutgers
JE 1 10:30 AM

Validating (d,pγ) as a Surrogate for Neutron Capture on Unstable Nuclei

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Neutron capture reactions are important for fundamental physics, such as understanding s- and r-process nucleosynthesis of heavy elements, as well as applications in nuclear energy, nuclear forensics and stockpile stewardship. There has been a long tradition of measuring these reactions directly and the U.S. National Nuclear Data Center maintains an evaluation of existing data. In addition, the ENDF/B file includes neutron capture cross section values for all nuclei and over a wide range of energies, including many unstable species for which no measurements have been made. Given the importance of neutron capture cross sections it is important to validate a surrogate [2] for (n,γ) that can provide insight into these values, even with large effective neutron-energy bins. We have recently measured the ^{95}Mo(n,γ) reaction at LANSCE and the ^{95}Mo(d,pγ) reaction at Texas A & M as part of a focused effort to validate (d,pγ) as a surrogate for neutron capture. The ^{95}Mo(n,γ) cross section is known [3]. The (d,pγ) reaction is a good

candidate for a surrogate reaction that would use radioactive beams in inverse kinematics on deuterium targets. Exploiting radioactive ion beams enables measurements of nuclear reactions on very short-lived nuclei (e.g., $t_{1/2} \approx 1$ s). The challenges in validating a surrogate for neutron capture will be discussed, as well as a presentation of the current status of the experimental analysis and interpretation. This work supported in part by the U.S. Department of Energy NNSA and Office of Nuclear Physics.
Corresponding author: A. Ratkiewicz
[1] http://www.nndc.bnl.gov/capgam/ [2] Jutta E. Escher, Jason T. Burke, Frank S. Dietrich, Nicholas D. Scielzo, Ian J. Thompson, and Walid Younes, Rev. Mod. Phys. **84**, 353 (2012) and references therein. [3] A.R. de L.Musgrove, B. J. Allen, J. W. Boldeman, R. L. Macklin, Nucl. Phys. **A270**, 108 (1976)

JE 2 11:00 AM

Neutron-induced Capture Cross Sections of Actinides via the Surrogate-Reaction Method

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Neutron-induced cross sections of short-lived nuclei are crucial for reactor physics. In particular, (n, γ) cross sections on minor actinides are one of the largest sources of uncertainty in modeling new reactors for nuclear waste transmutation using fast neutrons. However, very often the high radioactivity of the actinide samples makes the direct measurement of these cross sections extremely difficult. The surrogate-reaction method is an indirect way of determining cross sections for nuclear reactions that proceed through a compound nucleus. This technique may enable neutron-induced cross sections to be extracted for short-lived nuclei that otherwise cannot be measured. However, because of the dependence of the populated spin-parity distribution on the entrance channel, the validity of the surrogate method has to be investigated. The CENBG collaboration has successfully applied this technique to determine the (n,f) cross sections of several short-lived nuclei [1]. Since few years we investigate the validity of the surrogate technique to determine capture cross sections. For this purpose we studied recently the surrogate reactions ^{174}Yb(^{3}He,^{4}He)^{173}Yb and ^{174}Yb(^{3}He,p)^{176}Lu to infer the well known ^{172}Yb(n, γ) and ^{175}Lu(n, γ) cross sections, respectively. The surrogate gamma-decay probabilities found are several times higher than the neutron-induced ones. This is due to the high spin-parity selectivity of neutron emission [2]. This selectivity is expected to strongly decrease with increasing mass of the decaying nucleus and with increasing excitation energy. To verify this conjecture we have made an experiment at the Oslo Cyclotron in June 2012 to study the reactions ^{238}U(d,pγ)^{239}U, ^{238}U(^{3}He,tγ)^{238}Np, ^{238}U(^{3}He,^{4}Heγ)^{237}U as surrogates for the ^{238}U(n, γ), ^{237}Np(n, γ) and ^{236}U(n, γ) cross sections, respectively. The experimental procedure and the first results will be presented.
[1] G. Kessedjian et al., Phys. Lett. B 692 (2010) 297 [2] G. Boutoux et al., Phys. Lett. B 712 (2012) 319

JE 3 11:20 AM

Surrogate Research at JAEA/Tokyo Tech

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Japan Atomic Energy Agency
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Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research
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We will present a status of researchs in surrogate reaction method using heavy-ions to determine neutron fission and capture cross sections of unstable nuclei. We take advantage of having 1) an electrostatic tandem accelerator which can deliver highly mono-energetic beams of heavy ions, 2) rich experience in in-beam γ spectroscopy, 3) rich experience in measuring fission fragments induced by heavy-ions, 4) nuclear theory and evaluation experiences. We have construced appratus to measure fission fragments and γ-rays in coincidence with ejectiles by which we can identify the populated compound nuclei. Primarily, we used ^{18}O-induced reactions as well as ^{3}He-induced reactions. We also investigated conditions under which which such measurements lead to correct neutron cross sections. Results of the theoretical researches were published in a series of papers[1-4]. In this presentation, status of results of the above researches will be summarized.
[1] S. Chiba and O. Iwamoto, Phys. Rev. C **81**, 044604-1-6(2010). [2] K. Ogata, S. Hashimoto and S. Chiba, J. Nucl. Sci. Technol. **48**, 1337-1342(2011). [3] Y. Aritomo, S. Chiba and K. Nishio, Phys. Rev. C **84**, 024602-1-10(2011). [4] S. Chiba, O. Iwamoto and Y. Aritomo, Phys Rev. C **84**, 054602-1-5(2011).

Session KA Diseminations, New Formats and International Collaborations
Wednesday March 6, 2013
Room: Met East at 1:30 PM
Chair: Jag Tuli, NNDC - BNL
KA 1 1:30 PM

Working Party on International Nuclear Data Evaluation Co-operation (WPEC)

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The OECD Nuclear Energy Agency (NEA) is organizing a co-operation between the major nuclear data evaluation projects in the world. The co-operation involves the US ENDF project, the NEA Data Bank JEFF project, the Japanese JENDL project, and through collaboration with the International Atomic Energy Agency (IAEA) also non-OECD projects such as the Russian BROND and the Chinese CENDL projects. The NEA Working Party on International Nuclear Data Evaluation Co-operation (WPEC) is composed of about 20 core members representing worldwide evaluation projects. The WPEC meets annually to discuss progress within each evaluation project and to review nuclear data challenges and problems common to all projects. Needs for improvement of nuclear data are addressed by collaborative efforts in the framework of dedicated WPEC subgroups, consisting of experts from the different evaluation projects. The results of these subgroups are published in reports issued by the NEA. Twenty-eight reports have been published so far. Studies recently completed comprise a number of works related to nuclear data covariance and associated processing issues, as well as more specific works related to the gamma production from fission-product capture reactions, the uranium-235 capture cross-section, the EXFOR database,

and the quality of nuclear data for advanced reactor systems. Ongoing activities focus on methods and issues for the combined use of integral experiments and covariance data, the evaluation of plutonium-239 in the resonance region, scattering angular distribution in the fast energy range, and reporting/usage of experimental data for evaluation in the resolved resonance region. Future activities will include two new subgroups on improved fission product yield evaluation methodologies and on modern nuclear database structures beyond the ENDF format. In addition to the above mentioned short-term, task-oriented subgroups, the WPEC also hosts a longer-term subgroup charged with reviewing and compiling the most important nuclear data requirements in a high priority request list (HPRL). The present contribution will briefly review recent achievements of the WPEC, outline ongoing activities and plans for future activities and challenges in the field of evaluated nuclear data.

KA 2 2:00 PM

International Effort to Define a New Nuclear Data Structure

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Brookhaven National Laboratory

Current evaluated nuclear data formats like ENDF date to the 1960s. These formats limit the type of reactions and particles that can be represented as well as the precision of the data. With the formation of NEA/WPEC subgroup 38, the international nuclear data community has begun an effort to design a new structure for storing evaluated nuclear data. The first meeting for subgroup 38 will be held in early December of 2012. Prior to the international effort on a new evaluated nuclear data structure, Lawrence Livermore National Laboratory (LLNL) began working to develop a new nuclear data structure called Generalized Nuclear Data (GND) which, it is hoped, will facilitate the international effort. GND is nearly complete and LLNL has developed routines to convert ENDF data to and from GND as well as converting LLNL's legacy ENDL format to GND. An overview of GND and the current development within subgroup 38 will be presented. This work has been supported by Department of Energy contract No. DE-AC52-07NA27344 (Lawrence Livermore National Laboratory) and by funds from the Nuclear Data Program Initiative of the American Recovery and Reinvestment Act (ARRA).

KA 3 2:20 PM

Toward More Complete and Accurate Experimental Nuclear Reaction Data Library (EXFOR) - International Collaboration Between Nuclear Reaction Data Centres (NRDC)

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During more than four decades since the first neutron-induced reaction data exchange among the Four Centres in 1970, the international experimental nuclear reaction data library (EXFOR) has always been a

most essential resource for all researchers and developers in nuclear sciences and applications who desire to perform their works based on the latest experimental facts derived from modern facilities and techniques. The International Network of Nuclear Reaction Data Centres (NRDC) coordinated by the IAEA Nuclear Data Section has successfully collaborated in maintenance and development of the EXFOR library. Currently fourteen data centres from eight countries (China, Hungary, India, Japan, Korea, Russia, Ukraine and USA) and two international organisation (IAEA, OECD/NEA) are sharing the responsibility of compilation of neutron-, charged-particle- and photon-induced reaction data published in the open literature, and the total number of experimental works will shortly reach 200,000. As the scope of published data expands (e.g., to higher energy, to heavier projectile) in order to meet the needs from the frontier of nuclear sciences and applications, it becomes nowadays a hard and challenging task to maintain both completeness and accuracy of the whole EXFOR library. Nevertheless, more than 60 journals are scanned on a regular basis and compiled in a timely manner. Recently we found that about 20-30% of the experiments for light charged-particle (p, d, t, ^{3}He, α) induced reaction activation cross sections are still missing, and we are compiling old but important data retroactively. We also try to make selected recommended values (e.g., thermal cross sections [1]) available. In addition, intensive corrections of existing EXFOR entries by various automatic checking initiated by the WPEC SG30 activity [2] are on-going. EXFOR users often report compilation mistakes which were not detectable automatically, and their feedback has been systematically collected and shared by NRDC for further improvement of the library. Also development of new formats for covariance data has been discussed in recent years for neutron-induced reaction cross sections in both resonance and fast neutron regions [3]. The IAEA Nuclear Data Section collected various recommendations from user communities through the several IAEA meetings [4] and their implementations were discussed in recent annual NRDC meetings. The paper describes the main NRDC product - the EXFOR library - its content and evolution to responds to user's needs with highlights on recent developments.
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KA 4 2:40 PM

Structure for Storing Properties of Particles (POP)

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Evaluated nuclear databases are critical for application such as astrophysics, energy, medicine, and homeland security. Particle masses, nuclear excitation levels, and other "Properties of Particles" are essential for making evaluated nuclear databases. Currently, these properties are obtained from various databases that are stored in outdated formats. A "Properties of Particles" (POP) structure is being designed that will allow storing all information for a particle in a single place, so that each evaluation, simulations, model calculations, etc. can link to the same data. Information provided in POP will include properties of nuclei, gammas and electrons (along with other particles such as pions, as evaluations extend to higher energies). Presently, POP has been implemented to adopt masses from the Atomic Mass Evaluation version 2003 (AME2003) [1], and level schemes and gamma decays from the Reference Input Parameter Library (RIPL-3) [2]. The data are stored in a hierarchical structure. An example of how POP stores nuclear masses

and energy levels will be presented here. "This work was performed under the auspices of Department of Energy contract No. DE-AC52-07NA27344 (Lawrence Livermore National Laboratory)."

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Session KB Integral Experiments
Wednesday March 6, 2013
Room: Met West at 1:30 PM
Chair: Mohamed Sawan, University of Wisconsin
KB 1 1:30 PM

What If Lady Godiva Was Wrong?

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The experiment from which benchmark specifications of "Lady Godiva" were derived consisted of a bare sphere of highly enriched uranium (HEU) comprised of nested hemispheres. That experiment was performed in the early 1950s and the critical configuration was evaluated and published in the International Handbook of Evaluated Criticality Safety Benchmark Experiments in 1995 with the identifier HEU-MET-FAST-001. The benchmark eigenvalue is reported as 1.000 ± 0.001, which is representative of a very high quality benchmark experiment. Our current neutronic codes and cross section data are tailored to provide qualitative results that concur with the Godiva benchmark. But what if our understanding of the experiment wasn't perfect? Since 1995, a multitude of additional high-fidelity HEU metal benchmark data have been evaluated and published, including data for several assemblies that were performed at the Oak Ridge Critical Experiments Facility (ORCEF) and others at the Russian Federal Nuclear Center - Institute of Technical Physics (RFNC-VNIITF). Furthermore, the rigor through which benchmark experiments are examined has increased over the past two decades. Eigenvalue calculations of the HEU metal benchmark experiments from ORCEF and VNIITF consistently calculate slightly low, possibly indicating that our fast neutron cross section data for ^{235}U may not be as well known as hoped. It is recommended that we not just reevaluate the Godiva benchmark data, but also evaluate a more recent bare critical sphere experiment performed at ORCEF in 1971.

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KB 2 2:00 PM

Shielding Design Calculations for the ESS Target Station High Activated Components

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The European Spallation Source (ESS) is the European common effort in designing and building a next generation large-scale user facility for studies of the structure and dynamics of materials. The ESS target, moderators and reflectors system through interactions with 5 MW proton beam (2.5 GeV, 20 Hz) will produce long pulse (2.8 ms width) neutrons in subthermal and thermal energy range. These neutrons are further transported to a variety of neutron scattering instruments. The aim of this work is to assess the strategy to be used for safely handling and shipping of the high activated components of ESS target station. For safe maintenance, during operation as well as handling, transport and storage of the components of the

ESS target station after their lifetime, detailed knowledge about the activation induced by the impinging protons and secondary radiation fields is required. The Monte Carlo transport code MCNPX2.6.0 was coupled with CINDER90 version 07.4 to calculate the residual nuclide production in the main items of the system: target wheel and the shaft, moderator-reflector plug, beam window plug, shutters. Dose equivalent rates due to the residual radiation were further calculated with the MICROSHIELD and MCNPX codes using photon sources resulting from CINDER. Various decay times after ceasing operation of each component were considered. The activation and decay heat density distributions of all these components together with the derived dose rates were analyzed to assess the best strategy to be used for their safely remove and transport to a hotcell, eventual dismantling, storage on-site and shipping off-site as intermediate level waste packages. The derived photon sources were used afterwards to design the shielded exchange flasks that are needed to remove and transport each component after its lifespan to a hotcell. Design of a multi-purpose cask able to accommodate the different highly activated components and shipping them to external conditioning facility was further developed. For this purpose, the photon source term of each of the analyzed item was derived taken into consideration previously estimated decay time on-site prior the cask loading. The main criterion used for optimization of the thickness and material selection of the shielding of the flasks, in agreement with Swedish legislation and ADR provisions, is that the dose rate must not exceed 2 mSv h^{-1} on the outer surface and 0.1 mSv h^{-1} at a distance of 1 m. The calculated parameters for the shield of the components with high dose rates will be used for detailed design and manufacturing of the exchange flasks. Obtained results for the off-site shipping cask are discussed in order to derive the requirements to be fulfilled for the type B(U) package design approval.

KB 3 2:20 PM

Distribution of Radionuclides in MEGAPIE, a Proton Irradiated LBE Target

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At the moment, several technologies are developed to reduce the amount and the radiotoxicity of residual waste from nuclear power plants. Promising techniques that could be employed for this purpose are fast reactors or Accelerator Driven Systems (ADS) that use liquid heavy metal as reactor coolants and/or material for generating fast neutrons in spallation targets. In some of these innovative reactor designs, lead or lead-bismuth eutectic (LBE) is used as the liquid metal. In an ADS, additional radioactivity is formed in the spallation unit by interactions of high energy and secondary particles with the target material. Data on this residue nuclide production are essential for benchmark theoretical predictions as well as analyzing safety hazards of future LBE cooled nuclear facilities during and after operation, including the options of intermediate or final disposal [1]. A prototype of a lead-bismuth spallation target, MEGAPIE (MEGAwatt PIlot Experiment) [2], was operated close to the megawatt regime (0.8 MW) in the spallation source SINQ (Swiss Spallation Neutron Source) at PSI in 2006. The MEGAPIE target was 5.35 meter long and filled with 87 litres of LBE. It was irradiated with 575 MeV protons for 123 days, starting from August 21st 2006, receiving a total charge close to 3 Ah [3]. To determine the radionuclide inventory of this target, an extensive sampling program was performed in the hot cells of PSIs' Hotlab, starting in May 2011 and ending in the beginning of 2012. In total 74 samples from different positions in the target were taken, 30 from LBE/steel interfaces and the LBE/cover gas interface in order to study enrichment effects at these positions and the remaining samples comprising the bulk LBE. All samples were measured by γ-spectrometry without prior chemical separation, analyzed and compared with activation calculations of Zanini et al. [4]. The radionuclides that were definitely identified by γ-spectrometry are ^{60}Co, ^{101}Rh, ^{102}Rh, ^{108m}Ag, ^{110m}Ag, ^{133}Ba, ^{172}Hf/Lu, ^{173}Lu, ^{194}Hg/Au, ^{195}Au and ^{207}Bi. For some of these nuclides, such as ^{207}Bi, ^{194}Hg/Au, ^{101}Rh and ^{102}Rh, the activities can be easily evaluated from the γ-spectrometry results obtained without prior chemical separation, while other nuclides that were unambiguously identified require chemical separation from the matrix before they can be quantified (^{108m}Ag, ^{110m}Ag, ^{195}Au). There are certainly also a large number of additional nuclides that will be only detectable after chemical separation like the long-lived ^{129}I, ^{36}Cl or the α-emitting $^{208-210}$Po and ^{148}Gd. To present the general results on the radionuclide inventory and distribution in the MEGAPIE target in a concise way, we focus on ^{207}Bi, ^{194}Au and ^{173}Lu as leading nuclides. Here, ^{207}Bi represents the target material itself. ^{194}Au represents noble metals that have a high solubility and low chemical reactivity in the eutectic, while ^{173}Lu represents the rare earth elements that are highly reactive and sensitive to oxidation. ^{207}Bi is homogeneously distributed in the target, whereas ^{194}Au and ^{173}Lu are inhomogeneously distributed. While ^{194}Au is found in varying amounts in all of the samples that have been analysed, ^{173}Lu is only found in samples from the LBE/steel and LBE/cover gas interfaces and not in the bulk LBE, indicating strong separation effects. Moreover, the separation of ^{129}I and ^{36}Cl from the residue by distillation in a N_2-stream was performed for about 30 samples. The activity of these nuclides will be studied by Accelerator Mass Spectrometry (AMS). First results should be available by the end of 2012. Furthermore, the separation and analysis of α-emitting $^{208/209/210}$Po from LBE by deposition onto a silver disc was started. First results indicate that $^{208-210}$Po is not homogeneously distributed in the target.

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KB 4 2:40 PM

Measured and Calculated Iron Filtered Neutron Spectra Using Different Data Libraries for Calculation

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The Iron filtered leakage neutron spectra measurements have been done on the following benchmark assemblies: reactor Iron filtered beam of the thickness 67 cm at PTB Braunschweig (Germany) and of the thickness 120 cm at NRI Rez on LWR-15 reactor (Czech Republic). The leakage neutron spectra from Iron spheres with diameter of 30, 50, 100 cm with the Cf-252 neutron source placed into the centre of iron sphere were measured. Neutron spectra were measured also on reactor pressure vessel model of the mock-up WWER-1000 reactor at LR-0 research reactor in Rez. The measurement places were positioned (among other points) on the inner surface of the reactor pressure vessel (RPV), in the 1/4 thickness of the RPV and at the RPV back side. RPV model was represented by the Iron slab of the 20 cm thickness. The proton recoil method was used for neutron spectra measurement. The adequate MCNP neutron spectra calculations (C) based on different data libraries (ENDF/B-VII.1, JEFF-3.1.2, BROND-3, JENDL-4.0, CENDL-3.1 and TENDL-2011) have been done for most of the above mentioned Iron assemblies and compared with measurements (M). The analysis of C/M values is focused to neutron energy interval 0.06 - 1.3

MeV. Some repeated differences between measurements and calculations using different data libraries are observed in various experimental assemblies.

Session KC Evaluated Nuclear Data Libraries
Wednesday March 6, 2013
Room: Empire East at 1:30 PM
Chair: Tim Johnson, NNDC - BNL
KC 1 1:30 PM

Current Status of Evaluated Nuclear Data of Mn-55

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Manganese is a common alloying material in steels and thus represents an important structural material. The radiative capture cross section of manganese is also a dosimetry reaction, therefore good knowledge of its nuclear data is desirable. The new resonance parameters from Oak Ridge that are included in the ENDF/B-VII.1 evaluation of manganese remove the long-standing discrepancy between the thermal cross section and resonance integral measurements by the activation technique. The overall trends in the resonance data are supported very well by simulating the Grenoble lead-slowing-down experiment. The remaining outstanding problems are the following:

- Resolved resonance parameters extend to 0.125 MeV and the unresolved resonance parameters are defined up to 1 MeV. However, experimental data indicate that there is significant structure in the cross sections up to about 4 MeV. At 1 MeV the calculated fully self-shielded capture cross section differs from the one at infinite dilution by about 30%. The Oktavian benchmark experiment measuring the leakage spectrum from a manganese sphere with a D-T source in the centre strongly supports the need to consider self-shielding to higher energies, since the calculated spectrum shows a distinct discontinuity at 1 MeV.

- Measurements of elastic scattering angular distributions with a fairly good energy resolution are available near 1 MeV and they show significant structure. The average cosine of scattering derived from the data also shows structure, but it is not directly correlated with the fluctuations of the elastic cross sections.

In an attempt to remove some of the deficiencies in the current evaluated nuclear data of manganese, the available experimental data in the EXFOR database were carefully selected and renormalized to more recent standards, if necessary. Model calculations were performed with the EMPIRE code to obtain the reference evaluation and the covariance matrix prior. The new feature in the calculations is the use of adjustment factors, which compensate the deficiencies of the models in a reasonably consistent manner and allow for the observed medium-range fluctuations in the cross sections. These can be used in combination with the unresolved resonance parameters without double-counting the self-shielding effects. The new evaluation of manganese is being tested on various benchmark experiments.

KC 2 2:00 PM

R-matrix Analysis for n+^{16}O Cross-Sections up to $E_n = 6.0$ MeV with Covariance

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Oxygen is one of the most important materials in nuclear applications such as reactors, in the form of water and oxide. Therefore, both experimental and theoretical studies have been devoted to know the accurate neutron cross sections for ^{16}O over the years. Nowadays, the oxygen data in the evaluated nuclear data libraries such as ENDF/B-VII.1, JENDL-4 and JEFF-3.1.2 are believed to be reasonable, since they well perform in criticality benchmarks. Since there are increasing demands for giving uncertainties in evaluated cross sections to estimate the margin of integral calculations, the covariance data are available in ENDF/B-VII.1 and JENDL-4 for ^{16}O cross sections. However these covariances are estimated in a simple way inferred only from experimental information. This situation is also true for many other light nuclei. Purpose of this work is to estimate n+^{16}O cross sections and their uncertainties by analysing experimental data with theoretical model. We carry out the R-matrix analysis for the ^{17}O system to deduce model parameters with uncertainties up to $E_n = 6.0$ MeV. Because the (n, α) reaction channel opens at about $E_n = 2.4$ MeV, two partitions of the ^{17}O system - ^{16}O+n and ^{13}C+α - are considered in the analysis. Measured data we use are neutron total cross section for ^{16}O and ^{13}C$(\alpha, n)^{16}$O reaction cross sections. The covariance matrix is obtained by propagating uncertainties of model parameters to the cross sections. The uncertainty we obtained is strongly dependent on the resonant behavior.

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Progress in Developing Nuclear Reaction Calculation Code CCONE for Higher Energy Nuclear Data Evaluation

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The nuclear reaction calculation code CCONE [1] was developed and used for the nuclear data evaluation for JENDL/AC-2008 and JENDL-4.0. It is planned to extend the evaluated data in JENDL-4.0 toward higher energy. To adapt the CCONE code to the high energy nuclear data evaluation, the pre-equilibrium exciton model part has been extended to be able to calculate multiple particle emission. It is realized by sequential calculation of exciton states for all residual nuclei left by particle emissions. In addition, Iwamoto-Harada cluster coalescence model has been incorporated in the multiple-emission exciton model to improve calculation accuracies of cluster emission spectra such as alpha particles. The calculated results of light particle emission spectra are compared with experimental data and evaluated data.
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KC 4 2:40 PM

New Resolved Resonance Region Evaluations for ^{63}Cu and ^{65}Cu to Support Nuclear Criticality Safety Analyses

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Over the past decade, a discrepancy between the computed eigenvalues and the experimentally recorded eigenvalues of criticality safety benchmark experiments containing copper was noticed by the nuclear data and criticality safety community [1]. The most notable of these benchmarks is the set of highly enriched uranium metal fuels with copper reflectors from the Zeus experiment, that is, HEU-MET, taken from the ICSBEP compilation [2]. Used as a minor structural material in many nuclear facilities, copper is an important structural component in Scandinavian spent fuel casks. To refine prediction of experimental values for copper-containing benchmarks with a new copper cross section evaluation would be vital to the safe operation of the advanced fuel cycle and from a criticality safety point of view. The need for a new resonance evaluation was reflected in the United States Department of Energy (DOE) Nuclear Criticality Safety Program (NSCP) Five-Year Execution Plan where ^{63,65}Cu were identified by the Nuclear Data Advisory Group (NDAG) as "Important for measurement and evaluation in the next five years" [3]. The objective of this study is to address the issue discussed above by doing a new cross section evaluation in the Resolved Resonance Region (RRR) for the two isotopes of copper. While applying the R-Matrix SAMMY [4] method using the Reich-Moore (RM) approximation, the evaluation of a consistent set of resonance parameters for ^{63,65}Cu is under way in the neutron energy range of 10^{-5}eV up to 99.5 keV. The extension of the RRR from 99.5 keV to 300 keV will also be performed. Invaluable information to the evaluation process is provided by the ^{63,65}Cu (n,γ) high-resolution measurements performed by Guber et al. at GELINA in 2011. Capture cross section measurements reveal resonances that are impossible to identify from the transmission experiments alone. By combining capture measurements with transmission data, one obtains a way of assigning the spin (total angular momentum) of nuclear resonances less ambiguously. In the thermal energy range, cross section data are based on independent measurements performed by Sobes et al. [5] at the MIT Nuclear Reactor (MITR). In the full paper we will present the evaluation methodology as well as benchmarking efforts on the ICSBEP benchmark models sensitive to copper, such as Zeus copper-reflected experiments [2] and newly evaluated Scandinavian criticality safety experiments from the 1960s [6]. This new evaluation is done in support of the DOE Nuclear Criticality Safety Program (NCSP).
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Session KD Fission Yields
Wednesday March 6, 2013
Room: Empire West at 1:30 PM
Chair: Alan Nichols, University of Surrey

KD 1 1:30 PM

Uncertainty Propagation of Fission Product Yield Data in Spent Fuel Inventory Calculations

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Uncertainty propagation in complex computational problems can be carried out by the random perturbation of input data sampled from a probability distribution derived from the evaluated mean and standard deviation of each datum input into the computer code with subsequent analysis of the results giving the distribution of the calculated parameter of interest about its mean. However, this basic approach ignores the correlations between the data. For neutron cross-sections it is currently possible to use a "Total Monte Carlo" approach to consider those correlations resulting from the processes of evaluation, processing and application solution [1], but for correlations resulting from experimental measurements and for other types of data, whose evaluation method is not yet fully automated, alternative methods are required. The ACAB inventory code [2] is being developed to handle such correlations but require the data covariance matrices. This work considers the generation of such covariance matrices for fission product yield data. Spent fuel inventory calculations use independent fission product yields as an input. These yields are derived from the large data set of published measurements including mostly chain and cumulative yields with relatively few independent yield measurements. The independent yields and their uncertainties in evaluations are thus determined from semi-empirical models with parameters fitted from the available data [3]. However, the cumulative yields can be calculated from the independent yields and the respective nuclides' decay data. As more cumulative yield measurements are available than independent yields and typically have smaller uncertainties, it is possible to use these measurements to produce covariance matrices to better estimate the uncertainties of fission product nuclide number densities during fuel irradiation and cooling. A method to determine these independent fission product yield covariance matrices is presented. This paper studies the use of random perturbation of nuclear data. Firstly, the effect of different probability distribution functions on a simple decay chain is shown and important conclusions high-lighted. Then the method is demonstrated for a fission pulse decay heat calculation using the FISPIN code [4] with and without the new covariance contributions to the decay heat uncertainties. The potential of using this method for more general inventory codes is then discussed.

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KD 2 2:00 PM

Mass Yield Distribution in the 45- and 80-MeV Bremsstrahlung-Induced Fission of ^{232}Th

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The yields of various fission products in the 45- and 80-MeV bremsstrahlung-induced fission of ^{232}Th have been determined by off-line γ-ray spectrometry using the electron linac at Pohang Accelerator Laboratory of Korea. The mass yield distributions were obtained from the fission yield data using charge distribution corrections. The peak to valley (P/V) ratio, average light mass ($< A_L >$), heavy mass ($< A_H >$) and neutron number ($< \nu >$) at different excitation energy for $^{232}Th(\gamma$, f) was obtained from the mass yield data of present and earlier work form literature and compared with the similar data in ^{232}Th(n, f). It was found that (i) the mass yield distribution in $^{232}Th(\gamma$, f) is triple humped, similar to $^{232}Th(n, f)$. (ii) The yields of fission products around mass number 133-134, 139-140, 144-145 and their complementary products are higher compared to other fission products due to nuclear structure effect. (iii) With excitation energy, the yields of fission products for mass number 133-134 symmetric products increase, whereas it decreases for mass number 143-144. (iv) The yields of symmetric products increase and thus the P/V ratio decrease with excitation energy. However, it is surprising to see that the increase trend of symmetric products yields and decrease trend of P/V ratio for $^{232}Th(\gamma, f)$ and ^{232}Th(n, f) are not similar unlike in the fissioning systems $^{238}U(\gamma, f)$ and ^{238}U(n, f). (v) The $< A_L >$, $< A_H >$ and $< \nu >$ at different excitation energy for $^{232}Th(\gamma, f)$ and $^{232}Th(n, f)$ are similar unlike in the fissioning systems $^{238}U(\gamma, f)$ and $^{238}U(n, f)$, where they are different. This research partly was supported by the National Research Foundation of Korea (NRF) through a grant provided by the Korean Ministry of Education, Science & Technology (MEST) in 2011 (Projects No. 2011-0006306 and No. 2011-0025762), by the World ClassUniversity (WCU) program (Grant No. R31-30005), and by the Institutional Activity Program of Korea Atomic Energy Research Institute.
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KD 3 2:20 PM

Independent Isotopic Product Yields in 25 MeV and 50 MeV Charged Particle Induced Fission of ^{238}U and ^{232}Th

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Reliable data of independent fission product yields at intermediate energy are important for the technical application of nuclear energy production and transmutation of nuclear waste in hybrid reactors [1] and for developing the advanced GEN-IV nuclear reactors [2]. Though data for neutron-induced fission are required in the first place, charged-particle induced fission data are valuable as well. Experimental data on fission yields in these energies are sparse, and calculated data are used for the applications. The charged-particle induced fission yield data are often important in the adjustment of the model parameters, see e.g. [3]. Recently, a new method to determine the isotopic fission yields in charged-particle induced fission has been developed at the IGISOL facility in the accelerator laboratory of the University of Jyväskylä [4]. The method is combining the capability of an ion guide based mass separator (IGISOL technique) to produce an ion beam from every element and the unambiguous identification of the fission products by their mass using a Penning trap (JYFLTRAP) as a high mass resolving power filter [5]. This far the independent isotopic yields for most elements from Zn to La in 25 MeV proton-induced fission of ^{238}U and

^{232}Th, for Zn, Ga, Rb, Zr, Pd and Xe in 50 MeV proton-induced fission of ^{238}U and for Zn, Ga, Rb, Sr, Cd and In in 25 MeV deuterium-induced fission of ^{238}U have been measured. There is also an on-going program [6] to study directly the yields of neutron-induced fission in the future at the renewed IGISOL facility [7] utilizing the high intensity proton beams from the new MCC30/15 light-ion cyclotron and a proton-neutron converter target. The experimental results of the charged-particle induced fission yields will be presented and compared with previous results and available experimental models. In particular, the results are compared with the two-component exciton model of Rubchenya [8].

[1] C.D. Bowman et al., Nucl. Instr. and. Meth. A 320 (1992) 336 [2] J. Bouchard, in "Proceedings of the International Conf. on Nuclear Data for Science and Technology," April 22-27, 2007, Nice, France, 2008 CEA, DOI: 10.1051/ndata:07718. [3] A. C. Wahl in "Fission product yield data for the transmutation of minor actinide nuclear waste," Vienna, International Atomic Energy Agency, 2008 - http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1286_web.pdf [4] P. Karvonen et al., Nucl. Instr. and Meth. B 266 (2008) 4454 [5] H. Penttilä et al., Eur. Phys. J. A 44 (2010) 147 [6] M. Lantz et al., in Physica Scripta, Topical issue: 12th Nordic Conference on Nuclear Physics (in press) [7] H. Penttilä et al., J. Korean Phys. Soc. 59 (2011) 1589 [8] V. Rubchenya, J. Äystö, Eur. Phys. J. A 48 (2012) 44

KD 4 2:40 PM

SPIDER: A New Instrument for Fission Fragment Yield Measurements

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Properties of fission fragment are closely related to the process in which they are created. Measurements of the mass, charge and kinetic energy of fragments following fission can help better understand this complex process, and helps validate new theoretical models. Fission product yields are also of practical importance in nuclear technology, as they can be used as a diagnostic tool. While the fission process has been extensively studied since its discovery more than 70 years ago, the energy dependence of the yields of specific fragments in neutron-induced fission is poorly understood. A new instrument, SPIDER, is currently being developed to address this issue by measuring the mass, charge, and kinetic energy of fission fragments as a function of incident-neutron energy. The instrument is based on the 2E-2V method, in which the velocity and kinetic energy of fragments are measured in coincidence to determine their masses. Additionally, by using Bragg peak spectroscopy, the charge of a fragment can be identified. A prototype instrument has been developed, and preliminary results indicate that 1 mass unit resolution is feasible using this approach. A larger detector array is currently being designed, and will be used at the Los Alamos Neutron Science Center (LANSCE) to study fission fragment yields from thermal neutron energies up to at least 20 MeV.

Session KE Neutron Cross Section Measurements
Wednesday March 6, 2013
Room: Central Park East at 1:30 PM
Chair: Alexandru Negret, IFIN-HH
KE 1 1:30 PM

Neutron-Induced Reactions on U and Th - New Cross-Section Measurements via AMS

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Existing data for neutron-induced reactions on U and Th have been measured via detection of the prompt radiation, by the activation technique and by detection of emitted particles. A major difficulty in these experiments is the discrimination against the strong γ-background (e.g. from the competing fission channel) or unfavourable decay schemes. Up to now, no measurements have been performed for such reactions applying accelerator mass spectrometry (AMS) except recent work at the VERA (Vienna Environmental Research Accelerator) laboratory. Recent studies exhibit some discrepancies at keV and MeV energies between major nuclear data libraries for ^{238}U(n,γ), ^{232}Th(n,γ) but also for (n,xn) reactions. A similar difference for the cross section ratio ^{238}U(n,γ)/^{197}Au(n,γ) was found between data based on TOF and prompt γ-detection. Some of those ratio measurements may be biased because of the difficulties in detecting all the gamma rays emitted by the ^{238}U(n,γ) and ^{197}Au(n,γ) reactions. Our method based on direct atom-counting has the advantage that the involved systematic uncertainties are in no way correlated with the uncertainties inherent e.g. to the TOF technique. Therefore, such data provide important and independent information for key reactions of reactor physics. We have extended our previous (n,γ) measurements on ^{235,238}U using AMS to higher neutron energies and to additional reaction channels. Natural uranium and thorium samples were exposed to neutrons of energies between 0.5 and 23 MeV at IRMM. After the activation, the production of longer-lived nuclides was quantified by AMS. The radionuclides counted via AMS were either the direct product of a reaction or a decay-product of a directly produced short-lived nuclide. A particular feature of the U and Th isotopes are the low (n,2n) and (n,3n) thresholds; even the ^{232}Th(n,4n) reaction could be studied. We will present new data for ^{232}Th(n,γ), ^{232}Th(n,2n), ^{232}Th(n,4n) and ^{232}Th(n,α), as well as for ^{238}U(n,γ) and ^{238}U(n,3n).

KE 2 2:00 PM

MANTRA: An Integral Reactor Physics Experiment to Infer the Capture Cross-Sections of Actinides and Fission Products in Fast and Epithermal Neutron Spectra

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This paper will present an update on an on-going integral reactor physics experiment whose objective is to infer the effective neutron capture cross-sections for most of the actinides of importance for reactor physics and fuel cycle studies. Some fission products are also being considered. The principle of the experiment is to irradiate very pure actinide samples in the Advanced Test Reactor at INL and, after a given time, determine the amount of the different transmutation products. The determination of the nuclide densities before and after neutron irradiation will allow inference of effective neutron capture cross-sections. The list of actinides is the following: Th-232, U-233, U-235, U-236, U-238, Np-237, Pu-239, Pu-240, Pu-242, Pu-244, Am-241, Am-243, Cm-244 and Cm-248. The list of fission products is the following: Sm-149, Eu-153, Cs-133, Rh-103, Ru-101, Nd-143, Nd-145, Pd-105. In order to obtain effective neutron capture cross-sections corresponding to different neutron spectra, three sets of actinide samples are being (or will soon be) irradiated: the first one is filtered with cadmium and the other two are filtered with boron different thicknesses (5 mm and 10 mm). The irradiation of the 5-mm-boron-filtered samples started in February 2012 and that of the cadmium-filtered one is scheduled to start in the September-October 2012 timeframe. Both irradiations should be completed by the end of this year. The determination of the atom densities before and after irradiation will be carried out both at INL and ANL, using respectively the ICPMS available at the Analytical Lab and the AMS of the ATLAS facility. In order to provide accurate measurements the ATLAS facility had to undergo some upgrade such as the implementation of a laser ablation technique in the ion source and of a highly efficient sample changer. This work is supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under DOE Idaho Operations Office Contract DE-AC07-05ID14517 as well as by the ANL Contract DE-AC02-06CH11357 and by the ATR National Scientific User Facility.

KE 3 2:20 PM

Measurements of Capture Gamma Rays from the Neutron Resonances of ^{74}Se and ^{77}Se at J-PARC/MLF/ANNRI

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Selenium-79 is one of the most important long-lived fission products in the transmutation study. However, there is no experimental cross section data of ^{79}Se because it is difficult to prepare a sample. Therefore, we have started a systematic measurement of neutron capture cross sections and gamma-ray spectra of stable Se isotopes in order to improve the evaluated neutron capture cross sections of ^{79}Se. In this work, we measured the capture gamma rays from the neutron resonances of ^{74}Se and ^{77}Se. Since ^{74}Se is an even-even nucleus in which neutrons are filled up the $2p_{1/2}$ orbit from a simple shell model, the strong correlation between initial and final states of the primary gamma-ray transitions is expected. Selenium-77 is the only stable Se isotope with odd mass number. So the neutron capture gamma-ray spectra of ^{77}Se are expected to contain useful information for evaluation of ^{79}Se with odd mass number. A neutron time-of-flight method was adopted for the measurements with a 4π Ge spectrometer installed at the Accurate Neutron-Nucleus Reaction measurement Instrument (ANNRI) in the J-PARC Material and Life science experimental Facility (MLF). The gamma-ray pulse-height spectra corresponding to the 27-eV resonance of ^{74}Se and the 113-, 212-, 291-, 342-, 690- and 864-eV resonances of ^{77}Se were obtained by gating on the TOF regions, respectively. The relative intensities of those primary transitions were derived and compared with the previous experimental data. For the 27-eV resonance of ^{74}Se, a strong primary transition to the 293-keV state was observed. As for ^{77}Se, the quite differences of the decay pattern were found between the resonances. This work was supported by JSPS KAKENHI Grand Number 22226016.

KE 4 2:40 PM

Measurements of Thermal Neutron Capture Cross Sections of ^{136}Ce, ^{156,158}Dy, and ^{168}Yb

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For several low abundance stable nuclei, the thermal neutron capture cross sections are not well measured, while the cross sections for isotopes with high abundances are already well measured. Therefore, we can obtain the cross sections of low abundant isotopes, which are not known well, by comparing the yields of gammas from the neutron captures by various isotopes in the foils. Our experiments, different from the commonly used method of using gold foil as reference, are performed using natural foils for which we know the relative abundances of all isotopes and thermal neutron capture cross sections. The advantage of this method is the cancellation of potential systematic errors from thermal neutron flux, flux profile, foil thickness, foil size, and irradiation time. We have measured the capture cross sections of ^{136}Ce, ^{156,158}Dy, and ^{168}Yb isotopes with natural foils, using the high thermal neutron flux from the reactor HANARO at KAERI, and have obtained new cross section values for ^{136}Ce(n,γ), ^{156,158}Dy(n,γ), and ^{168}Yb(n,γ) reactions.

Session LA Neutron Cross Section Measurements
Wednesday March 6, 2013
Room: Met East at 3:30 PM
Chair: Franz-Josef Hambsch, EC-JRC-IRMM
LA 1 3:30 PM

Plutonium and Uranium Prompt-Fission-Neutron Energy Spectra (PFNS) from the Analysis of Neutron Data from two US Nuclear Explosions

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The neutron experiment (NUEX) was a common diagnostic on nuclear device tests conducted at the Nevada Test Site (NTS). In these experiments neutrons from a device pass up a collimated line of site, and in the case of a Faraday cup (FC) NUEX, the neutrons pass through a thin CH2 foil. Some of these neutrons interact with the nuclei in the foil, generating light charged particles (predominantly protons) which are collected in a Faraday cup. The time dependence of the Faraday cup current is a measure of the energy spectrum of the neutrons that leak from the device. With good device models and accurate neutron-transport codes, the leakage spectrum can be converted into a prompt fast-neutron-induced fission-neutron energy spectrum (PFNS) from ∼1 to 11 MeV. This has been done for one of our last events containing a plutonium primary, where the NUEX data were of a particularly high quality, and for an earlier event containing a uranium primary. The fission-neutrons in these devices were produced by fission events induced by neutrons over a broad range of energies. We have inferred 2 MeV n + 239Pu and n + 235U fission-neutron spectra for outgoing neutron energies from 1.5 to 10.5 MeV, in 1-MeV steps. These spectra are in good agreement with the Los Alamos fission model [1].

[1] D. G. Madland and J. R. Nix, Nucl. Sci. and Eng. 81, 213 (1982), and http://t2.lanl.gov/data/fspect.

LA 2 4:00 PM

A New Measurement of the Neutron Capture Cross Section of ^{235}U Below 5 keV

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The neutron microscopic capture cross section for ^{235}U is a critical parameter for the design and operation of nuclear reactors. The evaluated nuclear data libraries of ENDF/B-VII.1 and JENDL-4.0 have nearly identical values for the neutron capture cross section for neutron energies below 0.5 keV. In the most recent release of the JENDL library the onset of the unresolved resonance region (URR) was changed from 2.25 keV to 0.5 keV, and in this region the average neutron capture cross section from ENDF/B-VII.1 is about 10% higher than that from JENDL-4.0. In an attempt to address the discrepancies between the libraries, a new measurement of the neutron capture cross section of ^{235}U was conducted at the Gaerttner LINAC Center located at Rensselaer Polytechnic Institute. This measurement used a 16 segment γ-multiplicity NaI(Tl) detector to detect the prompt gammas emitted from neutron interactions with a highly enriched ^{235}U sample. Using the time-of-flight method, detected events were recorded and grouped based on the total gamma energy per interaction and observed multiplicity. A method was developed to separate fission from capture based on total energy deposition and gamma multiplicity. Application of this method in the thermal and resonance region below 0.5 keV for both the fission and capture cross section produced cross sections in excellent agreement with both the ENDF/B-VII.1 and JENDL-4.0 evaluations. The measurements support the conclusion to lower the ^{235}U neutron capture cross section below the ENDF values in the energy range 0.5-2.25 keV.

LA 3 4:20 PM

Neutron Capture Cross Sections and Gamma Emission Spectra from Neutron Capture on ^{234,236,238}U measured with DANCE.

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An accurate knowledge of the gamma-ray strength function and level density is needed for the first-principles calculation of neutron-capture cross sections. A constraint on these quantities is provided by measurements of gamma-ray emission spectra. We will present neutron-capture cross sections from 10 eV to 10 keV and gamma-emission spectra from several isolated neutron resonances in ^{234,236,238}U, measured using the DANCE detector at LANSCE. The measurements will be compared to cross-section calculations and gamma-emission calculations made using different models for the radiative strength function. DANCE is a calorimetric 4π array consisting of 160 BaF2 crystals, designed for studying neutron capture on small

samples of rare or radioactive nuclides. The measurements were made at the Manuel J. Lujan, Jr. Neutron Scattering Center at the Los Alamos National Laboratory, under the auspices of the U.S. Department of Energy contract DE-AC52-06NA25396.
Presenting author: Shea Mosby

LA 4 4:40 PM

Neutron-Induced Fission Cross Section Measurements at LANSCE

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A well established program of neutron-induced fission cross section measurement at Los Alamos Neutron Science Center (LANSCE) is supporting fast nuclear reactor technology. The incident neutron energy range spans from sub-thermal up to 200 MeV by combining two LANSCE facilities, the Lujan Center and the Weapons Neutron Research center (WNR). The time-of-flight method is implemented to measure the incident neutron energy. A parallel-plate fission ionization chamber is used for fission fragment detection. The event rate ratio between the investigated foil and a standard ^{235}U foil is translated into a fission cross section ratio. Thin actinide targets with deposits of <200 μg/cm^2 on stainless steel backing are used in the fission chamber. Since the last ND2010 meeting the new measurements include ^{236}U data which are being analyzed, and ^{234}U data acquired in the 2011-2012 LANSCE run cycle. The new data complete the full suite of Uranium isotopes which were investigated with this experimental approach in addition to previously measured data for ^{237}Np, $^{239-242}$Pu, and ^{243}Am. Having data for multiple Uranium isotopes will support theoretical modeling capabilities and strengthens nuclear data evaluation. This work has benefited from the use of the Los Alamos Neutron Science Center at the Los Alamos National Laboratory. This facility is funded by the US Department of Energy and operated by Los Alamos National Security, LLC under contract DE-AC52-06NA25396.

LA 5 5:00 PM

Measurements relevant to high energy neutron spectrum (> 10 MeV) by using Yttrium threshold detectors

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Study of deep subcritical electronuclear systems and radioactive waste transmutation using relativistic beams from the accelerator, which we are involved in, is performed within the project "Energy and Transmutation of Radioactive Wastes" (E&T RAW). This work is a preliminary step toward the study of the physical properties of ADS systems, in which a deeply subcritical active core is irradiated by a pulsed beam of relativistic deuterons. The long-range goal is the study of the possibilities of such systems with maximally hard neutron spectrum, to carry out transmutation of RAW. Results of two different experiments

"Quinta" (2011) and "Energy plus Transmutation" (2006-2009) are presented. The experiment assemblies (U/Pb model about 1m length) was irradiated by 1 to 6 GeV deuteron beam (Dubna NUCLOTRON) and we obtain neutron energy spectrum inside whole 3D model by using threshold energy reaction in yttrium (Y-89) probes. The average neutron flux density per deuteron in three neutron energy ranges (11,5-20.8, 20,8-32.7, 32,7-100 MeV) for the different deuteron beam energies is presented. Main different between those two experiments is the type of core (target), lead or natural uranium. Theoretical calculations give us information about quite big different in average neutron flux density in those two cases. We will try to prove and show it on base of experimental data.

LA 6 5:15 PM

Neutron Capture Reaction on ^{173}Lu Isotope at DANCE

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A highly gamma radioactive target, 3.7 GBq, of ^{173}Lu isotope was placed inside the DANCE array [1] (Detector for Advanced Neutron Capture Experiments) at Los Alamos to study the neutron radiative capture on an unstable isotope. This target was produced using successively, proton irradiation of Hf sample at the Isotope Production Facility, chemical separation of Hf and Lu in hot cell and electrodeposition at Los Alamos. A 100 μ g/cm^2 relatively pure target of ^{173}Lu was obtained containing a fraction of ^{175}Lu used in the data analysis as a reference. Measurements of radiative capture cross section on ^{173}Lu were achieved at the LANSCE spallation neutron source facility in Los Alamos over the neutron energy range from thermal up to 1 keV. A special configuration was necessary to perform the experiment using the DANCE array due to the high gamma activity of the target. We will report on the target production, the experiment and the results obtained for the radiative capture on ^{173}Lu. Radiative capture cross section will be obtained for the first time on this unstable nucleus. Some resonances could be characterized. A comparison with a recent data evaluation will be presented. This work has benefited from the use of the Lujan Center at the Los Alamos Neutron Science Center, funded by the DOE Office of Basic Energy Sciences and Los Alamos National Laboratory funded by the Department of Energy under contract W-7405-ENG-36.
[1] M. Heil et al, Nucl. Instr Meth. A 459, 229 (2001)

LA 7 5:30 PM

Precision Measurement of Neutron Capture in ^{238}Pu at DANCE

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Cross sections of neutron capture and neutron induced fission in actinides are important to many applications in nuclear physics, nuclear power generating industry, and Stockpile Stewardship program. Most common challenges in these measurements are inherited radioactivity of a target, and difficulty in distinguishing (n,g) from other reaction channels, such as fission, that may contribute to background. We have successfully performed the first cross section measurement in a laboratory environment of the neutron capture in Pu-238 using DANCE [1] and PPAC [2]. DANCE is a 4π γ-ray calorimeter designed at LANL. It consists of 160 BaF2 crystals capable of measuring total and individual energies of γ-ray cascades from neutron capture. PPAC is a gas filled parallel plate avalanche counter designed to tag fission events and thus distinguish γ-rays between capture and fission. It fits inside the DANCE beam pipe, has fast timing (1.7 ns), capable of high counting rate, and very resistant to radiation damage. Because of its low mass, PPAC attenuates only <1% of the 1-MeV capture and fission γ-rays emitted by the target. DANCE together with the new capability of PPAC can now successfully measure neutron capture and fission simultaneously on small radioactive samples. Two Pu-238 targets, with total masses of 396 and 40 mkg, were measured at DANCE with and without PPAC. Before that, the only available 238Pu(n,g) cross section was obtained by Silbert [3] in 1972 using a nuclear explosion as a neutron source. Design and details of the experiment will be presented. In addition, the 238Pu(n,g) cross section in the incident neutron energy range 0.025 eV - 40 keV will be presented and compared against Silbert's experimental and ENDF evaluated data sets. This work was performed under the auspices of the US Department of Energy by Los Alamos National Laboratory under Contract DE-AC52-06NA25396 and Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

[1] M. Heil et al., Nucl. Instrum. Methods Phys. Res. A 456 (2001) 229. [2] C.Y. Wu at al., Nucl. Instrum. Methods, manuscript submitted. [3] M.G. Silbert, J.R. Berreth, Nucl. Sci. and Eng., v. 52, p. 187, (1973).

Session LB Evaluated Nuclear Data Libraries
Wednesday March 6, 2013
Room: Met West at 3:30 PM
Chair: Jag Tuli, NNDC - BNL
LB 1 3:30 PM

Development of JENDL Decay and Fission Yield Data Libraries

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The decay and fission yield data of fission products have been developed for decay heat calculation as JENDL (Japanese Evaluated Nuclear Data Library) family as JENDL/FPD-2011 and JENDL/FPY-2011. The data in the previous decay data file, JENDL FP Decay Data File 2000, have been updated based on the ENSDF (Evaluated Nuclear Structure Data File) data file. Newly measured decay energy values by TAGS (Total Absorption Gamma-ray Spectroscopy) method have been incorporated into the file. The fission yield data have been updated from the data in the JENDL-4 library. The main change came from the change of decay chains adopted in the decay data file. The number of nuclides are kept consistent between the decay data file and the fission yield file. The decay heat calculations were performed using the both updated data and compared with some measured decay heat data. The uncertainty analyses were also performed and have given the uncertainties. The components of the uncertainties were also identified from the uncertainty analyses. Similar uncertainty analyses were applied to the calculations using the ENDF and JEFF files. Their comparison with those of the JENDL library was also shown.

LB 2 4:00 PM

Table of $E0$ Electronic Factors for Conversion Electron Probabilities

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The accurate knowledge of conversion coefficients is essential to evaluate total electromagnetic transition rates and to normalize decay schemes. The new theoretical conversion coefficient tables [1,2,3] represent a major improvement in terms of accuracy and coverage for elements between $Z = 5$ and 126. On the other hand, there is no universal table available yet for electric monopole (E0) transitions connecting states with the same spin–parity. In this paper we report on the tabulation of $\Omega(E0)$ electronic factors for electron conversion in $Z = 2$ to $Z = 96$ elements and all possible $s_{1/2}$ and $p_{1/2}$ atomic shells. The calculations have been carried out with a modified version [4] of the relativistic Hartree–Fock–Slater method developed by Pauli and Raff [5]. The data tables presented here cover transition energies from 1 keV up to 6000 keV, similar to our recent ICC tabulations. In contrast to the internal conversion coefficients, the $\Omega(E0)$ electronic factors, can not be directly determined experimentally. Instead, the ratios of $\Omega(E0)$ values, which are proportional to the ratios of the corresponding conversion electron intensities, can be compared to theoretical ratios. A list of 80 experimental $\Omega(E0)$ ratios are presented in the first time for transitions in $Z = 8$ to $Z = 98$ nuclei and are compared to theory. A systematic difference of $\sim 5.5\%$ has been identified, namely theory overestimates experiment. For routine use of the new table with BrIcc [2], we propose to assign a general uncertainty of 5.5% to the $\Omega(E)$ values.
[1] I.M. Band, M.B. Trzhaskovskaya, C.W. Nestor, Jr., P.O. Tikkanen, S. Raman, At. Data Nucl. Data Tables **81** (2002) 1. [2] T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor, Jr., Nucl. Instr. Meth. in Phys. Res. A **5**89 (2008) 202. [3] T. Kibédi, M.B. Trzhaskovskaya, M. Gupta, A.E. Stuchbery, At. Data Nucl. Data Tables **98** (2012) 313. [4] G. Gosselin, P. Morel, Phys. Rev. **C 70** (2004) 064603. [5] H.C. Pauli, U. Raff, Comp. Phys. Comm. **9** (1975) 392.

LB 3 4:20 PM

Survey and Evaluation of the Isobaric Analog States

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Isobaric analogue states (IAS) can be used to estimate the mass of nuclei belonging to isobars of the same isospin multiplet set. The *Atomic Mass Evaluation (AME)* had previously evaluated the experimental data used to establish the mass of these states. These masses were also used to establish a semi-empirical relationship between the members of any given mass multiplet via the *isobaric mass multiplet equation, IMME.* The experimental and IMME estimated IAS data have not been published in the *AME* since 1993 [1]. However, given the recognized importance of isobaric states, it has been decided to reactivate these IAS studies, initially instigated by Aaldert H. Wapstra. In this conference we describe the reaction data used to establish the IAS. Cases where reaction data provide a better mass precision as compared to decay

data will be presented. The particular cases of *N=Z, T=1* ground states, and fragmented states will also be discussed. This work is an extension and update of the work carried out by Aaldert H. Wapstra until 2003.

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LB 4 4:40 PM

Systematics of Evaluated Double-Beta Decay Half-Life Times

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A new evaluation of $\beta\beta(2\nu)$ half-life values and their systematic are presented. These recommended values extend the previous evaluation [1] and include analysis of all recent measurements. $T^{2\nu}_{1/2} \sim 1/E^8$ systematic trend has been observed for ^{128,130}Te recommended values. Such trend indicates similarities for nuclear matrix elements in Te nuclei and was predicted for $\beta\beta(2\nu)$-decay mode [2,3]. Current results are compared with large-scale shell-model calculations and experimental works.

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LB 5 5:00 PM

Method of Best Representation for Averages in Data Evaluation

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A novel statistical approach to the averaging procedures in data evaluation is developed based on producing a mean probability density function to represent the data set. This Method of Best Representation (MBR) is shown to have desirable properties including being robust to outliers and agreement with the standard weighted average (weighting by the reciprocal of the square of the uncertainty in the measurement) in the case of non-discrepant data. Examples from isotopic half-life and gamma-ray intensity data will be discussed to illustrate the method.

LB 6 5:15 PM

Neutron Cross Section Evaluation of Tantalum and Tungsten

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The evaluation of neutron cross sections and covariances is presented for tungsten and tantalum which are considered as a prime candidate of plasma facing materials in fusion reactors and/or a structural material of Korea Helium Cooled Ceramic Reflector (HCCR) Test Blanket Module (TBM). The neutron cross sections and energy and/or angular dependent neutron spectra from existing libraries such as ENDF/B-VII.1, JENDL-4.0 and JEFF-3.1 show some discrepancies with the measured data available for tungsten and tantalum. Moreover, the integral tests of neutron production from these libraries failed to reproduce the leakage neutron measurements of OKTAVIAN. In response to these situations, the neutron cross sections for ^{181}Ta and ^{180,182,183,184,186}W were newly evaluated and compared with the existing libraries

and the measured data available. This work aims at providing the reliable evaluation data and their covariances above resonance region rather than a full energy range from 10^{-5} eV to 20 MeV. The thermal and resonance data were taken from the ENDF/B-VII.1, while the data above resonance region have been calculated by using the EMPIRE code system that has been used to provide a number of consistent and complete evaluations. The covariance data were generated through the KALMAN filtering implemented in the EMPIRE system, which use the sensitivity matrices by variations of model parameters and the available measurements.

LB 7 5:30 PM

An Evaluation of the Scattering Law For Light and Heavy Water in ENDF-6 Format, Based on Experimental Data and Molecular Dynamics

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There exist only two evaluations of the scattering law for light and heavy water available in ENDF format [1,2]. Both evaluations are based on experimental data measured by Haywood in the 60's, and use a free gas model to represent the translational motion of the molecules. These evaluations are acceptable for reactor applications, but show significant discrepancies with total cross section measurements in the sub-thermal range and with angular distributions of the differential cross, caused by the simplified structure and dynamics used in these models. In this work we present an evaluation in ENDF-6 format of the scattering law for light and heavy water computed using the LEAPR module of NJOY99 [1]. The models used in this evaluation are based on experimental data on light water dynamics measured by Novikov [3], partial structure factors obtained by Soper [4], and molecular dynamics calculations performed with GROMACS [5] using a reparameterized version of the flexible SPC model by Toukan and Rahman [6]. The models use the Egelstaff-Schofield diffusion equation for translational motion, and a continuous spectrum calculated from the velocity autocorrelation function computed with GROMACS. The scattering law for H in H_2O is computed using the incoherent approximation, and the scattering law D and O in D_2O are computed using the Sköld approximation for coherent scattering. The calculations show a significant improvement over ENDF/B VI and ENDF/B VII when compared with measurements of the total cross section, differential scattering experiments and quasi-elastic neutron scattering experiments (QENS).
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LB 8 5:45 PM

The Production and Performance of JEFF3.1.2 Nuclear Data Libraries in ANSWERS Codes

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The JEFF3.1 evaluated nuclear data library was released in 2005 and represented the culmination many years of measurement and evaluation. As a result of some issues identified by the validation of the JEFF3.1 library, a small number of nuclides were re-evaluated to improve results and were released as JEFF3.1.1, in 2009. The latest version of the JEFF library, JEFF3.1.2, was released in January 2012. This incorporated new evaluations of the hafnium resolved resonance range and the inclusion of gamma production data for 89 fission products (representing 99% of fission product absorption). The ANSWERS Monte Carlo code MONK can be run using discrete energy dependence, by utilising a broad group (i.e. 172 groups) nuclear data library, or using continuous (or point) energy. This latter option removes the approximations inherent in using discrete energy groups. To run in point energy mode, MONK uses the BINGO [1] collision processor and associated point energy nuclear data library. BINGO is the successor to the DICE collision processor which utilised a hyper-fine energy group scheme (13193 groups). For the point energy BINGO library, it is necessary transform the evaluated data from the standard ENDF-6 format, to a form that allows efficient Monte-Carlo sampling. This is done using a code called the BINGO Pre-Processor (BPP). The BPP uses the NJOY nuclear data processing code to reconstruct and Doppler broaden the cross-sections to form a smoothly varying function of energy. The secondary angle and energy data for emitted neutrons are transformed into equi-probable bins or probability functions. The broad group library used by MONK is identical with the library applied in the ANSWERS deterministic neutronics code, WIMS. For this library, NJOY is again used to reconstruct and Doppler broaden the cross-sections but, in this case, NJOY is further used to produce the group averaged data for both the cross-sections and emitted data. These data are then transformed into the specific form required for the WIMS library. This paper will describe the methodologies used to generate the BINGO point energy and WIMS broad group libraries. It will also present MONK benchmark results for libraries derived from the JEFF3.1.2 evaluated data library.
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Session LC Nuclear Data Covariances
Wednesday March 6, 2013
Room: Empire East at 3:30 PM
Chair: Emil Betak, Slovak Academy of Sciences
LC 1 3:30 PM

On the Use of Zero Variance Penalty Conditions for the Generation of Covariance Matrix Between Model Parameters

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Analytic and Monte-Carlo algorithms have been developed and implemented in the nuclear data code CONRAD to generate covariances between model parameters. However, in the resolved resonance range of the neutron cross sections, thousands model parameters and experimental data points are needed to describe the main neutron reactions of interest for the nuclear applications. In practice, all of the model parameter covariances cannot be simultaneously estimated from well-defined sets of experimental data.

The situation becomes more and more complex when the number of open reaction channels increases. This optimization problem is nonconvex in general, making it difficult to find the global optima. A solution to simplify the problem consists of dividing the model parameter sequence into blocks of variables, the uncertainties of which can be propagated through fixed-order sequential data assimilation procedures. According to definition and nomenclature used in statistics, we can identify the "observable", "latent" and "nuisance" variables. Observable variables can be directly determined from the experimental data. Latent variables (as opposed to observable variables) may define redundant parameters or hidden variables that cannot be observed directly. This term reflects the fact that such variables are really there, but they cannot be observed or measured for practical reasons. Nuisance variables (i.e. experimental corrections) correspond to aspect of physical realities whose properties are not of particular interest as such but are fundamental for assessing reliable model parameters. The methodology consists in calculating cross-covariance matrix between Gaussian distributed parameters by introducing "variance penalty" terms. This approach was proposed by D.W. Muir for determining the contribution of individual correlated parameters to the uncertainty of integral quantities. It provides a useful understanding of how the model parameters are related to each other and ensures the positive-definiteness of the covariance matrix. Performances of the analytic and Monte-Carlo models will be illustrated with covariances calculated between new Am-241 resonance parameters recently established in the frame of the IRMM/CEA collaboration.

LC 2 4:00 PM

Evaluation of Uncertainties in β_{eff} by Means of Deterministic and Monte Carlo Methods

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Due to the influence of the delayed neutrons on the reactor dynamics an accurate estimation of the effective delayed neutron fraction (β_{eff}), as well as good understanding of the corresponding uncertainty, is essential for reactor safety analysis. The interest in developing the methodology for estimating the uncertainty in β_{eff} was expressed in the scope of the Uncertainty Analysis in Modelling (UAM) project of the OECD/NEA. A novel approach for the k_{eff} sensitivity and uncertainty analysis, based on the derivation of the Bretscher's approximate equation (prompt k-ratio method) was proposed and demonstrated at the UAM-5 meeting in 2011 [1, 2]. This paper presents the results of the calculations of β_{eff} and the corresponding uncertainties obtained using both deterministic and Monte Carlo methods. A series of critical benchmark experiments from the ICSBEP and IRPhE databases, such as GODIVA, JEZEBEL, SNEAK-7A & -7B, LEU-SOL-THERM-02 were studied. β_{eff} values were calculated by the exact expression from the direct and adjoint fluxes (using SUSD3D and DANTSYS codes) and using Bretscher's method (MCNP, DANTSYS). The uncertainty analyses were performed using the SUSD3D deterministic generalised perturbation code and the XSUSA random sampling code applied with multi-group neutron transport codes (XSDRN, DANTSYS, and KENO). Using the JENDL-4 covariance matrices the typical β_{eff} uncertainty was found to be around 3% and is generally dominated by the uncertainty of nu-delayed; depending on the considered assembly, nu-prompt, inelastic and fission cross-section uncertainties may also give significant contributions. Excellent agreement between the β_{eff} and their uncertainties, calculated by the above methods was observed, validating in this way the mathematical methods and procedures developed. The measurements of β_{eff} in combination with the sensitivity profiles and the uncertainties can be exploited for the nuclear cross-section validation, complementing thus the information obtained from the k_{eff} measurements.

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LC 3 4:20 PM

Sensitivity and Uncertainty Analysis for Minor Actinide Transmuters with JENDL-4.0

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To improve the design accuracy for the next generation of nuclear reactors, much effort has been devoted to understanding uncertainties on the reactor physics parameters with the use of the sensitivity and uncertainty (S/U) analysis and the corresponding covariance data. In particular, the nuclear design of the minor actinide (MA) transmuters such as the accelerator-driven system (ADS) and fast reactor (FR) requires reliable covariances, as well as cross-sections, for MAs. So far target nuclides and reactions used for the S/U analysis have been limitted to major ones. However, analyses by limited data could lead to misunderstanding about the target accuracy assessment. For example, despite the fact that fission-related parameters such as the fission cross-section (σ_{fis}) and neutron multiplicity (ν) have considerable impacts on the uncertainties on the reactors, contributions of the fission neutron spectrum have not yet been discussed. To identify which parameters have an effect on the uncertainty of the design parameters on the MA transmuters, inclusive covariance data with respect to both the target nuclides and reactions are needed. To meet this requirement, the Japanese Evaluated Nuclear Data Library (JENDL-4.0) [1], released in 2010, places much emphasis on the improvements of the covariance data; covariances for all reactions of almost all nuclides, as well as reaction parameters, were newly evaluated and/or revised based on available experimental data and theoretical calculations using the nuclear data evaluation codes. The objective of this study is to derive the reactor physics parameters with total uncertainty on ADS and FR with the use of the JENDL-4.0 cross-section and covariance data, and compare to the older one, JENDL-3.3. For ADS, the basic concept investigated in Japan Atomic Energy Agency (JAEA) [2] was adopted, namely the 800 MW_{th} lead-bismuth eutectic (LBE) cooled type ADS with nitride fuel (MA ratio: 63.7 wt%). For FR, we selected the 3,600 MW_{th} sodium-cooled type FR with MOX fuel (MA ratio: 5.0 wt%) based on the concept investigated in the feasibility study in Japan [3]. As the reactor physics parameters, the criticality (k_{eff}), coolant void reactivity, and Doppler reactivity was analyzed. Then, to identify the cause of the differences of the parameters between the two libraries, we analyezed differences by nuclies and reactions with the use of the sensitivity coefficients calculated by the sensitivity calculation code, SAGEP [4]. We also investigated nuclide- and reaction-wise uncertainties on the two reactors and compare the differences of the uncertainties between JENDL-4.0 and JENDL-3.3.

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LC 4 4:40 PM

Propagation of Neutron Cross Section, Fission Yield, and Decay Data Uncertainties in Depletion Calculations

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A complete reactor physics study requires not only the calculation of the values of interest but the assessment of their uncertainties arising from the nuclear data used. XSUSA represents a validated methodology to propagate cross-section uncertainties and analyze their impact on reactor analysis. However, until recently, it did not include the propagation of fission yields and decay constants uncertainties, relevant magnitudes for burn-up calculations and isotopic predictions. We describe in this paper a technique to propagate these fission yields and decay data uncertainties following the XSUSA procedure, that is, the generation, from the basic nuclear data, of varied libraries to be used by SCALE6.1 for reactor calculations. SCALE6.1 employs the ORIGEN-S module to perform depletion calculations. An automated process to vary the ORIGEN-S fission yields and decay input libraries according to the uncertainties found in the nuclear data files has been developed and applied to the ENDF/B-VII library. In order to study the impact of the uncertainties on depletion calculations, a light water reactor pin cell model as defined in the UAM Phase I Benchmark has been used. 1.000 depletion calculations were executed repeatedly using the different varied libraries. Various cases have been studied, perturbing (1) the fission yield libraries, (2) the decay libraries, (3) the neutron cross section libraries, and (4) all libraries simultaneously. This strategy helps us to shed light on the separate and combined effect of their uncertainties on the multiplication factors and isotopic content during the depletion cycle. It turns out that for the system under consideration, the multiplication factor uncertainty is dominated by the neutron cross section uncertainties. For certain isotopes, however, fission yield und decay data uncertainties may give significant contributions to the uncertainties of the respective concentrations.

LC 5 5:00 PM

Uncertainty Study of Nuclear Model Parameters for the n+^{56}Fe Reactions in the Fast Neutron Region Below 20 MeV

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With the development of Gen-IV reactors, advanced fuel cycles, transmutation and shielding design, the need of neutron cross section covariance data (uncertainties and correlations) is becoming increasingly important. In this work, random parameter variation is applied tothe neutron optical model potential (OMP) of ^{56}Fe by using the Total Monte Carlo method [1]. The uncertainties of total, elastic, non-elastic cross section as well as angular distribution and their correlations have been obtained based on the existing experimental data. Also, by using a parameter rejection method based on experimental data, a correlation matrix for the OMP parameters is obtained. The impact of these OMP parameter uncertainties on all partial channels for n+^{56}Fe reaction is investigated with the TALYS nuclear model code[2]. Furthermore, the impact of other model parameter uncertainties such as level density and gamma width on each partial channel is investigated. By using random sampling within the appropriate uncertainty ranges, more than 300 random evaluations of ^{56}Fe are presented. These are provided for reactor simulation codes for nuclear data error propagation.

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LC 6 5:15 PM

Monte Carlo Sensitivity and Uncertainty Analysis with Continuous-Energy Covariance Data

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Hyung Jin Shim, Chang Hyo Kim
Seoul National University

In the Monte Carlo (MC) sensitivity and uncertainty (S/U) analysis [1] with continuous-energy cross section libraries, the sensitivities of a tallied parameter can be estimated based on the multi-group relative covariance data. In our previous study [2], it was presented that the k uncertainties estimated by using different continuous-energy cross section libraries but the same multi-group covariance data may be significantly different each other because of limitation of the relative covariance approach. In order to overcome the multi-group approximation of the covariance data, we present a method to directly use the covariance files in the MC sensitivity calculations. The k uncertainties due to the multi-group and continuous-energy covariance data are compared for various criticality benchmark problems.
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[1] H. J. Shim, et al., "McCARD: Monte Carlo Code for Advanced Reactor Design and Analysis," Nucl. Eng. Technol., 44, 161-176 (2012). [2] H. J. Park, H. J. Shim, C. H. Kim, " Uncertainty Quantification in Monte Carlo Criticality Calculations with ENDF0B-VII.1 Covariance Data," Trans. Am. Nucl. Soc., 106, 796 (2012).

Session LD Nuclear Astrophysics
Wednesday March 6, 2013
Room: Empire West at 3:30 PM
Chair: Ani Aprahamian, University of Notre Dame
LD 1 3:30 PM

The "Karlsruhe Astrophysical Database of Nucleosynthesis in Stars" project - Status and Prospects

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The nuclei heavier than iron are produced mainly by the "slow" and the "rapid neutron capture process," and a third subset of processes which is responsible for up to 35 stable proton-rich "p nuclei." The first two involve neutron capture reactions and β-decays, whereas the main reaction mechanism for the "p nuclei" is the "gamma process" which requires also proton- and alpha-induced reactions within the Gamow window

of T=2-3 billion Kelvin. The "Karlsruhe Astrophysical Database of Nucleosynthesis in Stars" (KADoNiS) project is an online database for experimental cross sections relevant to the s-process and p-process. It is available under http://www.kadonis.org and consists of two parts. Part 1 is an updated sequel to the previous Bao et al. compilation for stellar (n,gamma) cross sections relevant to nucleosynthesis in the Big Bang and in the s-process [1]. This database was launched in 2005 and is updated every 2 years [2,3]. Until now, recommended Maxwellian averaged cross sections (MACS) at stellar temperatures between kT=5 and 100 keV are given for more than 350 isotopes on the s-process reaction path. After the last full update in 2011 the database was further extended into the neutron-rich region taking into account the requirements of modern stellar s-process models, and by inclusion of (n,p) reactions of light isotopes. The second part of the KADoNiS project is a collection of all available experimental cross sections in or close to the respective Gamow window for the "gamma process" and the comparison with various theoretical models. In 2006 a first trial within the KADoNiS project was launched, but it lasted until 2010 until this part was improved in collaboration with the ATOMKI Debrecen and the updated p-process database was published [4,5]. We will give an overview about the KADoNiS project and present the status and improvements of the s-process database which is just about to be published. I.D. is supported by the Helmholtz association via the Young Investigators project VH-NG-627. R.P. is supported by the Helmholtz association via the Young Investigators project VH-NG-327. T.Sz. is supported by EUROGENESIS OTKA-NN83261. Zs.F. is supported by OTKA K68809.
[1] Z.Y. Bao *et al.*, At. Data Nucl. Data Tables 76 (2000) 70. [2] I. Dillmann, M. Heil, F. Käppeler, R. Plag, T. Rauscher, and F.-K. Thielemann, AIP Conf. Proc. 819, 123 (2006). [3] I. Dillmann, R. Plag, F. Käppeler, T. Rauscher, Proc. "EFNUDAT Fast Neutrons - scientific workshop on neutron measurements, theory & applications," April 28-30 2009, Geel, Belgium, p.55. [4] T. Szücs, I. Dillmann, R. Plag, and Zs. Fülöp, Proceedings of Science (2011), PoS(NIC XI)247 [5] T. Szücs, I. Dillmann, R. Plag, and Zs. Fülöp, J. Phys.: Conf. Ser. 337, 012033 (2012).

LD 2 4:00 PM

Nuclear Spectroscopic Data for Nuclear Astrophysics

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Edinburgh University
D. Seweryniak, M.P. Carpenter, C.J. Chiara, R.V.F. Janssens, S. Zhu
Physics Division, Argonne Nat. Laboratory

The talk will consider spectroscpic measurements at the interface between nuclear astrophysics and nuclear structure (see [1] for a recent example). In particular the talk will focus on high resolution studies of key resonances relevant for elemental emissions from novae explosions, and cosmic gamma ray emitters. In particular there will be an emphasis on work performed using the Gammasphere array at Argonne National Laboratory and how these studies are complemented and built on by other techniques.
[1] D.T. Doherty et al., Phys. Rev. Lett. 108 262502 (2012)

LD 3 4:20 PM

Neutron Capture Reactions for the Astrophysical s-process in the Fe/Ni Region

Claudia Lederer, Oliver Meusel, Ralf Plag, Rene Reifarth, Kerstin Sonnabend, *Goethe University Frankfurt, Germany.* Nicola Colonna, *INFN Bari, Italy.* Carlos Guerrero, *CERN, Switzerland.* Frank Gunsing, *CEA Saclay, France.* Franz Kaeppeler, *Karlsruhe Institute of Technology, Germany.* Cristian Massimi, *INFN Bologna, Italy.* the n_TOF Collaboration, *www.cern.ch/ntof.*

Nuclear reaction data provide a crucial input to study the generation of elements in the cosmos. Elements heavier than Fe are mainly synthesized by neutron capture reactions, which can be divided in two processes, the slow neutron capture process (s-process) and the rapid neutron capture process (r-process). The s-process takes place in environments of relatively small neutron densities and the reaction path proceeds close to the valley of stability. The r-process is attributed to scenarios with very high neutron densities, driving the reaction path towards the neutron rich side. The s-process abundances are strongly correlated to their stellar neutron capture cross sections, that is the energy dependent cross section averaged over the stellar neutron spectrum. Such cross sections can be measured directly via time-of-flight techniques or activating the material with a quasi-stellar neutron spectrum produced in the laboratory. I will present recent measurements of (n, γ) reactions in the Fe/Ni mass region studied by the time of flight technique at the n_TOF facility at CERN, including the measurement on the radioactive nucleus ^{63}Ni. The neutron time-of-flight facility n_TOF is a spallation neutron source, combining a high instantaneous neutron flux with a high energy resolution due to its neutron flight path of 185 m. Neutrons are produced from thermal energies to several GeV, covering the entire energy range of astrophysical interest. Neutron captures reactions are measured via detecting the prompt γ-emission of the compound nucleus. Furthermore, I will talk about the complementary activation technique and new possibilities for both methods at the highly intense neutron source FRANZ (Frankfurt Neutron Source of the Stern Gerlach Zentrum), which is currently under construction at the University of Frankfurt.

LD 4 4:40 PM

The A = 130 Solar-System r-process Abundance Peak - from Initial Build-Up to Decay Back to β-stability

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Since the seminal work of Burbidge et al., Cameron, and Coryell more than 50 years ago, the ability to correctly reproduce the total Solar-System (SS) isotopic r-process abundance pattern has served as a key test for the nuclear-physics data input far from b-stability, and nucleosynthesis models. In this context, the A = 130 abundance peak is of particular importance because, on the one hand, its formation is directly related to the N = 82 shell closure below doubly-magic Sn-132 and, on the other hand, represents the major bottle neck for the r-process matter flow to heavier elements up to the A = 195 abundance peak and the actinide r-chronometers. The quality and usefulness of such calculations have been aided over the past 20 years by the use of (i) improved r-process models, (ii) a consistent theoretical nuclear-physics input, and (iii) the inclusion of experimental nuclear data of (today) about 80 isotopes between Fe and Te that directly lie in the r-process "boulevard". As object examples, using the theoretical nuclear-physics input based on the older mass formula ETFSI-Q, as well as new mass model FRDM 2012 [1], we present new parameterized nucleosynthesis calculations of an r-process in high-entropy-winds of core-collapse supernovae. For different choices of correlated astrophysical parameters for medium-temperature, hot and cold r-process conditions, we study in detail the formation of the A = 130 abundance peak and follow the modulation of its initial shape during the complete freezeout and beta-decay back to stability. We will present time-scales for reaching the first stable isotopes, such as 124Sn, 130Te and 136Xe. In this context, we will emphasize the importance of beta-delayed neutron emission and its late recapture, in some cases leading to minor

production of historical "s-only" isotopes.
Corresponding author: W.B. Walters

[1] P. Möller & K.-L. Kratz, to be submitted to ADNDT

LD 5 5:00 PM

Measurement of the Thulium Stellar Cross Section at kT=30 keV by Activation with an Innovative Method

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The production of Maxwell-Boltzmann neutron spectra is of interest in several fields. Maxwellian-averaged cross sections (MACS) ranging from kT=5 keV to 120 keV are key parameters in the calculation of the astrophysical reaction rates of nucleon, photon and charged-particle interactions with the different elements and their isotopes needed among other things for the description of observed elemental abundances. Spectrum average (SPA) cross sections measured in the well-characterized maxwellian neutron spectrum with high accuracy could be used for the validation of nuclear data libraries in the above-mentioned energy range. Both the library cross-section value and corresponding covariances could be challenged. The estimated uncertainty from the nuclear data library of SPA cross sections is directly linked to off-diagonal elements of the uncertainty matrix; therefore the uncertainty of the calculated SPA cross-section is sensitive to librarian covariances. The energy range ∼100-200 keV is also extremely important in the description of fast neutron systems (e.g. for fast Generation-IV reactors). The MACS of the different elements can be measured directly by activation providing a maxwellian neutron spectrum at the sample position. Beer and Käppeler [1] is considered the classical work in this field, they showed the possibility to produce a quasi maxwellian neutron spectra at kT=25 keV by the Li-7(p,n) reaction at proton energy near-threshold. Then the MACS at the reference temperature (30 keV) can be obtained by a correction of the spectrum and an extrapolation from 25 to 30 keV. Mastinu *et al* [2] proposed a new method for producing maxwellian neutron spectra at different temperatures [3], in particular a very accurate maxwellian spectrum at kT=30 keV can be achieved. While the classical method uses monochromatic proton energy, the key point of the Mastinu *et al* method is to shape the proton beam to a particular distribution near-threshold the Li-7(p,n) reaction by means of an energy degrader that can be made of different material and thicknesses. The Mastinu *et al* method is used to measure by activation the MACS of the Tm169(n,g) reaction at kT=30 keV using Au-197(n,g) as a reference. The available experimental data for this reaction is rather limited and there is only one available data for the MACS at kT=30 keV obtained by the TOF technique [4]. The method will be explained and the results will be shown. Around 13% of the solar abundance of Thulium is made by the slow neutron capture process. Astrophysical implications will be discussed for nucleosynthesis in stars driven by s-process.

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LD 6 5:15 PM

Beta Decay in The Region Of Neutron-Deficient ^{69,70,71}Kr

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Proton-rich nuclei beyond the $N = Z$ line play a key role in our understanding of astrophysics, weak-interaction physics, and nuclear structure. The decay of ^{69}Kr ($T_z = -3/2$) is of particular interest as it populates states in the proton-unbound nucleus ^{69}Br, critical to the rapid proton-capture (rp) process thought to power type I x-ray bursts. During the astrophysical rp process, 2p-capture reactions through ^{69}Br can bypass the "waiting-point" nucleus ^{68}Se [1]. The bypass-reaction rate depends strongly on the proton-capture Q value. A β-decay experiment was conducted at GANIL which utilized implant-β-proton and β-γ correlations to study nuclear structure and decay properties primarily related to the β decays of ^{69,70,71}Kr. Neutron-deficient isotopes ranging from Zn to Kr were implanted into a Si-DSSD detector located at the focal plane of the LISE spectrometer in which spatially and temporally correlated implantation and decay events were studied. Gamma rays were detected in surrounding EXOGAM high-purity germanium clover detectors. We measured β-decay half lives for ^{69,70,71}Kr of 27(3) ms, 40(6) ms, and 92(9) ms, respectively, and identified approximately 200 ^{69}Kr implantation-decay events. We observed a dominant β-decay branch to the isobaric analog state (IAS) in ^{69}Br which then decays to the first excited state in ^{68}Se, a decay path which strongly constrains the spin and mass of ^{69}Kr. Our measured IAS energy, however, disagrees by approximately 1 MeV from the previously adopted value of 4.07(5) MeV [2]. Data from this work represents new measurements that are valuable for updating ENSDF, RIPL, and decay databases, as well as for clarifying existing ambiguities. An overview of the results from our analysis of implanted neutron-deficient nuclei and their implications will be presented.
$\star$ This work is supported by the U.S. DOE Office of Nuclear Physics, Contract No. DE- AC02-06CH11357.

[1] H. Schatz et al., Phys. Rep. **96** (1998). [2] X.J. Xu et al., Phys. Rev. C **55**, R553 (1997).

LD 7 5:30 PM

The (n, α) Reaction in the S-Process Branching Point ^{59}Ni

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The (n, α) reaction in the radioactive ^{59}Ni is of relevance in nuclear astrophysics as it can be considered as the first branching point in the astrophysical s-process. Its relevance in nuclear technology is especially related to material embrittlement in stainless steel. However, there is a strong discrepancy between available experimental data and the evaluated nuclear data files for this reaction. At the n_TOF facility at CERN, a dedicated system based on sCVD diamond detectors was setup to measure the ^{59}Ni(n, α) cross section. The results of this measurement, with special emphasis on the dominant resonance at 203 eV, will be presented. CIVIDEC Instrumentation GmbH, Vienna, Austria, sponsored this work.

LD 8 5:45 PM

Uncertainties in Astrophysical β-decay Rates from the FRDM

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β^{-}-decay rates are of crucial importance in stellar evolution and nucleosynthesis, as they are a key component in stellar processes. Tabulated values of the decay rates as a function of both temperature T and density ρ are necessary input to stellar evolution codes such as MESA [1], or large-scale nucleosynthesis simulations such as those performed by the NuGrid collaboration [2]. It is therefore of interest to know the uncertainties on the nuclear reaction rates and the effects of these uncertainties on stellar structure and isotopic yields. At Los Alamos National Laboratory, β-strength functions and reaction rates for nuclei ranging from ^{16}O to ^{339}136 and extending from the proton drip line to the neutron drip line are calculated from the starting point of nuclear ground-state masses and deformations based on the finite-range droplet model [3, 4]. In this work we investigate the effect of model uncertainty on astrophysical β^{-}-decay rates from Ref. [4]. The sources of uncertainty considered are Q values and deformation for more than 5,000 nuclei with transitions from ground-state in the parent to excited-states in the daughter. The rates and their uncertainties are generated for a variety of temperature and density ranges, corresponding to key stellar processes. We demonstrate the effects of these rate uncertainties on isotopic abundances using the NuGrid network calculations.
[1] B. Paxton, L. Bildsten, A. Dotter *et al.*, Astrophys. J. Suppl. Ser., **192**:3 (2011). http://mesa.sourceforge.net/. [2] F. Herwig, M. E. Bennet, S. Diehl *et al.*, *"Nucleosynthesis simulations for a wide range of nuclear production sites from NuGrid"* in Proc. of the 10th Symp. on Nuclei in the Cosmos (NIC X), 23 (2008). http://www.astro.keele.ac.uk/nugrid. [3] P. Möller, J. R. Nix, W. D. Myers, and W. J. Swiatecki, At. Data Nucl. Data Tables **59** (1995) 185. [4] P. Möller, J. R. Nix, and K.-L. Kratz, At. Data Nucl. Data Tables **66** (1997) 131.

Session LE Experimental Facilities and Techniques
Wednesday March 6, 2013
Room: Central Park East at 3:30 PM
Chair: Enrico Chiaveri, CERN
LE 1 3:30 PM

The Neutrons For Science facility at SPIRAL-2

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The “Neutrons For Science” (NFS) facility will be a component of SPIRAL-2 laboratory under construction at Caen (France). The SPIRAL-2 facility will be dedicated to the production of high intensity of Radioactive Ions Beams (RIB). The high-power, superconducting driver LINAG (linear accelerator of GANIL) will accelerate deuteron beams to produce neutrons by breakup reactions on a C converter.These neutrons will induce ^{238}U fission producing radioactive nuclei. Additionally to the RIB production the Linag Experimental Area (LEA) will allow to use stable beams (protons, deuterons as well as heavy ions) delivered by the accelerator: NFS is one of the two facilities of the LEA. NFS will be composed of a pulsed neutron beam for in-flight measurements and irradiation stations for cross-section measurements and material studies. The beams delivered by the LINAG will allow producing intense pulsed neutrons sources in the 100 keV-40 MeV energy range. Continuous and quasi-monokinetic energy spectra will be available at NFS respectively produced by the interaction of deuteron beam on thick Be converter and by ^{7}Li(p,n) reaction on thin converter. The flux at NFS will be up to 2 orders of magnitude higher than those of other existing time-of-flight facilities in the 1 MeV - 40 MeV range. Irradiation stations for neutron, proton and deuteron induced reactions up to 40 MeV will also allow to perform cross-sections measurements by activation technique. NFS will be a very powerful tool for physics, fundamental research as well as applications like the transmutation of nuclear waste, design of future fission and fusion reactors, nuclear medicine or test and development of new detectors. The facility and its characteristics will be described, and several examples of the first potential experiments will be presented.

LE 2 4:00 PM

Fast Neutron Induced Reactions at the Nelbe Time-Of-Flight Facility

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The compact neutron-time-of-flight facility nELBE at the superconducting electron accelerator ELBE of Helmholtz-Zentrum Dresden-Rossendorf is currently being rebuilt. From the beginning of 2013 a new enlarged experimental hall with a flight path of up to 10 m will be available. As the neutron radiator consists only of a liquid lead circuit no moderated neutron are produced and also the background from capture gamma rays is very small [1]. The useful neutron spectrum extends from some tens of keV to about 10 MeV. As the electron bunch length is only a few ps the energy resolution in the MeV range is dominated by the timing resolution of the detectors. nELBE is intended to deliver cross section data of fast neutron nuclear interactions e.g. for the transmutation of nuclear waste and improvement of neutron physical simulations of innovative nuclear systems. The inelastic scattering of ^{56}Fe was investigated both with a double-time-of-flight experiment i.e. the scattered neutron and the de-excitation photon are measured in coincidence using a BaF_2 scintillator and plastic scintillator arrays. In the same experiment, the gamma production cross section was measured with an HPGe detector and the inelastic neutron scattering cross section to the first few excited states in ^{56}Fe was determined. An experiment to measure the neutron induced fission cross section of ^{242}Pu using fast ionisations chambers with homogeneous actinide deposits is in preparation [2]. The neutron total cross sections of Au and Ta were determined in the energy from 200 keV to 7 MeV using a plastic scintillator in a transmission experiment. This work is supported by the EURATOM FP7 project ERINDA and by the German Federal Ministry of Education and Research (03NUK13A). * also at Technische Universität Dresden, Institut für Kern- und Teilchenphysik, Dresden, Germany.

[1] R. Beyer et al., Journal of Instrumentation 7 C02020 (2012) [2] T. Kögler et al., contribution to this conference

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LE 3 4:20 PM

Impact of the Energy Dependent DDXS on Determination of Resonance Parameters

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This paper is sequential to former studies dealing with the impact of the resonant Double Differential Cross Section-DDXS on core parameters and in particular on the line shape of resonance fitting with which resonance parameters are being tested (or modified). The introduction of the Doppler Broadening Rejection Correction - DBRC into Monte Carlo codes enabled a better insight of simulation of the multiple scattering effect in Time of Flight - ToF measurements. Previous studies have shown that experimental line shapes could be better fitted by introduction of a better DDXS model. Nevertheless, it was shown in some cases that the quality of the models could be simplified as far as the complexity of the full DDXS is concerned. Strictly speaking, on can get a better fitting by introduction only the correct temperature without the energy dependency in the vicinity of the resonance or sometimes a higher multiple scattering order (Y^n, n=1..20), yet with the corrected asymptotic model (0 K) could suffice. This study extends the above and is based on dedicated measurements to investigate in more detail the quality of the physical model of the DDXS (temperature or/and resonance or/and solid state effect) and in return to analyse if and how could the resonance parameters themselves be updated to get a better quality of specific resonant nuclear data. In contrary to further measurements we focus in this work mainly on the resonance wings via a combined self indication measurement and a DBRC based MC simulation. Examples based on measurements of ^{197}Au and ^{238}U will be given.

LE 4 4:40 PM

The LENOS Project at Laboratori Nazionali di Legnaro of INFN-LNL

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LENOS (Legnaro NeutrOn Source) project at the Laboratori Nazionali di Legnaro of INFN (Italy) is a neutron irradiation facility for nuclear astrophysics studies and validation of evaluated nuclear data libraries. It is based on a high current low energy RFQ. The facility under construction will use the 5 MeV, 50 mA proton beam of RFQ under test at LNL to produce an unprecedented neutron flux, precisely shaped to a Maxwell- Boltzmann energy distribution at variable temperature kT. A new method has been proposed to obtain the desired neutron spectra at different stellar energies and a dedicated target, able to

sustain a very high specific power, has been developed. We will present the facility, the method used to shape the neutron beam, the preliminary results of the high power test of the micro-channel water cooled target and the preliminary results of the validation measurement. Waiting for LENOS facility, currently we are carrying out measurements at existing low power electrostatic accelerators, using other degrees of freedom available in order to shape accurately the proton beam to a desired distribution. An overview of recent measurements together with the capability of using additional degrees of freedom to achieve more accurate Maxwellian distributions at temperatures higher than 50 keV will be presented.

LE 5 5:00 PM

A New Signal Processing Technique for Neutron Capture Cross Section Measurement Based on Pulse Width Analysis

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We have been developing an NaI(Tl) spectrometer for neutron capture cross section measurement at the Materials and Life Science Experimental Facility (MLF) of the Japan Proton Accelerator Research Complex (J-PARC). The NaI(Tl) spectrometer was installed at the beam line of the Accurate Neutron Nucleus Reaction Measurement Instrument (ANNRI) in the MLF. The purpose of the NaI(Tl) spectrometer is (1) to provide reliable nuclear data by combining with measurement using a Ge spectrometer installed upstream of the ANNRI beam line and (2) to extend the achievable high energy limit of measurement beyond the Ge spectrometer measurement, using faster signal response of an NaI(Tl) detector than a Ge detector. To achieve the second goal, electronics and data acquisition system with a small dead time are required. Thus, we developed a new fast signal processing technique for neutron capture cross section measurement based on pulse width analysis. In the technique, pulse width of anode negative signals from photomultiplier tubes of the NaI(Tl) spectrometer were determined from time under a threshold level measured with a fast time digitizer (FAST ComTech MCS6). Then, the pulse width of each signal was converted to the pulse height from width-height calibration measurement using standard gamma-ray sources, and discrete gamma-rays from the neutron capture reactions, ^{28}Si(n,γ)^{29}Si and ^{14}N(n,γ)^{15}N. To test this pulse width method, we carried out cross section measurement of the ^{197}Au(n,γ)^{198}Au and ^{99}Tc(n,γ)^{100}Tc reactions. The pulse-height weighting technique was applied to derive the neutron capture cross sections. In this presentation, we present the whole scheme of the signal processing and data analysis, and compare the obtained cross sections with the evaluated nuclear data.

LE 6 5:15 PM

Neutron Flux Characterization of the Cold Beam PGAA-NIPS Facility at the Budapest Research Reactor

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A reliable flux characterization is essential for facilities using neutron beams. The NIPS station at the Budapest Research Reactor (BRR) has recently been equipped with neutron-tomographic equipment. In addition to this, the beam could be characterized using a large surface wire chamber (on loan) applying time-of-flight method. The energy distribution was measured at 3 horizontal positions with this latter in pinhole geometry, while the spatial inhomogeneity was measured with our new neutron-tomographic equipment. The PGAA-NIPS facility at the BRR is heavily involved in the determination of nuclear data for reactor and other applications [1]. The cold neutron beam makes it possible to avoid problems arising from non 1/v behavior of nuclei. Moreover, the parallel use of neutron imaging and prompt gamma-ray measurements of the same object gives a unique possibility for target characterization. The influence of the energy and spatial distributions of the beam on the measurements of partial gamma-ray production cross sections as well as on the total neutron capture cross sections will be discussed. The experimental stations are open for the user community. For European users, in the nuclear data field, support can be obtained from the EU FP7 ERINDA project (http://www.erinda.org/). Other users can make proposals on bilateral agreement bases. * This work is supported by the NAP VENEUS OMFB 00184/2006 and the NORMA_10 OMFB-00494/2010 projects.

[1] EFNUDAT - Slow and Resonance Neutrons. The 2nd EFNUDAT Workshop on Neutron Measurements, Theory and Applications, 23-25 September 2009, ed. T. Belgya, 1-174. Budapest, Hungary: Institute of Isotope, Hungarian Academy of Sciences (2010).

LE 7 5:30 PM

New Method for Measurement of Neutron Detector Efficiency up to 20 MeV

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The efficiency of a neutron detector is an extremely important characteristic for successful experiments in nuclear and neutron physics. This characteristic of the detector depends not only on scintillator properties but includes strong influence on the detector environment and should be investigated experimentally as well as by model calculations. For many fundamental measurements (like the angular distribution of (n,p) scattering with an accuracy 1%) and applied tasks (such as measurements of standard neutron fields with energies up to 20 MeV with accuracy 1-2%), the request for accuracy is very high. The realization of this request is not a simple task. In this report we suggest a new method for the measurement of the neutron detector efficiency. It is based on the obvious fact that the neutron yield from a symmetric reaction (one in which the projectile and the target are identical) is the same for a forward angle θ, and the supplementary back angle 180-θ, in the Center of Mass System, however the neutron energies at the corresponding angles in the Laboratory System are different. Thus, the relative efficiency at two energies can be measured directly. By changing the beam-energy, and analyzing reaction with excitation of the separate levels a large set of efficiency ratios can be obtained. The ^{6}Li(^{6}Li,n) is a very attractive candidate to cover the energy range 1-20 MeV with input Li ion energy of 4-12 MeV. Starting from excitation of high energy levels (neutron energy 2-8 MeV) we may move up to 20 MeV neutrons. The low energy range of the efficiency may be estimated relative to the ^{252}Cf spontaneous fission neutron standard. In the report, we discuss the

method itself, and its application for the ^{6}Li(^{6}Li,n), ^{12}C(^{12}C,n), and D(d,n) reactions, and demonstrate the results for a NE213 detector. This work is in support of the NIFFTE Fission TPC measurements.
Corresponding author: Thomas N. Massey

LE 8 5:45 PM

Development of an Array of Liquid Scintillators to Measure the Prompt Fission Neutron Spectrum at LANSCE

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Higher quality measurements of outgoing prompt neutron spectra from neutron-induced fission as a function of the incoming neutron energy are needed. These data can be used in designing new fast reactors, predicting criticality for safety analyzes, and developing techniques for global security applications. As part of the program to measure the prompt fission neutron spectra (PFNS) from the fission of ^{239}Pu at the Los Alamos Neutron Science Center, we are developing a new array of liquid-scintillator detectors. This array will be used to measure the PFNS over a range of outgoing neutron energies from approximately 600 keV to 12 MeV and incident neutron energies from 0.5 to 30 MeV. The array consists of 54 liquid scintillators mounted on two separate stands. Each stand consists of 3 arcs, with a single arc holding 9 detectors. The 9 detectors are spaced apart by 15° in the polar angle starting at $\theta = 30°$ and ending at $\theta = 150°$. The 3 arcs on each stand are placed 33° apart; this spacing can be widened to 45° if desired. The 17.8 cm diameter faces of the detectors are located 1 m from the sample center, giving a 10.7 % coverage of 4π for the entire array. The liquid-scintillator cells contain EJ309 liquid and are coupled to Hamamatsu photomultiplier tubes. A complete characterization of the detectors and the array as a whole will be carried out, targeted at understanding the light-output curves, efficiencies, and the neutron multiple-scattering backgrounds. This work benefits from the LANSCE accelerator facility and is supported by the U.S. Department of Energy under contracts DE-AC52-06NA25396 (LANL) and DE-AC52-07NA27344 (LLNL).

Session MA Plenary Thursday
Thursday March 7, 2013
Room: Met East at 8:30 AM
Chair: Mark Chadwick, LANL
MA 1 8:30 AM

Connecting the dots, or nuclear data in the age of supercomputing

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The recent availability of massive amount of computing power have enabled several advances in the field of nuclear data evaluations. Separately, each of these advances are already significant, but together they have the potential to completely change our perspective on the process of nuclear data evaluation. The first advance rests on the use of modern nuclear model codes like TALYS [1] and the Monte-Carlo sampling of the model parameter space. Along with a code system developed in Petten, which automates the production of ENDF-6 formatted files, their processing and their use in reactor calculations, this constitutes the so called Total Monte-Carlo approach [2], which directly links physical model parameters with calculated integral quantities like Keff. Together with the Backward-Forward Monte-Carlo [3] method for weighting samples according to their statistical likelihood, the Total Monte-Carlo method can be applied to complete isotopic lines in a consistent way to simultaneously evaluate nuclear data and the associated uncertainties. The second advance lies in the use microscopic models for nuclear reaction calculations. For example, making use of QRPA excited states calculated with the Gogny D1S interaction in combination with a microscopic pre-equilibrium model allows to solve the long standing problem of the origin of the ad-hoc pseudo-states that had to be introduced in evaluated data files to account for the Livermore pulsed sphere experiments. The third advance lies in the recent optimization of the Gogny D1M [4] effective nuclear interaction that includes constraints form nuclear masses and corrections at the beyond the mean field level. All these advances are only made possible by the availability of vast amount of computing power, and even higher computing resources will allow to connect them, going continuously from the parameters of the nuclear interaction to reactor calculations. However, such scheme will probably only be usable for applications if a few tuning knobs are introduced in it. These few knobs will have to be calibrated versus differential and integral experiments.

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MA 2 9:15 AM

Exploring new neutron-rich nuclei with the Facility for Rare Isotope Beams

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About 100 years after Rutherford discovered the atomic nucleus the limits of what combinations of protons and neutrons can make up a nucleus are still only known for the lightest elements. Exploring the nuclear landscape and pushing towards the limits of nuclear existence is important for the understanding of the strong force and the element formation in the universe. The discovery of new isotopes is the first step in the study of the properties of the most exotic nuclei. Estimates indicate that the Facility for Rare Isotope Beams, FRIB, could produce 1000 new isotopes and allow the detailed study of nearly 4500 isotopes. An overview of the discovery of nuclides and the projected capabilities of FRIB will be presented.

Session NA Neutron Cross Section Measurements
Thursday March 7, 2013
Room: Met East at 10:30 AM
Chair: Allan Carlson, NIST
NA 1 10:30 AM

Capture Cross-section Measurement of ^{241}Am at J-PARC/MLF/ANNRI

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Accurate determination of the neutron capture cross sections of radioactive nuclei is required in the fields of nuclear waste transmutation study and also nuclear astrophysics. The accurate neutron-nucleus reaction measurement instrument (ANNRI), which was installed in the materials and life science experimental facility (MLF) at the J-PARC, is expected to satisfy these demands. The capture cross section of ^{241}Am was measured using a high efficiency Ge spectrometer installed in the ANNRI. By taking advantage of its high gamma-ray energy resolution, background components were precisely subtracted. The capture cross section of ^{241}Am was deduced for a neutron energy region between 0.01 and 20 eV. The obtained cross section and the Westcott factor are compared with the preceding experiments and evaluated values. This work was supported by JSPS KAKENHI Grant Number 22226016.

NA 2 11:00 AM

Neutron-Induced Cross Sections Measurements Of Calcium

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Among its many applications, calcium is a constituent of concrete and is very frequently found in combination with uranium and/or mixed with radioactive waste. The US Department of Energy Nuclear Criticality Safety Program (NCSP) has identified calcium as a nuclide needing improvement for supporting criticality safety analyses. In particular, a consistent set of covariance data is needed in the evaluation to support sensitivity/uncertainty analyses. As a result, the NCSP initiated new neutron-induced cross section measurements on calcium to support the development of a new cross-section evaluation in the resonance region.. The objective of this paper is to present the results of the calcium cross-section measurements and data analysis. Two types of experiments were performed at the Geel Electron Linear Accelerator (GELINA) of the Institute for Reference Material and Measurements of the Joint Research Centers, European Union. A metallic calcium target was placed in Flight Path 14 at a distance of 60 m from the neutron production target to measure neutron capture with 4 C_6D_6 detectors. Due to its reactivity with air, the metallic calcium sample was encapsulated in a thin-wall aluminum container. To correct for the effect of the aluminum, an empty container of the exact same dimensions was also measured. The same sample was used in a transmission experiment to determine the total cross section. The sample was placed in Flight Path 4 at a distance of 50 m from the neutron target. A 1.27-cm thick 6Li glass detector was used to detect the sample-transmitted neutron. The empty aluminum container served in the open beam as a compensator for the aluminum in the sample. The final paper will provide the experimental details and compare the measured cross-section data for calcium with cross sections calculated from the latest evaluated data files. ORNL is managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. The U.S. Department of Energy Nuclear Criticality Safety Program sponsored the work that is presented in this paper

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NA 3 11:20 AM

Measurements of keV-Neutron Capture Cross Sections and Capture Gamma-Ray Spectra of Pd Isotopes

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The nuclear transmutation of long-lived fission products (LLFPs) generated in nuclear fission reactors into stable or short-lived nuclides by neutron capture reaction is expected to reduce the impact of nuclear waste disposal on the environment. Palladium-107 (half life: 6.5x10^6y) is one of the most important LLFPs, and its neutron capture cross sections are important for the study of LLFP transmutation systems. On the other hands, the capture cross sections of stable Pd isotopes also affect the performance of a transmutation system without isotope separation. Therefore, their capture cross sections as well as those of ^{107}Pd are important for the R & D of nuclear transmutation systems. Additionally, capture gamma-ray spectra contain much information on important physical quantities such as gamma-ray strength function, and the information is quite useful for theoretical calculation of neutron capture cross sections of Pd isotopes, especially ^{107}Pd. From the viewpoint mentioned above, we started a systematic study on keV-neutron capture cross sections and capture gamma-ray spectra of Pd isotopes (^{104,105,106,108,110}Pd and ^{107}Pd), using a time-of-flight method with a pulsed ^{7}Li(p,n)^{7}Be neutron source and a large anti-Compton NaI(Tl) gamma-ray spectrometer. We have completed the measurements for ^{104,105,106,108,110}Pd in the neutron energy region from 15 to 100 keV and measurements ^{104,105,106}Pd at around 550 keV. This contribution presents the results of those measurements. This work was supported by JSPS KAKENHI Grant Number(22226016).

NA 4 11:40 AM

Isotopic Mo Neutron Total Cross Section Measurements in the Energy Range 1 to 620 keV

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The Gaerttner LINAC Center is home to a 60 MeV electron linear accelerator (LINAC) that is used as a pulsed neutron source for neutron time-of-flight (TOF) measurements. High resolution cross section measurements of isotopically enriched molybdenum samples were performed at the RPI LINAC Center with a newly developed Mid-Energy ^{6}Li-glass Neutron Detector Array (MELINDA) positioned at the 100-meter experimental flight station. The neutron transmission detector system employs four identical cube-shaped modules. Each module consists of a 1.27 cm thick ^{6}Li-glass scintillator, two out-of-beam photomultiplier tubes, and a low-mass, light-tight aluminum casing with inner reflective surfaces. The modular design of the system allows operational reliability, relatively easy maintainability, and lower overall life-cycle costs than a single all-in-one detector system. Fast electronics were employed to take full advantage of the fast ^{6}Li-glass scintillator response time and narrow LINAC neutron burst width (10-15 ns). Transmission measurements were performed by placing a sample in a collimated neutron beam and measuring the number of neutrons passing through the sample with the neutron detector and comparing with the number detected with no sample in the beam. The measurements provide transmission data that cover the energy range between 1 keV - 620 keV performed on highly enriched metallic samples of four stable molybdenum isotopes, ^{95}Mo, ^{96}Mo, ^{98}Mo and ^{100}Mo. New methods were developed to accurately determine important data reduction parameters from these transmission measurements including the detector resolution, dead time, and a precise characterization of the observed background in each measured sample. A unique method to measure the different background components (neutron and γ-ray) was performed by cycling different materials with saturated resonances into the beam. The dominant time-dependent γ-ray background component, which is mainly a result of thermal neutron capture in the water moderator of the neutron producing target, was determined by placing several thicknesses of polyethylene in the beam and extrapolating the γ-ray background to zero-thickness polyethylene. Saturated notch filters of Na, Al, Mg, S, Li, and Be were used to determine the time-dependent neutron background at specific energies across the energy range of interest. In the resolved resonance region (RRR), new high-accuracy resonance parameters were extracted from fitting experimental data using the multilevel R-matrix Bayesian code SAMMY. In the unresolved resonance region (URR), fits to the total cross sections were obtained using the Bayesian Hauser-Feshbach statistical model code FITACS, which is currently incorporated into the SAMMY code.

Session NB Benchmark and Testing
Thursday March 7, 2013
Room: Met West at 10:30 AM
Chair: Ulrich Fischer, Karlsruhe IT
NB 1 10:30 AM

TENDL-2012 Processing, Verification and Validation Steps

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Recent advances and improvements in the proper interpretation and extension of nuclear data in the ENDF-6 format, and the willingness of the processing communities to interact with all application communities, together with better physics have made the goal of a unified, converged format for a truly general purpose nuclear data library attainable. Earlier attempts to move toward a universal format frame for nuclear data files, JEFF-3.0/A, ENDF/B-VI HE, EAF-2010 and TENDL-2011 have paved the way finally to manage to bridge the gap that currently separates general and special purpose file format frames. The unified format exemplified in TENDL-2012, entirely based on the original ENDF-6 format frame, now makes the spine of a new set of nuclear data libraries and forms that are required to feed modern transport and inventory simulation codes. The data structure, also including covariance, is such that it allows the secular processing codes to be used simultaneously and in parallel to process, but also independently verify, all intermediate and final forms useful to the many applications that need them: transport, shielding, inventory and astrophysics. The comprehensive, complete and diverse resulting processed data forms have already been successfully connected, verified and validated when used in conjunction with the inventory code FISPACT-II and the Monte Carlo transport code TRIPOLI-4.8. Criticality, decay heat and inventory integral measurement benchmarking activities are been assessed in order to verify and validate the concatenation of often complex procedures and processes. The results of these assessments will lead to further enhancements for the next generation of the TENDL library. This work was funded by the RCUK Energy Programme under grant EP/I501045.

NB 2 11:00 AM

Use of a Continuous Integration and Deployment Software to Automate Nuclear Data Verification and Validation

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Data verification and validation are critical to ensuring the quality of a nuclear data library prior to its release. However, these essential but tedious processes have always placed enormous strain on NNDC's limited manpower resources, especially in the final months leading to the scheduled release. Cognizant of this issue, the NNDC has implemented a highly-automated system code-named ADVANCE which is based on the continuous integration and deployment framework that originated from the software industry. ADVANCE uses readily available open-source software components to deliver its powerful functionalities for the benefit of NNDC and the nuclear data community. Since the release of the ENDF/B-VII.1 library, it has been used to automatically run all ENDF checking programs, pre-processing and processing codes, and pertinent MCNP5 benchmark calculations each time a new or revised evaluation is committed to the ENDF repository on NNDC's GForge collaboration server. Processing results will then be posted on NNDC's Web site for the concerned evaluator to review. This talk and paper will present in detail ADVANCE's underlying software components and how they tightly work together to ensure the quality of every new or revised evaluation while providing immediate feedback to the evaluator. Furthermore, current development efforts to enhance the capabilities of ADVANCE will also be discussed.

NB 3 11:20 AM

Benchmarking of ENDF/B-VII and JENDL-4.0 in the Fast Neutron Range

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AWE.Plc

The recent releases of the ENDF/B-VII.1 [1] and JENDL-4 [2] libraries represent a significant upgrade in data for a number of nuclides. As part of its data release process the AWE Nuclear Data team assesses the internationally available data, through rigorous validation and verification. A part of this validation process involves Benchmarking of new data using a suite of ICSBEP [3] Benchmarks. K-effectives are calculated and compared to the published benchmark values. A number of other metrics are compared to determine which data shows the "best fit" to the benchmark results. These metrics include a χ^2 like measure, $\chi^2_{sys} = \Sigma\frac{(k_{calc}-k_{exp})/(\delta k_{exp})^2}{n}$ and a measure of the average difference between calculated and benchmark k- effectives $\langle|\Delta|\rangle = \Sigma\frac{|k_{calc}-k_{exp}|}{n}$ This benchmarking is then used to help make an informed decision as to which data is recommended for use by AWE's user base. This initial work focuses on fast benchmark systems as defined in the ICSBEP Handbook. K-effectives are calculated for a number of fast systems with a wide range of materials. Validation metrics are calculated and compared for both libraries and compared to their predecessors. Calculations are in the main performed using a proprietary 1D Sn neutron transport code and comparisons are made with MCNP [4] calculations. Benchmark calculations will be shown and discussed; discussion will focus on the general fit of each of the calculations to the benchmark results with particluar emphasis placed on bare spheres such as JEZEBEL and GODIVA.
 [1] "ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data", M.B. Chadwick, M.W. Herman, P. Oblozinsky et al., NDS112, 2887 (2011). [2] "JENDL-4.0: A New Library for Nuclear Science and Engineering", K Shibata, O Iwamoto, T Nagakawa et al., J Nucl Sci Technol, 48(1), 1-30, (2011). [3] "International handbook of evaluated criticality saftey benchmark experiments", J.B Briggs et al., Tech Report NEA/NSC/DOC(95)04/I, (2004). [4] "MCNP- A General Monte Carlo N-Particle Transport Code, Version 5", X-5 Monte Carlo Team, LANL Tech Report LA-UR-03-1987, (2003).

NB 4 11:40 AM

Re-analysis of Fusion Relevant Benchmark Experiments Using Recent Nuclear Data Libraries

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With the release of ENDF/B-VII, JENDL-4.0 and JEFF-3.1.2 a set of up-to-date nuclear data libraries has been made available which are also suitable for fusion technology applications. These data libraries complement the Fusion Evaluated Nuclear Data Library (FENDL) which is developed under the auspices of the IAEA/NDS to provide a qualified data library for fusion applications. The version FENDL-2.1, assembled in 2003, currently serves as the reference data library for ITER nuclear design analyses. A major update of this library has been provided with the FENDL-3 project of the IAEA, resulting in the recent starter library FENDL-3/SLIB, release 4. In this work, we re-analyse a wide range of fusion relevant benchmark experiments conducted previously with 14 MeV neutron generators at Frascati, ENEA (FNG), the Technical University Dresden (TUD) and the Fusion Neutron Source (FNS) at Tokai-mura, Japan. Our special focus is on two breeding blankets experiments, which have been performed previously in the frame of the European fusion programme on two mock-ups of the European Helium-Cooled-Lithium to Lead (HCLL) and Helium-Cooled-Pebble-Bed (HCPB) test blanket modules (TBMs) for ITER. Tritium production rates as well as the neutron and photon spectra measured in these mock-ups are compared with calculations using the FENDL-3/SLIB, release 4 and state-of-the-art nuclear data evaluations, JEFF-3.1.2, JENDL-4.0 and ENDF/B-VII. Because nuclear data for lead and beryllium have a large impact on the calculation for these mock-up experiments, several clean benchmark experiments relevant to the experiments are also analysed. The paper describes detailed results of the analyses performed on the benchmark experiments. The comparison includes results obtained previously with the FENDL-2.1 data library and concludes with recommendations on the use of the data libraries for fusion applications.

Session NC Nuclear Data Covariances
Thursday March 7, 2013
Room: Empire East at 10:30 AM
Chair: Sam Hoblit, NNDC - BNL
NC 1 10:30 AM

Estimation of Nuclear Reaction Model Parameter Covariances and the Related Neutron Induced Cross Sections with Physical Constraints

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In neutron induced reactions between 0 eV and 20 MeV, a general problem arises during the evaluation of cross sections. Most of the time, the evaluation work is done independently between the resolved resonance range and the continuum, giving rise to mismatches for the cross sections, larger uncertainties on boundary and no cross correlation between high energy domain and resonance range. This paper will present several methodologies that may be used for avoiding such effects. A first idea based on the use of experiments overlapping two energy domains appeared in a near past. It will be reviewed and extended to the use of systematic uncertainties (normalization for example) and for integral experiments as well. In addition, we propose a methodology taking into account physical constraints on an overlapping energy domain where both nuclear reaction models is used (continuity of both cross sections or derivatives for example). The use of Lagrange multipliers (related to these constraints) in a classical generalized least square procedure will be presented as well the numerical algorithm that may be used to find the minimum of such a cost function. Some academic examples will then be presented for both point-wise and multigroup cross sections.

NC 2 11:00 AM

Uncertainty Propagation with Fast Monte Carlo Techniques

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Since 2008, several methods for nuclear data uncertainty propagation based on Monte Carlo techniques were developed and presented. They are based on a two-step approach: (1) the random sampling of nuclear model parameters to generate n nuclear observables such as cross sections, nubar (or alternatively n perturbations of nuclear observables, based on covariance information), and (2) the use of these random nuclear data in n calculations with a particle transport code ($n \simeq 1000$). With the use of a stochastic simulation code, each individual calculation is usually time-consuming because the statistical uncertainty of the stochastic simulation should be smaller than the nuclear data uncertainty. Repeated n times, the Monte Carlo uncertainty propagation with a Monte Carlo particle transport code becomes a large computer-time consumer. To remedy this problem, two methods of "fast" uncertainty propagation with a Monte Carlo simulation code were developed, first at GRS and later at NRG. They provide a substantial reduction of the number of Monte Carlo histories needed. In favorable cases, the uncertainty of a quantity can be calculated in only twice the amount of computer time that is needed for the quantity itself. In this way, the use of Monte Carlo uncertainty propagation method is possible without a large computer cluster. The new methods will be presented and results will be compared for criticality and burn-up calculations.

NC 3 11:20 AM

Propagation of Nuclear Data Uncertainties for ELECTRA Burn-Up Calculations

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The European Lead-Cooled Training Reactor (ELECTRA) [1] has been proposed as a training reactor for fast systems within the Swedish nuclear program. It is a low-power fast reactor cooled by liquid pure lead and includes many attractive safety features such as negative coolant and fuel temperature coefficients. It is important that these features are retained during the full lifetime of the core. In this work we investigate the uncertainty in the fuel inventory of ELECTRA during the reactor life and how this affects the safety of the reactor. For this we use the Total Monte Carlo approach [2] for burn-up calculations on the ELECTRA design. I.e., a reaction model code system, in our case a TALYS based [3], is used. The nuclear models input parameters are randomized within their uncertainties and a large set of nuclear data libraries are generated. The libraries are used as inputs to reactor codes, in our case SERPENT [4], to perform uncertainty analysis of nuclear reactor inventory during burn-up. The uncertainty in the inventory during the life of the reactor, combined with the uncertainty in the cross-section, is subsequently used to assess the uncertainties in the safety parameters.

[1] Wallenius, J., Suvdantsetseg, E., and Fokau, A., 2012. ELECTRA: European Lead-Cooled Training Reactor. Fission Reactors. Nuclear Technology 177, p. 303-313. [2] Koning, A.J., and Rochman, D., 2008. Towards sustainable nuclear energy: Putting nuclear physics to work. Annals of Nuclear Energy 35, p. 2024-230. [3] Rochman, D., and Koning, A.J., 2011. How to randomly evaluate nuclear data: A new data adjustment method applied to Pu-239. Nuclear Science and Engineering 168(1), p. 68-80 [4] J. Leppanen, 2010. Psg2 / serpent - a Continuous-energy Monte Carlo Reactor Physics Burnup Calculation Code, Technical report, VTT Technical Research Centre of Finland, Finland, http://montecarlo.vtt.fi.

NC 4 11:40 AM

Total Monte-Carlo Method Applied to a Pressurized Water Reactor Fuel Assembly - Quantification of Uncertainties due to ^{235,238}U, ^{239,240,241}Pu and Fission Products Nuclear Data Uncertainties

D.F. da Cruz, D. Rochman and A.J. Koning
Nuclear Research and Consultancy Group NRG

The Total Monte-Carlo (or TMC) method has been applied to a single pressurized water reactor fuel assembly to quantify the uncertainties in reactivity and discharged fuel inventory as a result of uncertainties in nuclear data. Different from the perturbation-theory-based methods applied for decades, TMC relies on the higher computational power available nowadays to propagate uncertainties from nuclear data to reactor physics parameters. TMC involves a large number of calculations for the same model, performed with different nuclear data in each of them. This paper discusses the uncertainty analysis on reactivity and inventory for a Westinghouse 3-loop fuel element as a result of uncertainties in nuclear data of the actinides ^{235,238}U and ^{239,240,241}Pu, and of a set of the 119 most important fission products. A fuel assembly fuelled with UO_2 fuel with 4.8% enrichment has been selected. TMC has been applied using the deterministic transport code DRAGON. This code package includes the necessary tools for the generation of the few-groups nuclear data libraries by applying the data processing code NJOY and using directly data contained in the nuclear data evaluation files. The nuclear data used in this study is from the JEFF3.1 evaluation. The ENDF nuclear data files for the actinides ^{235,238}U and ^{239,240,241}Pu, and for the fission products (randomized for the generation of the various DRAGON libraries) are taken from the nuclear data library TENDL-2012. The total uncertainty (obtained separately for each of the isotopes considered by randomizing all nuclear data in the ENDF files) on the reactor parameters has been split into different components (different nuclear reaction channels). Both the effects of transport data and fission yields have been studied. Results show that the combined uncertainty on reactivity as result of nuclear data uncertainties in all considered isotopes is reasonably constant during fuel burnup and amounts to about 0.7%. At zero burnup only transport data from ^{235}U and ^{238}U deliver an important contribution, whereas at discharge burnup ^{235}U and ^{239}Pu represent the largest effects, followed by ^{238}U. Uncertainties in transport data from all 119 fission products have only a secondary effect on the final uncertainty, although not negligible (they account for 5% relative of the total). The uncertainties on discharged fuel inventory varies typically in the range 1-15%, depending on the particular element, except for some fission products produced only in small concentrations for which the uncertainties can be as high as 35%. For the important actinide isotopes the uncertainties stay below 5%. For most fission products the largest source of uncertainty is attributed to uncertainties in fission yields of the most important fissile isotopes ^{235}U and ^{239}Pu. For the inventory of the most important actinides the uncertainties on the transport data of ^{235,238}U and ^{239}Pu are the major contributors.

Session ND Beta Delayed Neutrons
Thursday March 7, 2013

Room: Empire West at 10:30 AM
Chair: Alejandro Sonzogni, NNDC - BNL
ND 1 10:30 AM

Sensitivity Analysis for Reactor Stable Period Induced by Positive Reactivity Using One-Point Adjoint Kinetic Equation

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In order to better predict a dynamic behavior of a nuclear fission reactor, an improvement of the delayed neutron parameters is essential. The present paper specifies important nuclear data for a reactor kinetics: Fission yield and decay constant data of germanium-86, some bromine isotopes, rubidium-94, yttrium-98m and some iodine isotopes. Their importances are also quantified as sensitivities with a help of the adjoint kinetic equation, and it is found that they are significantly dependent on an inserted reactivity (or a reactor stable period). Moreover, dependence of sensitivities on nuclear data files are also quantified using the latest files. Even among the currently evaluatad data files, there are large differences from a view point of the delayed neutrons.

ND 2 11:00 AM

First Compilation and Evaluation of Beta-Delayed Neutron Emission Probabilities and Associated Half-lives in the Non-Fission Region (A $\leq$ 72)

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Results of the first complete compilation and evaluation of delayed-neutron emission (including multiple neutron emission) probabilities and associated half-lives will be presented for all the known beta-delayed neutron emitters (those for which the Q(β-n) value is positive) in the non-fission region, A $\leq$ 72. A total of 101 one-neutron emission probabilities as well as 173 half-lives have been evaluated, with far fewer evaluated multiple neutron emission probabilities due to a lack of measurements. The recommended values will be discussed in terms of systematics and available theoretical calculations for the nuclei in this mass region.

ND 3 11:20 AM

Beta-decay Study of Neutron-Rich Isotopes ^{93}Br and ^{93}Kr

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Half-lives are some of the most fundamental observables for radioactive nuclides. Many nuclear theories aim to reproduce known values and extrapolate (or predict) these properties for nuclides, which are presently beyond experimental reach. Nuclear properties may change significantly in non-trivial way when one is moving away from the valley of stability; therefore, the precise and correct experimental determination of observables is of great importance for most exotic isotopes. The region around Z = 40 and N = 56 subshell closures is rich in many interesting and surprising nuclear structure features e.g. a sudden onset of deformation beyond A = 96. The interpretation of many phenomena relies on comparison of experimental data with theoretical calculation therefore the accurate knowledge of basic observables is crucial. Additionally some of the proposed r-process scenarios include the nuclides of interest of this work The calculations of the r-process abundances requires knowledge of both half-life and beta-delayed neutron branching ratio. We present new studies of ^{93}Br, ^{93}Kr and ^{94}Kr activities. These short-lived neutron rich nuclei were produced in proton-induced fission of ^{238}U at the HRIBF facility at Oak Ridge. Their beta-decays were restudied by means of high resolution on-line mass separator and digital beta-gamma spectroscopy methods. The half-life value of $T_{1/2}$ = 145(10) ms measured for ^{93}Br is significantly different from previously adopted $T_{1/2}$ =102(10) ms, while the ^{94}Kr half-life measured to be 210(20) ms agrees with earlier results. Beta-delayed branching ratio of P_n = 70(10) % derived for ^{93}Br precursor agrees with a previously published value of P_n = 68(7) % which was however adopted without an experimental evidence for the result. The beta-gamma decay properties of ^{93}Br differ from the previously reported decay scheme and now include additional gamma transitions of 588 keV and 769 keV following beta-delayed neutron emission. The latest measurement of ^{93}Kr half-life found in literature dates back to 1976, the recommended value is $T_{1/2}$ =1.289(12) s, in slight discrepancy with our result $T_{1/2}$ =1.20(5) s. A careful analysis of literature points to the possible deficiencies affecting the recommended half-life result. Research performed as a Eugene P. Wigner Fellow and staff member at the Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract DE-AC05-00OR22725.

ND 4 11:40 AM

New Beta-Delayed Neutron Measurements in the Light-Mass Fission Group

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The phenomenon of beta-delayed neutron emission is of fundamental importance in the operation and control of power reactors. Although quantitatively small, the delayed neutron fraction modulates effectively the changes of reactor power to sudden changes of the reactivity. The total number of delayed neutrons per fission $\overline{\nu}_d$ can be obtained from summation calculations based on fission yields Y and neutron emission probabilities P_n. An improvement of the accuracy of such calculations requires an improvement in the knowledge of both experimental quantities [1]. In particular for Gen IV reactors with a high content on minor actinides the fission product distribution could be quite different from conventional reactors. A sensitivity study was performed at both thermal and fast neutron energies and for major an minor actinides to determine which fission products contributing significantly to $\overline{\nu}_d$ should be revisited experimentally in view of the current uncertainties. Following this study a measurement of P_n values has been carried out at the chemically insensitive IGISOL mass separator installed at the University of Jyväskylä (JYFL) with the BELEN 4π neutron counter [2]. Furthermore aiming at an improved accuracy of the measurements, the

JYFLTRAP Penning trap was coupled to the separator in order to produce isotopically pure radioactive beams of the species under study. In this first measurement the selection of nuclei was further constrained by their interest in astrophysics and nuclear structure studies. During the astrophysical rapid (r) neutron capture process an initial distribution of very neutron rich isotopes is produced in a very short time, which afterwards decay back to stability. This initial abundance distribution is altered by the delayed neutron emission process, which shifts the β-decay flow to lower masses and provides an additional source of neutrons for late captures. The nuclei finally selected are relatively close to the r-process path and above ^{78}Ni, influencing the first r-abundance peak. The measured P_n will provide also information about the fraction of the β-strength distribution S_β lying above the neutron separation energy S_n which can be compared with theoretical calculations. The preliminary results of the analysis of this experiment together with the implications will be presented.

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Session NE Space and Medical Applications
Thursday March 7, 2013
Room: Central Park East at 10:30 AM
Chair: Sylvie Leray, CEA Saclay
NE 1 10:30 AM

The FLUKA Code: Developments and Challenges for High Energy and Medical Applications

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The FLUKA code is used at CERN for all beam-machine interaction and radioprotection calculations, and for the design of future projects. These tasks require reliability and predictive power over a very wide energy and projectile range, spanning from few tens of MeV to TeV's, and from proton and neutron to pion, antinucleon, (anti)hyperon, neutrino and heavy ion interactions. As a consequence sophisticated nuclear models able to deliver reliable predictions over such a vast projectile and energy range must be developed and constantly improved in order to fulfil the tasks. Other applications of the code are becoming more and more popular, from space radiation to hadrotherapy calculations. The latter field is particularly demanding and FLUKA is the core tool used at the HIT and CNAO hadrotherapy facilities in Europe. A review of the most recent developments and achievements of the nuclear models embedded in the FLUKA code will be given, with particular emphasis on physics problematics of interest for CERN and medical applications.

NE 2 11:00 AM

Correlation Between Asian Dust (yellow dust) and Specific Radioactivities of Fission Products Including in Airborne Samples in Tokushima, Shikoku Island, Japan, due to the Fukushima Nuclear Accident

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The serious accident of the Fukushima Daiichi Nuclear Power Plants (FNPP), was caused by the great tsunami following the East Japan Earthquake on March 11, 2011. According to several numerical estimates based on observed radiation dose data at survey points around FNPP, Japan Atomic Energy Agency reported that total activities of released airborne radioactive cesium isotope (Cs-137) would amount to about 15 PBq, and also that total activities of strontium (Sr-90) would be three decades smaller than that of Cs-137 [1]. The airborne radioactive isotopes from FNPP were measured by analyzing aerosols at Tokushima, Shikoku Island in western Japan about 700 km away from Fukushima. So far, our research group has carried out continuous monitoring of airborne radionuclides at Tokushima to measure the environmental radioactivities associated with naturally occurring nuclides (Pb-214, Bi-214, Pb-212, and so on.) which depend on the annual variation of weather. In the airborne sample collected on 23 March, 2011, the fission product I-131 originated from FNPP was first detected at Tokushima through the continuous monitoring. In addition, other radionuclides of Cs-134 and Cs-137 from FNPP were also observed in the beginning of April, 2011. All those maximums of specific radioactivities of I-131, Cs-134, and Cs-137 were observed to be about 2.5 to 3.5 mBq/m^3 in the airborne sample collected on 6th April. During the present course of the continuous monitoring, we also had first observed both the seasonal Asian Dust (yellow dust) and those radionuclides from FNPP at the same time in the beginning of May. We found that those specific radioactivities of I-131, Cs-134 and Cs-137 fission products decrease drastically only for the period of Asian Dust, however, those levels of naturally occurring nuclides do not vary well. To elucidate the characteristic interaction decreasing those specific radioactivities due to Asian Dust in detail, there is a need to investigate the correlation between radioactivities and trace- and macro-elemental concentrations contained in the collected aerosol materials. It is remarkable that an isotope ratio of radionuclides (*e.g.* Cs-134, 137 and Sr-90) to stable nuclides (*e.g.* Cs-133 and Sr-88) changes before and after Asian Dust. In the present work, we report not only a detection of those radionuclides originated from FNPP, but also a rapid analytical method for determining those elemental concentration and isotope ratios using a quardrupole-based ICPMS system with Dynamic Reaction Cell (ICP-DRC-MS) combined with an automated SPE (Solid Phase Extraction) system. An aerosol material extraction procedure followed by homogenizer equipment with the grinding of a glass sample filter was employed to effectively concentrate elements of interest into the matrix using NOBIAS chelate and UTEVA resins with complex sequential processes programed on the automated SPE system.

[1] Japan Atomic Energy Agency, "Estimation of total released activities by Fukushima Nuclear Accident and the reconstruction on the simulated distribution process",
http://nsed.jaea.go.jp/ers/environment/envs/FukushimaWS/index.htm. (2011).

NE 3 11:20 AM

^{33}S(n,α) Cross Section Measurement at n_TOF: Implications in Neutron Capture Therapy

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The $^{33}S(n,\alpha)$ cross section is of interest in medical physics since it has been proposed as a possible/alternative cooperating target to boron neutron capture therapy due to the remarkable feature of the $^{33}S(n,\alpha)$ reaction channel at epithermal neutron energies: alpha particle energy above 3 MeV in absence of gamma emission. The scarce experimental data which are available at present show that, in principle, the lowest-lying and strongest resonance occurs at neutron energy of 13.5 keV. Epithermal neutron beams of around 10 keV are considered the optimal ones for neutron capture therapy. According to the available data, the resonance peak at that energy is larger than the hydrogen elastic scattering cross section, the dominant mechanism of epithermal neutron interactions in tissue. Nevertheless, the set of resonance parameters which determine the ^{33}S(n,alpha) cross section at these energies present important discrepancies (more than a factor two) between different measurements and they are not described by the most popular evaluated data bases such as ENDF or JENDL. The present work aims to contribute in this aspect which is evinced by Monte Carlo simulations that, even based on the most conservative values of the lowest resonances, have shown a noticeable local increase of the dose at the isotope site with a neutron beam of 13.5 keV [1,2]. Preliminary tests of the measurement of the $^{33}S(n,\alpha)$ reaction were successfully performed at n_TOF-CERN during 2011. In particular, the first low-lying resonance was measured (with low statistics) using a micromegas-type detector and with the $^{10}B(n,\alpha)$ cross section as a standard. The results of this test will be shown. The kerma-fluence factors corresponding to ^{10}B, ^{33}S and those of a standard four-component ICRU tissue have been calculated for using them is Monte Carlo simulations of the dose deposited on tissue. The comparison between different evaluated data and experimental data will be shown. Following its approval by the ISOLDE and Neutron Time-Of-Flight (INTC) committee at CERN, the measurement of $^{33}S(n,\alpha)$ reaction cross section will be performed at n_TOF-CERN in October-November 2012 [3]. The results of a preliminary data analysis will be shown, too.

[1] I. Porras, Enhancement of neutron radiation dose by the addition of sulphur-33 atoms. Phys. Med. Biol. **53** (2008) L1-L9. [2] I. Porras, Sulfur-33 nanoparticles: A Monte Carlo study of their potential as neutron capturers for enhancing boron neutron capture therapy of cancer. Applied Radiation and Isotopes **69** 2011)1838-1841. [3] J. Praena et al, Micromegas detector for 33S(n,alpha) cross section measurement at n_TOF, CERN-INTC-2012-006 / INTC-P-322 (04/01/2012).

NE 4 11:40 AM

Production of High Specific Activity ^{186}Re for Cancer Therapy Using $^{nat,186}WO_3$ Targets in a Proton Beam

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Rhenium-186 is a β-γ emitter with a half-life of 90.64 h and a β end-point energy of 1.07 MeV. The isotope is suitable to treat cancers with small dimensions (mm range). Moreover, its γ-emission at 137.15 keV is in the energy range suitable for both γ-camera and SPET imaging. Current production methods rely on the neutron capture induced reaction $^{185}Re(n,\gamma)$ in a reactor and are associated with low specific activities (0.6 kCi/mmol), thereby limiting the application of the isotope to palliative treatments. Production via charged particle irradiation of enriched ^{186}W results in a ^{186}Re product with a much higher specific activity; allowing its use in therapeutic nuclear medicine. Initially, a test target of pressed, sintered $^{nat}WO_3$ (25.2 g; 2.54 mm thick) was proton irradiated at the Los Alamos Isotope Production Facility (LANL-IPF) to evaluate radionuclide product yields, impurities, irradiation parameters and wet chemical Re recovery for a bulk production. We demonstrated that ^{186}Re can be isolated in 97% yield from irradiated $^{nat}WO_3$ targets within 12 h of end of bombardment (EOB) via an alkaline dissolution followed by anion exchange. Tungsten (VI) oxide can be easily recycled for recurrent irradiations. A ^{186}Re batch yield of 42.7 $\pm$ 2.2 μCi/μAh (439 $\pm$ 23 MBq/C) (with respect to ^{186}W content) was obtained after 24 h in an 18.5 μA proton beam. The target entrance energy was determined to be 15.6 MeV, and the specific activity of ^{186}Re at EOB was measured to be 1.9 kCi (70.3 TBq)/mmol. Based upon our studies of $^{nat}WO_3$, a target of enriched $^{186}WO_3$ is used in a second experiment; a proton beam of 250 μA for 24h provides a batch volume of roughly 250 mCi (9.25 GBq) of ^{186}Re at EOB with a specific activity approaching the theoretical value of 35kCi/mmol (1295 TBq/mmol) and a superior radionuclidic purity.

Session NF Nuclear Power Applications
Thursday March 7, 2013
Room: Central Park West at 10:30 AM
Chair: Winfried Zwermann, GRS
NF 1 10:30 AM

Reactivity Impact of ^{2}H and ^{16}O Elastic Scattering Nuclear Data for Critical Systems with Heavy Water

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The accuracy of deuterium nuclear data at thermal and epithermal neutron energies is important for reactor physics simulations of heavy water (D_2O) reactors. The main subjects having noticeable reactivity impact for critical systems involving D_2O are the value of the elastic scattering cross section at thermal neutron energies, $\sigma_{s,th}$, the degree of backscattering in ^{2}H(n,n)^{2}H elastic scattering at neutron incident energies $E < 3.2$ MeV, which is characterized by the average scattering cosine, $\bar{\mu}$, in the centre-of-mass reference frame, and the adequacy of their numerical representation in evaluated nuclear data libraries. We discuss how the uncertainty in the thermal scattering cross section of ^{2}H(n,n)^{2}H propagates to the uncertainty of the calculated neutron multiplication factor, k_{eff}, in thermal critical assemblies with heavy water neutron moderator/reflector, such as the ZED-2 reactor in the Chalk River Laboratories. The method of trial evaluated nuclear data files (Replica Method), in which specific cross sections are individually perturbed, is used to calculate the sensitivity coefficients of k_{eff} to microscopic nuclear data, such as $\sigma_{s,th}$ and $\bar{\mu}$. The thermal elastic scattering cross section data for ^{16}O(n,n)^{16}O used in various modern nuclear data libraries are found to be too high compared with the best available experimental measurements. The reactivity impact of revising the ^{16}O scattering data downward to be more consistent with the best measurements was also tested using the Replica Method. We discuss how the uncertainty in the thermal scattering cross section of ^{16}O(n,n)^{16}O propagates to the uncertainty of the calculated k_{eff} in thermal critical assemblies. For example, large reactivity differences of up to about 5−10 mk (500−1000 pcm) were observed using

^{16}O data files with different elastic scattering data (MF=3 MT=2 data block of corresponding ENDF-format files) in MCNP5 simulations of the Los Alamos National Laboratory HEU heavy water solution thermal critical experiments included in the ICSBEP handbook. Finally, we discuss the low-epithermal asymptotic behavior of $\sigma_{tot}(D_2O)$ vs. E, in which σ_{tot} is built from the evaluated nuclear data files of ^2H and ^{16}O and compare it with the available experimental data and nuclear theory estimates for neutron scattering on heavy water. The calculations of neutron-deuteron scattering cross sections are based on solving the quantum three-body problem, using the Bonn-B NN potential and the three-nucleon Canton-Schadow force. A multi-channel algebraic scattering (MCAS) methodology is applied to obtain a better understanding of low-energy neutron scattering from ^{16}O (and ^{18}O).

NF 2 11:00 AM

Nuclear Data Library Effects on High-Energy to Thermal Flux Shapes around PWR Control Rod Tips

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The development of a high-fidelity computational scheme to estimate the accumulated fluence at the tips of PWR control rods (CR) has been initiated at the Paul Scherrer Institut (PSI). Both the fluence from high-energy (E>1 MeV) neutrons as well as for the thermal range (E<0.625 eV) are required as these affect the CR integrity through stresses/strains induced by coupled clad embrittlement / absorber swelling phenomena. The concept of the PSI scheme under development is to provide from validated core analysis models, the volumetric neutron source to a full core MCNPX model that is then used to compute the neutron fluxes. A particular aspect that needs scrutiny is the ability of the MCNPX-based calculation methodology to accurately predict the flux shapes along the control rod surfaces, especially for fully withdrawn CRs. In that case, the tip is located a short distance above the core/reflector interface and since this situation corresponds to a large part of reactor operation, the accumulated fluence will highly depend on the achieved calculation accuracy and precision in this non-fueled zone. There, the coupling of the flux shapes between different energy ranges will strongly depend on scattering and absorption effects in the coolant and structural materials combined with axial/radial neutron leakage and/or streaming effects. The objective of the work presented in this paper is to quantify the influence of nuclear data on these effects and on the predicted flux shapes at the CR tips situated at both fully withdrawn and partially inserted positions, by (1) conducting a systematic comparison of modern neutron cross-section libraries, including JENDL-4.0, JEF-3.1.1 and ENF/B-VII.1, and (2) by quantifying the uncertainties in the neutron flux calculations with the help of available neutron cross-section variances/covariances data. For completeness, the magnitude of these nuclear data-based uncertainties will also be assessed in relation to the influence from other sources of modeling uncertainties/biases such as assumed local thermal-hydraulic conditions along the core exit and reflector zones, and neutron source approximations involved in the MCNPX modeling. On that basis, the role of nuclear data and the overall level of computational uncertainties that these can produce with regard to tip fluence predictions will be quantified for all relevant neutron energy ranges.

NF 3 11:20 AM

Prompt Time Constants of a Reflected Reactor

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Time eigenvalue of transportation equation, alpha, is defined to describe all neutrons' time behavior (increasing or decreasing) in a nuclear reactor. Its number reflects the criticality also. The time constant, especially prompt time constant, had been studied for 60 years. However, the standard point kinetic model cannot explain well the experimental data of some reflected reactors, especially the reactor with the hydrogen reflector. In the region of analytical method, many works contains too much mathematics, which are not easy to calculate and compare with experimental data. G. D. Spriggs' one-group, two-region kinetic model based on Avery-Cohn model is simple, calculable. The model introduces simple probability relationships essential to calculating the coupling parameters between core and reflector [1] and derives the reflected-core inhour equation which contains multiple decay modes. However, Spriggs model cannot describe well the multiple time constants of the thermal reflected reactor. In this kind of reactor, thermal neutrons with long lifetime contribute much to the time constant. Because of importance of thermal neutrons in such fast-thermal reactor, we present a simplified two-group; two-region kinetic model (2G2R) based on Spriggs model, and rewrites the reflected-core inhour equation. With the help of the numerical method, we perform the analytical calculation on the coupling parameters, neutron lifetimes and first and secondary time constant of a hypothetical reactor, and compared with the numerical methods, the Monte-Carlo method and the stochastic neutron kinetics. The results of 2G2R model agree well with the Monte-Carlo time fitting method which can be thought as an experiment in computer.
[1]. G. D. Spriggs et al., "Two-Region Kinetic Model for Reflected Reactor", Ann. Nucl. Energy, 24, 205, (1997).

NF 4 11:40 AM

ATR HEU and LEU Core Kinetics Parameters Calculation by MCNP5 Version 1.60 Adjoint-Weighted Method

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The Advanced Test Reactor (ATR), currently operating in the United States, is a high power research reactor used for nuclear material testing at very high neutron fluxes. Powered with highly enriched uranium (HEU), the ATR has a maximum thermal power rating of 250 MWth. Because of the large core fuel loading with $^{235}U \sim 43$ kg, the ATR is assessing the feasibility of converting HEU driven reactor cores to low-enriched uranium (LEU) cores. The present work investigates the impact on the safety related kinetic parameters of the LEU alternate Monolithic foil-type (U-10Mo) fuel with external ^{10}Be absorber (0.58 g) in fuel element side-plates, as compared to the HEU reference case. The calculated safety related kinetic parameters, such as the effective neutron generation time, Λ_{eff}, and the effective delayed neutron fraction, β_{eff}, are of considerable importance in the fast transient safety analysis of the ATR. These parameters are typically calculated using deterministic codes. For complex nuclear systems, such as the ATR with its HEU/LEU fuel elements, water coolant, and beryllium (Be) reflector, the Monte Carlo method, specifically MCNP5 version 1.60, is the preferred calculation tool because of its ability to handle continuous energy cross-sections and detailed geometries. MCNP5 version 1.60 has a newly added option (KOPTS KINETICS=YES) to calculate the effective (i.e. adjoint-weighted) neutron generation time (Λ_{eff}), and delayed neutron fraction (β_{eff}), which can be executed to accurately calculate the ATR HEU and LEU core's kinetics parameters. In this work, the neutron generation time and delayed neutron fraction for ATR HEU/LEU core will be directly calculated using a single code, without having to generate energy-dependent cross-sections or approximate geometries.

1. Monte Carlo Codes (XCP-3), X Computational Physics Division, Los Alamos National Laboratory "MCNP5 - 1.60 - A General Monte Carlo N-Particle Transport Code", Version 5/1.60, Forrest Brown, Brian Kiedrowski, Jeffrey Bull , "MCNP5-1.60 Release Notes," LA-10-06235. 2. B. C. Kiedrowski, F. B. Brown, P.H. Wilson, "Adjoint-Weighted Tallies for k-Eigenvalue Calculations with Continuous-Energy Monte Carlo," LA-UR-10-01824, 2010. 3. "Upgraded Final Safety Analysis Report for the Advanced Test Reactor," Idaho National Laboratory, SAR-153, 2011.

Session OA Nuclear Fission
Thursday March 7, 2013
Room: Met East at 1:30 PM
Chair: Stephan Pomp, Uppsala University
OA 1 1:30 PM

Monte Carlo Hauser-Feshbach Calculations of Prompt Fission Neutrons and Gamma Rays

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Primary fission fragments are perhaps the best example of the formation of compound nuclei, and the statistical description of their decay within the Hauser-Feshbach (HF) formalism is expected to work quite well. In the energy regime typical of low-energy fission reactions, the fragments are formed with 15-20 MeV excitation energy on average, and mostly neutron and gamma-ray evaporations will be contributing to their de-excitation. The study of these prompt neutrons and gamma rays is very useful from a fundamental point of view to better understand the mechanisms at play near the point of scission, as well as for practical applications and signatures of the fission process. We have developed a Monte Carlo Hauser-Feshbach (MCHF) code, named CGMF, to study the de-excitation of the fission fragments. The Monte Carlo method provides information on distributions and correlations of the emitted particles, which would be very cumbersome to extract from standard deterministic approaches. While average quantities such as the average prompt fission neutron multiplicity and spectrum can be calculated with simpler models, it's only by studying distributions and correlations that one can achieve a better physical understanding and provide new tools for nuclear technologies. We have performed MCHF calculations of the neutron-induced reactions on ^{235}U, ^{239}Pu and spontaneous fission of ^{252}Cf. We present numerical results for those three cases and discuss the choice of model input parameters. In particular, the initial excitation energy and spin distributions of the initial fission fragments are discussed in view of results on the mass-dependent average neutron multiplicity and gamma-ray emission. The role of collective vs. intrinsic excitation energies and their distribution between the two fragments is discussed at length. Our conclusion emphasizes the important role that accurate experimental data could play in differentiating among several theoretical models of fission.

OA 2 2:00 PM

Event-by-Event Fission Modeling of Prompt Neutrons and Photons from Neutron-Induced and Spontaneous Fission with FREYA

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The event-by-event fission Monte Carlo code `FREYA` (Fission Reaction Event Yield Algorithm) generates large samples of complete fission events [1-3]. Using `FREYA`, it is possible to obtain the fission products as well as the prompt neutrons and photons emitted during the fission process, all with complete kinematic information. We can therefore extract any desired correlation observables. Concentrating on ^{239}Pu(n,f), ^{240}Pu(sf) and ^{252}Cf(sf), we compare our `FREYA` results with available data on prompt neutron and photon emission and present predictions for novel fission observables that could be measured with modern detectors. We also describe how `FREYA` is being made available to the user community. The work of R.V. was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. The work of J.R. was performed under the auspices of the U.S. Department of Energy by Lawrence Berkeley National Laboratory under Contract DE-AC02-05CH11231.
[1] J. Randrup and R. Vogt, Phys. Rev. C **80**, 024601 (2009). [2] R. Vogt and J. Randrup, Phys. Rev. C **84**, 044621 (2011). [3] R. Vogt and J. Randrup, in preparation.

OA 3 2:20 PM

Investigation of n+^{238}U Fission Observables

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The Monte Carlo simulation of the fission fragment deexcitation using FIFRELIN code [1] is used to study fission observables from fast fission of ^{238}U using multi-modal parameters from Birgersson et al. [2] but also mass yields and kinetic energy data as a function of pre-neutron fragment mass. This release of the code is able to simulate prompt neutrons and gammas from two different calculation schemes (i) an uncoupled scheme (in the sense neutron/gamma) using Weisskopf statistical theory and (ii) a coupled scheme based on Hauser-Feschbach statistical theory recently implemented [3]. A quick review of the models and hypothesis used in the code FIFRELIN is presented, and fission observables such as prompt spectra and multiplicities of the reaction ^{238}U(n,f) for several incident neutron energies are calculated using different model parameters and discussed.
[1] O. Litaize, O. Serot, Physical Review C82, 054616 (2010). [2] E. Birgersson, A. Oberstedt, S. Oberstedt, F.-J. Hambsch, Nuclear Physics A817, 1-34 (2009). [3] D. Regnier, O. Litaize, O. Serot, Physics Procedia 31, 59 (2012).

OA 4 2:40 PM

Study for Heavy-Ion Induced Fission for the Heavy Element Synthesis

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Fission fragment mass and kinetic energy distributions were measured in the reactions of ^{30}Si, ^{31}P, ^{34,36}S, ^{40}Ar, ^{40,48}Ca + ^{238}U at energies around the Coulomb barrier [1-3]. The mass distributions changed drastically with incident energy. The results are explained by a change of the ratio between fusion and quasifission with nuclear orientation. A calculation based on a fluctuation dissipation model reproduced the mass distributions and their energy dependence [4]. Fusion probability was defined as the ratio of fusion-fission events to total fission events and was obtained in the calculation to determine the cross sections to produce superheavy nuclei (SHN). The calculated cross sections agreed with the experimental data for ^{263,264}Sg [2] and ^{267,268}Hs [3] produced in the reactions of ^{30}Si+^{238}U and ^{34}S+^{238}U, respectively. It is shown that the reaction at sub-barrier energies can be used for heavy element synthesis. The calculation for ^{48}Ca+^{238}U also demonstrated that the SHN can be produced at lower incident energies than those used to produce the copernicium isotopes in [5,6], suggested that more neutron rich SHN can be produced with smaller number of neutron evaporation.

[1] K. Nishio *et al.*, Phys. Rev. C, **77**, 064607 (2008). [2] K. Nishio *et al.*, Phys. Rev. C,**82**, 044604 (2010). [3] K. Nishio *et al.*, Phys. Rev. C, **82**, 024611 (2010). [4] Y. Aritomo *et al.*, Phys. Rev. C, **82**, 044614 (2012). [5] Yu.Ts. Oganessian *et al.*, Phys. Rev. C, **70**, 064609 (2004). [6] S. Hofmann *et al.*, Eur. Phys. J. A **32**, 251 (2007).

Session OB Beta Delayed Neutrons
Thursday March 7, 2013
Room: Met West at 1:30 PM
Chair: Balraj Singh, McMaster U.
OB 1 1:30 PM

Beta Delayed Neutron Spectroscopy on the r-process Path

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Beta-delayed neutron emission (βn) is a dominant decay channel for the majority of very neutron-rich nuclei on the r-process path. This is due to nuclear structure effects, which drive the population of neutron-unbound states in beta-decay daughters. A majority of the r-process nuclei cannot be synthesized, thus astrophysical nucleosynthesis calculations are forced to use input data provided by theory, which may not always be reliable due to inherent complexity of the many body problem. Because they directly probe relevant physics on the microscopic level, energy-resolved measurements of the beta-decay strenght distribution constitute a better test of nuclear models than traditionally used gross properties like lifetimes

and branching ratios. Neutron spectroscopy is required for investigations of decays of the most neutron-rich isotopes because the dominant part of the beta decay strength is encoded in the decay energy carried by the emitted neutron. The Versatile Array of Neutron Detectors at Low Energy (VANDLE) [1] was commissioned at the Holifield Radioactive Ion Beam Facility (HRIBF). The HRIBF used proton-induced fission of ^{238}U to produce intense and high isotopic purity beams of neutron-rich nuclei. Neutron energy spectra in key regions of the nuclear chart were measured near the shell closures at ^{78}Ni and ^{132}Sn, and for the deformed nuclei near ^{100}Rb. Many of the studied nuclei lie directly on proposed r-process paths. Of the almost thirty βn emitters studied, only a few relatively long-lived isotopes were previously investigated. For some of the most exotic nuclei, narrow and intense peaks in the neutron energy distribution indicate the presence of resonances, which are most likely signatures of the excitation of "core" states. In several cases, relatively high-energy neutrons are observed. Selected results will be presented. This research was sponsored in part by the National Nuclear Security Administration under the Stewardship Science Academic Alliances program through DOE Cooperative Agreement No. DE-FG52-08NA28552
[1] C. Matei et al., Proceedings of Science, NIC X, 138 (2008)

OB 2 2:00 PM

A New Approach to Estimating the Probability for β Delayed Neutron Emission

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The probability for emitting a neutron following β decay, P_n, is critical in many areas of nuclear science from understanding nucleosynthesis during the r-process to control of reactor power levels and waste management. As the P_n value is an observable which is not trivial to measure or calculate, indirect empirical approaches have attempted to characterize measured P_n values based on the total Q value of the decay and the neutron separation energy, S_n, in the daughter nucleus and from these systematics provide estimates of P_n values in unexplored regions of the nuclear chart. A new approach to P_n systematics will be described which incorporates the half-life of the decay and the Q value for the β-delayed neutron emission. This prescription correlates the known data better and thus improves the estimation of P_n values for neutron-rich nuclei. Such an approach can be applied to generate input values for r-process network calculations or in the modeling of advanced fuel cycles. The possibility that these systematics can reveal information on the β-strength function to levels above the neutron separation energy will also be explored. Work supported by the DOE Office of Nuclear Physics under Contract No. DE-AC02-98CH10946.

OB 3 2:20 PM

Beta-delayed Neutron Spectroscopy with Trapped Ions

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Neutrons emitted following the β decay of fission fragments play an important role in many fields of basic and applied science such as nuclear energy, nuclear astrophysics, and stockpile stewardship. However, the nuclear data available today for individual nuclei is limited for the vast majority of neutron emitters, the energy spectrum has not been measured and some recent measurements have uncovered discrepancies as large as factors of 2-4 in β-delayed neutron branching ratios. Radioactive ions held in an ion trap are an appealing source of activity for improved studies of this β-delayed neutron emission process. When a radioactive ion decays in the trap, the recoiling daughter nucleus and emitted radiation emerges from the ~ 1 mm^3 trap volume and propagates through vacuum with minimal scattering. For the first time, β-delayed neutron spectroscopy is being performed using trapped ions by identifying neutron emission from the large nuclear recoil it imparts and using this recoil energy to reconstruct the neutron branching ratios and energy spectra. Results from a recent proof-of-principle measurement of the β-delayed neutron spectrum of Iodine-137 will be presented and plans for future experiments using the intense fission fragment beams from the Californium Rare Isotope Breeder Upgrade (CARIBU) facility at Argonne National Laboratory will be discussed. This work was supported by U.S. DOE under Contracts DE-AC52-07NA27344 (LLNL), DE-AC02-06CH11357 (ANL), DE-FG02-98ER41086 (Northwestern U.), and NSERC, Canada, under Application No. 216974.

OB 4 2:40 PM

New Measurements in the Neutron Rich Region Around N=126 for β-decay and β-delayed Neutron Emission Data at GSI-FRS

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Neutron rich nuclei in the mass region around N=126 have scarce available information about their nuclear properties. Actually, theoretical calculations are difficult to validate on the basis of the few experimental information available so far. This contribution aims to present new data of half lives and β-delayed neutron emission around ^{214}Tl and ^{211}Hg regions, including isotopes observed for the first time, obtained from a recent experiment performed at the RIB facility of GSI-FRS (Germany). The detectors used in the experiment were an implantation and β detector based on a silicon array of highly segmented DSSD's and an updated version of the BEta deLayEd Neutron detector (BELEN) developed at UPC (Barcelona), which consisted of 30 ^{3}He-counters embedded in a polyethylene matrix. An advantage compared to previous similar experiments was due to an innovative self-triggered acquisition system, which allowed us to enhance the neutron detection probability when compared to conventional analogue acquisition systems. The analysis of the half lives and β delayed neutron emission probabilities will be presented as well as final results of these quantities.

Session OC Nuclear Astrophysics
Thursday March 7, 2013
Room: Empire East at 1:30 PM
Chair: Boris Pritychenko, NNDC - BNL
OC 1 1:30 PM

Wanted! Nuclear Data for Dark Matter Astrophysics

Paolo Gondolo
University of Utah

The nature of cold dark matter is one of the big unsolved questions in physics. A wide spectrum of astronomical observations from small galaxies to the largest scales can be consistently explained by the presence of dark matter, in an amount equal on average to about five times the mass in ordinary matter. It is empirically known that no known particle can be cold dark matter, and many theories exist for dark matter as a new elementary particle. Numerous searches for dark matter particles are under way: from production of new candidates in high-energy accelerators, to direct detection of dark matter-nucleus scattering in underground observatories, to indirect detection of dark matter signals in cosmic rays, gamma rays, or stars. Direct and indirect dark matter searches rely on observing an excess of events above background, and a lot of controversies have arisen over the origin of measured excesses (dark matter signal or misconstrued background?). In my talk I will show that nuclear physics data have become important for dark matter searches. With the new high-quality cosmic ray measurements from the AMS-02 experiment, the major uncertainty in modeling cosmic ray fluxes is in the nuclear physics cross sections for spallation and fragmentation of cosmic rays off interstellar hydrogen and helium. The understanding of direct detection backgrounds is limited by poor knowledge of cosmic ray activation in detector materials, with order of magnitude differences between simulation codes. A scarcity of data on nuclear structure functions, especially spin structure functions, blurs the connection between dark matter theory and experiments. What is needed, ideally, are new measurements using polarized beams against nuclear targets to furnish spin structure data, and proton beams and perhaps helium beams against isotopes of He, Li, Be, B, C, N, O, Fe, Ni (for indirect searches) and Ge, Xe, Ar (for direct searches).

OC 2 2:00 PM

Experimental Studies of the ^{13,14}B(n,γ) Rates for Nucleosynthesis Towards the r process

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Model calculations of r-process nucleosynthesis within a neutrino-driven wind scenario indicate that light, neutron-rich nuclei, may have a crucial influence on the final r-process abundances [1]. Sensitivity studies identified the most influential reactions, which include succesive (n,γ) reactions running through the isotopic chain of neutron-rich boron isotopes [2]. However, nuclear reaction rates of unstable nuclei far from stability are rarely known and very difficult to determine experimentally. Therefore, the corresponding time-reversed reactions were investigated in a kinematically complete measurement in inverse kinematics via Coulomb dissociation at relativistic energies. A primary beam of ^{40}Ar was fragmented and the desired isotopes were separated from the primary beam using a fragment separator (FRS). A secondary beam of ^{14,15}B was then directed onto a Pb-target to investigate the interaction with the Coulomb field. The experiment was performed at the LAND/R^{3}B setup at the GSI Helmholtzzentrum fuer Schwerionenforschung GmbH.
[1] M. Terasawa et al., APJ, **562**, 470-479, (2001) [2] T. Sasaqui et al., APJ **634**, 1173-1189, (2005)

OC 3 2:20 PM

R-matrix Analysis of Reactions in the ^{9}B Compound System

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Reactions in the ^{9}B compound system are analyzed with the *R*-matrix code *EDA*, developed by Hale and collaborators, using all the known elastic and reaction data, in a four-channel treatment. The data include elastic ^{3}He+^{6}Li differential cross sections from 0.7 to 2.0 MeV, integrated reaction cross sections for energies from 0.7 to 5.0 MeV for ^{6}Li(^{3}He,p)^{8}Be* and from 0.4 to 5.0 MeV for the ^{6}Li(^{3}He,d)^{7}Be reaction. Capture data have been added to the previous analysis with integrated cross section measurements from 0.7 to 0.825 MeV for ^{6}Li(^{3}He,γ)^{9}B. The resulting resonance parameters are compared with tabulated values, and previously unidentified resonances are noted. The possible relevance of this analysis for big bang nucleosynthesis and other astrophysical applications is addressed and $< \sigma v >$ data for these reactions are presented.

OC 4 2:40 PM

Astrophysical S$_{bare}$(E) Factor of the ^{6}Li+d and ^{7}Li+p Reactions

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School of Nuclear Science and Technology, Lanzhou University

Cross sections of nuclear reactions far below the Coulomb barrier are very important for various astrophysical applications as well as for thermal nuclear fusion experiments. Since the cross section σ(E) decreases nearly exponentially as E decreases, it is converted into an astrophysical S(E) factor by the definition S(E) = σ(E)Eexp($2\pi\eta$(E)). In the very low energy region, the screening effect of the environment (for ex. surrounding electrons) enhances the S(E) strongly. Thus, one faces the difficulty of deducing the nuclear S$_{bare}$(E), which corresponds to the nuclear reaction between two bare nuclei. Although the S$_{bare}$(E) in the ^{6}Li+d and ^{7}Li+p reactions have been reported in [1], the enhancement of the S(E) cannot be explained well by the screening potential predicted by atomic physics. We have measured the reaction rates of the ^{6}Li+d and ^{7}Li+p reactions in the different environment: the target Li is in liquid phase. The measurements were performed for the bombarded energies from 25 to 70 keV with the experimental setup described in [2]. In this work we discuss the S$_{bare}$(E) by analyzing our experimental data together with those so far reported. It is known that the measured S(E) factor is modified as S(E) = f(E,U$_s$)S$_{bare}$(E), where f(E,U$_s$) is the enhancement factor (approximately = exp($\pi\eta$Us/E)) and U$_s$ is the screening energy. In order to determine the S$_{bare}$(E) of the ^{6}Li+d and ^{7}Li+p, we set the policy for the analysis; the S$_{bare}$(E) depends only on the nuclear reaction but U$_s$ depends on the environment. In the analyses, therefore, we introduced S$_{bare}$ independently for the ^{6}Li+d and ^{7}Li+p reaction and U$_s$ independently for the difference of target conditions (the U$_s$ should be same for both reactions measured in the same environment). By searching for the parameters in S$_{bare}$ and U$_s$ so as to reproduce all the experimental S(E), we determined S$_{bare}$ for both nuclear reactions and U$_s$ for both target conditions simultaneously. The astrophysical S$_{bare}$(0) values are 19.7 (0.5) MeVb and 62.3 (1.5) keVb for the ^{6}Li+d and ^{7}Li+p reaction, respectively. The U$_s$ values are 220 (40) eV for the atom target and 436 (50) eV for the liquid Li. It should be noticed that the U$_s$ for the atom target is consistent with the one predicted with adiabatic approximation.
[1] S. Engstler et al., Z. Phys. A342 (1992) 471. [2] K.H. Fang et al., J. Phys. Soc. Jpn. 80 (2011) 084201.

Session OD Nuclear Structure and Decay
Thursday March 7, 2013
Room: Empire West at 1:30 PM
Chair: Tibor Kibedi, Australian National University
OD 1 1:30 PM

Determination of absolute Gamow Teller transition probabilities in exotic fp-shell nuclei

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Weak interaction processes play an essential role in many astrophysical scenarios. In many cases their description involves a knowledge of the properties of many nuclei that have to be theoretically modeled since experimental information is not available. It is essential that sufficient experimental data are available to test, constrain and guide the theoretical models. This paper concerns the determination of the absolute value of the Gamow-Teller transition strength B(GT) in fp-shell nuclei. These nuclei are important e.g. in neutrino induced reactions at the violent core-collapse stage of type II supernovae. Experimental B(GT) values can be obtained from charge-exchange (CE) reactions on stable nuclei or from beta decay since they involve the same operator. These two studies are to a large extent complementary, each having their own advantages and disadvantages. Assuming isospin symmetry one can combine the results from both types of study on mirror nuclei to determine absolute B(GT) values. This method, the so-called 'merged analysis' is very powerful since it allows B(GT) determinations for GT transitions starting from very unstable nuclei if the beta-decay $T_{1/2}$ and the Q-beta value are precisely known and if the relative B(GT) values are studied in CE reactions for the mirror nucleus. In order to determine the degree of precision of this method a campaign has been launched at several different laboratories to study the decays of T_z=-1 and T_z=-2 nuclei in the fp shell with the aim of comparing the results with the results from CE experiments on the corresponding T_z=+1 and T_z=+2 mirror nuclei carried out at RCNP (Japan). Recent experimental developments have made this comparison effective. On the one hand there has been a substantial improvement in resolution in studies of (^{3}He,t) CE reactions at RCNP. On the other hand the use of fragment separators to create and identify short-lived nuclear species has improved experimental accessibility to the beta decays of exotic nuclei (all nuclei studied here have $T_{1/2}$ of the order of 100 ms). We will present here a summary of the results with special emphasis on the precise beta decay studies obtained at the GSI and GANIL facilities. The experiments include DSSD implantation- beta- proton detectors and Ge-gamma arrays. The experiments resulted in $T_{1/2}$ determinations for more than 20 nuclei with one to two orders-of-magnitude improvement in accuracy and absolute branching ratios to excited states up to 5 MeV excitation in nuclei where typically only the branching to the lowest state was known previously. A special effort has been made to determine the strength of the g.s to g.s beta decay branch, which is notoriously difficult to measure.

OD 2 2:00 PM

Half-life Measurements of Excited Levels in Fission Products Around a Mass Number of 150

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Tokushima Graduate School, Japan. A. Taniguchi, *Research Reactor Institute, Kyoto University, Japan.* M. Shibata, *Radioisotope Research Center, Nagoya University, Japan.*

Half-lives of nuclear excited levels relate γ transition probabilities and nuclear matrix elements, which are, for example, used for investigating nuclear structure and for modifying nuclear models. Therefore, data on level half-lives are one of the most essential properties in fields of nuclear science and technology. These data have been accumulated through many sophisticated experiments, and evaluated for conveniences of various applications. In spite of these efforts, experimental half-lives are known only for a limited number of levels in β unstable nuclides, owing to difficulties both of measuring the half-lives and of producing the nuclides. In order to measure level half-lives around 0.1-10 ns by means of the β-γ-γ delayed coincidence technique, a new spectrometer has been installed to the on-line isotope separator at the Kyoto University Reactor. As described in details in ref. [1], the spectrometer consists of a $LaBr_3$, a plastic scintillator and an HPGe detector. The $LaBr_3$ detector is used as a fast γ detector, whereas the HPGe detector is used to select a desired γ branch. A β signal from the 1-mm-thick plastic scintillator starts the functioning of a time-to-amplitude converter module. Time resolutions (FWHM) were found to be 375 ps for the 1333-keV, and 601 ps for 99-keV γ rays. This means that our spectrometer is capable of measuring the level half-lives down to sub-nanosecond range. Using this experimental apparatus, we have performed half-life measurements for neutron-rich rare-earth nuclides around a mass number of 150. These nuclides were produced by the thermal neutron-induced fission of ^{235}U, ionized by a thermal ion source, and mass-separated with a mass resolution of about 600. Until now, we successfully observed new level half-lives in ^{148}Pr [1] and ^{149}Nd (partly reported in ref. [2]). In this conference, we will present an overview of the measuring setup as well as the latest experimental results including new level half-lives in ^{149,150}Pr. This work was supported by a Grant-in-Aid for Scientific Research (no. 23540344) from Japan Society for the Promotion of Science.
[1] Y. Kojima *et al.*, Nucl. Instr. Meth. A 193-197 **659** (2011) . [2] Y. Kojima *et al.*, KURRI Prog. Rept. (in press).

OD 3 2:20 PM

Sensitivity of the r-process to structure and masses far from stability

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The rapid neutron capture process (r-process) is thought to be responsible for the creation of more than half of all elements beyond iron. The scientific challenges to understanding the origin of the heavy elements beyond iron lie in both the uncertainties associated with astrophysical conditions that are needed to allow an r-process to occur and a vast lack of knowledge about the properties of nuclei far from stability. There is great global competition to access and measure the most exotic nuclei that existing facilities can reach, while simultaneously building new, more powerful accelerators to make even more exotic nuclei.
I will talk about an attempt to determine the most crucial nuclei and most crucial properties to measure using an r-process simulation code.
This work has been supported by the National Science Foundation under contract number PHY0758100 and the Joint Institute for Nuclear Astrophysics, PHY0822648

OD 4 2:40 PM

Evidence for the Exchange Effect in Low-Energy Beta Decays

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Metallic magnetic calorimeters have been shown to be a powerful experimental technique to study the energy spectra of beta particles having a maximum energy of about 1 MeV. The beta spectrum of Pu-241 was recently measured using a metallic magnetic calorimeter [1]. The energy resolution, 29 eV at 5.9 keV, and the energy threshold, 300 eV, allow testing the theoretical beta spectra calculations with an accuracy never before achieved. The spectrum from [1] has already been compared to classical beta calculations [2], and in this framework a significant deviation of the experimental spectrum below 5 keV could not be explained. The exchange effect has been given as a possible cause, and indeed calculations confirm that this atomic effect explains a large part of this deviation. More recently, the beta spectrum of Ni-63 was measured with the same experimental technique. Comparison with a theoretical spectrum calculated taking into account the exchange effect exhibits an excellent agreement. Calculation of exchange effect is detailed following the formalism set out in [3]. The remained discrepancy at low energy in the Pu-241 beta spectrum is discussed reviewing the influence of possible other effects. Exchange correction is found to be very sensitive to screening effect due to the electron cloud of the daughter nucleus. For radionuclides with high Z, this work has demonstrated the necessity to take into account the spatial variation of the nuclear charge experienced by the ejected electron to accurately correct for screening.
[1] M. Loidl, M. Rodrigues, B. Censier, S. Kowalski, X. Mougeot, P. Cassette, T. Branger, and D. Lacour, Appl. Radiat. Isot. 68, 1460 (2010). [2] X. Mougeot, M.-M. Bé, V. Chisté, C. Dulieu, V. Gorozhankin, and M. Loidl, in LSC2010, International Conference on Advances in Liquid Scintillation Spectrometry, edited by P. Cassette, Radiocarbon (University of Arizona, Tucson, 2010) pp. 249-257. [3] M. R. Harston and N. C. Pyper, Phys. Rev. A 45, 6282 (1992).

Session OE Cross Section Measurements
Thursday March 7, 2013
Room: Central Park East at 1:30 PM
Chair: Rian Bahran, RPI
OE 1 1:30 PM

Nuclear Data Measurement Activities at CIAE

Xichao Ruan, Weixiang Yu, Long Hou, Yi Yang
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China Institute of Atomic Energy (CIAE) is one of the most important bases for nuclear data measurement in China. In this talk, the nuclear data measurement activities at CIAE in recent years will be presented. The secondary neutron emission DX and DDX measurement, the integral experiment for nuclear data benchmarking, the excitation function measurement and the neuron induced fission yields measurement carried out in recent years will be introduced. Furthermore, some new facilities and proposed plans (e.g. A Gamma ray Total Absorption Facility (GTAF) for (n, γ) reaction cross section measurement, the back streaming white neutron beam for nuclear data measurement at China Spallation Neutron Source (CSNS)) for nuclear data measurement will also be presented. These projects are carried out to feed the needs for nuclear energy development (new generation of nuclear reactors, ADS, etc) and nuclear data evaluation in China.

OE 2 2:00 PM

Measurements of Neutron Cross Sections for Chromium, Yttrium and Terbium at 197 MeV

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Neutron-induced reaction cross sections are essential to cosmochemists aiming to decipher the cosmic-ray irradiation history. These cross section data also serve as a comprehensive nuclear database for estimating residual radioactivities in accelerator facilities. Neutron cross sections in the energy range above 100 MeV have scarcely been measured experimentally; exceptions are for the target materials C, Cu, Pb, Bi and a few others. In many instances the neutron cross section is based on the corresponding proton cross section, the assumption being that above 100 MeV they are similar. Cross sections also can be calculated from physic-based codes. In this work, we measured reaction cross sections of radionuclides produced through nuclear spallation reactions from Cr, Y and Tb induced by neutrons at 197 MeV; our experiments are the first to report these cross sections. The irradiations were carried out using neutrons produced through Li-7 (p,n) reaction at N0 beam line in the Research Center for Nuclear Physics (RCNP), Osaka University. To estimate quasi-monoenergetic neutron induced cross sections, the target stacks of Cr, Y and Tb were irradiated on the two angles of 0 and 25 degrees for the axis of the primary proton beam. The yields of the spallation products were measured by gamma-ray spectrometry. Neutron cross sections were estimated by subtracting the yields produced in the samples placed on 25 degree from those of 0 degree to correct the contribution of the low energy tail in the neutron spectrum. The results obtained in this work will be compared to the cross section data for the same target materials with 287 and 386 MeV neutrons in our previous work. We will also compare neutron cross sections obtained to those from calculation codes.
Corresponding author: S. Sekimoto

OE 3 2:20 PM

Partial Photoneutron Cross Sections for ^{207,208}Pb

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Using linearly-polarized laser-Compton scattering γ-rays, partial $E1$ and $M1$ photoneutron cross sections along with total cross sections were determined for ^{207,208}Pb at four energies near threshold by measuring anisotropies in photoneutron emission. Separately , total photoneutron cross sections were measured for ^{206,207,208}Pb with a high-efficiency 4π neutron detector. The $E1$ strength dominates over the $M1$ strength in the neutron channel where $E1$ photoneutron cross sections clearly show extra strength of the pygmy dipole resonance in ^{207,208}Pb near the neutron threshold corresponding to 0.32% - 0.42% of the Thomas-Reiche-Kuhn sum rule. Several μ_N^2 units of $B(M1)\uparrow$ strength were observed in ^{207,208}Pb just above neutron

threshold, which correspond to an $M1$ cross section less than 10% of the total photoneutron cross section. This contribution is based on our recent publication [1].
Corresponding author: H. Utsunomiya

[1] T. Kondo, H. Utsunomiya, S. Goriely et al., Phys. Rev. C 86, 014316 (2012).

OE 4 2:40 PM

Experimental Level Densities and Gamma Strength Functions with the Oslo Method

S. Siem, A. Bürger, F. Giacoppo, A. Görgen, M. Guttormsen, T.W. Hagen, A.C. Larsen, H.T. Nyhus, J. Rekstad, T. Renstrom, S.J. Rose, G. M Tveten., *University of Oslo, Dept. of Physics, P.OBox 1048 Blindern, 0316 Oslo, Norway.* L. A. Bernstein, D. Bleuel,, *Lawrence Livermore National Laboratory 7000 East Avenue, Livermore, CA 94550, USA.* F. Gunsing, *CEA Saclay, DSM/Irfu/SPhN, F-91191 Gif-sur-Yvette Cedex, France.* A. Schiller, A. Voinov, *Department of Physics and Astronomy, Ohio University, Athens, Ohio 45701, USA.* M. Wiedeking, *iThemba LABS, P.O. Box 722, 7129 Somerset West, South Africa.* J.N. Wilson, *Institut de Physique Nucleaire d'Orsay, 15 rue G. Glemenceau, 91406 Orsay Cedex, France.*

The nuclear physics group at the Oslo Cyclotron Laboratory has developed a unique technique to extract simultaneously the level density and γ-strength function from primary γ-ray spectra [1]. These are fundamental properties of the atomic nucleus and important input parameters in reaction cross-section calculations, used in reactor physics simulations and astrophysics models of formation of heavy elements in explosive stellar environments. I will give a short description of our facility and the Oslo method. Then the latest result from experiments done in Oslo will be presented, including resent data on actinide nuclei, relevant for the Thorium fuel cycle, where we observe a large orbital scissors strength for several actinide nuclei [2]. We have also observed another resonance around 7-9 MeV in Sn isotopes which might be due to neutron skin oscillations [3]. Both these resonances increase the gamma decay probability and should be included cross-sections calculations. Finally an unexpected enhancement of the γ-strength function at low gamma energy has been observed in several nuclei [4]. This low energy enhancement has the potential of increasing neutron-capture rates with up to two orders of magnitude if also present in very neutron-rich nuclei [5]. The present status of the low-energy enhancement, including new data on Cd and Zr, will also be presented.

[1] A. Schiller et al., Nucl. Instrum. Methods Phys. Res. **A 447**, 494 (2000). [2] M.Guttormsen et al. submitted to Phys. Rev. Lett [3] H.K. Toft et al., Phys. Rev. **C 81**, 064311 (2010). Phys. Rev. **C 83**, 044320 (2011) [4] A. Voinov et al., Phys. Rev. Lett **93**, 142504 (2004); M. Guttormsen et al., Phys.Rev. **C 71**, 044307 (2005); [5] A.C. Larsen et al., Phys. Rev. **C82**, 014318 (2010).

Session OF Nuclear Data Adjustment
Thursday March 7, 2013
<u>Room</u>: Central Park West at 1:30 PM
<u>Chair</u>: Alain Santamarina, CEA Cadarache
OF 1 1:30 PM

Multigroup Cross Section Adjustment Based on ENDF/B-VII.0 Data

G. Palmiotti, M. Salvatores, H. Hiruta, R. D. McKnight, G. Aliberti, M.W. Herman, S. Hoblit, P. Talou
INL, CEA, ANL, BNL, LANL

Under the Advanced Reactor Concepts (ARC) program funded by DOE NE (Nuclear Energy) Office an activity devoted to reduce uncertainties associated to the main neutronic parameters relevant to advanced systems (reactors and associated fuel cycles) assessment and design has been carried out in the last few years. The aim of this activity is to produce a set of improved nuclear data to be used both for a wide range of validated advanced fast reactor design calculations and for the assessment of innovative fuel cycles, and for providing guidelines for further improvements of the ENDF/B files (i.e., ENDF/B-VII.0, and future releases). The process for producing the improved (i.e., with reduced uncertainties) nuclear data involves several ingredients and steps: selection of a set of relevant experiments, sensitivity analysis of selected configurations including reference design configurations, production and use of science based covariance data for uncertainty evaluation and target accuracy assessment, analysis of experiments using the best methodologies available, use of calculation/experiment discrepancies in a statistical data adjustment process. The most recent adjustment performed uses a 33 group energy structure, ENDF/B-VII.0 as starting data, COMMARA 2.0 covariance matrix, and more than 100 integral experiments. It is important to underline that the COMMARA data file (now widely recognized internationally) has been developed in the frame and consistently with the needs of this project. The set of integral experiments includes very well characterized and complementary systems. Among those that have been utilized we can list: small and very hard spectrum (e. g., GODIVA and JEZEBEL), medium and large systems (ZPR6-7, ZPPR9 and ZPPR10), and power reactors (e. g., JOYO, PHENIX). For the purpose of the project, detailed validated models of the experiment were used, and gathered in a unique database that allows the preservation of past high quality experimental programs. The integral measured quantities used in the adjustment range from critical mass to spectral indexes, from sodium void reactivity to control rod worth. Uncertainties were also reassessed for all the experimental values, based on past information and best practices. Of particular importance were separated isotope sample and special pin irradiation experiments (e. g., PROFIL and TRAPU) that have allowed adjustment of minor actinide and fission product data. In the full paper results will be presented with the most significant feedback for the ENDF/B-VII.0 provided by isotope, reaction, and energy range. The results of the statistical data adjustment should, as much as possible, translate in nuclear data file improvements.

OF 2 2:00 PM

Towards unified reaction cross sections through assimilation of integral and differential experiments.

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The classical method of adjusting multi-grouped reaction cross sections to a specific set of integral experiments or applications often result in cross sections that are difficult to apply to other situations where the adjustments are not applicable or the specific energy grouping or weighting is inappropriate. To address these issues we will discuss efforts underway at the NNDC at Brookhaven National Laboratory with collaborators at Idaho National Laboratory to assimilate integral experiments to produce adjusted differential reaction cross sections that can be applied to a variety of applications without the need for grouping or adjustments tailored to specific needs. This method uses the Empire code [1] to model various materials and determine the sensitivity of the reaction cross sections to the model parameters and their covariances as fit to differential data. Our collaborators at INL determine the sensitivity of integral experimental quantities to the reaction cross sections. Folding these then results in sensitivities of the integral experiments to underlying model parameters, which can then be used to fit the integral data using the covariances from differential data. This results in a set of model parameters and reaction cross sections and uncertainties that simultaneously account for both the differential and integral measurements which can then be applied to a wide variety of experiments and designs without the need for further adjustment. We also will discuss a method under development at the NNDC where the differential cross sections are used in monte-carlo simulations of integral experiments as an alternative method for including their sensitivities to model parameters. The results of these studies as applied to few important materials will be presented.

[1] M. Herman, R. Capote, B. V. Carlson, P. Oblozinsky, M. Sin, A. Trkov, H. Wienke, and V. Zerkin. "Empire: Nuclear reaction model code system for data evaluation." Nuclear Data Sheets, **108** (12): 2655-2715, 2007.

OF 3 2:20 PM

Uncertainty Assessment for fast Reactors Based on Nuclear Data Adjustment

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For the purpose of safety assessment, IRSN studies issues of use of high-accurate codes and methods for fast reactor simulation and uncertainty study. The unbiased Monte Carlo methods (MCNP code and SCALE sequences) are used together with deterministic methods (ERANOS code) for computation of fast system neutronics parameters. The cross-section adjustment technique has been recently implemented in the IRSN's in-house BERING validation tool in order to establish values for the robust biases and uncertainties in these parameters. The adjustment technique is used for consolidation of a prior set of integral parameters measured in benchmark experiments and a corresponding set of calculated parameters obtained with mentioned computational codes. A better understanding of the performance of the adjustment methodology is needed in order to improve the confidence concerning its validity and applicability for uncertainty assessment. The benchmark exercise, established by the OECD/NEA Working Party on International Nuclear Data Evaluation Co-operation (WPEC) Subgroup 33, offers a very good opportunity to learn the drawbacks and advantages of the adjustment and to test BERING performance. The benchmark exercise has been proposed with the aim to test different methods of nuclear data adjustment and different sets of covariance data, so as to reduce the design uncertainties of a particular type of sodium-cooled fast reactor. The exercise uses a single, limited set of integral experiments and measurements, which include K_{eff} for Jezebel, Jezebel-^{240}Pu, Flattop-^{240}Pu, ZPR6-7, ZPR6-7 with high ^{240}Pu content, ZPPR-9 and Joyo MK-1; reaction rates for Jezebel, Flattop-^{240}Pu, ZPR6-7 and ZPPR-9; and sodium void effects for ZPPR-9. The final results are tested on a model of the Advanced Fast Burner Reactor (ABR) with plutonium oxide fuel and a model of the Fast Breeder Reactor (FBR) core. Every participant to the benchmark is supposed to use the same integral experiment values and uncertainties, but their own calculated values, sensitivity coefficients, and adjustment method. Own or same initial cross sections and nuclear data covariances can be used depending on step of the exercise. The full paper will present IRSN's results of the benchmark exercise generated using different sets of input data: integral parameters and sensitivity coefficients computed by the deterministic ERANOS code and the Monte Carlo and deterministic SCALE6.0 sequences; ENDF/B-VI.8 and ENDF/B-VII cross-section data; COMMARA 2.0 and TENDL-2011 covariances; with and without integral correlations provided by JAEA. The outcomes of BERING will be analyzed and compared in order to demonstrate whether the results of the adjustment converge when using different input cross-section covariances. The impact of different calculation methods' approximation bias will also be shown.

OF 4 2:40 PM

New JEFF-3.2 Sodium Neutron Induced Cross-Sections Evaluation for Neutron Fast Reactors Applications: from 0 to 20 MeV

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The current JEFF-3.1.1 sodium evaluation shows large discrepancies with the microscopic measurements available on the EXFOR database. Furthermore, no cross-sections covariance matrices are available in this file, which are of interest for fast reactor applications. In the framework of the ASTRID project (French sodium fast reactor), a new sodium evaluation, from 0 to 20 MeV, have been carried out using the CONRAD code. This file contains both re-evaluated nuclear data and covariances and is divided in two energy regions: the resolved resonances range and the continuum part. The resonance range has been extended up to 2 MeV (previously 350 keV) and converted in the Reich-Moore R-Matrix approximation. Larson's total cross-section and the recent high-resolution inelastic cross-section measurements from IRMM were used during the data assimilation. For the continuum region, a simultaneous analysis of different reaction measurements (total, inelastic, charged particle, capture) has been performed with the ECIS/TALYS codes, interfaced with CONRAD, and an overall good agreement has been achieved. The covariances data have been produced with a Monte-Carlo marginalization procedure which consists in propagating all experimental systematic uncertainties to the nuclear reaction model parameters. This ^{23}Na evaluation has been successfully processed and tested on several neutronic benchmarks. It will be proposed for the future JEFF-3.2 library.
Presenting author: Cyrille de Saint Jean

Session PA Neutron Cross Section Measurements
Thursday March 7, 2013
Room: Met East at 3:30 PM
Chair: Peter Schillebeeckx, EC-JRC-IRMM Geel
PA 1 3:30 PM

Investigation of Neutron-Induced Reactions at n_TOF: Overview of the 2009-2012 Experimental Program

Carlos Guerrero, on behalf of the n_TOF Collaboration
CERN

The neutron time-of-flight facility n_TOF is operating at CERN (Switzerland) since 2001, having started in 2009 the second phase (n_TOF-Ph2) with an upgraded spallation target. Since then, the ambitious program carried out includes a large number of experiments in the fields of nuclear technology, astrophysics, basic physics, detector development and medical applications. Following a brief description of the n_TOF facility and its characteristics, the physics program at n_TOF will be discussed and a detailed summary of the measurements performed between 2009 and 2012 will be presented. Special attention will be given to those experiments that have been most challenging, are more important for a particular field, have reached unprecedented levels of accuracy, or have been carried out for the first time ever.

PA 2 4:00 PM

Analysis of ^{241}Am(n,γ) Cross Section with C_6D_6 Detectors at the n_TOF facility (CERN)

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The interest for nuclear data in the actinide region is constantly renewed by the reactor physics community, both for generation IV reactor designs or transmutation studies. Indeed the NEA has placed several minor actinides, including ^{241}Am, on its High Priority Request List for cross section measurements. In this context, and as a part of the FP7-ANDES project, the (n,γ) reaction yield of ^{241}Am has been measured in 2010 at the n_TOF facility at CERN. The method used was time-of-flight (TOF) spectrometry, and two C_6D_6 scintillators were used for gamma-ray detection. The discussion will focus on detection efficiency, background estimation, and normalization. The R-matrix resonance analysis in the resolved resonance region (RRR) will then be detailed, and will be compared to current evaluations and previous data. Significant improvement, mostly through the extension of the RRR from 150 eV to 300 eV has been possible. Level densities and neutron strength functions extraction through a statistical analysis will be presented. Finally, the unresolved resonance region analysis, based on an ensemble average of the R-Matrix expressions, will be exposed, and compared to recent evaluations and previous work.

PA 3 4:20 PM

Neutron Capture Cross Section of ^{239}Pu

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LANL
A. Chyzh, J. M. Gostic, R. A. Henderson, E. Kwan, C-Y. Wu
LLNL

High fidelity measurements of ^{239}Pu(n, γ) are required for both nuclear energy campaigns and improved understanding of reaction diagnostics for defense programs. As part of the Advanced Reactor Concepts (ARC) program, a new design of reactors is being considered for safe and cost-effective use in the United States and around the world. While traditional reactor designs have relied on light water reactors, the reactors planned for ARC will have a fast neutron spectrum, requiring improved nuclear data in the keV regime. These measurements are particularly challenging on fissile isotopes as the fission γ spectrum does not present unique features which can be used to discriminate fission γ-rays from neutron capture. The Los Alamos Neutron Science Center (LANSCE) provides a high intensity neutron flux from thermal to several hundred keV. Coupled to this intense neutron source, the Detector for Advanced Neutron Capture Experiments (DANCE) provides a highly segmented 4π measurement of the γ-ray energy and multiplicity distributions. Finally, a specially designed Parallel Plate Avalanche Counter (PPAC) detected coincidence fission fragments. Together, these instruments were used to provide a new high fidelity measurement of neutron capture on ^{239}Pu. Existing measurements extend up to 10 keV incident neutron energy, while measurements planned for Fall of 2012 will push the measurement up to several hundred keV. The simultaneous measurement of (n,γ) and (n,f) events resulting from a single sample allowed the (n,γ) cross section to be measured as a ratio to fission with reduced systematic uncertainty. Similar techniques applied to ^{235}U resulted in an uncertainty of 3% at 10 keV. Results from the current analysis on ^{239}Pu will be presented.

PA 4 4:40 PM

High-precision measurement of the ^{238}U(n,γ) cross section with the Total Absorption Calorimeter (TAC) at nTOF, CERN

Toby Wright, Jon Billowes, Tim Ware, *University of Manchester (UK).* Carlos Guerrero, the n_TOF Collaboration, *CERN, Switzerland.* Daniel Cano Ott, *CIEMAT, Spain.* Frank Gunsing, C. Lampoudis, E. Berthoumieux, *CEA, France.* Cristian Massimi, Federica Mingrone, *Universita di Bologna, Italy.*

The uncertainty in the neutron capture cross section of ^{238}U introduces limitations in the simulation of present, Gen III+ LWRs and Gen IV fast reactors. Sizable inconsistencies in this cross section still appear in the epithermal energy region up to 25 keV, as is summarized on the NEA High Priority Request List of measurements. In this context, the Accurate Nuclear Data for nuclear Energy Sustainability (ANDES) project from the European Commission 7th Framework Programme aims, among others, to achieve the required precision and improve the measurements of the ^{238}U cross section data. This neutron capture cross section has been measured at the n_TOF facility at CERN with two different detector set-ups, and also measurements have been performed at GELINA at IRMM, with the aim of reducing the uncertainty in the cross section down to 2%, leading to the most accurate ^{238}U neutron capture cross section to date. This contribution focuses specifically on the time-of-flight measurement carried out with the Total Absorption Calorimeter (TAC) at the CERN neutron-spallation source n_TOF. The TAC is an array of 40 BaF2 scintillators and has a large solid angle coverage, high γ-ray total absorption efficiency, reasonable energy resolution, high segmentation and fast time response. The preliminary results in the energy range between 0.3 eV and 100 keV will be presented. These include the corrections associated to the background subtraction, normalization, detection efficiency and pile-up effects. A comparison with the existing evaluated cross sections and previous measurements will also be presented.

PA 5 5:00 PM

Results on the ^{236}U Neutron Cross Section from the n_TOF Facility

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One of the main goals of the n_TOF experimental program is to measure with high resolution and high accuracy neutron-induced reaction cross sections of interest for advanced nuclear technologies. In this respect, capture and fission cross sections have been measured at n_TOF for various U and Pu isotopes, as well as for a variety of Minor Actinides. As part of this extensive program, the capture cross section of ^{236}U has been recently measured. Together with the fission data previously obtained at n_TOF, these cross sections are of interest for the development of the Th/U fuel cycle for energy production, as well as for studies of advanced reactor technology for nuclear wastes incineration. In order to minimize systematic uncertainties, the capture cross section was measured with two detection systems: a pair of low neutron sensitivity C_6D_6 detectors and a BaF_2 Total Absorption Calorimeter. The suitable features of the facility, in particular the high instantaneous flux and high resolution of the neutron beam, in combination with the high performance detection systems have allowed us to determine the cross section and the associated resonance parameters with an accuracy better than the required value of 10%. The results of the measurements will here be presented, in comparison with (scarce) previous data and current evaluations.

PA 6 5:15 PM

New Measurement of the ^{25}Mg(n, γ) Reaction Cross Section

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We have recently re-measured the neutron capture cross section of the stable ^{25}Mg isotope at the neutron time-of-flight facility n_TOF at CERN, using C_6D_6 liquid scintillators. This experiment aims at the improvement of existing data of interest for nuclear astrophysics and is part of an ongoing study for a comprehensive discussion of the s-process abundances in red giant stars. The measurement is carried out under similar conditions as for the Mg-experiment that was completed at n_TOF during 2003, with some important improvements in the experimental setup. In particular i) a metallic ^{25}Mg-enriched sample is used instead of a MgO powder sample used in the previous measurement, which prevented us from minimizing the uncertainty of the measured cross section; ii) the use of such a self-sustaining sample does not require an aluminum canning, which introduced an important background contribution in the past; iii) borated water is used as neutron-moderator, a new feature of the n_TOF facility that strongly reduces the background due to gamma rays traveling in the beam. In the present contribution we show the impact of these improvements on the quality of the measured cross section. The preliminary results and the astrophysical implications will be presented as well.

[1] C. Massimi, P. Koehler et al. (The n_TOF collaboration), Phys. Rev. C **85**, 044615 (2012)

PA 7 5:30 PM

Measurement of the ^{237}Np(n,f) Cross Section with the MicroMegas Detector

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In the present work, the measurement of the ^{237}Np(n,f) cross section with reference to the standard ^{238}U(n,f) reaction was attempted with a new MicroMegas detector [1], based on the innovative Microbulk technology, especially developed at CERN [2] for these measurements. The incident monoenergetic neutron beams with energies in the range 4-6 MeV were produced via the ^{2}H(d,n) reaction at the neutron beam facility of the Institute of Nuclear Physics at the NCSR "Demokritos". Four actinide targets (^{237}Np, two ^{238}U and ^{235}U) and the corresponding MicroMegas detectors were assembled in an especially made chamber full of Ar/CO_2 at a proportion 80/20 and around atmospheric pressure. The actinide targets used are in the form of very thin disks of actinide oxides deposited on a 100 μm Al backing. The mass of the isotope of interest and impurities was quantitatively determined via alpha spectroscopy. Furthermore, their thickness and homogeneity have been examined via the RBS (Rutherford Backscattering Spectrometry) technique. Monte-Carlo simulations were performed with the code MCNP5 [3] implementing the neutron beam setup and the MicroMegas assembly in order to determine the neutron flux at the position of each target. Additional simulations with FLUKA [4] were performed, studying the energy deposition of the fission fragments in the active area of the detector, in order to accurately estimate the efficiency. Good discrimination of the heavy and light mass peaks of the fission fragments was achieved. The cross section results are in agreement with previous data and will be presented and discussed. This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

[1] Giomataris, Ph. Rebourgeard, J. P. Robert and G. Charpak, Nucl. Instrum. Methods Phys. Res. Sect. A 376, 29, (1996). [2] S. Andriamonje et al. (The n_TOF Collaboration), Journal of the Korean Physical

Society, Vol. 59, No. 2, August 2011, p. 1597-1600. [3] F. B. Brown, R. F. Barrett, T. E. Booth, J. S. Bull, L. J. Cox, R. A. Forster, T. J. Goorley, R. D. Mosteller, S. E. Post, R. E. Prael, E. C. Selcow, A. Sood, and J. Sweezy, Trans. Am. Nucl. Soc. 87, 273 (2002). [4] "FLUKA: a multi-particle transport code", A. Ferrari, P.R. Sala, A. Fasso, and J. Ranft, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

Session PB Benchmark and Testing
Thursday March 7, 2013
Room: Met West at 3:30 PM
Chair: Skip Kahler, LANL
PB 1 3:30 PM

Benchmark Calculations for Reflector Effect in Fast Cores by Using the Latest Evaluated Nuclear Data Libraries

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Japan Atomic Energy Agency (JAEA)

The impact of the scattering angular distributions (μ-bar) and scattering cross-sections on neutron multiplication factor (k_{eff}) values has been recently pointed out for small fast reactor cores with reflector. In Working Party on International Nuclear Data Evaluation Cooperation (WPEC) of OECD/NEA, the subgroup 35 (Scattering Angular Distribution in the Fast Energy) has started their activities in 2012. Integral benchmark tests in which the scattering data play important role are necessary for evaluation for these. In the present paper, benchmark calculations for reflector effects in fast cores are presented out by using the latest major evaluated nuclear data libraries, JENDL-4.0, ENDF/B-VII.1 and JEFF-3.1.2. In the benchmark tests, the FCA X-1 and -2 cores, the Joyo Mk-I and -II cores, the ZPR-3/53, -3/54 and the ZPR-6/10 cores were applied as comparable core sets with blanket and reflector. The FCA X-1 and X-2 cores were constructed at the Fast Critical Assembly (FCA) facility of JAEA for the mockup experiments of the Joyo Mk-II core. The FCA X-1 core was surrounded by depleted uranium blanket and the X-2 core by sodium and stainless steel reflector while the compositions of the two cores were identical. The Joyo Mk-I and Mk-II cores were constructed at the experimental fast reactor Joyo of JAEA. The Joyo Mk-I core was surrounded by UO2 blanket and the Mk-II core by stainless steel reflector. The ZPR-3/53, -3/54 and ZPR-6/10 cores were constructed at the Zero Power Reactor (ZPR) critical assembly of ANL. The ZPR-3/53 was surrounded by depleted uranium blanket and the ZPR-3/54 by iron reflector while the compositions of the two cores were identical. The ZPR-6/10 was surrounded by stainless steel reflector and the core composition was different from those of ZPR-3/53 and -3/54. We analyzed reflector effects by comparing the ratio of calculation to experimental (C/E) values of k_{eff} between the cores with reflector and blanket, e.g. the FCA X-1 and X-2 cores. The k_{eff} calculations were performed by using the continuous energy Monte Carlo code MVP. Sensitivity analyses were also done to specify the source of k_{eff} difference among the nuclear data libraries. Sensitivity coefficients were obtained by diffusion calculations using a generalized perturbation code, SAGEP. In the benchmark test for the FCA cores by JENDL-4.0, there are no dependence of the C/E values between the FCA X-1 (depleted uranium blanket) and X-2 (stainless steel reflector) cores. On the contrary, by ENDF/B-VII.1, there appears a significant underestimation for the FCA X-2 core with reflector. From the sensitivity analysis, the different behaviors of the C/E values between JENDL-4.0 and ENDF/B-VII.1 are due to the discrepancies of μ-bar of Cr-52 and Na, the elastic scattering cross-section of Fe-57, Ni-60 and Al. This paper presents the results of the other cores and the JEFF-3.1.2. Finally, recommendations to nuclear-data study are summarized on the scattering-related data evaluation.

PB 2 4:00 PM

Analysis of the Neutronic Properties of the Prototype FBR Monju Based on Several Evaluated Nuclear Data Libraries

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Research Institute of Nuclear Engineering, University of Fukui

In a recent study [1] an uncertainty analysis was presented for the criticality of the prototype FBR Monju using JENDL-4.0. In the course of the research for that paper, a considerable deviation was found for the reactivity as a function of which set of nuclear data was used. This deviation occurred in the analysis of Monju as well as in the analysis of benchmark experiments. In some cases, the deviation is larger than the expected error margins due to uncertainties in the nuclear data. The analyses of the neutronic properties of Monju published by JAEA were obtained using highly specific code systems using cross sections and covariance data that are specially adjusted for Monju, so in that sense it is not surprising that calculations with unadjusted data give different results. However, in general it would be desirable that evaluated nuclear data is of such a quality that adjustment for a specific application is not necessary. Besides, FBRs that are being designed for future applications, such as ASTRID (France) and JSFR (Japan) have design features for which no or very few experimental data are available. This means that a proper data adjustment is difficult or even impossible, and one may need (expensive) measurement campaigns to obtain enough experimental information to perform a proper data adjustment. To see how well modern nuclear data is capable of predicting the neutronic properties of an FBR, we are analyzing the prototype FBR Monju with the well-established ERANOS software. An automated system to generate cross sections and covariance data for ERANOS has been created. Monju was operated in 1994 / 1995 and 2010, and the 15-year shutdown period has caused considerable changes in the fuel composition (increase of Am-241). For the 1994 core and the 2010 core, we calculated the criticality, isothermal temperature coefficient, the effective delayed neutron fraction, etc, as well as the associated uncertainties. The goal of the work is to evaluate the performance of unadjusted, best-estimate nuclear data evaluations for fast reactor applications. Present study includes the FY2011 results of the “Core R & D program for the commercialization of the fast breeder reactor by utilizing Monju”, entrusted to the University of Fukui by the Ministry of Education, Culture, Sports and Technology of Japan (MEXT)
Corresponding author: Naoki Yamano
[1] P. Tamagno and W.F.G. van Rooijen, “Uncertainty Analysis of the prototype FBR Monju with the JENDL-4.0 nuclear data set”, accepted for publication in Annals of Nuclear Energy (2012).

PB 3 4:20 PM

Impact on Advanced Fuel Cycle and its Irradiated Fuel due to Nuclear Data Uncertainties and Comparison Between Libraries

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An adequate determination of safety and economical margins of nuclear systems relies directly on the uncertainties of nuclear data. One of the ANDES project objectives is to enhance the European capability to produce covariance data for isotopes which are important for advanced reactors, as identified from recent sensitivity studies on GEN-IV reactors and ADS. Thus, the new covariance data for nuclear reactions, radioactive decay and fission yields will be processed and used in reactor/fuel cycle codes to calculate their impact on advanced reactor and fuel cycle parameters such as EFIT. Different nuclear data libraries and sources of uncertainty will be compared, and also new fission yields covariance data generated under the

framework of ANDES project will be propagated and compared with other covariance data. The impact of the fission product nuclear data uncertainties on the inventory of the irradiated fuel will be analysed. Thus, a complete study of the importance of nuclear data uncertainties on advanced fuel cycle and inventory of irradiated fuel will be performed by using the ACAB code, which includes all the capabilities for nuclear data uncertainty propagation by a Monte Carlo approach. The research leading to these results has received funding from the European Atomic Energy Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n 249671, (FP7-EURATOM-FISSION-2009:Project ANDES/249671). Also, it has been partially supported by "Ministerio de Educación (Ministry of Education)" of Spain through the FPU Program for teaching and researching formation (Programa de Formación de Profesorado Universitario) under grant AP2009-1801 for the first author.

PB 4 4:40 PM

Sensitivity of the Shielding Benchmarks on Variance-Covariance Data for Scattering Angular Distributions

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The nuclear data libraries for neutron interactions recently made available (ENDF/B-VII.1 [1], JENDL-4.0 [2], JEFF-3.1.1 [3]) contain more and more variance-covariance data. These data focus on resonance parameters and cross sections reactions. However, for some nuclei, variance-covariance data on scattering anisotropy distributions are available. In this context, the TENDL-2011 [4] library is an exception because it contains uncertainties for all the nuclei. Furthermore, this library provides a set of 31 evaluations for each nucleus in agreement with uncertainties on nuclear data. In the case of shielding and propagation of neutrons in a material thickness, two types of data are important because they impact the neutron flux : the interaction cross sections and angular distributions (energetic distributions) of scattering reactions. The neutron flux of high energy (above $100keV$) is particularly important in these studies and cross sections from various libraries are in relatively good agreement taking into account uncertainties available in evaluations. For energies higher than $1MeV$, angular distributions of scatterings are increasingly anisotropic and significant differences appear between the various libraries. These uncertainties on the angular distributions should be correlated with the uncertainties on cross sections, which is unfortunately not the case. In this paper, we present the impact of uncertainties on scattering anisotropies on the propagation of neutrons in a bulk of iron, that is the ASPIS benchmark from the SINBAD Database [5]. For this, there are two possibilities: the use of 31 evaluations of ^{56}Fe from the TENDL2011 library or the use of covariance matrices available in several libraries. The first solution is the simplest to implement. It implies computation time and post processing for the analysis of results. The second solution requires the treatment of evaluation ahead of simulation code. The ERRORJ (from NJOY [6]) and PUFF [7] codes do not process extensively these informations. Therefore, we developed a module for processing such data. For application to neutron transport, we use the Monte Carlo code TRIPOLI-4 [8]. As expected, the variance-covariance data on angular distributions of scattering reactions have the greatest impact on the dosimeter of sulfur. Indeed, the reaction used has a threshold of about 1.6 MeV and this dosimeter is very sensitive on neutron fluxes between the threshold and 3.5 MeV, i.e. the range in which distributions become highly anisotropic and where the variance-covariance are significant.
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PB 5 5:00 PM

MCNP6 Fission Cross Section Calculations at Intermediate and High Energies

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MCNP6 has been Validated and Verified (V&V) against intermediate- and high-energy fission-cross-section experimental data. A previously unobserved error in the calculation of fission cross sections of ^{181}Ta and other nearby target nuclei by the CEM03.03 event generator in MCNP6 and a technical "bug" in the calculation of fission cross sections with the GENXS option of MCNP6 while using the LAQGSM03.03 event generator were detected during our current V&V work. After fixing both these problems, we find that MCNP6 using the CEM03.03 and LAQGSM03.03 event generators calculates fission cross sections in a good agreement with available experimental data for reactions induced by nucleons, pions, and photons on both subactinide and actinide nuclei (from ^{165}Ho to ^{239}Pu) at incident energies from several tens of MeV to about 1 TeV.

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Development Progress of the GAIA Nuclear Data Processing Software

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The *Institut de Radioprotection et de Surete Nucleaire* (IRSN), which provides technical support of the French nuclear safety authority, has started the development of a software tool called GAIA for nuclear data processing. This is motivated by specific nuclear data needs established by computations for nuclear safety assessment that cannot be always solved using existing processing codes. An example would be the treatment of energy dependent isomeric branching ratio data (taken from MF9 in the ENDF-6 format) required for depletion calculations. The objective of the new GAIA software is not only to address our current needs but also to anticipate future applications. A PhD focusing on resonance reconstruction with R-matrix theory and Doppler broadening has been initiated in 2011 as part of this work. To provide maximum flexibility, GAIA is being developed in C++ in an object-oriented way. Data extraction from the evaluated nuclear data files, resonance reconstruction, Doppler broadening, etc. are performed by independent modules. This object-oriented design also makes GAIA independent of the input formalism which is currently limited to ENDF-6 formatted files. The full paper will provide a general status of the development of GAIA and its validation before focusing on the concrete developments for resonance reconstruction and the Doppler broadening treatment. To provide maximum flexibility, GAIA is capable of reconstructing various resonances formalisms such as SLBW, MLBW, Reich-Moore and Adler-Adler in addition to the general R-matrix formalism. The reconstructed cross sections are compared with those generated by NJOY and PREPRO for which we observe a very good agreement. Several Doppler broadening strategies will be proposed and demonstrated, including the approach adopted by NJOY and PREPRO (by integrating a linearized cross section).

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Study of Nuclear Decay Data Contribution to Uncertainties in Heat Load Estimations for Spent Fuel Pools

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During and following the Fukushima events, a renewed in-depth assessment of the design and safety of spent nuclear fuel pools (SFP) at nuclear power plants was requested by all national regulators. Within this context, the Paul Scherrer Institut (PSI) supported the Swiss regulator to evaluate as function of cooling time, the expected fuel rod behaviour of a realistic modern BWR core stored in a SFP assuming a sudden loss of cooling capacity. As part of this, two independent depletion/decay codes and associated libraries were employed to estimate the heat loads, namely CASMO-5M with a special decay calculation option and ORIGEN-2.2. Although a satisfactory agreement between the codes was obtained for the total pool heat load, this was found to result from compensating effects, namely opposite trends in terms of predicted decay heat for fresh versus highly burnt assemblies. Moreover, for low to moderate burnups, the code agreement in terms of predicted activities was found to be consistent with the corresponding decay heat results. However, for high burnup fuel, opposite trends were obtained between activity and heat load estimations. This prompted the need to study in more details, the differences between the codes. In the context of cooling and decay calculations, the employed nuclear data libraries were obviously considered as the main first component to start these studies. Thereby, and partly in line with the renewed interest to review more closely nuclear data used for decay heat and source term estimations, the objective of this paper is to assess the impact of the employed nuclear data libraries on the results obtained by CASMO-5M and ORIGEN-2.2 for the given SFP configuration. To start, a comparison between both codes is presented, both for a complete depletion/decay calculation as well as for a decay-only analysis using the same initial nuclide compositions. Then, for the nuclides and associated decay chains identified as contributing mostly to the SFP heat loads, a review of the employed nuclear data (decay constants, energy-per-decay, branching ratios) is performed. In relation to this, a CASMO analysis is repeated using for the most relevant nuclides, decay data taken from the ORIGEN library. Thereby, the impact of these specific data versus other sources of differences, including numerical methods as well as other nuclear data, is isolated and quantified. As a last step, for the same nuclides, a review and comparison of decay data is conducted for a wide range of libraries, and from this, uncertainty ranges are estimated. These uncertainties are then propagated through stochastic sampling in CASMO-5M decay calculations. On this basis, the level of uncertainty in predicted heat load/activities is quantified and discussed in relation to the identified main contributors and associated uncertainty ranges.

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Preequilibrium Emission of Light Fragments in Spallation Reactions

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Emission of light fragments (LF) from various nuclear reactions is a scientifically interesting and open question. Different reaction mechanisms contribute to their production; the relative roles of each, and how they change with incident energy, mass number of the target, and the type and emission energy of the fragments is not completely understood. None of the available models are able to accurately predict emission of LF from arbitrary reactions. However, the ability to describe production of LF (especially at intermediate and high energies) from many reactions is important for different applications, such as cosmic-ray-induced Single Event Upsets (SEU), radiation protection, and cancer therapy with proton and heavy-ion beams, to name just a few. The CEM03.03 and LAQGSM03.03 event generators in MCNP6

describe quite well the spectra of fragments with sizes up to ^{4}He across a broad range of target masses and incident energies (up to $\sim$ 5 GeV for CEM and up to $\sim$ 1 TeV/A for LAQGSM). However, they do not predict well the high-energy tails of LF heavier than ^{4}He. Most LF with energies above several tens of MeV are emitted during the preequilibrium stage of a reaction. The current versions of the CEM and LAQGSM event generators do not account for preequilibrium emission of LF larger than ^{4}He. The aim of our work is to extend the preequilibrium model in them to include such processes, leading to an increase of predictive power of LF-production in MCNP6. Extending our models to include emission of fragments heavier than ^{4}He at the preequilibrium stage provides much better agreement with experimental data. Recent data measured by Hagiwara et al. at the National Institute of Radiological Science (NIRS) of Japan and by Goldenbaum et al. (the Proton Induced SpAllation (PISA) collaboration) at COSY (COoler SYnchrotron) of the Jülich Research Center are analyzed and compared with our results.

Session PC Nuclear Reaction Models
Thursday March 7, 2013
Room: Empire East at 3:30 PM
Chair: Roberto Capote, IAEA - NDS
PC 1 3:30 PM

Numerical Simulations for Low Energy Nuclear Reactions to Validate Statistical Models

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The statistical theories - the Hauser-Feshbach model with the width fluctuation correction - play a central role in studying nuclear reactions in the fast energy region, hence the statistical model codes are essential for the nuclear data evaluations nowadays. In this paper, we revisit issues regarding the statistical model calculations in the fast energy range, such as the inclusion of the direct channels, and the energy averaged cross sections using different statistical assumptions. Although they have been discussed for a long time, we need more precise quantitative investigations to understand uncertainties coming from the models deficiencies in the fast energy range. For example, the partition of compound formation cross section into the elastic and inelastic channels depends on the elastic enhancement factor calculated from the statistical models. In addition, unitarity of S-matrix constrains this partition when the direct reactions are involved. Practically some simple assumptions, which many nuclear reaction model codes adopt, may work reasonably for the nuclear data evaluations. However, the uncertainties on the evaluated cross sections cannot go lower than the model uncertainty itself. We perform numerical simulations by generating the resonances using the R-matrix theory, and compare the energy (ensemble) averaged cross sections with the statistical theories, such as the theories of Moldauer, HRTW (Hofmann, Richert, Tepel, and Weidenmueller), KKM (Kawai-Kerman-McVoy), and GOE (Gaussian orthogonal ensemble). The scattering matrix elements for the direct reactions are calculated with the CC (coupled-channels) model, and they are incorporated into the simulations. These calculations are also compared with the statistical Hauser-Feshbach model with the transmission coefficients calculated with the CC model, which is often employed in the nuclear data evaluations for actinides.

PC 2 4:00 PM

Theoretical Analysis of Gamma-ray Strength Function for Pd Isotopes

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The gamma-ray strength function (GSF) is one of the important elements to understand capture reaction process by fast neutrons. The GSF is directly determined from measured data of photonuclear reaction. However, information of the GSF below the neutron binding energy (BE) is not obtained from those data. In order to fix the GSF below the BE, it is effective to use the measured spectrum of gamma-rays emitted by neutron capture reaction, since the gamma-ray spectra are strongly affected by the GSF in the energy region. In this work the evaluation of GSF was carried out by using gamma-ray spectra and cross sections of neutron capture reactions for stable Pd isotopes and cross sections of photonuclear reaction for natural Pd. The former data were recently measured with an anti-Compton NaI(Tl) spectrometer at Tokyo Institute of Technology. Theoretical analysis was performed by applying CCONE code for nuclear reaction calculation. As a result, we derived GSF which reproduced the both data simultaneously. The cross section and gamma-ray spectrum for Pd-105 calculated on the basis of the GSF show a good agreement with the recently measured data. The cross section decreases from that of JENDL-4.0 by 8% in the keV energy region. This work was supported by JSPS KAKENHI Grant Number 22226016.

PC 3 4:20 PM

Statistical Properties of Nuclei by the Shell Model Monte Carlo Method

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The shell model Monte Carlo (SMMC) approach provides a powerful method for calculating microscopically the statistical properties of nuclei such as level densities in the presence of correlations. This method enables us to carry out calculations in model spaces that are many orders of magnitude larger than spaces that can be treated with conventional methods. We present a number of recent developments:
(i) *Heavy nuclei.* We extended the SMMC approach to heavy nuclei using spaces of dimension $\sim 10^{29}$ [1]. A conceptual challenge is whether a truncated spherical shell model can describe the proper collectivity observed in such nuclei and in particular the rotational character of strongly deformed nuclei. We have studied the crossover from vibrational (spherical) to rotational (deformed) nuclei in families of samarium and neodymium isotopes [2]. Such a crossover can be identified by the temperature dependence of $< \mathbf{J}^2 >$ where $\mathbf{J}$ is the total angular momentum. The latter observable and the state densities are found to be in good agreement with experimental results.
(ii) *Collective enhancement factors.* We have calculated the collective enhancement factors of level densities versus excitation energy [2], and found that the decay of vibrational and rotational enhancements is correlated with the pairing and shape phase transitions, respectively. (iii) *Odd-even and odd-odd nuclei.* The projection on an odd number of particles leads to a sign problem in SMMC. We developed a method to calculate the ground-state energy of a system with an odd number of particles that circumvents this sign problem and applied it to calculate pairing gaps [3].
(iv) *State densities versus level densities.* The SMMC approach has been used extensively to calculate state densities. However, experiments often measure level densities, in which levels are counted without including their spin degeneracies. A spin projection method [4] enables us to also calculate level densities in SMMC. We have calculated the level density of ^{162}Dy and found it to agree well with neutron resonance

and level counting data, and with the level density measured by the "Oslo" method [5]. This work was supported in part by the Department of Energy grant DE-FG-0291-ER-40608.

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The Theoretical Calculation of Actinide Nuclear Reaction Data

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Neutron-induced reactions on Actinides in the energy range below 200 MeV are of fundamental importance in the field of nuclear energy and nuclear transmutation. For example, these interactions dominate neutron generation and neutron transport in accelerator supported nuclear reactors, such as proposed accelerator driven systems. Knowledge of accurate neutron-induced fission cross sections is crucially important for the design of various reactor systems. On the other hand, since neutron, proton, deuteron, triton, and alpha-particle emission double differential cross sections and spectra provide a complementary information on prompt fission neutrons and nuclear reaction mechanisms, theoretical model calculation can provide more information about nucleus structure and nuclear reaction. All cross sections of neutron-induced reactions, angular distributions, double differential cross sections, angle-integrated spectra, prompt fission neutron spectra, γ-ray production cross sections and energy spectra are calculated by using theoretical models for n+^{232}Th, ^{233,234,235,236,237,238}U, ^{237}Np, ^{239,240,241,242}Pu, ^{241,242,243}Am at incident neutron energies from 0.01 to 200 MeV. The optical model, the unified Hauser-Feshbach and exciton model which included the improved Iwamoto-Harada model, the fission model, the linear angular momentum dependent exciton density model, the coupled channel theory, the distorted wave Born approximation and recent experimental data are used. The present consistent theoretical calculated results are in good agreement with recent experimental data for incident neutron energy 200 MeV. The evaluated data of neutron induced nuclear reaction from ENDF/B-VII, JENDL-4.0 are compared with present calculated results and existing experimental data. The calculated results are given in ENDF/B format.
Presenting author: Hairui Guo

PC 5 5:00 PM

Cluster Emission for the Pre-Equilibrium Exciton Model with Spin Variables

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Angular momentum variables have been added into the pre-equilibrium exciton model by Obložinský and Chadwick [1] to handle the equilibration process, nucleon- and γ-emissions. The emission of ligth clusters (complex particles), i.e. deuterons to α's, remained essentially intact by this effort. Our approach stems from the Iwamoto-Harada(-Bisplinghoff) model [2–4], generalized by us some years ago [5]. Having in mind the importance of nuclear deformation on the α emission, demonstrated by Blann and Komoto [6],

we follow the way initiated recently [7] and combine — though in a simplified manner — all the ingredients together. Finally, we illustrate our approach on some examples.

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Angular Momentum Distribution of Fission Fragments

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Accurate modeling of prompt neutron and gamma-ray emission depends strongly on the initial angular momentum of the fragments. However, no direct measurements of this quantity are available and, typically, it has to be extracted from other fission observables such as isomeric ratios [1], gamma-ray de-excitation feeding patterns of the ground-state bands [2] and angular anisotropy of prompt-fission gamma-rays [3]. The interpretation of measured isomeric ratios using statistical models [4] has been extensively used for the determination of initial angular momentum of primary fission fragments. In this work, we use the recently developed code CGMF [5], based on the Monte-Carlo Hauser-Feshbach approach, to simulate the de-excitation of fission fragments. The isomeric ratios of the selected fission products are calculated as a function of the initial angular momentum of the primary fission fragments, and compared with the available experimental data. Finally, our results are used in full scale simulations of the primary fission fragment de-excitation. Simulated prompt fission gamma-ray properties will be compared to recent experimental results on prompt fission gamma-ray energy and multiplicity distributions obtained at DANCE facility at LANSCE.

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Average Description of Dipole Gamma-Transitions in Hot Atomic Nuclei

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Statistical description of the gamma-transitions in atomic nuclei using the radiative strength functions (RSF) [1,2] is discussed. The practical semiphenomenological methods of the RSF calculations based on

excitation of the isovector giant dipole resonance (GDR) [1-3] are overviewed. New variant of modified Lorentzian approach [1,2] for calculation of electric dipole RSF is proposed and tested. In this approach, an RSF shape parameter ("energy-dependent width") is given as a function of the first quadrupole state energy in order to more properly taken into account nuclear structure peculiarities. New database and systematics for the GDR parameters [2,3] are used for the calculations of the energy-dependent widths. The excitation functions and gamma-ray spectrum from (n,xγ) reactions on middle-weight and heavy atomic nuclei are calculated with different RSF shapes to choice optimal expression for the RSF.
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On the Mechanism of Neutron Emission in Fission (2013)

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The Monte Carlo model for detailed calculation of the neutron emission in fission has been developed. The model is based on traditional assumption: formation of compound nucleus, decay to fission fragments, and neutron emission from exited FF after their total acceleration. Input parameters are: two dimensional distribution of fission fragments (FF) yield versus masses and total kinetic energy (TKE), masses and binding energies for all FF, absorption cross sections, level density (LD). The model is similar to well known LANL model [1]. The main difference is the application of LD instead of Weisskopf assumption (E*exp(-E/T)). This approach, and model for LD calculation were tested with neutron spectra in (p,n) reactions [2]. Additional tests were applied for verification of MC code: - neutron multiple emission, - energy-angular distribution with transformation from CMS to LS. Model outputs are: neutron spectra for any selected mass and TKE in Centre of Mass and Laboratory systems, neutron multiplicity versus FF masses and TKE, neutron energy-angular distribution in LS. The conclusion of [1] the present calculation suggest that there is no need for the extra neutron source - is very optimistic. The bulk of experimental data cannot be described in the frame of traditional model. The possible (most realistic) explanation is that main assumption is wrong. More than 35% of fission events in neutron induced fission of 235U at thermal point have another mechanism of emission than traditional one. This conclusion is rather interesting for basic science. However, it is very difficult to understand, can this fact explain existing difference between microscopic and macroscopic data? Old problem (more than 50 years) is still urgent now.
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Session PD Fission Yields
Thursday March 7, 2013
Room: Empire West at 3:30 PM
Chair: Herbert Faust, Institut Laue-Langevin
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Fission Activities Around the Lohengrin Mass Spectrometer

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The “Lohengrin” mass spectrometer is one of the forty instruments built around the reactor of the Institute Laue-Langevin (France) which delivers a very intense thermal neutron flux. Usually, Lohengrin was combined with a high-resolution ionization chamber in order to get good nuclear charge discrimination within a mass line, yielding an accurate isotopic yield determination. Unfortunately, this experimental procedure can only be applied for fission products with a nuclear charge less than about 42, i.e. in the light fission fragment region. Since 2008, a huge collaboration has started with the aim of studying various fission aspects, mainly in the heavy fragment region. For that, a new experimental setup which allows the isotopic identification by γ-ray spectrometry has been developed and validated. This technique was applied on the ^{239}Pu(n$_{th}$,f) reaction where about 65 fission product yields could be measured with an uncertainty that has been reduced on average by a factor of 2 compared to that previously available in the nuclear data libraries. The same γ-ray spectrometric technique is currently applied on the study of ^{233}U(n$_{th}$,f) reaction. Our aim is to deduce charge and mass distributions of the fission products and to complete the experimental data that exist mainly for light fission fragments. Lastly, the measurement of 41 mass yields from the reaction ^{241}Am(2n$_{th}$,f) has been also performed. One of the main motivations for this measurement is to determine whether there is a difference in mass and isotopic yields between the isomeric state and the ground state of ^{242}Am. In addition to these activities on fission yield measurements, various new nanosecond isomers were discovered. Due to the fact that some nanosecond isomers decay by a highly converted internal transition, their presence can be revealed from a strong deformed ionic charge distribution compared to a normal Gaussian shape. For some of these isomers, their half-life could be also estimated. Lastly, a new neutron long-counter detector (called LOENIE for LOng-counter with ENergy Independent Efficiency), designed to have a detection efficiency independent of the detected neutron energy has been built. Combining this neutron device with a Germanium detector and a beta-ray detector array allowed us to measure the probability to emit delayed neutrons (Pn) of some important fission products for reactor applications.

PD 2 4:00 PM

Conservation of Isospin in n-Rich Fission Fragments

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On the occasion of the 75th anniversary of fission phenomenon, we present a surprisingly simple result which highlights the important role of isospin and its conservation in neutron rich fission fragments. We have analysed and investigated the fission fragment mass distribution from two recent measurements using the heavy-ion reactions 238U(18O,f) [1] and 208Pb(18O,f) [2] along with the isobaric yields from the thermal neutron fission in the reaction 245Cm(n th.,f) [3]. We find that the conservation of total isospin explains the overall trend in the observed relative yields of fragment masses in each fission pair partition in a strikingly precise manner. The effect of shell structure becomes visible only at the magic numbers. The isospin values involved in the fission of heavy nuclei are very large making the effect dramatic. The fission fragments formed are highly neutron rich nuclei with the value of Tz = (N-Z)/2 becoming very large [4]. An important theoretical paper by Lane and Soper [5] emphasised the importance of this increase arguing that isobaric spin becomes a good quantum number in heavy nuclei. The large neutron excess has absolutely pure isospin and strongly dilutes the isospin impurity of the remaining part of the system with N=Z [4,5]. Our results indicate that the fission fragments and their relative intensities have already been decided even before the fission has occurred. The energy dependence of the fission fragments distribution will follow from the relative intensities of the different partitions which has to be obtained from detailed calculations. This opens the way for more precise calculations of fission fragment distributions in heavy nuclei. These findings may have far reaching consequences for the drip line nuclei, HI fusion reactions, and calculation of decay heat in fission phenomenon.

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Accurate Fission Data for Nuclear Safety

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The Accurate Fission data for Nuclear Safety (AlFONS) project aims at high precision measurements of fission yields, using the renewed IGISOL mass separator facility in combination with a new high current light ion cyclotron at the University of Jyväskylä. The 30 MeV proton beam will be used to create fast neutron spectra and possibly also thermal spectra, before reaching the fission target. Thanks to a series of mass separating elements, culminating with the JYFLTRAP Penning trap, it is possible to achieve a mass resolving power in the order of a few hundred thousands [1]. The successful operation of nuclear power plants shows that the current knowledge of the underlying nuclear physics processes is generally sufficient. Predictions of macroscopic reactor parameters with model codes, as well as calculations of the isotopic composition of spent nuclear fuel, are in reasonable agreement with reality. Nevertheless, more accurate nuclear data would improve, e.g., the predictions of fuel compositions and hence both safety and fuel economy. Furthermore, although the thermal neutron induced fission yield of ^{235}U is rather well known this is generally not the case for the fission yields of other actinides, e.g. ^{232}Th and ^{239}Pu, important in many Generation IV reactors. Therefore, reliable and accurate nuclear data is a key element for the successful development of Generation IV reactors. We will here present the experimental setup and scientific program of the AlFONS project in relation to existing and future reactor concepts.

[1] H. Penttilä, P. Karvonen, T. Eronen et al. "Determining isotopic distributions of fission products with a Penning trap." The European Physical Journal A 44 (2010) 147-168.

PD 4 4:40 PM

Fission Fragments Yield Measurement in Reverse Kinematics at GSI, the SOFIA Experiment

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Fragment yields and energy spectra are some of the most stunning observables in the nuclear fission process. At low excitation energy, they are ruled by nuclear structure properties. The Fission Fragment (FF) distribution exhibits, for most actinides, an asymmetric mass split, which has been studied since the discovery of the nuclear fission process. The SOFIA (Studies On FIssion with Aladin) experiment, performed in August 2012, aimed at measuring those quantities for the fission of a broad range of long- and short-lived actinides and lighter nuclei. We took advantage of the reverse kinematics technique at relativistic energies at the GSI (Darmstadt, Germany) facility to perform a high resolution experiment, where the mass number, the nuclear charge of both FFs together with the Total Kinetic Energy (TKE) could be measured. Secondary actinide beams produced at the FRagments Separator (FRS) induced electromagnetic fission in a uranium active target. All Fission Fragments were collected in a high efficiency recoil spectrometer designed by our collaboration and based on the use of the large acceptance ALADIN magnet. The performances of the developed detectors together with the nuclear charge and mass number resolutions will be detailed in my talk.

PD 5 5:00 PM

Experimental Neutron-Induced Fission Fragment Mass Yields of ^{232}Th and ^{238}U at Energies from 10 to 33 MeV

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Development of nuclear energy applications requires data for neutron-induced reactions for actinides in a wide neutron energy range. Here we describe measurements of pre-neutron emission fission fragment mass yields of ^{232}Th and ^{238}U at incident neutron energy from 8 to 33 MeV. The measurements were done at the quasi-monoenergetic neutron beam of the Louvain-la-Neuve cyclotron facility CYCLONE; a multi-section twin Frisch-gridded ionization chamber was used to detect fission fragments. For the peak neutron energies at 32.8, 45.3 and 59.9 MeV, the details of the data analysis and the experimental results were published in Ref.[1]. In this work we present data analysis in the low-energy tail of the neutron energy spectra. The preliminary measurement results are compared with available experimental data and theoretical predictions.

[1] I.V. Ryzhov *et al.*, Phys. Rev. C 83, **054603** (2011)

PD 6 5:15 PM

FALSTAFF : a New Tool for Fission Fragment Characterization

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FALSTAFF
Collaboration

The Neutrons for Science (NFS) facility will be one of the SPIRAL2 installations. The NFS time-of-flight hall will allow studying neutron-induced reactions for energies going from some hundreds of kev up to 40 MeV. Taking advantage of this new installation, the development of an experimental setup for a full characterization of actinide fission fragments in this energy domain has been undertaken. In the literature, fission fragment isotopic yields are scarce and neutron multiplicities are poorly known. All these data are of particular interest for the nuclear community in view of the development of the fast reactor technology and of reactors dedicated to the incineration of minor actinides. These arguments have motivated the development of a new detection system called FALSTAFF (Four Arm cLover for the STudy of Actinide Fission Fragments). Based on time-of-flight and residual energy technique, the setup will allow the simultaneous measurement of the complementary fragments velocity and energy. The necessary timing resolution will be obtained by using secondary electron detectors for the TOF measurement. Segmented Ionisation chambers will be placed behind the stop detector to measure the fragment residual energies. The nuclear charge and the kinetic energy of the two fragments in coincidence will be measured. The combined measurements of velocity and energy provide information on the mass of the fragments before and after the neutron evaporation. Neutron multiplicity as a function of the mass distribution may then be deduced directly from the difference between pre- and post-neutron masses. In this paper, the motivations for the FALSTAFF experiment will be presented. The experimental setup will be described and the performances of main detectors of FALSTAFF will be discussed. Expected resolutions based on realistic Geant4 will be shown. Preliminary results of a prototype experiment with a Cf source will be presented.

PD 7 5:30 PM

Measurements of the Mass and Isotopic Yields of the 233U(nth,f) Reaction at the Lohengrin Spectrometer

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Growing world energy consumption has renewed the interest in nuclear power. The rise of nuclear reactors implies the study of innovative systems that could rely not only on the currently used fuel cycle of Uranium-Plutonium (U-Pu), but also on the Thorium-Uranium (Th-U) one. The studies of different innovative fuel cycle aspects such as calculation of residual heat or poison concentration in the fuel, requires the knowledge of detailed isotopic and mass fission yields. An experimental campaign has been initiated within the frame of a collaboration between the Institut Laue-Langevin and French laboratories from CEA and CNRS to complete the existing data on fission products yields. This paper will present the analysis and the

definitive results of the measurements of the isotopic and mass fission yields for the 233U(nth,f) reaction performed at the Lohengrin recoil mass spectrometer of the ILL. The spectrometer separates the fission products according to their mass over ionic charge and kinetic energy over ionic charge. The mass yields were obtained with an ionisation chamber after separation by the spectrometer. The isotopic yields were determined with a different set-up composed of two high purity Germanium clover detectors that was placed subsequent to the spectrometer. An innovative analysis method developed for the Lohengrin spectrometer will be presented, where the final results happen to be independant from the previous evaluations, which is usually not the case. To provide experimental covariance data, detailed consideration has been given to the uncertainties and their correlations during the various experimental phases of this work.
Corresponding author: C. Sage

PD 8 5:45 PM

Precision Velocity Measurements of Fission Fragments Using the SPIDER Detector[1]

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Unit mass resolution of fragments from neutron-induced fission may be achieved if a fragment's energy and velocity can be measured to high enough precision. The SPIDER detector measures position and TOF using a system of thin carbon foils, electrostatic mirrors, microchannel plates, delay-line anodes, and a fast TDC to achieve the requisite precision for velocity. Tests have been conducted using spontaneous fission(^{252}Cf) and alpha (^{229}Th) sources. To date, timing resolution of 300 ps (FWHM) has been achieved corresponding to $< 1\%$ uncertainty in velocity measurements of fission fragments over a 50 cm flight path length. Optimization of the position and TOF portion of the SPIDER detector will improve the timing resolution. The most recent results will be presented and discussed. [1]Work supported by grants for LDRD Project 20110037DR.

Session PE Nuclear Physics Education
Thursday March 7, 2013
Room: Central Park East at 3:30 PM
Chair: Peggy Norris, Black Hills State University
PE 1 3:30 PM

The Stewardship Science Academic Alliance: A Model of Education for Fundamental and Applied Low-Energy Nuclear Science

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Nuclear structure, reaction and decay data have important applications in nuclear energy, national security, and nuclear medicine. National security applications can be broadly characterized as stewardship science and include homeland security, nuclear forensics, and non-proliferation, as well as stockpile stewardship. The Stewardship Science Academic Alliance (SSAA) was inaugurated 10 years ago by the National Nuclear Security Administration of the US Department of Energy to enhance connections between NNSA laboratories and the activities of university scientists and their students in research areas important to NNSA, including low-energy nuclear science. The SSAA supports the Stewardship Science Graduate Fellowships and a large number of individual investigator projects, including one Center of Excellence in low-energy

nuclear science. SSAA research directions in low-energy nuclear science include: neutron, gamma, and ion-induced reactions with stable and unstable nuclei, physics of the fission process, and properties of prompt fission products. The present talk would present an overview of how the SSAA activities help to educate early career low-energy nuclear scientists and prepare them for careers in applied and basic nuclear structure, reaction and decay studies. This work is supported in part by the National Nuclear Security Administration under the Stewardship Science Academic Alliances program through DOE Cooperative Agreement No. DE-FG52-08NA28552.

PE 2 4:00 PM

Educational Outreach Efforts at the NNDC

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National Nuclear Data Center, Brookhaven National Laboratory

The National Nuclear Data Center (NNDC) at the Brookhaven National Laboratory is well known for its work in storage and retrieval of neutron and non-neutron nuclear data and the dissemination of the Evaluated Nuclear Data File (ENDF) and the Evaluated Nuclear Structure Data File (ENSDF) as well as providing information on its web site and distributing the Nuclear Wallet Cards. In the last few years, NNDC has become involved in an outreach effort to the global scientific educational community. NNDC is involved in an international project to develop a Periodic Table of the Isotopes for the Educational Community in an effort to help illustrate the importance of isotopes in understanding the world around us. This effort should help teachers to better understand the concept of nuclides and isotopes and to aid them in introducing these concepts to students from the high school to the graduate school level. The print version of this project uses the framework of the Periodic Table of the Elements, which many teachers and students might recognize. The Table provides the usual information for each element plus a color-coded pie chart displaying all of the stable and radioactive isotopes that occur in terrestrial samples of that element found in nature. The isotopic abundance of each of these isotopes is depicted by the relative size of the pie slice associated with that isotope. The mass number of each isotope appears around the outside of the chart. Each mass number is shown in black for the stable isotopes and in red for radioactive ones. Auxiliary data available for each element includes a table of numeric information listing the isotopes with their atomic masses and isotopic abundances for those isotopes shown on each element's pie chart. In addition, all of the presently known isotopes for that element are displayed in one of three half-life ranges. To illustrate the importance of isotopes in our everyday life, there are descriptions of selected applications of stable and/or radioactive isotopes of each element provided in one or more of seven possible topic areas (industry, medicine, forensic science, earth and planetary science, etc.) There is a student's introduction available and a teacher's guide. An interactive, electronic version of this Table is presently in development. Future plans involve developing interactive digital learning objects (DLO) and teacher lesson plans to encourage those teachers who may know little about isotopes to introduce this subject to their students.

PE 3 4:20 PM

Recruitment and Retention of Students in the Nuclear Sciences: A Study of the Gender Gap Between Physics and Astronomy

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Megan L. Grunert
Western Michigan University, Department of Chemistry and Mallinson Institute for Science Education

The increasing need for nuclear scientists has been recently fueled by concerns over an aging nuclear arms stockpile and a failing economy that may be invigorated by developments in the STEM fields [1-2]. One aspect of promoting a pipeline of new researchers is ensuring constant recruitment and retainment of talented students into the field of physics. One group prime for recruitment makes up 57% of the US university population but only 18% of physics PhD students, women [3]. This is in comparison to the similar field of astronomy, which is comprised of 40% women at the PhD level [3]. This study will present results from a qualitative study, using PER methodology, investigating the gender gap between physics and astronomy. Implications for recruitment and retention will be discussed. Results suggest an emphasis on undergraduate mentoring and skill development are key to transition into graduate programs, while the facilitation of graduate student study groups, access to lab opportunities early in their programs, and a supportive faculty are key to student persistence.
[1] E.A. Hanushek, L. Woessman, & Organisation for Economic Cooperation and Development.The high cost of low educational performance: The long-run economic impact of improving PISA outcomes. OECD Publishing, (2010) [2] United States. Dept. of Defense, United States. Dept. of Energy, & United States. National Nuclear Security Administration. National security and nuclear weapons in the 21st century. Washington, D.C.: U.S. Dept. of Energy, [National Nuclear Security Administration], U.S. Dept. of Defense, (2008). [3] AIP Statistics (2012). http://www.aip.org/statistics/

PE 4 4:40 PM

Student Undifferentiated Views of Ionizing Radiation and Trouble With Atoms

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Black Hills State University

The Radioactivity By Inquiry Project is developing inquiry-based materials for teaching radiation literacy at the high school and college levels. Prior research on learning in physics found that students initially do not distinguish between radiation and the radioactive source. The undifferentiated view is that radiation is "bad stuff", that there is no difference between radiation and radioactivity, and that radiation causes contamination. To understand radiation students must distinguish between radiation and radioactive materials, understand atoms as sources and victims of radiation and ultimately view radiation as more of a process than a material. This talk will describe how we characterize students' initial and developing ideas about radiation, what seems to be necessary to understand radiation, and quantify student progress towards differentiation. We find that differentiating fully and abandoning the view of "radiation as stuff" involves a long and challenging process that some students find difficult to complete. This work is supported by NSF DUE grant 0942699. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

PE 5 5:00 PM

Comparing Knowledge Based Views of Pre-Service Teachers with Experts on Nuclear Physics

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Univeristy of South Africa

"Socio-scientific" issues normally have their basis in the sciences but involve forming opinions and making choices at personal or societal levels [1]. People are often either too worried or sometimes not worried due

to their lay conceptions on radiation and risk [2]. Reasons could be because debates on socio-scientific issues are presented in the media but often in an unscientific way and this could lead to society forming misconceptions about nuclear physics [1,2,3]. Our assumption is that student teachers who have more content knowledge will demonstrate a better understanding of radiation physics because they had been exposed to the topic for longer and in more depth. One way of assessing this assumption could be by extending the knowledge base of an experimental group (n = 25) by equipping them with knowledge on nuclear physics and comparing this to a control group (n = 36) who had no formal training on nuclear physics. These participants were all pre-service teachers because they would be teaching the next generation from a university in South Africa. Furthermore, 5 experts (2 nuclear energy engineers from industry and 3 professors in physics) were asked to complete the same questionnaire to use as yardstick. A questionnaire was used that was based on one developed by Colclough et al (2011) in their study to determine pre-service teachers' subject knowledge of and attitudes about radioactivity and ionizing radiation. All respondents had to answer the 25 questions comprising of a 6 point lickert scale and indicate the reasons for their answers. Only questions assessing knowledge of radiation in general and radiation applications (8 of the 25) were considered in this study. Questions such as "A nuclear power plant even in perfect working condition still emit dangerous levels of radiation to the environment; I would eat an apple that had been placed close to a radioactive source; I would not eat a banana that had been placed near to a radioactive source" were asked. It was found that the experimental group agreed in 6 of the 8 questions with the experts. The 2 questions that they disagreed upon was the latter and "X-rays used in medical diagnosis is a perfectly save form of radiation". The control group indicated that it would be safer to eat a banana rather than an apple because a banana is covered with a peel which could protect the food. Furthermore not even the experts had consensus on the issue of X-rays in a medical context. Their views differed because some considered the accumulated dose that a radiographer might be exposed to in their work. We acknowledge the fact that socio-scientific issues are very complex. From this limited study we disagree with the statement that "it is unlikely that traditional educational practice in which science is presented mainly as a factual system will properly equip the up-coming generation to make decisions about them" [1]. From the findings a critical level of knowledge would be an advantage to make informed choices. However, no generalisations can be made due to the limited sample and further investigation is needed on this topic. Furthermore, in the new South African curriculum nuclear energy aspects have been omitted and a similar trend is found in other countries.. "in most countries children are not presented with an accurate scientific explanation of radiation.."[3]. This raises a concern.
[1] Kilnic A Boyes E and Stanisstreet M 2012 Exploring students' ideas about risk and benefits of nuclear power using risk perception theories. J Sci Educ Technol DOI 10.1007/s10956-012-956-012-9390-z [2] Eijkelhof, H. M. C. 1996. Radiation risk and science education. Radiation Projection Dosimettry 68(3/4) 273-278 [3] Neumann S and Hopf M 2012 Students conceptions About Radiation: Results form and explorative interview study of 9th grade students. J Sci Educ Technol DOI 10.1007/s10956-012-956-012-9369-z [4] Colclough ND Lock R and Soares A 2011. Pre-service teachers' subject knowledge of and attitudes about radioactivity and ionising radiation. Int J Sci Educ 33 (3).423-446

PE 6 5:15 PM

Harmonization of Curricula in Nuclear Education: Could One Fit for All?

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In many cases, professional activities in the nuclear arena may differ as much as driving a car differs from riding a bike or piloting a plane. Accordingly, the development of a common academic background for different scientists - physicists, engineers, chemists, biologists, physicians, dentists, veterinarians, pharmacists and agronomists - enrolled in nuclear studies has been a challenge for academic boards of graduate programs. Taking a look at some institutes in Brazil [1] and abroad, we can identify nuclear graduate programs demanding only one compulsory course - workload from 60 to 90 hours to introduce and to form the foundation of Nuclear Sciences for a wide range of professional backgrounds. Consequently Nuclear Theory, its concepts and ideas have been briefly presented by this induction course which is intended to be a friendly comprehensible start for a heterogeneous student community. Additionally, following a current directive emphasized in the last years in many countries, graduate programs generically have limited coursework requirements in order to reduce the time expectation of earning degree. Occasionally deeper courses in Nuclear Theory have not been taught due to their non-compulsory status that has resulting in low demand, not enough to set up classes. The sum of these facts sometimes may hold back physicists, chemists and engineers to deepen their knowledge on specific matters of Nuclear Sciences especially those demanding significant skills on Differential Calculus and Physics. This discussion paper is intended to stimulate discussion and debate the lack of worldwide curricular guidelines for nuclear sciences students. Some curricular structures are presented and discussed. Furthermore, it presented some initiatives of the IAEA Nuclear Knowledge Management Subprogramme (NKM) to facilitating nuclear education, training and information exchange [2].

[1] Avelar A.C. Nuclear engineering education in Brazil: Review and prospects DOI: 10.1007/s10967-007-7282-8 Journal of Radioanalytical and Nuclear Chemistry, Vol. 279, No.1 (2009) 349-354 [2] IAEA International Atomic Energy Agency Status and trend in Nuclear Education IAEA Nuclear Energy Series No. Ng-T-6.1, Vienna, ISBN 978-92-0-109010-2. (2011) 227 pp.

Session PF Cross Section Measurements
Thursday March 7, 2013
Room: Central Park West at 3:30 PM
Chair: Heikki Pentilla, University of Jyvaskyla
PF 1 3:30 PM

Study of Nuclear Reactions Between ^{235}U Target and Proton or ^{3}He Beam at Low Energies

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Short-lived isotopes of Np and Pu, and especially the nuclides ^{236}Pu ($t_{1/2}$=2.858 y) and ^{235}Np ($t_{1/2}$=396.1 d), are convenient tracers e.g. for studying the distribution and the biological pathways of long-lived plutonium and neptunium released in the environment e.g. in nuclear accidents. Recently, the commercial availability of these isotopes has anyhow become limited. Our group has studied systematically the ways to produce different short-lived Np and Pu isotopes [1-2], in order to be able to prepare the needed tracers for our own use. For this purpose, it is important to have all the needed data to be able to select suitable irradiation conditions in case there are limitations either on target or beam availability, or special requirements on the radiochemical purity of the tracer. The studies have involved measuring cross sections of several direct and indirect reaction paths between $^{236,238}U$, ^{237}Np targets and p and 3He beams. In this work, we have used a set of highly enriched ^{235}U targets and have extended the study to ^{235}U(p,xn) reactions in the energy range of 6.5 - 16.1 MeV and $^{235}U(^{3}He$,xnyp) reactions in the energy range of 20.6 - 42 MeV. These reactions lead to radiochemically interesting short-lived actinides ^{236}Pu, ^{237}Pu, ^{235}Np, ^{234}Np, and ^{236m}Np. 1 mg/cm^2 thick ^{235}U targets stacked with energy-degrader foils were irradiated with protons using the accelerators in the Laboratory of Radiochemistry, University of Helsinki (cyclotron IBA10/5) and in the Accelerator Laboratory of Åbo Akademi University (cyclotron MCG-20), and with ^{3}He in the Accelerator Laboratory of University of Jyväskylä (cyclotron K130). After irradiation the targets were measured with gamma and alpha spectrometers. The measurements were followed by dissolution of the targets and chemical separation of fission products, neptunium and plutonium from the target material. The radioactivities of the chemically separated reaction products were measured and the reaction cross sections calculated. The data obtained from the experiment resulted in earlier unknown excitation functions on proton/^{3}He induced nuclear reactions in ^{235}U.

[1] J. Aaltonen, P. Dendooven, E.A. Gromova, S.-J. Heselius, V.A. Jakovlev, W.H. Trzaska, Radiochimica Acta 91 (2003) 557. [2] J. Aaltonen, E.A. Gromova, K. Helariutta, V.A. Jakovlev, W.H. Trzaska, J. Huikari, V.S. Kolhinen, S. Rinta-Antila, Radiochimica Acta 93 (2005) 377.

PF 2 4:00 PM

Measurement of 100- and 290-MeV/u Carbon Incident Neutron Production Cross Sections for Carbon, Nitrogen and Oxygen

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Heavy ion cancer therapy has been increased by reason of its clinical advantages. During the treatment, the secondary particles such as neutrons and γ-rays are produced by nuclear reactions of heavy ions incident on a nucleus in a patient's body. Estimation of the secondary neutron yield data is essential for assessment of radiation safety on both of workers and public in treatment facilities. Accurate data for neutrons with energy around 1 MeV is required because neutrons in this energy region have large relative biological effectiveness. We have measured the neutron yields from carbon ions incident on carbon, nitrogen and oxygen targets for neutron energies below 1 MeV in wide angular range from 15 to 90 degrees with 100- and 290-MeV/u. The experiment was performed at the PH2 course of Heavy Ion Medical Accelerator in Chiba (HIMAC), National Institute of Radiological Sciences. The 100- and 290-MeV/u carbon ion beams were delivered from the HIMAC synchrotron via a 0.5 mm thick NE102A plastic scintillator (beam monitor) to a target in order to monitor the number of incident carbon ions. The average beam intensity was 3- 5x10^5 ions/3.3sec. For carbon, an aluminum nitride and an aluminum oxide plates were used as targets. The target thicknesses were chosen for an incident carbon to deposit its energy of 10 - 15 % in the targets. Measurement using an aluminum plate as a target was also done to obtain components of neutron from aluminum element in AlN and Al_2O_3 targets. Three NE213 organic scintillators 12.7 cm thick and 12.7 cm in diameters were adapted to measure higher energy neutrons. And three NE213 scintillators 5.08 cm thick and 5.08 cm in diameter were applied for lower energy neutron measurement. An NE102A plastic scintillator was set in front of each NE213 scintillator to discriminate between charged and non-charged particles as a veto counter. Both size detectors were placed at 15, 30, 45, 60, 75 and 90 degrees. The neutron energy was measured by the time-of-flight (TOF) technique between the beam monitor and an NE213 scintillator. A measurement with 100 cm long iron bars between the target and each NE213 scintillator was also carried out to evaluate neutron contribution from the floor and other items in the experimental area. In data analysis, charged particle and γ-ray events were eliminated using light output spectra of veto counters and pulse shape discrimination for light output of NE213 scintillators, respectively. The light output spectrum of the beam monitor was analyzed to separate one carbon ion incident event from ones with two and more incident ones. The SCINFUL-QMD code was used to obtain the detection efficiencies of NE213 scintillators with consideration of neutron scattering effect by the aluminum case of the scintillator. By using the experimental data, the validity of the calculation results by Particle and Heavy ion Transport Code (PHITS) was examined. Application of the PHITS code for shielding design of heavy ion therapy facilities will be also discussed with the verification in the presentation.

PF 3 4:20 PM

Deuteron Induced Reactions on Rare Earths: Experimental Excitation Functions and Comparison with Code Results

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In the frame of our systematic investigation of excitation functions of light charged particle induced nuclear threshold reactions we recently studied deuteron reactions (up to 50 MeV incident energy) on rare earth targets. In nine stacked foil experiments, using the external 50 MeV deuteron beam of the CGR-960 cyclotron of the UCL (Louvain la Neuve, Belgium), the activation products of La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu were investigated. The production of radioisotopes with half-life longer than a couple of hours was assessed non-destructively (no chemical separation) by repeated high resolution gamma-spectrometry. Cross sections were calculated based on the general activation formula and with the irradiation data, target characteristics and measured activities as input parameters. All results are relative to recommended cross section values for monitor reactions on Al or Ti. Results for more than 100 residual activation products are obtained, including some medically or technically relevant radionuclides as 177Lu, 169Yb, 167Tm, 166Ho, 153Sm, 139Ce, 152,154Eu. Examples will be discussed and comparisons with the scarce literature data will be made. Most of the reactions are studied for the first time, especially in the higher energy domain. The experimental results are also compared with cross sections values predicted in blind calculation by theoretical codes. Apart from the on-line library TENDL-2011, based on the 1.4 version of the TALYS codes family, also the results obtained with the updated versions ALICE-D and EMPIRE-D (adapted for deuteron induced reactions) are presented. Although calculations can describe rather well now (d,xn) reactions, pathways where charged particles or clusters are emitted still show large discrepancies. This research is supported by FWO-Vlaanderen and the Hungarian Academy of Science.

PF 4 4:40 PM

Carbon Fragmentation Measurements and Validation of the Geant4 Nuclear Reaction Models for Hadrontherapy

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The use of heavy-ion beams in hadrontherapy is motivated by the highly localized dose distribution they provide at the end of the radiation range, i.e. the Bragg peak, and by the enhanced relative biological effectiveness with respect to photon or proton irradiation [1]. Thanks to these advantages, carbon beams are currently used in some hadrontherapy facilities around the world. However, as carbon nuclei penetrate the human tissues, they may undergo inelastic nuclear reactions leading to the production of secondary fragments. Such fragments generate a spatial dose distribution, inside and outside the tumor region, different from that of the primary beam and their different linear energy transfer results in a different biological effectiveness for the same delivered dose. All these effects arising from the carbon fragmentation have to be correctly evaluated when planning a tumor treatment. In treatment planning systems the only way to overcome the shortcomings of analytical calculations is the use of reliable Monte Carlo codes. However, the physical models used in the Monte Carlo codes need to be tuned and validated by experimental fragmentation data. Since a limited set of experimental fragmentation cross sections is available and in particular, to our knowledge, no double differential fragmentation cross sections at intermediate energies are present in literature, a systematic of high quality double differential cross section measurements is mandatory. In order to provide an extensive set of fragmentation data to benchmark the Monte Carlo codes for their use in hadrontherapy, we have studied the fragmentation of a ^{12}C beam at 62 AMeV on a thin Carbon target at the INFN - Laboratori Nazionali del Sud (LNS) in Catania. The double differential cross sections and the angular distributions of the secondary fragments have been measured over a wide angular range at intermediate energy. The availability of double differential fragmentation cross sections at intermediate energy is of particular interest in order to accurately predict the fluences of the secondary fragments and their angular distributions within the human tissues. Indeed, although therapeutic carbon beams have energies of the order of hundreds MeV/u, the carbon ions lose their energy passing through the patient's body so that the inelastic nuclear reactions may occur at energies much lower than the incident ones. Our measurements offer, therefore, a unique opportunity to test the performances of the nuclear reaction models implemented in the Monte Carlo codes for their use in hadrontherapy. In this contribution, together with the experimental results, we will also discuss the comparison between the measured fragmentation cross sections and the Geant4 [2] Monte Carlo predictions. In particular, two Geant4 nuclear reaction models, the Binary Light Ions Cascade and the Quantum Molecular Dynamic, have been compared and validated. Our results represent the first comparison of the Geant4 nuclear reaction models performed so far by using experimental data obtained with a thin target at intermediate energies. This work was supported by the Ion Beam Applications (IBA) company and by the European Space Agency (ESA) - tender AO6041.

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PF 5 5:00 PM

Measurement of Isomeric Yield Ratio for ^{nat}Sm(γ,xn)^{143m,g}Sm Reaction with Bremsstrahlung Energies

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We measured the isomeric yield ratio for the photonuclear reaction of ^{nat}Sm (γ,xn)^{143m,g}Sm by using the activation method with bremsstrahlung beam. The high purity natural Sm foil in disc shape was irradiated with beam of energy range from 40 to 60 MeV. The experiment was performed at the 100-MeV electron linac of Pohang Accelerator Laboratory. The induced activity in the irradiated Sm foil was measured by the high-purity germanium detector (HPGe) and the experimental data was analyzed through the Gamma Vision program. The present results are the first measurement at bremsstrahlung energies above the giant dipole resonance region and the obtained data was compared with the corresponding values found in the literature. The study of isomeric yield ratio is useful for understanding of nuclear reaction mechanism, approaching of nuclear structure and testing of theoretical nuclear models.
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PF 6 5:15 PM

New Measurements of the ^{241}Am(n,2n)^{240}Am Cross Section

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The study of ^{241}Am(n,2n)^{240}Am reaction is important as Am is one of the most abundant isotopes in the spent fuel cycle and one of the most highly radiotoxic among the actinides. Five recent works provide data from threshold to 20 MeV, with severe discrepancies among them in the energy region 10 to 12 MeV [1,5]. In order to resolve these discrepancies between the existing data, new measurements have been performed at the 5 MV Tandem T11/25 accelerator laboratory of NCSR "Demokritos," with a high purity Am target provided by JRC-IRMM, Belgium. Due to its high radioactivity (5 GBq), the Am target was placed inside a 3 mm lead cylindrical shielding and was irradiated with 10.4 and 10.8 MeV neutrons. Gamma-ray spectra were taken at a distance of 10 cm from a Ge detector, before and after the irradiation, to ensure that there is no contamination in the 987.8 keV photopeak from the decay of the ^{240}Am residual nucleus. The efficiency of the detection setup, including the extended geometry of the Am sample, was extracted by using two different techniques, an experimental and a simulated one. The cross section has thus been deduced with respect to the ^{27}Al(n,α)^{24}Na, ^{93}Nb(n,2n)^{92m}Nb and ^{197}Au(n,2n)^{196}Au reference reactions, implementing

the activation technique. This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.
Corresponding author: R. Vlastou
[1] A. A. Filatenkov and S. V. Chuvaev, Phys. At. Nucl. 63, 1504(2000). [2] R. W. Lougheed, W. Webster, M. N. Namboodiri, D. R. Nethaway, K. J. Moody, J. H. Landrum, R. W. Hoff, R. J. Dupzyk, J. H. McQuaid, R. Gunnink., Radiochim. Acta90, 833 (2002). [3] G. Perdikakis, C. T. Papadopoulos, R. Vlastou, A. Lagoyannis, A. Spyrou, M. Kokkoris, S. Galanopoulos, N. Patronis, D. Karamanis, C. Zarkadas, Phys. Rev. C 73, 067601(2006). [4] A. P. Tonchev, C. T. Angell, M. Boswell, A. S. Crowell, B. Fallin, S. Hammond, C. R. Howell, A. Hutcheson, H. J. Karwowski, J. H. Kelley, Phys. Rev. C 77, 054610 (2008). [5] C. Sage, V. Semkova, O. Bouland, P. Dessagne, A. Fernandez, F. Gunsing, C. Nastren, G. Noguere, H. Ottmar, A. J. M. Plompen, P. Romain, G. Rudolf, J. Somers, and F. Wastin. Phys. Rev.C 81, 064604 (2010).

PF 7 5:30 PM

Activation Cross Sections of Deuteron Induced Nuclear Reactions on Natural Titanium up to 24 MeV

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Activation cross-sections of the natTi(d,x)43,44m,44g,46,47,48Sc,48V nuclear processes were measured up to 24 MeV energy by using a stacked-foil activation technique in combination with HPGe γ-ray spectrometry using the AVF cyclotron of the RIKEN Wako Institute, Japan. The present data were compared with the theoretical calculations based on the TALYS and the Empire codes, and found only a partial agreement among them. The thick target integral yields, i.e., induced radioactivity per unit fluence of 24 MeV deuteron were also deduced from the measured cross-sections of the investigated radionuclides. Note that, natTi(d,x)48V cross sections find significance in monitoring of deuteron beam from thershold to 50 MeV. The present experimental results will play an important role in enrichment of the literature data base for deuteron-induced reactions on natural titanium leading to various applications.

PF 8 5:45 PM

Double Differential Cross Sections for Light-Ion Production from C, O, Si, Fe and Bi Induced by 175 MeV Quasi-Monoenergetic Neutrons

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Accelerator-driven incineration of nuclear waste may play an important role in future scenarios both in countries investing in the nuclear renaissance and in countries deciding to phase out nuclear energy. However, development of accelerator-driven systems requires new and more reliable neutron-induced cross-section data in the intermediate region from 20 to 200 MeV. In this energy region the entire structural properties of the target nucleus may participate in the nuclear reaction, and the nuclear data community expressed the need to obtain benchmark experimental data to improve present models and evaluated nuclear data libraries [1]. A series of neutron induced cross-section measurements at 96 MeV have been conducted at the The Svedberg Laboratory (TSL), Uppsala [2]. However, experimental data are still scarce above 100 MeV. In this perspective, we have measured cross-sections for light-ion production in the interaction of 175 MeV quasi-monoenergetic neutrons with C, O, Si, Fe and Bi. Measurements were conducted at TSL using the Medley spectrometer [3]. We will present inclusive double-differential cross-sections for production of protons, deuterons, tritons, ^{3}He and α-particles, at eight angles in the laboratory system, from 20 deg to 160 deg. Experimental data are compared with model calculations obtained with INCL4.5-Abla07, TALYS, a modified version of JQMD [4], and MCNP6. All models are able to reproduce the trends in the experimental data, however no approach gives a satisfactory representation of all cross sections data. The most crucial aspect is to describe the formation and emission of composite particles in the pre-equilibrium state. We will discuss reaction mechanisms and we will propose a modified version of the Kalbach systematics that improves TALYS results for proton- and neutron-induced reactions at energies above 100 MeV [5].
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Session QA Plenary Friday
Friday March 8, 2013
Room: Met East at 8:30 AM
Chair: Elizabeth McCutchan, NNDC - BNL
QA 1 8:30 AM

A Nuclear Data Project on Neutron Capture Cross Sections of Long-Lived Fission Products and Minor Actinides

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Japan Atomic Energy Agency
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We are performing a nuclear data project entitled "Systematic Study on Neutron Capture Reaction Cross Sections for the Technological Development of Nuclear Transmutation of Long-Lived Nuclear Wastes". The objective of the present project is to contribute to the improvement of nuclear data library, by making the precise measurements of neutron capture cross sections of Long-Lived Nuclear Wastes (LLNWs) such as Zr-93, Tc-99, Pd-107, I-129, Np-237, Am-241, Am-243, Cm-244, and Cm-246, analyzing the measured results theoretically, and supplying reliable calculated capture cross sections for the LLNWs. The measurements are being performed by using the Accurate Neutron-Nucleus Reaction Measurement Instrument (ANNRI) in the Materials and Life Science Facility (MLF) in the Japan Proton Accelerator Research Complex (J-PARC) as well as other facilities such as the Pelletron facility of the Tokyo Institute of Technology and the electron liner accelerator facility of the Kyoto University. The measured capture cross sections and gamma-ray spectra will be theoretically analyzed simultaneously. Finally, theoretical calculation will be performed for the LLNWs. This contribution presents the outline of the project, and individual results are presented by other contributions. This work was supported by JSPS KAKENHI Grant Number 22226016.

QA 2 9:15 AM

Minor Actinides, Major Challenges: The Need and Benefits of International Collaboration in Nuclear Data

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MANREAD is a co-ordinated research project of the IAEA Nuclear Data Section. It brought together experts in measurements of minor actinide nuclear data to assess the current status of the available experimental data, to summarize recent and stimulate ongoing and new measurements. Using key feedback from major recent minor actinide nuclear data evaluations from CIAE, IPPE, JAEA and Minsk, this comprehensive review allowed to identify major deficiencies in the experimental database, and areas where the accuracy of data is insufficient for applications. Prospects for improvement of nuclear data measurements were identified showing that important progress may be made with new facilities and with new experimental and measurement techniques. Alongside with this are new developments in nuclear modelling that will allow better predictions especially when benchmarked against new good quality measurements. It is expected that the final report will provide important guidance for new measurements and evaluations of minor actinide nuclear data. An overview will be presented of the contents of the project and the achievements of the various parts.
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Session RA Nuclear Fission
Friday March 8, 2013
Room: Met East at 10:30 AM
Chair: Ramona Vogt, ORNL
RA 1 10:30 AM

Fission Fragment Yield, Cross Section and Prompt Neutron and Gamma Emission Data from Actinide Isotopes

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The Institute for Reference Materials and Measurements (IRMM) has a long-standing tradition in fission fragment (FF) yield measurements. In recent years fission-fragment distributions of isotopes with vibrational resonances in the sub-threshold fission cross section have been investigated like ^{234,238}U [1,2]. Implementation of multi-modality in fission cross-section models may explain the connection between resonance structures and the observed FF yield fluctuations. For ^{234}U, the impact of the experimentally observed [3] and theoretically predicted [4,5] relative increased neutron multiplicity for the heavy fragments with higher incident neutron energies has been studied. The impact is found to be noticeable on post-neutron mass yields, which are the relevant quantities for a-priori waste assessments. The fission cross sections for ^{240,242}Pu at threshold and in the plateau region are being investigated within the ANDES project [6]. The results show some discrepancies (up to 12 %) to the ENDF/B-VII evaluation mainly for ^{242}Pu around 1 MeV, where the evaluation exhibits a resonance-like structure not observed in the present work. The requested target accuracy in design studies of innovative reactor concepts like Gen-IV is in the range of a few percent. In order to be able to respond to requests for measurements of prompt neutron and gamma-ray emission [7,8] in fission IRMM has also invested in setting up a neutron and gamma-ray detector array. The neutron array is called SCINTIA and has so far been tested with ^{252}Cf(SF). For gamma-ray multiplicity and spectrum measurements lanthanum- and cerium-halide detectors are being used, and first quantitative results for ^{252}Cf(SF)and ^{235}U(n$_{th}$, f) will be reported.
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RA 2 11:00 AM

Dynamical Scission Model

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The sudden approximation has been recently used to calculate microscopic scission-properties during the low-energy fission of ^{236}U [1,3]. The purpose of the present paper is to go beyond this mathematical approximation and consider the real physical situation in which the scission process, i.e., the transition

from two fragments connected by a thin neck (α_i) to two separated fragments (α_f) takes place in a short but finite time interval ΔT. For this we follow the evolution from α_i to α_f of all occupied neutron states by solving numerically the two-dimensional time-dependent Schrödinger equation with time-dependent potential. Calculations are performed for mass divisions from $A_L = 70$ to $A_L = 118$ (A_L being the light fragment mass). The exact duration of the neck rupture is unknown. ΔT is therefore taken as parameter having values from 0.25×10^{-22} to 9×10^{-22} sec. The resulting scission neutron multiplicities ν_{sc} and primary fragments' excitation energies E^*_{sc} are compared with those obtained in the frame of the sudden approximation (that corresponds to $\Delta T = 0$). As expected, shorter is the transition time more excited are the fragments and more neutrons are emitted, the sudden approximation being an upper limit. For $\Delta T = 10^{-22}$ sec, which is a realistic value, the time dependent results are 20% below this limit. For transition times longer than 6×10^{-22} sec the adiabatic limit is reached. The spatial distribution of the neutron emission points at scission is also calculated as function of the transition time ΔT. Together with the current density, it provides a detailed picture of the emission mechanism and a hint for the angular distribution of the scission neutrons with respect to the fission axis. Finally, the contributions of the light and of the heavy fragments to ν_{sc} and to E^*_{sc} are estimated.
[1] N. Carjan, P. Talou, O. Serot, Nucl. Phys. A **792**(2007) 102 [2] N. Carjan, M. Rizea, Phys. Rev. C **82** (2010) 014617 [3] N. Carjan, F.-J. Hambsch, M. Rizea, O. Serot, Phys. Rev. C **85** (2012) 044601

RA 3 11:20 AM

Investigating the Dynamics of Fission at High Excitation Energy in Reactions Induced by Relativistic Protons and Deuterons on Lead

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Several observables such us total fission cross sections, pre-saddle neutron and gamma emission or the measurement of the fission time using crystal blocking techniques show clear indications for a delay of fission at high excitation energies when compared to other de-excitation channels, namely particle evaporation [1]. This delay is explained as the manifestation of transient effects produced by the coupling between intrinsic and collective degrees of freedom in fission [2]. This coupling can be macroscopically understood as a dissipative process. Moreover, the investigation of proton induced fission on lead is relevant for the radiological characterization of spallation targets. In this work we will present measurements of total fission cross sections and charge distributions of the fission fragments produced in proton and deuteron on lead reactions at relativistic energies. The experiment was performed in inverse kinematics at GSI Darmstadt. Beams of lead ions were accelerated by the SIS18 synchrotron at 500 A MeV impinging then onto a liquid hydrogen/deuterium target. Projectile reaction residues, in particular fission fragments flying forward, were identified using a set of plastic scintillators and ionization chambers. Measured data were used to benchmark model calculations describing residual nuclei production in spallation reactions. In particular we used several model calculations to prove the sensitivity of the width of the charge distributions of the fission fragments to the temperature reached by the fissioning system at saddle. The deduced temperatures are clearly influenced by transient effects which cool down the fissioning nuclei from ground to saddle.
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[1] D. Jacquet and M. Morjean, Prog. Part. and Nucl. Phys. 63 (2009) 155 [2] P. Grangé, L. Jun-Qing and H.A. Weidenmuller, Phys. Rev. C 27 (1983) 2063

Session RB Benchmark and Testing
Friday March 8, 2013
Room: Met West at 10:30 AM
Chair: Marie-Anne Descalle, LLNL
RB 1 10:30 AM

Seeking Reproducibility in Fast Critical Assembly Experiments

Morgan C. White
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Critical assembly experiments have taken on a preeminent role in the understanding of nuclear data uncertainty quantification within simulations. Differential nuclear data, e.g. cross sections or emission spectra, often have uncertainties that lead to larger than desirable uncertainties in integral quantities in simulations, e.g. k-effective or activations. Further, correlations between differential data are difficult to establish and often unavailable. Critical assembly measurements typically provide much tighter constraints on the integral quantities of interest and add the missing correlations between the differential data. Given the importance of critical assembly measurements in providing the key constraints within many applications, it is vital to understand the uncertainties in these measurements. Unfortunately, many of the experiments were performed at a time when expectations were considerably lower then the goals of today, often 0.5% uncertainty in k-effective was adequate where 0.1-0.2% is now desired. Re-examination of articles and logbooks has shown the excellent work often done and led to modern benchmark evaluations near these desired accuracies. However, uncertain or even missing data have left questions whose time is gone. There are cases of remarkable consistency; the three key US, French and Russian bare plutonium assemblies provide confidence that we have a solid understanding of plutonium-239. It is thus more deeply troubling that the bare highly-enriched uranium (HEU) assemblies, where there are considerably more data, are discrepant substantially beyond the assigned uncertainties. This is most likely due to errors in accounting for or the reporting of experimental uncertainties but it raises the question of the overall reproducibility of the critical measurements. A proposal for a new high-precision HEU benchmark has been accepted and scheduled for completion in 2014 at the US National Critical Experiment Research Cernter (NCERC) with the design of this suite of experiments ongoing in 2013. These measurements will examine the reproducibility of the systematic uncertainties. Variations will attempt to examine systematic effects due to materials characterization, experimental repeatability, 1-D, 2-D and 3-D perturbations, and the influence of the experimental facility, e.g. assembly structure, detector systems and room return. A discussion of the planned experiments and analysis will be presented.

RB 2 11:00 AM

Benchmarking TENDL-2012

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At the end of 2012, the next version of the nuclear data library TENDL will be released. This version, TENDL-2012, will yet again include systematic improvements over the previous versions. The time is then ripe for extensive testing of this library using integral benchmarks, similar to the benchmarking that was performed for ENDF/B-VII.1, JENDL-4.0 and JEFF-3.1.1. This means that the next version of TENDL will be used in benchmark calculations for criticality safety, for shielding, and for the effective delayed neutron fraction. The calculations will be done in such a way that the results can be compared in the most

straightforward manner with the results obtained earlier for ENDF/B-VII.1, JENDL-4.0 and JEFF-3.1.1: the input decks will be identical, the version of MCNP will be identical, and the processing of the nuclear data will be identical. The only differences will be due to the nuclear data, and therefore all differences between the calculated benchmark results will be attributable to the nuclear data library having switched from, say, ENDF/B-VII.1 to TENDL-2012. The results of the calculations will be available in time for publication at the Conference in March 2013. The benchmarking will include more than 1900 criticality safety cases from the International Criticality Safety Benchmark Evaluation Project, ranging from low-enriched uranium, compound fuel, thermal spectrum ones (LEU-COMP-THERM), to mixed uranium-plutonium, metallic fuel, fast spectrum ones (MIX-MET-FAST). For fusion shielding many benchmarks were based on IAEA specifications for the Oktavian experiments (for Al, Co, Cr, Cu, LiF, Mn, Mo, Si, Ti, W, Zr), Fusion Neutronics Source in Japan (for Be, C, N, O, Fe, Pb), and Pulsed Sphere experiments at Lawrence Livermore National Laboratory (for ^{6}Li, ^{7}Li, Be, C, N, O, Mg, Al, Ti, Fe, Pb, D2O, H2O, concrete, polyethylene and teflon). The new functionality in MCNP to calculate the effective delayed neutron fraction was tested by comparison with more than thirty measurements in widely varying systems. Among these were measurements in the Tank Critical Assembly (TCA in Japan) and IPEN/MB-01 (Brazil), both with a thermal spectrum, and two cores in Masurca (France) and three cores in the Fast Critical Assembly (FCA, Japan), all with fast spectra.
Presenting author: A.J. Koning

RB 3 11:20 AM

Bayesian statistical analysis applied to NAA data for neutron flux spectrum determination

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In this paper, we present a statistical methodology to analyze the neutron activation data and to evaluate the neutron flux and its energetic distribution. The neutron activation analysis (NAA) technique was used to perform an absolute measurement of the neutron flux. Many samples containing a known amount of parent nuclei were irradiated at the TRIGA Mark II reactor of Pavia University (Italy) and the activation rate of a large number of isotopes was measured through gamma-ray spectroscopy with very low background HPGe detectors. In order to have an accurate determination of the activation rate, the measurements were repeated on different HPGe detectors and Monte Carlo codes based on GEANT4 were developed to evaluate the gamma detection efficiency for every radioisotope of interest.

Then the activation data of the different isotopes were combined to evaluate the energy spectrum of the neutron flux. For this purpose a system of linear equations, containing the group cross section data and the experimental results of the activation rate, should be solved. Since the coefficients and the parameters of this system are affected by experimental uncertainties, a rigorous statistical approach is fundamental to get the correct physics results.

The Bayesian statistical approach allows to solve this kind of problems by including the uncertainties of the coefficients and the a priori information about the flux. A program for the analysis of Bayesian hierarchical models, based on Markov Chain Monte Carlo (MCMC) simulations, is used to describe a statistical model of the problem and to determine the flux energy group distributions.

This methodology has been tested using the activation data acquired in two different irradiation facilities of the TRIGA reactor. The results presented in this paper show that this technique of analysis is promising, since it allows the evaluation of the flux energy groups and their uncertainties with great accuracy. The dependence of the results on the prior distribution choice and on the group cross section data was investigated, confirming the reliability of the analysis. Finally, the correlations between the different energy groups were evaluated, underlining the degree of information added by the experiment.

RB 4 11:40 AM

Verification of Current Version of ABBN Constants and CONSYST Code in Calculation of Criticality Benchmarks

Yury Golovko, Vladimir Koscheev, Gleb Lomakov, Gennady Manturov, Yevgeny Rozhikhin, Mikhail Semenov, Anatoly Tsiboulya, Andrey Yakunin

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The paper contains description of modern version of library of group constants ABBN which was prepared using NJOY from ROSFOND2010 evaluated nuclear data files and is assigned for calculations of models of perspective fast reactors. For verification of the ABBN constants Monte-Carlo calculations for many ICSBEP Handbook benchmark models were performed using continuous-energy and group-wise nuclear data and comparison with experimental data was made. For the comparison results of calculations using the previous version of constants ABBN-93 were also added. The main conclusion made from the results of comparison was that the methodical uncertainty caused by the applying the group-wise approach is less than 0.2%Δk/k.

Corresponding author: Gleb Lomakov

1.A.A. Blyskavka, G.N. Manturov, M.N. Nikolaev, A.M. Tsiboulia. "Multigroup Monte Carlo Code MMK-KENO," Preprint IPPE-3145, Institute for Physics and Power Engineering, Obninsk (2009). (In Russian.) 2."Multigroup Constant Set for Calculation of Neutron and Photon Radiation Fields and Functionals, Including the CONSYST2 Program," ORNL. RSICC DLC-182 (1995). 3.http://www-nds.iaea.org/exfor/endf.htm

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Session RC Nuclear Data Covariances
Friday March 8, 2013
Room: Empire East at 10:30 AM
Chair: Robin Forrest, IAEA
RC 1 10:30 AM

Applications of Nuclear Data Covariances to Criticality Safety and Spent Fuel Characterization

M. L. Williams, G. Ilas, W. J. Marshall, B. T. Rearden

Oak Ridge National Lab

During the last several years much advancement has been made in providing nuclear data covariances for nuclear technology applications. These advancements include new covariance evaluations released in ENDF/B-VII.1 [1] for many important nuclides, as well as more approximate "low fidelity" uncertainty data [2] for nuclides without covariance evaluations in ENDF/B nuclear data files. Using these resources, a comprehensive library of covariance data [3] has been developed for the SCALE code system. [4] This covariance library – along with the sensitivity/uncertainty (S/U) computation methods in SCALE – allow realistic uncertainty analysis of diverse types of applications. [5] Previously, most uncertainty analysis with SCALE has focused on determining uncertainties in the multiplication factor (keff) for criticality safety

applications. The SCALE S/U methodology was recently used in a comprehensive study to compute eigenvalue uncertainties for a large number of critical experiments. [6] In this paper we compare results obtained from uncertainty analysis using the SCALE nuclear data covariances, and the actual distribution of the computed benchmark multiplication factors. SCALE uncertainty analysis for critical eigenvalues is based on first order perturbation, which is a very efficient technique for determining the uncertainty in a single response (keff) for a fixed invariant system. At present this perturbation approach cannot be applied to burnup calculations where a large number of responses are of interest, and where the composition of the system (i.e., reactor) varies as a function of time due to non-linear interactions between the neutron flux and nuclide fields. A new method based on statistical sampling [7] has recently been developed for SCALE. When combined with a comprehensive covariance library, the statistical sampling method allows uncertainty analysis to be performed for reactor burnup calculations to obtain uncertainties in spent fuel responses, which are important for burned fuel transportation, on-site storage, and disposition. [8] Computed uncertainties are presented for time-dependent responses such as actinide and fission isotopics, decay heat, and decay activity, which depend on uncertainties in the nuclear data of many fission products and actinides.
[1] M. B. Chadwick, et al "ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data," Nuclear Data Sheets 112, 12, 2887-2996 (December 2011). [2] R. C. Little, et al., "Low-fidelity Covariance Project" Nuclear Data Sheets 109, 2828 (2008). [3] M. L. Williams and B. T. Rearden "Sensitivity/Uncertainty Analysis Capabilities and New Covariance Data Libraries in SCALE" Nuclear Data Sheets 109, 12, 2796-2800 (December 2008). [4] "SCALE: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design," ORNL/TM-2005/39, Version 6.1, Oak Ridge National Laboratory, Oak Ridge, Tennessee (June 2011). [5] B. T. Rearden, M. L. Williams, M. A. Jessee, D. E. Mueller, D. A. Wiarda. "Sensitivity and Uncertainty Analysis Capabilities in SCALE" Nuclear Technology 174, 236-288 (May 2011) [6] W. J. Marshall and B. T. Rearden, Criticality Safety Validation of SCALE 6.1, ORNL/TM-2011/450, Oak Ridge National Laboratory, Oak Ridge, Tenn., November 2011. [7] M. L. Williams, et al, "Development Of A Statistical Sampling Method For Uncertainty Analysis With Scale," PHYSOR 2012 - Advances in Reactor Physics , Knoxville, Tennessee, USA, April 15-20, 2012. [8] G. Ilas, I. C. Gauld, "Analysis of Uncertainty in Spent Nuclear Fuel Source Terms Due to Nuclear Data Uncertainties," Letter Report to Nuclear Regulatory Commission, ORNL/LTR-2012/34, Oak Ridge National Laboratory, (January 2012).

RC 2 11:00 AM

Pseudo-measure Simulations and Shrinkage for the Experimental Cross-Section Covariances Optimisation

S. Varet, P. Dossantos-Uzarralde, E. Bauge
CEA
N. Vayatis
ENS Cachan

It is well known that the experimental cross-section covariances play an important role in the evaluated cross-sections uncertainty determination (in particular in the generalized χ^2 minimisation). One can determine the experimental covariance matrix Σ from a classical uncertainty propagation formula and a detailed experimental process description. In particular, the determination of Σ requires the experimental parameters variances and covariances. However these data are rarely available. Another classical method is the Σ empirical estimator. However, most of the time, we only dispose on one measure per energy. Therefore the experiment repetitions aren't enough of them to use the classical empirical estimator. That's why we need to find alternatives for the Σ determination. Some of them, like kriging, consist in exploiting an *a priori* structure for the covariance matrix Σ. Nevertheless the imposed structure and the needed assumptions are not always realistic for cross-section measurements. In this general context our interest is focused on the construction of an efficient experimental covariance matrix estimator. Our approach is based on pseudo-measures simulations. To take into account the smoothness of the cross-section as a function of the energy, we simulate pseudo-measures as a gaussian noise centered on a SVM regression model. With the true measures and the pseudo-measures we can compute a Σ empirical estimator. We then quantify the obtained estimator quality with the help of a bootstrap approach. The problem is still that the estimation is not optimal. Thus, in order to optimize the resulting matrix, we have chosen to use the shrinkage approach. Indeed, the shrinkage approach consists in finding the optimal matrix (in the sense that it minimizes the error between the true matrix and its estimation) between the initial estimator and a target matrix that satisfies some properties we want to reach (invertibility, conditionning,...). All the results are illustrated with a toy model (where all quantities are known) and also with Mn^{55}_{25} cross-section measurements.

RC 3 11:20 AM

Inverse Sensitivity/Uncertainty Methods Development for Nuclear Fuel Cycle Applications

G. Arbanas, M. E. Dunn, and M. L. Williams
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The Standardized Computer Analyses for Licensing Evaluation (SCALE) [1] software package includes codes that propagate uncertainties available in the nuclear data libraries to compute uncertainties in nuclear application performance parameters (”responses”). We extend this capability to include an inverse sensitivity/uncertainty methodology that identifies the improved accuracy of nuclear data needed for computation of responses within their design tolerances. Because the cost of measuring and evaluating improved nuclear data is automatically optimized by this method, its application is expected to increase the effectiveness of nuclear data efforts. Our cost-minimization method combines differential and integral nuclear data measurements into a unified framework for the first time. Furthermore, it is directly applicable to thermal and intermediate neutron energy systems because it addresses the implicit neutron resonance self-shielding effects that are essential to accurate modeling of thermal and intermediate systems. Details of the inverse sensitivity/uncertainty methodology and its application will be demonstrated in the full paper. Notice: This abstract has been authored by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The U.S. Department of Energy Nuclear Criticality Safety Program sponsored the work that is presented in this paper.

[1] SCALE: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design, ORNL/TM-2005/39, Version 6.1, Oak Ridge National Laboratory, Oak Ridge, Tennessee, June 2011. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-785.

RC 4 11:40 AM

Generation of an S(α,β) Covariance Matrix by Monte Carlo Sampling of the Phonon Frequency Spectrum

Jesse C. Holmes, Ayman I. Hawari
Department of Nuclear Engineering, North Carolina State University, Raleigh, NC 27695 USA

Formats and procedures are currently established for representing covariance data in ENDF library files for many neutron reaction types. However, no standard exists for thermal neutron scattering cross section covariance data. These cross sections depend on the material dynamic structure factors, or S(α,β). The structure factors are a function of the phonon frequency spectrum, or density of states (DOS). Published ENDF thermal libraries are commonly produced by modeling codes, such as NJOY/LEAPR, which utilize the DOS as the fundamental input and directly output S(α,β) in ENDF format. To calculate covariances for the computed S(α,β) data, information about uncertainties in the DOS is required. The DOS is itself a PDF of available energy transfer quanta and can be determined by several methods. This work uses Hellmann-Feynman forces and lattice dynamics in the harmonic approximation to construct a dynamical matrix for natural silicon in α-quartz. The DOS is produced by randomly sampling wave-vectors (and their associated phonon frequency eigenvalues) in the first Brillouin zone [1]. By analysis of this methodology, the DOS can be parameterized pointwise into a set of random variables with a multivariate-PDF describing feature uncertainties in energy and in relative magnitude. This allows Monte Carlo generation of a set of perturbed spectra which can be sampled to produce the S(α,β) covariance matrix. With appropriate sensitivity matrices, the S(α,β) covariance matrix can be propagated to generate covariance matrices for integrated cross sections, secondary energy distributions, and coupled energy-angle distributions.
Corresponding author: Ayman I. Hawari
[1] B. D. Hehr and A. I. Hawari, "Calculation of the Thermal Neutron Scattering Cross Sections of α-Quartz (SiO_2)," PHYSOR-2008: *International Conference on the Physics of Reactors, Nuclear Power: A Sustainable Resource*, Interlaken, Switzerland (2008).

Session RE Nuclear Physics Education
Friday March 8, 2013
Room: Central Park East at 10:30 AM
Chair: Andy Johnson, South Dakota Center for Math and Science
RE 1 10:30 AM

The Davis-Bahcall Scholars Program: Instilling the Qualities of STEM Leadership in the Youth of South Dakota

Peggy McMahan Norris
Black Hills State University, Sanford Underground Research Facility

The Davis-Bahcall and Summer Science Scholars programs are summer enrichment opportunities for high-achieving 18- and 19-year-old students from South Dakota who are interested in Science, Technology, Engineering and Math (STEM) careers. The programs engage students during their transition from high school into the first two years of university. With the generous support of 3M Corporation, the state of South Dakota, South Dakota NSF EPSCoR, and the South Dakota Space Grant Consortium (funded by NASA), the program reached 70 students during its first four years of full operation in 2009-2012, plus a pilot phase in 2008. During the first four years of the program, various components of two-five week programs were tested, including:

- One-two week sessions at Sanford Underground Laboratory in Lead, SD
- One-week trips to the CERN and/or Gran Sasso laboratories in Europe
- One-two week programs at Fermilab or Brookhaven National Laboratory (Department of Energy laboratories)

- Three weeks academic study in physics at Princeton University, together with students from Italy
- Shorter visits to various laboratories and universities with projects in underground science or in nuclear and high energy physics

A serious effort has been made to maintain contact with the students as they progress through their undergraduate years, through the incentive of keeping them posted about internship opportunities. Surveys of all participants are conducted annually, achieving response rates above 50%. Students show a high level of interest and success in obtaining opportunities for undergraduate research either in their home institutions or in summer programs elsewhere. 67% of students in the most recent survey plan to attend post graduate school in science or engineering. In a state that does not have a university with a PhD program in physics, several students each year are pursuing physics majors with the intention of obtaining a PhD in physics outside of South Dakota. The first cohort of these students are now graduating from their undergraduate institutions and will be followed as they progress through graduate school.

RE 2 11:00 AM

Active Learning in Upper-Division Physics Courses

Charles Baily
University of Colorado at Boulder

There is substantial evidence from physics education research (PER) that introductory physics students learn and retain more when they are active participants in the classroom. Ongoing research at the University of Colorado and elsewhere has shown that upper-division students likewise benefit from the use of in-class "clicker" questions and other student-centered activities; and that active engagement in advanced physics courses can lead to increased learning (compared to standard lectures). This talk will address the why's and how's of transforming upper-division physics courses using research-based principles, and provide an overview of methods and resources available to instructors, with a particular focus on incorporating concept tests into advanced lectures.
Corresponding author: Bethany Wilcox

RE 3 11:20 AM

The Science of Nuclear Materials: A Modular, Laboratory-Based Curriculum

C.L. Cahill, W.J. Briscoe, G. Feldman
George Washington University, Washington, DC 20052, USA

We have developed a modular course for non-specialists, including laboratory activities, focused on the science of materials relevant to four primary areas: (a) the nuclear fuel cycle, (b) safeguards and security, (c) health and the environment, and (d) materials control and accounting. Our curriculum is "scenario-based" wherein real-world examples from each of the four focus areas (modules) drive the course content in terms of the fundamental scientific principles necessary to understand specific challenges. The hands-on laboratory component provides instruction in the basics of the instrumentation needed for these real-world scenarios, as well as an opportunity for guided inquiry, critical analysis, and problem solving in relevant situations. Our flexible course outline allows for multiple target audiences, including current GW students, incoming freshmen, and DC-based working professionals. The latter includes non-technical individuals within the nuclear security and safeguards arena, such as federal/state regulatory officials, national security policy

officials, industry representatives, and Congressional staff. In addition, we have instituted a rigorous plan for assessment, not only of student learning, but also of the sustainability of the course itself. We will present the outline of our course, as well as the details of the laboratory activities performed by the students. The results of our initial delivery of the course in the Fall 2012 semester will be discussed, including feedback from students and impressions from the instructors. This work was supported by NRC grant # NRC-HQ-11-G-38-0081.
Corresponding author: Gerald Feldman

RE 4 11:40 AM

What Students Think About Nuclear Radiation - Before and After Fukushima

Susanne Neumann
University of Vienna, Austrian Educational Competence Centre Physics

Preparing successful science lessons is very demanding. One important aspect a teacher has to consider is the students' previous knowledge about the specific topic. This is why research about students' preconceptions has been, and continues to be, a major field in science education research. Following a constructivistic approach [1], helping students learn is only possible if teachers know about students' ideas beforehand. Studies about students' conceptions for the major topics in physics education (e.g. mechanics, electrodynamics, optics, thermodynamics), are numerous and well-documented. The topic radiation, however, has seen very little empirical research about students' ideas and misconceptions. Some research was conducted after the events of Chernobyl (e.g. [2], [3]) and provided interesting insight into some of the students' preconceptions about radiation. In order to contribute empirical findings to this field of research, our workgroup has been investigating the conceptions students have about the topic radiation for several years (cf. [4]). We used children's drawings and conducted short follow-up interviews with younger students (from 9 to 12 years old) and more detailed interviews with 15-year-old students. In my talk, I would like to present our findings from the analysis of two sessions with 43 interviews each which we administered before and after Fukushima, respectively. Besides asking students about their general associations and emotions regarding the term radiation, we examined the students' risk perceptions of different types of radiation. Also, in open-ended questions we were able to detect students' conceptions about nuclear as well as other types of radiation that could be a hindrance to students' learning. Our results show that the students' associations with the term radiation are predominantly related to nuclear radiation. Their emotions concerning the word radiation are, to a high degree, negative and the idea that radiation, in general, is something harmful and bad is widely spread among students. Also, it seems to be very difficult for many students to combine the factual knowledge they learned in school (e.g. the three types of nuclear radiation and their properties) to the details they read in news reports about Fukushima. Since most students were not familiar with the idea of naturally occurring nuclear radiation, it does not seem surprising that a lot of them generally described radiation as something artificial and man-made. Also, none of the interviewed students reported applications of nuclear radiation in medicine or technology (besides its use in nuclear power plants). All of these results have shown to be even more extreme in the interview session that was conducted after the tragic events of Fukushima. As some of the students' conceptions seem to be inconsistent with the scientific concepts, we will also include suggestions for improving the teaching of the topic radiation in school.
[1] Duit, R., Treagust, D., & Widodo, A. (2008). Teaching science for conceptual change: Theory and practice. International handbook of research on conceptual change, 629-646. [2] Lijnse, P. L., Eijkelhof, H. M. C., Klaassen, C. W. J. M., & Scholte, R. L. J. (1990). Pupils' and mass-media ideas about radioactivity. International Journal of Science Education, 12(1), 67 - 78. [3] Verplanken, B. (1989). Beliefs, attitudes,

and intentions toward nuclear energy before and after Chernobyl in a longitudinal within-subjects design. Environment and Behavior, 21(4), 371-392. [4] Neumann, S., & Hopf, M. (2012). Students' Conceptions About 'Radiation': Results from an Explorative Interview Study of 9th Grade Students. Journal of Science Education and Technology, 1-9. doi: 10.1007/s10956-012-9369-9

Session RF Safeguards and Security
Friday March 8, 2013
Room: Central Park West at 10:30 AM
Chair: Krzysztof Rykaczewski, ORNL
RF 1 10:30 AM

Determination of the Sensitivity of the Antineutrino Probe for Reactor Core Monitoring

S. Cormon, V.M. Bui, M. Fallot, M. Estienne, A. Cucoanes, M. Elnimr, L. Giot, J. Martino, A. Onillon, A. Porta, F. Yermia, A.-A. Zakari-Issoufou
SUBATECH, CNRS/IN2P3, Université de Nantes, Ecole des Mines de Nantes, F-44307 Nantes, France

During the last years, world-wide efforts have been devoted to the research and development of a potential innovative safeguards tool: reactor antineutrino detection. The idea was born in the seventies from particle physics experiments that reactor antineutrinos could not only been used as a particle source for fundamental studies, but also could be used as a monitoring tool, as their properties reflect the fuel composition of a reactor core. The direct relationship between the antineutrino flux and energy spectrum at reactors and their power and fuel content has been demonstrated by reactor antineutrino experiments in the eighties and nineties. Recently "small" antineutrino detectors (less than 1t of liquid scintillator target) have been developed and have demonstrated a possible monitoring with a very simple detector placed at 25m from a PWR. Other detector design initiatives were born since then, and other safeguards-devoted experiments are taking data. In parallel, sophisticated simulations of reactors and their associated antineutrino flux have been developed to predict the antineutrino signature of fuel burnup and of a diversion. This prospective simulation work is complementary to the R & D of detection techniques. In order to determine how the antineutrino probe could be part of the future surveillance procedures, the characteristics of the antineutrino emission of all nuclear reactor designs have to be assessed. They will serve as well to determine the sensitivity goal of future antineutrino detectors devoted to reactor monitoring. The IAEA expressed its interest in the study of the performances of the antineutrino technique for safeguarding actual and future reactors, with emphasis on on-load reactors. To this aim we have started to study different reactor designs with our simulation tools. We use a package called MCNP Utility for Reactor Evolution (MURE), initially developed by CNRS/IN2P3 labs to study Generation IV reactors. The MURE package has been coupled to fission product beta decay nuclear databases for studying reactor antineutrino emission. This method is the only one able to predict the antineutrino emission from future reactor cores, which don't use the thermal fission of ^{235}U, ^{239}Pu and ^{241}Pu. It is also the only way to include off-equilibrium effects, due to neutron captures and time evolution of the fission product concentrations during a reactor cycle. We will present here the first predictions of antineutrino energy spectra from innovative reactor designs (Generation IV reactors). We will then discuss a summary of our results of non-proliferation scenarios involving the latter reactor designs, taking into account reactor physics constraints.

RF 2 11:00 AM

Prototype Neutron Portal Monitor Detector

Walter Schier
Department of Physics and Applied Physics, University of Massachusetts Lowell, Lowell, MA 01854

A very large drum-shaped neutron detector is being developed as a possible substitution for the standard Helium-3 Neutron Portal Monitor. Detection is based on the $^{6}Li(n,^{3}H)^{4}He$ reaction. The ^{6}Li is evaporated onto metal plates then covered with 8.5 x 10.5 inch ZnS(Ag) scintillation sheets and sealed about the edges. Approximately 40 detector plates will be arrayed in the 30-inch diameter light-tight drum-housing and viewed by a single 8-inch hemispherical photomultiplier tube without using light guides. Light collection tests are performed with a ^{210}Po alpha source on a ZnS(Ag) disk. Neutron detection studies include neutrons from a PuBe source and from the $^{7}Li(p,n)$ reaction at the UMass Lowell 5.5 MV CN van de Graaff accelerator.

RF 3 11:20 AM

Analysis of Pu Isotope in Melted Fuel by Neutron Resonance Transmission: Examination by Linear Absorption Model

F. Kitatani, H. Harada, J. Takamine, M. Kureta, M. Seya
Japan Atomic Energy Agency

Feasibility study of neutron resonance transmission analysis (NRTA) has been started to quantify nuclear materials in particle-like debris of melted fuel formed in severe accidents of nuclear reactor such as Fukushima Daiich nuclear power plants. The achievable measurement accuracy was examined by NRTA using a linear absorption model for the sample in which substances other than nuclear fuel materials, such as boron, were contained. In this study, boron and iron were considered to be contained in spent nuclear fuel as impurities. The D-T neutrons slowed down by a polyethylene moderator were considered to be used for NRTA. The neutron spectrum was calculated by Monte Carlo simulations. The neutron flight path is 5 m, that is the length between the neutron source and a neutron detector. Neutron absorption spectra were calculated using the total neutron absorption cross-section by JENDL-4.0. The absorption spectra together with their errors were evaluated. The achievable accuracy of Pu isotopic density was deduced as a function of neutron intensity and impurity density. This research was supported by JSGO/MEXT.

RF 4 11:40 AM

Reactor Monitoring with a Short Baseline Neutrino Detector

Yeongduk Kim, HANARO SBL collaboration
Sejong University, Korea

We plan to build a 500-liter liquid scintillator near to the core of HANARO research reactor in Korea. The reactor thermal power is 30MW. The purpose of the detector is two-fold: to investigate the postulated reactor neutrino oscillation at short baseline and to study reactor monitoring with a neutrino detector. The detector will have little overburden, and will be tested off-site from the reactor. Prior to 500-liter detector, we will construct a proto-type detector of 50-liter, and Gd and 6Li neutron capture will be compared with respect to background reduction. The proto-type detector will be used to minimize the background events with an identical depth of overburden. In this way, we can make sure that we can measure the reactor neutrinos with a significant signal to background ratio. Simulations on the neutrino energy spectra from various models on the fission rates will be presented.

Poster Session
PR 1

Pinning Down Uncertainties via Systematic Trends

M. G. Bertolli, T. Kawano, H. Little, *Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA.*

The calculation of neutron capture cross sections in a statistical Hauser-Feshbach [1] method has proved successful in numerous astrophysical applications. Of increasing interest is not only the calculated Maxwellian averaged cross sections (MACS) itself, but the associate uncertainty. Aspects of a statistical model that introduce a large amount of uncertainty are the level density model, γ-ray strength function parameter, and the placement of E_{low} – the cut-off energy below which the Hauser-Feshbach method is not applicable. The pre-equilibrium process has no impact on MACS for astrophysical energies, and so uncertainties for this are neglected. Utilizing the Los Alamos statistical model code $\mathtt{CoH_3}$ [2] we investigate the appropriate treatment of these sources of uncertainty via systematics of nuclei in a local region for which experimental or evaluated data is available. We will demonstrate the results of the investigation as a meaningful prescription in the statistical treatment of nuclei for which there exists little or no evaluated data for capture reactions, as well as for some nuclei for which data in the various evaluated libraries exhibits large differences. In order to show the impact of uncertainty analysis on nuclear data for astrophysical applications, these new uncertainties will be propagated through the nucleosynthesis code NuGrid [3]. This work was supported by the U.S. Department of Energy under contract DE-AC52-06NA25396.
[1] W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952). [2] T. Kawano, P. Talou, M. B. Chadwick, T. Watanabe, J. Nucl. Sci. Technol., **47**, 462 (2010). [3] F. Herwig, M. E. Bennet, S. Diehl, C. L. Fryer, R. Hirschi, A. Hungerford, G. Magkotsios, M. Pignatari, G. Rockefeller, F. X. Timmes, and P. Young, *"Nucleosynthesis simulations for a wide range of nuclear production sites from NuGrid"* in Proc. of the 10th Symp. on Nuclei in the Cosmos (NIC X), 23 (2008). http://www.astro.keele.ac.uk/nugrid.

PR 2

Are Meteorite Impacts Nuclear Events?

Richard B. Firestone, *Lawrence Berkeley National Laboratory, Berkeley, CA 94720.*

Global radiocarbon abundance has long been presumed to be in equilibrium between its production by cosmic rays and its β^--decay with a half-life of 5730 years. This formed the basis of radiocarbon dating, first developed by Libby[1] in 1949. Soon after it was discovered, by comparison with tree ring data, that there was substantially more radiocarbon in the past than today. This led to the measurement and evaluation of the IntCal[2] radiocarbon calibration curves, based on tree ring and marine sediment data for the past 50 kyr, for the correction of radiocarbon dates to calendar dates. I have shown[3] that the large increases global radiocarbon are mainly attributed to the explosions of four supernovae, ¡250 pc from earth, 44-, 37-, 32-, and 22-kyr ago. Another large increase is observed in the global radiocarbon record about 13 kyr ago, but this increase lacks the unique temporal signature of the earlier supernovae. This event coincides with the Younger Dryas (YD) extraterrestrial impact that is postulated to have caused the extinction of the mammoths and other megafauna and the sudden onset of a 1300 year period of global cooling[4]. Radiocarbon dating of numerous carbon samples taken from the YD impact layer gave anomalously young dates, sometimes hundreds of years into the future, despite indisputable stratigraphic evidence that they are about 13 kyr old. Similar, albeit smaller, increases in radiocarbon are also observed in the radiocarbon record coincident with the Tunguska (1908 AD), Japan (775 AD), Dark Ages (536 AD), and Great Flood (2807 BC) impacts. Meteors and comets travel at velocities 10-70 km/s impacting with sufficient energy to

initially raise temperatures to ¿10^7K at the impact site, well above the temperature necessary to sustain nuclear fusion. If the impact site were sufficiently hydrogenous, neutrons produced by D+D fusion could induce ^{14}N(n,p)^{14}C, enriching the radiocarbon abundance in the impact plume. In this talk I will compare the amount of ^{14}C that was produced globally at the time of the YD impact with calculated production rate if the impact occurred in water. This work was performed under the auspices of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.
[1] W. F. Libby, E. C. Anderson, and J. R. Arnold, Science 109, 227-228 (1949). [2] P.J. Reimer et al., Radiocarbon 51, 1111-1150 (2009). [3] R.B. Firestone, Evidence of four prehistoric supernovae <250 pc from Earth during the past 50,000 years, American Geophysical Union Fall Meeting, 14-18 December 2009, San Francisco, CA, paper PP31D-1386. [4] R.B. Firestone et al, Proceedings of the National Academy of Science 104, 16016-16021 (2007).

PR 3

The NeuLAND Detector for Studying (γ, n) Reactions for the Astrophysical s-process

Claudia Lederer, on behalf of the R3B collaboration (GSI), *Goethe University of Frankfurt, Germany.*

The key nuclear physics inputs for studying the astrophysical s-process are neutron capture cross sections. In general, such cross sections can be measured via the time-of-flight, or the activation technique. Some nuclides of interest, however, cannot be accessed by such direct measurements. This situation applies, when the nuclide is not long-lived enough to produce suitable amounts of sample material to be used in a direct measurement. In such cases the process can be studied indirectly by high energy (γ, n) breakup reactions in inverse kinematics. I will present the measurement of (γ, n) reactions at the LAND/R3B setup at GSI Darmstadt, focussing on the recent development of the high resolution fast neutron detector NeuLAND. This detection system will allow measurements of the (γ, n) channel with unprecedented accuracy and thus provide important information about neutron capture cross section on radioactive species in the astrophysically interesting energy regime.

PR 4

Nuclear Data Processing and Dissemination Efforts for Nuclear Astrophysics at ORNL

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At research facilities around the world, nuclear astrophysics measurements are being made with radioactive and stable beams to enhance our understanding of the evolution and explosion of stars and their creation of elements. For these extensive data to be effectively used in astrophysical simulations, they must be evaluated, processed, and disseminated to the community. As the amount of data acquired in this field increases, there have been efforts to streamline these processes. One example is an online software system, the Computational Infrastructure for Nuclear Astrophysics (CINA). Utilized by researchers in 126 institutions and 29 countries, CINA can generate thermonuclear reaction rates from nuclear data input, incorporate rates into libraries, and run and visualize astrophysics simulations with these libraries. CINA, freely available online at nucastrodata.org, consists of a suite of codes which provide data processing, management, visualization, and dissemination capabilities, as well as workflow management. We will describe some of these features of CINA with examples of reaction rate calculations, simulations, and disseminations.

PR 5

Low Level Densities of Exotic ^{131,133}Sn Isotopes and Impact on r-process Nucleosynthesis

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Neutron capture rates on unstable nuclei near the doubly-magic exotic ^{132}Sn were recently shown to significantly impact the synthesis of heavy elements in the r-process in supernovae [1]. These rates are usually determined from cross sections estimated with statistical models employing a Fermi gas level density formulation. Such an approach is only valid if the density of levels in the compound nucleus is sufficiently high. We examine the validity of this assumption for neutron capture on ^{130,132}Sn by making self-consistent calculations of single-particle bound and resonant levels in ^{131,133}Sn using the analytical continuation of the coupling constant (ACCC) based on a relativistic mean field (RMF) theory with BCS approximation. Knowledge of bound states with a strong single particle nature can be used to calculate direct neutron capture, and information on single particle resonances above the neutron capture threshold can be used to determine the level density for statistical models – as well as to calculate capture into individual resonances. Our RMF+ACC+BCS model predicts four strong single-particle bound levels in both ^{131,133}Sn with an ordering that agrees with recent transfer reaction experiments [2,3] and spacings that, while differing from experiment, are consistent between the Sn isotopes. In ^{131}Sn and ^{133}Sn, we also find at most one single-particle level in the effective energy range for neutron captures in the r-process – a density of levels too low for widely used traditional statistical model treatments of neutron capture cross sections on ^{130,132}Sn employing Fermi gas level density formulations. This work was supported by: US Dept. of Energy, Office of Nuclear Physics; the Joint Institute for Heavy Ion Research at ORNL; Topical Collaboration on Theory of Reactions for Unstable Isotopes (TORUS); National Natural Science Foundation of China; Beihang New Star; International Science and Technology Cooperation Projects of China; and Fundamental Research Funds for Central Universities of China.

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PR 6

KADoNiS: The Astrophysical p-process Database

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The KADoNiS (Karlsruhe Astrophysical Database of Nucleosynthesis in Stars) project is an online database (www.kadonis.org) for cross sections relevant to the s-process and the p-process. The nuclei heavier than iron are mainly produced by two neutron capture process, the so- called s- and r-processes. However, less than 1% of the heavy elements on the proton rich side of the valley of stability cannot be reached by neutron captures. These are the so called "p-nuclei," which are mainly produced by the "γ-process." This proceeds through gamma induced reactions on s- and r- seed nuclei in O/Ne burning shells of exploding massive stars. Modern astrophysical network calculations involving thousands of isotopes and ten thousands of reactions cannot fully reproduce the observed solar abundance of all p-nuclei, which led to the conclusion that the p-nuclei are produced by a superposition of different processes. Only a fraction of these reactions are

known experimentally, whereas the rest has to be inferred from statistical model calculations. Experimental proton- and alpha- induced reaction cross sections in the valley of stability can be used to finetune the statistical model calculations and make them more reliable for the extrapolation into the unknown regions. Up to now no compilation for the heavy charged particle reactions exists. For the p-process database of the KADoNiS project all available experimental data from (p,γ), (p,n), (p,α), (α,γ), (α,n) and (α,p) reactions in or close to the respective Gamow window were extracted from the EXFOR database. Our aim is to provide a user-friendly database based on the KADoNiS framework, where experimental data can be compared with state-of-the-art Hauser-Feshbach calculations. The p-process database of KADoNiS is especially useful for experimentalists to easily find and compare the existing data. It can be also useful for theoreticians to check the reliability of their calculations. We will give an overview about the p-process part of the KADoNiS project and present the status and improvements. T.Sz. and is Zs.F. are supported by EUROGENESIS OTKA-NN83261 and OTKA 101328. I.D. is supported by the Helmholtz association via the Young Investigators project VH-NG-627. R.P. is supported by the Helmholtz association via the Young Investigators project VH-NG-327.
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PR 7

Systematic Study of Maxwellian-Averaged Cross Sections from Precise AMS Measurements

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Accelerator mass spectrometry (AMS) is a relatively new technique for measuring cross sections independent of the half-lives of reaction products. For specific reactions the sensitivity of AMS offers a unique tool to pin down uncertainties, thus elucidating current open questions in nucleosynthesis, e.g. within the s- and p-process path. The combination of sample activation and subsequent AMS measurement was applied for a range of measurements where off-line decay counting is difficult or impossible due to long half-lives of reaction products or due to the absence of suitable γ-ray transitions. In particular, a series of samples was irradiated at Karlsruhe Institute of Technology (KIT) with neutrons simulating a Maxwell-Boltzmann distribution of 25 keV, and also with quasi-monoenergetic neutrons of energies up to 500 keV. The AMS measurement of such neutron (and charged-particle) induced cross sections were performed at the VERA (Vienna Environmental Research Accelerator) facility. This approach directly counts the produced atoms in the sample after the neutron activation rather than measuring the associated γ-radiation or the emitted particles during the irradiation. Recent AMS data for a series of neutron-capture reactions in the mass range between Be and U allow a systematic comparison with existing data from complementary techniques. Our results are based on individual AMS reference materials and the neutron fluence was determined relative to ^{197}Au(n,γ). This approach allows to generate cross section data with uncertainties between 2 and 5 %. The new data include neutron-capture measurements for ^{9}Be, ^{13}C, ^{35}Cl, ^{40}Ca, ^{54}Fe and ^{235,238}U, and for ^{14}N(n,p). We will also demonstrate the reproducibility and limits of this approach.

PR 8

Joint Neutron Noise Measurements on Metallic Reactor Caliban

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Caliban is a benchmarked, bare metallic reactor. It is operated by the Criticality, Neutron Science and Measurement Department, located on the French CEA Research center of Valduc. This reactor is a cylindre with a 19.5 cm diameter and a 25 cm height, composed of two blocks, a fixed one and a mobile one, with three control rods and one excursion rod. The four rods and the two blocks are composed from the same alloy of molybdenum and high enriched uranium. Its reactivity is controlled by moving the control rods and the mobile block, also called safety block. This parameter can vary from -20 $ below delayed criticality to 1.1 $ above delayed criticality. A central cylindrical cavity can be used to place samples or an external neutron source. This reactor is used to perform neutron noise measurements, that is to say to estimate the kinetic parameters of the reactor, such as reactivity or delayed neutron fraction, and the associated uncertainties, from Rossi or Feynman formalisms. The aim is to compare the measured parameters to the simulated ones, and to determine the relative contribution of uncertainties to the final result. Thus, these experiments improve the safety task of reactivity control far from criticality, with static methods, and the knowledge of the behaviour of a subcritical reactor. The uncertainties can be separated in three classes : - Some uncertainties are due to the knowledge of the experimental configuration, that is the reactivity of the reactor, or its description. The k_{eff} of a configuration can be checked by rod-drop dynamics experiment. - Other uncertainties are linked to the detection process. The neutron noise methods need to know precisely the detectors characteristics, their efficiencies (which vary with the distance between the reactor and the detector), their dead times or their decreasing time constants. - Final uncertainties are due to the analysis process, and the method to evaluate the uncertainties propagation. To maximize the knowledge of these uncertainties effect, a joint week of experiments was performed in June 2012 with a French team from the CEA, and an American team from the Los Alamos National Laboratory (LANL). The reactivity was varying from the lowest subcriticality to a few percents above delayed criticality. The same configurations were observed twice, using detectors of each team and switching them. The second class of uncertainties are thus reduced. Moreover, a joint week of analysis will take place in november 2012 in Los Alamos, to compare the analysis process. Each team will work with the data of the detectors of the other team, to reduce the third category of uncertainties. The results will then be use for calculation code qualification. This work is a part of a PHD work, begun in 2010 by the first author.

PR 9

^{10}B and ^{6}Li nuclear data measurements for incident neutron energies up to 3 MeV

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We present experimental methods for the measurement of the ^{10}B(n,α)^{7}Li and the ^{6}Li(n,t)^{4}He reactions for neutron energies up to 3 MeV, and preliminary data for the ^{10}B(n,α_0)/^{10}B(n,$\alpha_1\gamma$) branching ratios. The experimental setups were installed at the GELINA and the Van de Graaff facilities of the Institute for Reference Materials and Measurement of the European Commission. Our results show the need to investigate the MeV region for these reactions, since the ENDEF/B-VII evaluation agrees with our data up to 1.3 MeV and overestimates them above this limit.

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PR 10

NNDC Ensemble: A Software Platform for Effective Nuclear Data Projects Coordination and Collaboration

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In January 2010, the NNDC launched NNDC ensemble, the first-ever collaboration platform operated by the NNDC on behalf of the U.S. nuclear data community. This platform is being powered by GForge Advanced Server, an open-source collaboration software from the GForge Group, LLC. Since then, the platform has played an essential role in the coordination and collaboration of 37 nuclear data projects which include projects in support of the Nuclear Criticality Safety Program (NCSP), and the Data Assimilation and Adjustment project (COMMARA). In 2012, NNDC Ensemble's role was extended by becoming an integral part of ADVANCE, a continuous integration and deployment platform based on open-source software components, as its version control server. This poster presents how the NNDC and its collaborators around the world used the various components of NNDC Ensemble to eliminate the barriers of time and location and expedite the successful completion of development projects on nuclear data libraries and processing codes. The interface between NNDC Ensemble and ADVANCE will also be briefly discussed.

PR 11

Web Services at the NNDC

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The National Nuclear Data Center located in Brookhaven National Laboratory offers a variety of online services. These include nuclear data dissemination via products such as NuDat 2.0, Wallet Cards, ENSDF/XUNDL file retrievals for obtaining detailed nuclear structure information, and ENDF/EXFOR for cross section information, and more. In addition, a variety of analysis and utility codes useful for nuclear data are available, among many other services. A few of the online services available are presented.

PR 12

The Nuclear Science References (NSR) Database and Web Retrieval System

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The Nuclear Science References (NSR) database together with its associated Web interface [1], is the world's only comprehensive source of easily accessible low- and intermediate-energy nuclear physics bibliographic information for more than 200,000 articles since the beginning of nuclear science. The weekly-updated NSR database provides essential support for nuclear data evaluation, compilation and research activities. The principles of the database and Web application development and maintenance are described. Examples of nuclear structure, reaction and decay applications are specifically included. The complete NSR database is freely available at the websites of the National Nuclear Data Center http://www.nndc.bnl.gov/nsr and the International Atomic Energy Agency http://www-nds.iaea.org/nsr.

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PR 13

JANIS 4: An Improved Version of the NEA Java-based Nuclear Data Information System

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Recent development at the Nuclear Energy Agency (NEA) Data Bank of the Java-based Nuclear Data Information System (JANIS) is presented. JANIS is a display program designed to facilitate access to various kind of nuclear physics data, such as basic nuclear structure information, radioactive decay data, fission-fragment yields, cross-sections, energy and angular distributions etc. Its objective is to allow the user of nuclear data to access numerical and publication-ready graphical representations without prior knowledge of the storage format. The most common nuclear data formats are supported, and data originating from the major evaluated libraries, such as ENDF/B, JEFF, JENDL, etc. can be displayed, computed, compared together or with experimental nuclear reaction data from the EXFOR database. In addition, various navigation and search tools are available to explore NEA relational databases. The JANIS software can be launched online or as a standalone application. New features coming in the next release are described, including the possibility to display private data in simple ASCII format, the ability to save and restore the state of a JANIS session, and a new web interface that open new possibilities of nuclear data services. Some examples of the potential of JANIS for nuclear data users will be given and future developments exposed.

PR 14

MSU SINP CDFE Nuclear Databases For Science Research and Education

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The Moscow State University Institute of Nuclear Physics Centre for Photonuclear Experiments Data (Centr Dannykh Fotoyadernykh Eksperimentov - CDFE) participates of the IAEA Nuclear Reaction Data Centres Network [1]. With the aim of informational support of science research and education process CDFE is specialized in development of nuclear databases (DB) available through Internet [2]. Some of those really relational DB are based on the international sources and founds of data produced and maintained by Nuclear Reaction Data Centres Network and by USA NNDC and NSDD: - "Nuclear Reaction Database (EXFOR)": many data for reactions induced by photons, neutrons, charge particles and heavy ions; - "Complete Nuclear Spectroscopy Database "Relational ENSDF" contains many nuclear spectroscopy data for all known (3200) nuclides from the well-known international fund ENSDF (Evaluated Nuclear Structure Data File); - "Nuclear Physics Publications ("NSR" Database)" is the really relational DB based on the data fund of NSR (Nuclear Science References); - "Nucleus Ground and Isomeric State Parameters" combines many useful information on the nucleus as whole and its ground and isomeric states properties (masses, binding energy, nucleon separation energy, decay mode, energy of various decays, etc). Those databases used international sources of information but CDFE-developed powerful and flexible original Search Engines. Other databases are CDFE-produced and maintained: - digital "Chart of Giant Dipole Resonance Main Parameters" contains data on main parameters (energy position, amplitude, width, integrated cross section) of GDR for many nuclei; - digital "Chart of Nucleus Shape and Size Parameters" contains data on quadrupole moments, parameters of quadrupole deformation and charge radii for many

nuclei; - "Calculator and Graph Engine for Atomic nuclei Parameters and Nuclear reactions and Radioactive Decays Features" gives to one possibility for convenient calculation of: i) nucleus binding energy, ii) nucleon and nucleus separation energy, iii) decay energy, iv) reaction threshold and energy, v) nucleus fission parameters; graphical presentation of A-dependencies of data calculated is possible. All databases maintained by CDFE are widely used for many science research, primarily for investigation of systematical disagreements between the results of various photonuclear experiments and are the base for education of MSU Physics Faculty students. The work is partially supported by Russia Grant of Scientific Schools Supporting 02.120.21.485-SS, MINOBRNAUKA Contract 02.740.11.0242 and RFBR Grant N 09-02-00368.
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[1] International Network of Nuclear Reaction Data Centres, Prepared by Naohiko Otsuka and Svetlana Dunaeva, IAEA International Nuclear Data Committee, INDC(NDS)-0401, Rev.5, IAEA, Vienna, Austria, 2010. [2] http://cdfe.sinp.msu.ru

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PR 15

Advanced Features of the IAEA Nuclear Reaction Data Services

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Migration of EXFOR, CINDA and ENDF nuclear reaction databases to a modern computing environment [1], including relational databases and multiplatform object oriented languages, allowed to provide full functionality for database maintenance and improved retrieval capability [2] for external users (via Web and CD-ROM integrated systems) solving typical tasks of nuclear reaction data services, such as: data search, retrieval, simple calculations, presentation (formats, tables and plots). Permanent and intensive growth of IT technologies, especially in Internet, systems of programming, hardware makes possible to implement such tasks in the nuclear reaction data services with very limited resources, which few years ago nobody could even imagine. Several such projects are presented in this work. EXFOR data correction (renormalization) system. Tools for re-calculation absolute values from EXFOR data according to today's knowledge (new standards, decay data, abundance). The system has two parts allowing automatic renormalization using information from EXFOR library and correction factors based on additional information about experiments and evaluators' experience collected in the experts knowledge database. New output from EXFOR Web retrieval system. For advanced users building their applications using modern programming languages EXFOR retrieval system offers output in XML format. Users developing new methods and applications using statistical and systematic uncertainties and experimental covariance matrices are provided with computational data in C5, C5M format. Additionally they can construct correlation matrices using interactive Web tool. Web without Internet. This project implements complete standalone Web database retrieval system on USB memory stick or USB disk. It can include also various nuclear data applications. Allows to use Web EXFOR/CINDA/ENDF database retrieval systems locally without Internet. The package does not need any installation procedures. Web-Tools for compilers, evaluators and experimentalists provides server calculations, running utility codes and comparison users' data with central databases. A system integrating information from EXFOR, CINDA and NSR databases provides Web search helping to extend EXFOR database by missing data.
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PR 16

Calculation of Delayed Neutron Yields for Various Libraries

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This paper presents the comparison between the calculated delayed neutron yields and the recommended values proposed by Tuttle [1], the experimental data of Waldo [2] and those of Benedetti [3]. These data are given for thermal, fast, and high energy fission ranges. The calculation of total delayed neutron yields is performed either by the NJOY [4] nuclear data processing system or by the summation method [5]. In the NJOY calculation, the data used come from the general purpose evaluation files. The delayed neutron yields were calculated in thermal and fast energy groups using the weighting function composed of maxwellian, 1/E and fission spectrum. In the summation calculation, the data used are the delayed neutron branching ratios (also called delayed neutron emission probabilities) and the cumulative fission yields which are given for thermal, fast, high energy fission and spontaneous fission. These data are found in the Radioactive Decay Data and Fission Yield Data files (File 8) of nuclear data evaluations. The NJOY and the summation calculation were carried out with various libraries such as JEF-2, JEFF-3, ENDF/B-VI and ENDF/B-VII. The accuracy of the comparisons allow the validation of the data used in these libraries. This work is carried out in the frame of the expertise activity of the GALILEE project [6].
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PR 17

A Comparison of MCNP6 ^{233}U, ^{235}U and ^{239}Pu Delayed Neutron Emission and Experimental Measurements

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The assay of the magnitude and temporal behavior of delayed neutrons (DNs) enables the characterization of fissile isotopes and a determination of their relative quantities. Thus, the ability to accurately model these neutrons is of great importance to nuclear forensics and homeland security measures. The capability of MCNP6 to model these emissions was examined and compared to experimental measurements of the DNs produced by ^{233}U, ^{235}U and ^{239}Pu after thermal neutron induced fission. The fissile samples were prepared from aqueous certified reference materials with total fissile content ranging from 0.5 to 7 μg and subsequently irradiated in a SLOWPOKE-2 research reactor for durations up to 60 s. Samples were then sent via pneumatic tubing to an array of six ^{3}He detectors embedded in a paraffin moderator. The DNs produced were recorded in 0.5 s intervals, for 3 minutes after the irradiation time has elapsed. A MCNP6 model was created which reproduces irradiation conditions, counting geometry and temporal DN emission.

Pulse height tallies record DN count rates in 1 s intervals within the active zone of each detector to facilitate a direct comparison to experimental measurements. The detection efficiency of the counting arrangement was determined through a comparison of the amount of neutrons emitted from the fissile sample and the sum of pulses recorded. The efficiency of this arrangement as determined by MCNP6 was 37 % which agreed with experimental measurements of 34 ± 5 % (2 σ). Nuclear reactions and other effects within the ^{3}He detectors were successfully reproduced by MCNP6 through the inclusion of a Gaussian Energy Broadening (GEB) card. Two DN options provided by MCNP6, ACE (ENDF/B-VII.0), and CINDER (lib00c, Oct 2 2000), were examined for each isotope of interest. The ACE and CINDER input decks were identical with the exception of the DN option used. The magnitude of the DNs recorded by the MCNP6 pulse height tallies was successful when compared against experimental measurements for both ACE and CINDER, however the ACE option was a better predictor of measured temporal behavior in all cases. Future and ongoing work includes the measurement of delayed gammas produced from fissile isotopes and comparisons to MCNP6 predictions. This work was supported by the Advanced Simulation and Computing program at Los Alamos National Laboratory, the Director General of Nuclear Safety and Natural Sciences and Engineering Research Council of Canada.

PR 18

A TOF Spectrometer for β-delayed Neutron Emission Measurements

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The knowledge of the β-decay properties of nuclei lying far from stability contributes decisively to our understanding of nuclear phenomena. The accurate measurement of the half-lives, distribution of decay probabilities and particle emission probabilities provides essential data for the fields of fundamental physics, nuclear structure, astrophysics and nuclear technology. Beta-decay studies of exotic nuclei are one of the main goals of the DEcay SPECtroscopy (DESPEC) [1] experiment at the future FAIR facility [2] and at many other RIB facilities around the world. In particular, the measurement of the delayed neutron data, emission probabilities (P_n) and neutron energy spectra of neutron rich nuclei constitute an important challenge due to the key role that delayed neutrons play in relevant fields like in the nucleosynthesis r-process or in the kinetic control of advance reactor concepts. In order to determine the neutron energy spectra from neutron precursors as well as the emission probabilities, a time-of-flight spectrometer has been proposed. High energy resolution, high efficiency as well as n-γ discrimination capability and modularity are the main requirements for such a spectrometer. The MOdular Neutron time of flight SpectromeTER - MONSTER has been designed at CIEMAT after an extensive work consisting in Monte Carlo simulations and experimental tests of available materials. The spectrometer is based in BC501A liquid scintillators cells. A demonstrator is currently being assembled and tested. It consists in a set of 30 cylindrical cells of 20 cm diameter and 5 cm thickness, each one with an intrinsic efficiency ranging from 50% at 1 MeV to 28% at 5 MeV. The data taking will be made with high performance flash ADC boards also designed at CIEMAT. Each board will have a 12 bit resolution, 1Gsample/s frequency, and FPGA for the trigger logic, a DSP for the pulse shape analysis and 2 Gbytes internal memory for waveform storage. The demonstrator will be first used in early 2013 at the Cyclotron laboratory of the University of Jyväskylä.

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[1] HISPEC/DESPEC Collaboration web page: http://personal.ph.surrey.ac.uk/ phs1zp/Home.html [2] FAIR, Facility for Antiproton and Ion Research, web page: http://www.fair-center.eu

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PR 19

Composite Shielding Building Materials and Building Blocks for the Construction of Objects with a Low Internal Level of Ionizing Radiation

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New composite building materials and building blocks based on aggregate, with a low internal content of radionuclides, have been developed and submitted for patent protection, suitable for the construction of objects with a low internal level of ionizing radiation. With their help, it is possible to suppress adverse effects, especially of gamma and beta radiation and neutrons originating from artificial and natural radionuclides and from cosmic radiation, without the use of lead or other metallic materials. These building materials and components with a specific weight of about 2.4 g/cm3 allow the construction of shielding objects of different geometries, the optimization of the number of block layers and the construction of even very large shielding objects and low-background rooms, where the use of lead is impossible due to price or for other reasons. This results in a simple, cheap, environmentally-friendly and efficient reduction of background radiation for the purposes of research, experimental, medical, metrological and technological objects. A special advantage is the possibility of construction of shielding cells, where the detector assembly can be freely positioned in place of lead shielding structures firmly attached to the detector assembly. This allows even the placement of multiple detector assemblies inside the object and their simple transportability. Shielding objects are assembled from building blocks using a dry process; their stability is ensured by a system of locks. The objects can be therefore dismounted and the building blocks re-used. Individuals may handle the different types of components, including drop ceilings with a high loading capacity. The concentration of radon, thoron and their decay products inside the objects may be reduced by using filtering and ventilation equipment that provides a mild internal excess pressure. Shielding materials are suitable in particular for the measurement of materials, substances and objects with a low content of radionuclides in laboratories and technological facilities, where a low background radiation has to be achieved, e.g. for measurements during the release of a large quantity of waste when old nuclear facilities are dismounted. The contribution describes the results of measurement in the selection of suitable aggregate and other components originating from paleozoic geological formations, the results of optimization of the composite mixture and the geometry of building components, the method of preparation of different types of construction materials and components, the results of measurement of the internal content of natural radionuclides contained in the individual types, the results of measurement of the shielding abilities, including a comparison with metal shielding and practical examples for use.

PR 20

Cross-checking of Large Evaluated and Experimental Databases

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The Nuclear Energy Agency (NEA) Data Bank maintains large nuclear databases and makes them available to scientists and engineers through the web and the JANIS software, which facilitates the visualisation, comparison and manipulation of nuclear physics data. Recent development and implementation at the NEA Data Bank of methods for the verification of large experimental and evaluated databases are presented. This work is a follow up of activities initiated in the framework of Subgroup 30 of the NEA Working Party on International Nuclear Data Evaluation Co-operation, WPEC SG30, which was established to improve the accessibility and the quality of the EXFOR experimental nuclear reaction database

[1]. In line with SG30 recommendations, the NEA Data Bank and the Societe de Calcul Mathematique co-developed statistical methods to (i) assess the self-consistency of experimental or evaluated data, (ii) assess the consistency between experimental and evaluated data. These methods allow to assess the quality of the data and to detect aberrant values in large databases. An outline of the procedure to check the mutual consistency of experimental data for a given quantity is described in reference [2]. The focus of the present contribution is to describe the method developed to check the mutual consistency of data from different evaluated libraries (ENDF/B, JEFF, JENDL, TENDL, etc.) and to cross-check these evaluated data with experimental data (EXFOR). This approach aims to use the valuable information stored in evaluated files in order to assess the quality of some experimental data. In a complementary way, this cross-checking helps assess the quality of evaluated data by comparison with recommended experimental data and helps identify flaws in evaluated data files. The performance of this method on a selection of about two hundred test cases is discussed and results obtained using large experimental and evaluated databases hosted at the NEA Data Bank are presented.

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PR 21

Present Status of Evaluated Nuclear Data Library for Accelerator-Driven Systems in China

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The Aaccelerator-Driven System (ADS) is defined as a system driven by energetic particles of GeV range accelerated by a so-called high power accelerator incorporated normally with a target of a heavy element, which generates intense secondary particles, e.g., neutron, proton, etc., via the spallation nuclear process. The application of the scheme involves the nuclear transmutation for high level nuclear waste (HLW), plutonium burner for proliferation resistance, the energy production, fissile or tritium fuel breeding, neutron sources for material irradiation, neutron scattering science, industrial applications, and so on. To address these needs, a program is under way to develop new evaluated nuclear data libraries for incident protons and neutrons up to 200 MeV for a range of high-priority elements in the ENDF/B format. These evaluations are based on a combination of nuclear model calculations and measured data to evaluate cross sections. The theoretical model code UNF has been made based on the frame of the optical model, the unified Hauser-Feshbach and exciton model which includes Iwamoto-Harada model at incident neutron energies below 20 MeV. To keep the energy balance, the recoil effects are taken into account for all of the reaction processes. The nuclear reaction models code MEND which can give all kinds of reaction cross sections and energy spectra for six outgoing light particles (neutron, proton, alpha, deuteron, triton, and helium) and various residual nuclei in the energy range up to 250 MeV, has been developed. Fission is included as a decay channel, that is, a fission competitive width can be estimated at every step of the cascades. Fifteen uncoupled fission barriers are used to represent the fission system and describe different channels, respectively. All cross sections of neutron induced reactions, angular distributions, energy spectra and double differential cross sections are consistent calculated and evaluated for ^{23}Na, ^{24,25,26}Mg, ^{27}Al, ^{28,29,30}Si, ^{40,42,43,44,46,48}Ca, ^{50,52,53,54}Cr, ^{54,56,57,58}Fe, ^{59}Co, ^{58,60,61,62,64}Ni, ^{63,65}Cu, ^{90,91,92,94,96}Zr, ^{93}Nb, ^{92,94,95,96,97,98,100}Mo, ^{180,182,183,184,186}W, ^{204,206,207,208}Pb,

^{209}Bi, ^{232}Th, ^{237}Np, ^{232,233,234,235,236,237,238,239,240}U, ^{236,237,238,239,240,241,242,243,244,246}Pu, ^{241,242m,242,243}Am and ^{243,244,245,246,247,248}Cm at incident neutron and proton energies below 200 MeV, based on the nuclear theoretical models. All cross sections of proton induced reactions, angular distributions, energy spectra and double differential cross sections are consistent calculated and evaluated for ^{27}Al, ^{28,29,30}Si, ^{40,42,43,44,46,48}Ca, ^{50,52,53,54}Cr, ^{54,56,57,58}Fe, ^{59}Co, ^{58,60,61,62,64}Ni, ^{63,65}Cu, ^{90,91,92,94,96}Zr, ^{92,94,95,96,97,98,100}Mo, ^{180,182,183,184,186}W, ^{204,206,207,208}Pb, ^{209}Bi, ^{232}Th, and ^{235,238}U at incident neutron and proton energies below 200 MeV. Theoretical calculated results are compared with existing experimental data, and ENDF/B7 and JENDL-3. Good agreement is generally observed between the calculated results and the experimental data. Since the improved Iwamoto-Harada model has been included in the exciton model for the light composite particle emissions, the theoretical models provide the good description of the shapes and magnitude of the energy spectra and double differential cross section of emission deuteron, triton, helium and alpha. The evaluated data is stored using ENDF/B7 high-energy format.

PR 22

Evaluation of Neutron-Induced Reaction Cross Sections of Ta-181

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The knowledge of neutron-induced reaction cross sections and their uncertainties is an important prerequisite for the optimized choice of structural materials used in nuclear facilities. In this contribution neutron-induced reactions on Ta-181, an important component of several structural materials, are considered. Especially, a consistent set of angle-integrated neutron-induced reaction data of Ta-181 and associated covariance matrices in the energy range from 1 to 150 MeV are presented which have been obtained by the Full Bayesian Evaluation Technique [1] implemented in GENEUS. This method is based on Bayesian statistics and relies on a well-determined prior covariance matrix. In particular the presented evaluation makes use of the recently established prior structural materials library [2]. The measurement details of available experimental data have been studied in order to establish proper experimental covariance matrices, which are required for the Bayesian procedure. The results of the Full Bayesian Evaluation Technique are compared to available evaluated data files of Ta-181 and the differences are discussed. In addition, the possibility to include angle-differential data is addressed. Work supported by F4E within the FPA-168.
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PR 23

Nuclear Decay Data Evaluations at IFIN-HH, Romania

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An important IAEA Coordinated Research Project (CRP), F42006 "Updated decay data library for Actinides" was implemented during the period 2005-2012. The author participated in the CRP, as a representative of the Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), the Radionuclide Metrology Laboratory. Decay data for five Actinides nuclei were evaluated by the author, according to the procedures and rules of the international cooperation Decay Data Evaluation Project

(DDEP): ^{236}U, ^{234}Th, ^{228}Ra, ^{211}Bi and ^{211}Po. The most important results obtained, conclusions and some recommendations of the evaluator are presented. The IFIN-HH involvement in several new international and national research projects in the field is briefly mentioned; new evaluations and experimental determination of some nuclear decay data (photon absolute intensity, half-life) for nuclear medicine applications are foreseen. This work was supported by the IAEA, under the Research Contract RBF no. 13341/2005.
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PR 24

Actinide, Activation Product and Fission Product Decay Data for Reactor-Based Applications

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The UK Activation Product Decay Data Library was first released in September 1977 as UKPADD1, and the UK Heavy Element and Actinide Decay Data Library followed in December 1981 as UKHEDD1. Modest improvements have been made to UKHEDD leading up to 2007, while UKPADD has continued to be developed on an almost yearly basis. The contents of the most recent versions of UKHEDD (UKHEDD2.6, February 2008) and UKPADD (UKPADD6.12, March 2013) are described, together with the evaluation methodology and processing procedures adopted to produce the files in ENDF-6 format. Comprehensive sets of requested decay data have been evaluated on the basis of a series of well-defined specifications, and have been processed to yield complete and verified evaluated decay data files. Evaluated decay-data parameters within both libraries include half-lives, branching fractions, alpha, beta and gamma-ray energies and emission probabilities, total decay energies, mean and/or average alpha, beta and gamma energies, internal conversion coefficients, internal-pair formation coefficients, and all associated uncertainties. The computer-based files have been generated in ENDF-6 format, including lists of the references used to produce the proposed decay schemes and comments that identify any existing inadequacies. UKHEDD2.6 consists of recommended decay data files for 125 radionuclides, 50 of which were re-evaluated between January 2000 and February 2007 on the basis of improvements arising from timely laboratory measurements - these actinides and their natural decay products are identified with the operation, decommissioning and disposal of fission-based reactor facilities. UKPADD6.12 consists predominantly of recommended decay data for activation products of relevance to the European Fusion Programme, and a limited number of fission products identified with the operation, decommissioning and disposal of fission reactor facilities, along with various standards that are commonly used to calibrate gamma-ray spectrometers. The most recent evaluations undertaken in 2011/12 have generated recommended decay data for seven fission products that contribute significantly to the gamma dose in severe accident scenarios. Recommended decay data for a total of 595 radionuclides are contained within UKPADD6.12. All evaluations within UKHEDD and UKPADD have been carried out by A.L. Nichols, while processing and verification procedures were performed by AMEC staff at Winfrith. New versions of the UKHEDD and UKPADD libraries have regularly been submitted to the NEA Data Bank for possible inclusion in the JEFF library, and in this manner are readily accessible to the international community. Historically, data evaluations and assembly of many of the earlier files have been funded by BNFL plc, Sellafield, and the UK Department of Trade and Industry (work now identified with the UK Department of Energy and Climate Change) and Euratom through the UK Atomic Energy Authority/Euratom Fusion Association.
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PR 25

NUBASE2012

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The NUBASE database contains the basic properties of nuclides in their ground and long-lived (>100 ns) isomeric states: masses, excitation energies of isomers, half-lives, spins/parities, decay modes and their intensities. This database is mainly derived from Evaluated Nuclear Structure Data Files (ENSDF) and the Atomic Mass Evaluation (AME), as well as from experimental results from recent literature. NUBASE is widely used in fundamental researches and applied nuclear sciences. Meanwhile, NUBASE provides a consistent identification of the nuclear states involved in mass measurements that are used in AME evaluation to extract the reliable atomic mass values. The early versions of NUBASE were published in 1997[1] and 2003[2]. A new version NUBASE2012 will be published in December 2012 together with AME2012, thus for the second time after the coupled publication of AME2003 and NUBASE2003 evaluations. Since the publication of NUBASE2003 a wealth of new information has been gained experimentally, enriching significantly NUBASE2012 and giving new insight in nuclear structure. At this conference, I will present the most important new features brought by NUBASE2012. The new policies and adopted procedures in NUBASE2012 will also be presented.
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PR 26

Energy Scale Calibration and Off-Line Gain Stabilization of Scintillation Neutron Detectors

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The energy scale calibration (possible non-linearity effects) of a neutron detector and maintaining its stable operation during the rather long time between the efficiency measurement and the detector application is very important for realization of high accuracy in neutron experiments. We report the result of our present investigation of a NE213 liquid scintillation detector (12.7 cm diameter, 5.08 cm depth) in this presentation. The detector energy scale was calibrated with standard gamma-rays sources, in the electron energy range 0.3 MeV$_{ee}$ to 4 MeV$_{ee}$ ^{207}Bi, and ^{252}Cf sources, and background were measured during long duration experiments. The PH distributions for measurements at the end of each run were compared with the reference spectra. The gain correction was estimated by using the Least Squares Method with a non-linear fitting procedure. Our results demonstrate a rather large non-linearity of the scale and the importance of the off-line gain corrections.
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PR 27

Fast Neutron Spectroscopy with Cs_2LiYCl_6

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Neutron spectroscopy has re-emerged as a key area of research in nucleosynthesis science and nuclear structure, while having always been important in many applied nuclear fields, such as reactor control, fusion science, and homeland security. Technically, efficient, high resolution neutron spectroscopy has always been challenging, and so new technologies are constantly being sought. Cs_2LiYCl_6 (CLYC) has recently attracted interest as a thermal neutron detector due to its excellent neutron / gamma-ray pulse-shape discrimination and good energy resolution for both gamma-rays and neutrons. Preliminary work using a 1"x1" CLYC detector has yielded intriguing results for the possibility of employing CLYC for fast neutron spectroscopy. The response of this detector to mono-energetic neutrons was studied at the University of Massachusetts Lowell 5.5 MV Van de Graaf using neutrons with energies spanning range of 0.8 MeV to 2.0 MeV, produced via the ^{7}Li(p,n) reaction. In the fast neutron response, a broad continuum from the ^{6}Li(n,α) reaction was observed, and also a peak arising from the ^{35}Cl(n,p)^{35}S reaction, which had not previously been reported. This latter reaction, with a positive Q-value of 615keV, yields a single neutron-induced peak with a resolution of 9%, determined by the reaction kinematics, making CLYC a promising candidate as a fast neutron spectrometer in the energy range of 0.5 to 3 MeV. Simulations using MCNPX corroborate our initial findings and allow us to investigate methods by which the practical measurement range can be extended to at least 10 MeV. New results will be presented, covering neutron-gamma separation, energy resolution for gamma rays and neutrons, efficiency, and timing. This research was supported by grants from DOE Office of Science, NNSA, and the SBIR program.
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PR 28

X-Ray Fluorescence to Determine Zn in Bolivian Children Using Hair Samples

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With the aim of evaluating nutritional levels in Bolivian children (8-13 years-old), we carried out X-Ray Fluorescence measurements in hair samples of children belonging to different social classes and living either in rural areas or in cities. The aim of this study is to contribute to health policies tending to improve the global children health and consequently avoid malnutrition. Our method intends to have maximum reliability and at the same time be as simplest as possible from an experimental point of view. Additionally, we use this method to determine some contaminants such as Pb, As and Hg that could be present in children living in neighboring areas to mines and industries. Our work is complemented by some biological and medical tests.
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PR 29

Characterization of ^{235}U Targets for the Development of a Secondary Neutron Fluence Standard

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The MetroFission project, a Joint Research Project within the European Metrology Research Program (EMRP), aims at addressing a number of metrological problems involved in the design of proposed Generation IV nuclear reactors. As part of this project a secondary neutron fluence standard is being developed and tested at the neutron time-of-flight facility GELINA of the JRC Institute for Reference Materials and Measurements (IRMM). This secondary standard will help to arrive at the neutron cross section measurement uncertainties required for the design of new generation power plants and fuel cycles. Such a neutron fluence device contains targets for which the neutron induced cross section is considered to be a standard. A careful preparation and characterization of these samples is an essential part of the development of the secondary standard. In this framework a set of ^{235}U targets has been produced by vacuum deposition of UF_4 on aluminum backings by IRMM's target preparation group. These targets have been characterized for both their total mass and mass distribution over the sample area.

PR 30

Neutron Spectrum Determination of the p(35 MeV)-Be Source Reaction by the Dosimetry Foils Method

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The cyclotron based neutron generators of the broad- and quasi-monoenergetic spectra are operated at the NPI Rez Fast Neutron Facility utilizing the variable-energy proton beam (up to 37 MeV) and the D_2O (flow), Be (thick), and ^{7}Li(C) target stations. The intensity and the energy range of the produced neutron fields are suitable for the integral and differential validation of the neutron cross-sections within the ADTT- and fusion-relevant (IFMIF) research programs. In the neutron activation experiments, the irradiated samples are usually fixed in the vicinity of the source target, and the dimensions of the target and samples are comparable with the target-to-sample distance. Therefore, to determine the neutron spectral flux at the sample position from the cross-section data, a simple employment of the $1/r^2$ law is not relevant. Instead, the MCNPX calculations are required to take into account the space and energy integration of neutron yield observables over the geometry arrangement of activation experiment. Due to a usual lack of differential yield data at requested energy and angular range, the MCNPX calculations need to be validated against the independent experiments. Recently, the dosimetry-foils method was successfully used to the validation of the MCNPX prediction of spectral flux characteristics for the p+D_2O (thick) source. In the present work, this method was employed to determine the spectrum of the Be(p,xn) source reaction at the position of irradiated samples. The wide set of dosimetry foils (Al, Sc, Mn, Fe, Co, Ni, Ti, Y, In, Lu, Ta, Au, Nb, and Bi) was selected to cover the energy range under interest. In the experiment, the thick beryllium target was bombarded by the 35 MeV protons at beam current of 9 μA. Activated foils were investigated by the nuclear gamma-spectrometry technique (the HPGe detector). To unfold the neutron spectrum from resulting reaction rates, a modified version of the SAND-II code was used. Results and uncertainty of the validation are discussed in details.

PR 31

A CVD Diamond Detector for (n, α) Cross-section Measurements

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In the last years, the experimental program at the n_TOF facility at CERN has been extended to (n, cp) cross section measurements of astrophysical and medical interest. These measurements require using thin samples and often feature small cross sections, which results in small yields and thus call for a high-resolution and low-background detector. In this context, we have developed a dedicated device, based on the chemical vapor deposition (CVD) diamond technology. The high performance of the detector, an array of 9 sCVD diamonds, tested in 2011 and used in 2012 for a ^{59}Ni(n, α)^{56}Fe measurement, is presented here.
CIVIDEC Instrumentation GmbH, Vienna, Austria, sponsored this work.

PR 32

Gas-filled Parallel-Plate Avalanche Counters for Fission Studies

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To study the prompt gamma and neutron emission in either spontaneous or neutron-induced fission using the DANCE [1] or Chi-Nu [2] arrays respectively requires a starter detector to identify uniquely the fission event by detecting the fission fragments. A gas-filled parallel-plate avalanche counter (PPAC) has many advantages for this application such as fast timing (1 ns), resistance to radiation damage, and tolerance of high counting rate. Therefore, a new generation of PPAC was developed at Lawrence Livermore National Laboratory specifically for those arrays, located at Los Alamos Neutron Science Center (LANSCE), to make the needed measurements possible. For DANCE, a compact PPAC was fabricated with two anodes placed at 3 cm away on either side of the cathode [3]. The anodes are made of the 1.4 μm thick aluminized mylar. The cathode holds a 3 μm titanium foil with the electrodeposited target material that is sandwiched between two mylar foils of the same thickness. The target is double-sided using the electrodeposition cell described in Ref. [4]. For the Chi-Nu array, a low-mass multi-foil fission chamber was fabricated to accommodate 10 sets of PPAC [5]. Each one has the same geometrical arrangement of the anodes and cathode as the PPAC for DANCE. The targets were fabricated in a similar way except for the active areas: 4 cm in diameter for Chi-Nu and 0.7 cm diameter for DANCE. The design details and performances of these PPACs will be presented. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and Los Alamos National Laboratory under Contract DE-AC52-06NA25396.
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PR 33

Design of the MAESTRO Experimental Programme Dedicated to the Validation of Neutron Cross Sections: Preliminary Results for Rh, Co, V and Mn

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The MAESTRO experimental program has been designed to improve the accuracy of neutron cross sections of a wide range of structural, moderation, detection and absorption materials used for LWR applications. Pile-oscillation experiments and neutron activation analysis are performed in the MINERVE low power facility, located at Cadarache (France) . A first stage of the programme has been completed in 2011 with the measurement and analysis of samples made of pure Rh, Co, V and Mn rods, for the validation of GEN-III+ in-core instrumentation. A second phase will be conducted in 2012 and 2013 with pile-oscillation and activation analysis of 45 kinds of sample, including natural materials (Mg, Al, Si, Cl, Ca, Ti, Cr, Fe, Ni, Cu, Zn, Zr, Mo, Sn, V, Mn, Co, Nb, Rh, H2O, D2O, Be, C, CH2, Cs, Ag, In, Cd, Eu, Gd, Dy, Er, Hf), isotopic materials (107Ag, 109Ag, 153Eu), industrial alloys (Zy4, M5, SS304, SS316, Inconel-718, concrete) and calibration materials (Au, B, Li) In this paper the design studies of the programme, including the sample preparation, the core configuration and the optimization of experimental techniques are detailed. Then, preliminary results are presented concerning the analysis of neutron activation and pile-oscillation experiments of Rh, Co, V and Mn.

PR 34

Integral Cross Section Data Measurements Around 14 MeV for Validation of Activation Libraries

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The radioactive properties of materials over time, through and after the operation lifetime of a fusion device or power plant for example, may be simulated using the European Activation System II 2012 (EASY-II(12)). EASY-II(12) allows neutron-induced activation of materials by a range of different reactions. It has recently been updated with enhanced physics in the FISPACT-II inventory code and expanded nuclear data libraries which have now been released for wider use. To give users of EASY-II(12) confidence in the predictions of activation quantities it is necessary that the inventory code and the data libraries are validated. This is done by comparing the predictions of EASY-2012 with activation measurements made on materials relevant to fusion technology in well-characterised neutron fields. If the ratio of results from Experiment (E) and Calculation (C) is close to 1 then the data are validated. In other cases it may be necessary to change the library data to improve the C/E ratio. For the present and ongoing validation exercise, integral cross section data recently measured at the ASP 14 MeV irradiation are compared, where data exists, with integral data from other neutron irradiation facilities (extracted from the international EXFOR database) and with effective (collapsed) cross sections calculated from EASY-2012 cross section data evaluations. These are shown as plots of the C/E ratio. Integral cross section data is presented for reaction products resulting from irradiation of Nb, Cr, Au, Ag and Pb; with a focus on short-lived reaction products of potential interest to fusion device neutron diagnostics.

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PR 35

Progress on Consistent Nuclear Data Assimilation

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The major drawback of the classical adjustment method is the potential limitation of the domain of application of the adjusted data. The multigroup structure, the neutron spectrum used as weighting function and the code used to process the basic data file are significant constraints to these adjustments which are made on the multigroup data. A new approach has been developed in order to adjust physical parameters and not multigroup nuclear data with the objective being to correlate the uncertainties of some basic parameters that characterize the neutron cross section description to the discrepancy between calculated and experimental values for a large number of clean, high accuracy integral experiments. In an ND2010 paper, the first application of the methodology (applied to the nuclear data of 23Na and using neutron propagation experiments) was presented. This paper is devoted to progress made on the methodology when applied to fissile isotopes as well as to a fission product isotope. A series of integral experiments were analyzed using the EMPIRE evaluated files for 235U, 239Pu, 242Pu and 105Pd. In most cases, the results have deviated more with respect to those of the corresponding existing evaluations available for ENDF/B-VII. The observed discrepancies between calculated and experimental results (see below) were used in conjunction with the computed sensitivity coefficients and covariance matrix for nuclear parameters in the consistent data assimilation. As for 235U and 239Pu, the GODIVA and JEZEBEL experimental results (keff and spectral indices) were used in order to exploit information relative to the specific isotope of interest. The results obtained by the consistent data assimilation indicate that with reasonable modifications (mostly within the initial standard deviation) it is possible to eliminate the original discrepancies on the Keff of the two critical configurations. However, some residual discrepancy remains for a few fission spectral indices that are, most likely, to be attributed to the detector cross sections. Subsequently separated isotope irradiation experiments (PROFIL and TRAPU in the PHENIX reactor) were used for the improvement of 242Pu and 105Pd data. The results so far obtained indicate that a much general and robust approach based on physics arguments can be envisaged to improve nuclear data for a wider range of applications and consistently with the requirements of advanced simulation of reactors and associated innovative fuel cycles.

PR 36

Analysis of the Quality of Evaluated Data for Most Relevant Reactions of MYRRHA

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A typical way to quickly estimate the uncertainty induced by cross-sections in a neutronic calculation using MCNP is to look at the effect of changing the full cross section library from one to another. Typically, the well-known and available libraries ENDF/B-6 or 7, JEFF 3.x and JENDL-3 or 4 are being used. However, as these libraries tend to use the same experiments and even the same evaluations, there is worry for a "common mode failure". This exercise has been done for MYRRHA together with more extensive work using covariance data available in the JENDL-4.0 library. Based on this, a list of isotopes and reaction channels that are of importance for MYRRHA have been identified. Then, a study of the origin of the relevant data for this application will be performed. The study will compare nuclear data libraries, look into which evaluation methodology and experimental data have been used, and how these experimental data have been combined, and shared between libraries. Under the light of these results, the objective is to propose how these libraries could be improved with possible recommendations, additional measurements or new analysis. The research leading to these results has received funding from the European Atomic Energy Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement no. 249671, (FP7-EURATOM-FISSION-2009:Project ANDES/249671). Also, it has been partially supported by "Ministerio de Educación (Ministry of Education)" of Spain through the FPU Program for teaching and researching formation (Programa de Formación de Profesorado Universitario) under grant AP2009-1801

PR 37

Effect of New Cross Section Evaluations on Calculated Flux in Irradiation Positions of Egypt Second Research Reactor

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The objective of this paper is to study the effect of new cross section libraries which produced by IAEA nuclear data libraries updated in WLUP (WIMS Libraries Updates Project) on calculated flux in irradiation positions of Egypt second Research Reactor (ETRR-2). Standard computer codes such as a transport theory lattice simulation code WIMS-5B and diffusion theory based global core calculations computer code CITVAP v3.1 (new version of CITATION II developed by INVAP) were used to perform this study. For the proposed calculations, the following libraries have been used: WIMSD4 (69 energy groups), IAEA (69 energy groups), IAEA (172 energy groups). Evaluation of the 3D flux distribution in irradiation positions using CITVAP v3.1 code and macroscopic cross-section libraries generated using WIMS-5B is compared with experimental results. This work was supported by IAEA under some contract with EAEA.

PR 38

Sensitivity and System Response of Pin Power Peaking in VVER-1000 Fuel Assembly Using TSUNAMI-2D

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Computational determination of pin power peaking must be done during designing of fuel assemblies and preparation of fuel batches. Large expertise was accumulated in this field, but modern calculational tools offer more sophisticated approach. For safety reasons the fuel in nuclear reactors must be prepared in such a away that fission power distribution must be flat among the assemblies in the reactor core and fuel pins in all assemblies. System TSUNAMI [1] developed in Oak Ridge National Laboratory can be used for sensitivity and uncertainty analysis of various systems and their responses. In this case, TSUNAMI-2D was applied to calculation of fission power distribution in a fuel assembly of VVER-1000 reactor. Results from these calculations can be used to determination of sensitivity of fission power in selected pins to fissile material concentration in other fuel pins. Alternatively, it can help to determine the best position of a burnable absorber (Gd_20_3) containing fuel pins for suppression of excessive fission power in some fuel pins (close to the assembly periphery). Several cases were analysed. They differ in number and position

of gadolinium fuel pins. The sensitivity of pin power peaking is important also during reactor operation, therefore the calculations were repeated for several fuel compositions obtained by fuel burnup calculation. This work was supported by Technology Agency of the Czech Republic (project TA02020840).
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PR 39

Inelastic Thermal Neutron Scattering Cross Sections for Reactor-Grade Graphite

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Traditional calculations of the inelastic thermal neutron scattering cross sections of graphite are based on representing the material using ideal single crystal models. However, reactor-grade graphite represents a multi-phase material where graphite ideal crystals are embedded in a carbon binder matrix. Furthermore, the density of reactor-grade graphite is usually in the range of 1.5 g/cm^3 to approximately 1.8 g/cm^3, while ideal graphite is characterized by a density of nearly 2.25 g/cm^3. This difference in density is manifested as a significant fraction of porosity in the structure of reactor-grade graphite. To account for the porosity effect on the cross sections, classical molecular dynamics (MD) techniques were employed to simulate graphite structures with porosity concentrations of 10% and 30% relative to ideal graphite. This type of microstructure is taken to be representative of reactor-grade graphite. The phonon density of states for the porous systems were generated as the power spectrum of the MD velocity autocorrelation functions. The analysis revealed that for porous graphite the phonon density of states exhibit a rise in the lower frequency region that is most relevant to thermal neutron scattering. Furthermore, this rise increases as the porosity level increases. Using the generated phonon density of states, the inelastic thermal neutron scattering cross sections were calculated using the NJOY code system and compared to experimental measurements of total cross sections below the Bragg energy cut-off (approximately 2 meV) of graphite. In this case, the measured total cross sections represent mainly total inelastic scattering cross sections. While marked discrepancies exist between the calculations based on ideal graphite models and measured data, favorable agreement is found between the calculations based on porous graphite models and measured data. This work was supported by the DOE NEUP program.

PR 40

Innovative Reactors and Nuclear Data Needs

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A large spectrum of advanced nuclear reactors, ranging from evolutionary concepts to very innovative (e.g., GEN-IV or dedicated transmutation) systems using novel fuels and materials, are being studied by different organizations. The characteristics of such systems vary widely, depending on the design criteria and intended applications. For the most innovative of these concepts, core physics and safety simulations, using the latest neutron data and codes, point to the poor quality of nuclear data as the leading cause of larger-than-desired uncertainties in key engineering parameters. As a consequence, to preserve the targeted performance and avoid excessively conservative design margins, reactor physicists and engineers request substantial improvements in evaluated nuclear data files, sometimes without sufficient distinction, not realizing that these can translate into major nuclear physics measurement and modelling challenges. Assessing the "necessary and sufficient" improvements in evaluated nuclear data for innovative reactors is therefore a central issue. However, this is not as straightforward as one might expect, for reasons which are detailed in this paper, along with illustrative examples. Indeed, even though the theory and methods for error propagation are rather well established, difficulties still arise because the assessment process entails a number of assumptions and restrictions, the importance of which is not always fully appreciated. These include: (i) The strong dependence on the particular system under study and its detailed characteristics. The example of two large SFRs is given showing that, depending on the detailed core design, the computed uncertainties in major core parameters can differ by a factor of 1.6 to 4, for the same nuclear data file; (ii) The particular choice of design parameters, which can be complicated functions of nuclear and other data, and the corresponding targeted maximal uncertainties. Top-priority quantities impacting the feasibility or viability of a reactor concept are not always distinguished from less-critical quantities relating to performance optimization; (iii) The evaluation of missing a priori nuclear data uncertainties and associated correlations, with sufficient confidence so that they can be used reliably in error propagation calculations. Examples show that incomplete correlation information can lead to underestimation of some parameter uncertainty by a factor of two; (iv) The necessary compromise, or redistribution of effort, between several possible nuclear data improvement pathways, for the same end result; (v) The specific methods used to perform sensitivity, perturbation, and impact calculations. For these reasons, the nuclear data improvement needs assessed independently by different groups can differ notably, even when they relate to similar systems.

PR 41

Effect of Variations in Iron Cross Section in Thermal Region On VVER-1000 Neutronics

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The cross section of iron has an important impact on thermal neutron flux distribution in reactor pressure vessel. The thermal neutrons affect RPV activation, thus influence the composition of RPV and the distribution of originated nuclides. Moreover this cross section influences calculated prediction of pin power density in the boundary row of fuel pins. The relevance of this quantity is in fact that fuel conditions are a very important criterion reflected in limits and conditions of reactor operation, which must not be violated. For experimental determination of the thermal flux in RPV and pin power density in fuel the VVER-1000 Mock-up on reactor LR-0 was utilized. The thermal neutron flux distribution was determined by means of 3He reaction rate. The 3He proportional counter 6NH12.5 Canberra (active diameter 9mm, active length 125mm, 3He pressure 8 bar) was used for this purpose. The pin power density was measured by means of fission rate density which was determined using fission product activity. For this measurement, semiconductor gamma spectrometry with high energy resolution (approximately 2 keV at E_γ=1333 keV) and multichannel analyzer DSA2000 (Canberra) were employed. The high purity germanium coaxial detector (Ortec, relative efficiency 70%) was placed in a thick Pb cylindrical shield with 1x2 cm collimator. The calculations were performed using MCNP code (version MCNPX 2.6.0.). Various sets of nuclear data libraries were used in the calculation.

PR 42

Sensitivity and Uncertainty Analysis of the GFR MOX Fuel Subassembly

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In recent years nuclear energy has seen a renaissance giving the opportunity for innovative conceptual designs. For their deployment nuclear data definitely plays a role, but adequate validations and experimental data bases are so far largely missing [1]. A correct assessment of the uncertainty of the analytical parameters related to the reactor core performance resulting from uncertainties in the nuclear data is an important issue for designing a reactor, and it is certainly useful for identifying potential sources of computational biases. Thereby, sensitivity analyses provide a unique insight into the system performance being applicable to propagate the uncertainties in the cross-section data to uncertainties of the system response [2]. This study deals with sensitivity and uncertainty analyses and a benchmark similarity assessment of the MOX fuel subassembly designed for the Gas Cooled Fast Reactor (GFR) as a representative material of the core, serving to identify the main contributors to the calculation bias.
Corresponding author: Vladimir Necas
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PR 43

Results of Calculations of Criticality Parameters of Liquid Metal-Cooled Fast Benchmark Systems with the Use of ABBN Data Set

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The paper contains results of performed calculations of benchmark reactor-physics configurations from International Reactor Physics Experiment Evaluation Project (IRPHEP). Calculations of k-effective, spectral indices, sodium void coefficients, efficiency of control rods and fission rates distributions were compared with the experimental data. The set of experiments covers various types of fuel used in fast reactors - uranium, MOX and metal fuel. The calculations were performed using Monte-Carlo codes MMKKENO and MCNP and CONSYST/ABBN system. The current version of library of group constants ABBN is based on evaluated nuclear data files ROSFOND2010.
Corresponding author: Anton Peregudov
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PR 44

Nuclear Data Needs for the Neutronic Design of MYRRHA Fast Spectrum Research Reactor

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MYRRHA is the fast spectrum research reactor being developed at SCK-CEN, Belgium. It is supposed to operate both in critical and sub-critical (coupled with the proton linear accelerator delivering 600 MeV, 3.5 mA proton beam) operation modes. This is a pool type facility cooled with lead-bismuth eutectic (LBE). This LBE also serves as a spallation target for sub-critical operation mode. The facility is designed to operate with mixed oxide fuel. The pre-licensing phase will end in 2014 and to that date, among other tasks, the reference nuclear data (general and special purpose libraries) must be identified and validated. The Belgian licensing authorities require that further neutronic design and support works on MYRRHA must be performed with this selected, validated and approved data set. First step towards the creation and validation of such data set is the nuclear data sensitivity and uncertainty analysis with respect to MYRRHA. Using the covariance data available from recent generation general-purpose nuclear data libraries (JEFF-3.1.2, ENDF/B-VII.1, JENDL-4.0, TENDL-2011) it has been identified that the uncertainties for certain reaction types are underestimated and must be improved by setting up differential and integral experiments. The priority list for the general-purpose nuclear data for MYRRHA includes fission, neutron capture and (n,2n) cross-sections on Pu-238, Pu-239 neutron capture cross-section and fission neutron yields, fission neutron yield of Pu-240, fission and elastic scattering cross-sections of Pu-241, Bi-209 neutron capture and (n,2n) cross-sections, and Fe-56 neutron capture cross-section. The spallation target sub-assembly of MYRRHA running in sub-critical mode is capable to host devices dedicated for material testing for fusion research. It can provide high hydrogen- and helium-to-dpa ratios due to hard neutron spectrum (with the presence of high-energy tail) and very high flux. This implies that the nuclear data on gas production and radiation damage must be of high accuracy. The analysis of such data has been performed and uncertainties have been identified. The burn-up calculations for MYRRHA require not only the high-quality reaction cross sections but also the neutron-induced fission product yields represented as continuous energy data, especially in the fast energy region, to properly calculate the reaction rates. The sensitivity analysis of burn-up calculations to the prompt fission product yields has been performed and the problematic nuclides have been identified.

PR 45

EASY-II(12) Renaissance: n, p, d, α, γ-induced Inventory Code System

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The European Activation SYstem has been re-engineered and re-written in modern programming languages so as to answer today's and tomorrow's needs in terms of activation, transmutation, depletion, decay and processing of radioactive materials. The new FISPACT-II inventory code development project has allowed us to embed many more features in terms of energy range: up to GeV; incident particles: alpha, gamma, proton, deuteron and neutron; and neutron physics: self-shielding effects, temperature dependence and covariance, so as to cover all anticipated application needs: nuclear fission and fusion, accelerator physics, isotope production, stockpile and fuel cycle stewardship, materials characterization and life, and storage cycle management. In parallel, the maturity of modern, truly general purpose libraries encompassing thousands of target isotopes such as TENDL-2012, the evolution of the ENDF-6 format and the capabilities of the latest generation of processing codes PREPRO, NJOY and CALENDF have allowed the activation code to be fed with more robust, complete and appropriate data: cross sections with covariance, probability tables in the resonance ranges, kerma, dpa, gas and radionuclide production and 23 decay types. All such data for the five most important incident particles (n, p, d, α, γ) are placed in evaluated data files up to an incident energy of 200 MeV. The resulting code system, EASY-II(12) is designed as a functional replacement for the previous European Activation System, EASY-2010. It includes many new features and enhancements, but also benefits already from the feedback from extensive validation and verification activities performed with its predecessor. This work was funded by the RCUK Energy Programme under grant EP/I501045.

PR 46

'List-Mode' Data Acquisition and Analysis for a Compton Suppression System

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Compton Suppression techniques have been widely used [1] to reduce the Minimum Detectable Activity (MDA) of various radionuclides when performing gamma spectroscopy of environmental samples. This is achieved by utilising multiple detectors to reduce the contribution of photons that Compton Scatter out the detector crystal, only partially depositing their energy. Photons that are Compton Scattered out of the primary detector are captured by a surrounding detector, and the corresponding events vetoed from the final dataset using coincidence based fast-timing electronics. The current work presents the use of a Lynx^{TM} data acquisition module from Canberra UK (Harwell, Oxfordshire) to collect data in 'List-Mode' [2], where each event is time stamped for offline analysis. A post-processor developed to analyse such datasets [3] allows the optimisation of the coincidence delay, and then identifies and supresses events within this time window. This is the same process used in conventional systems with fast-timing electronics, however in the work presented, data can be re-analysed using multiple time and energy windows. All data is also preserved and recorded (in traditional systems, coincident events are lost as they are vetoed in real time), and the results are achieved with a greatly simplified experimental setup. Monte-Carlo simulations of Compton Suppression systems have been completed to support the optimisation work, and are also presented here. This work is supported by grants from the Engineering and Physical Sciences Research Council (EPSRC-UK).
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PR 47

Visualizing the Connections in the Exfor Database

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The EXFOR database contains many datasets (over 6160) in which the measured values are "reaction combinations", that is, they are not an absolute measurement of an experimental quantity. Rather, they are ratios of quantities, sums of quantities, or some other mathematical relation of experimental quantities. These reaction combinations couple large numbers of data sets together in non-trivial ways. In this poster I present a visualization of the coupled data used to derive cross material covariances for the COMMARA-3 library and I provide links to other, larger, visualizations on the NNDC website.

PR 48

Measurements of Inelastic Neutron Scattering from Carbon, Iron, Yttrium and Lead at 96 MeV

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Inelastic neutron scattering (n,n'x) is a pre-equilibrium reaction, i.e. an intermediate process between direct and compound nuclear reactions. The (n,n'x) reaction channel is much weaker than the elastic scattering (n,n) channel and there are very few data sets reported for inelastic neutron scattering at intermediate neutron energies (20 - 200 MeV). This work is an effort to provide more experimental data for the (n,n'x) reaction and was carried out at The Svedberg Laboratory in Uppsala at the quasi-mono-energetic neutron beam of 96 MeV. Using an extended data analysis of data primarily intended for measuring elastic neutron scattering only, it was possible to extract information on the inelastic scattering from several nuclei. An iterative forward-folding technique was applied, in which a physically reasonable trial spectrum was folded with the response function of the detector system and the output was compared to the experimental data. As a result, double-differential cross sections and angular distributions of inelastic neutron scattering from ^{12}C, ^{56}Fe, ^{89}Y and ^{208}Pb were obtained for the angular intervals 28 to 58 degrees for carbon, 26 to 65 degrees for iron and 26 to 52 degrees for yttrium and lead. The data sets cover an excitation energy range up to 45 MeV. In this paper, the forward-folding procedure including the detector response function is discussed, and results on double-differential cross sections and angular distributions for inelastic neutron scattering from ^{12}C, ^{56}Fe, ^{89}Y and ^{208}Pb are presented. Experimental data are compared to several model codes as well as existing experimental data for the reactions (n,n'x), (n,p'x) and (p,p'x).

PR 49

The Fission Cross Section of ^{240,242}Pu in the Neutron Energy Region up to 3 MeV

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For a sustainable nuclear energy supply a combination of present light water reactors, future advanced fast reactors and waste minimization in closed cycles with partitioning and transmutation is needed. This is the view of the Strategic Research Agenda of the European Technological Platform for a Sustainable Nuclear Energy (SNETP). In order to implement these novel nuclear systems and their respective fuel cycles it is necessary to improve the accuracy, uncertainties and validation of related nuclear data and models. Within the project ANDES (Accurate Nuclear Data for nuclear Energy Sustainability) a European wide effort has been started to measure critical reaction cross sections identified as being crucial for the development of innovative reactor concepts. The present work contributes to the improvement of the neutron-induced fission cross section of ^{240,242}Pu isotopes. These fission cross sections have been identified in a sensitivity analysis of many cross sections as being of highest priority for fast reactors. Target accuracies are very stringent and are required to be in the 1-3 % range for ^{240}Pu and 3-5 % for ^{242}Pu compared to current accuracies of about 6 % and 20 %, respectively. At JRC-IRMM, high quality ^{240,242}Pu targets have been prepared and shipped to the different partners in ANDES involved in these measurements. At Van de Graaff accelerator of JRC-IRMM several measurements have been performed to determine the fission cross section of ^{240,242}Pu relative to ^{237}Np and ^{238}U. A Frisch gridded ionisation chamber and a digital data acquisition system were used in the measurements. Since also the non-negligible spontaneous fission half life of both isotopes needs to be considered, also measurements of this quantity have been conducted. Preliminary results show an increasing of this value around 2 % for ^{242}Pu. So far cross sections for both isotopes have been determined up to 1.8 MeV showing some discrepancies (up to 12 %) to the ENDF/B-VII

evaluation mainly for ^{242}Pu around 1.1 MeV where the evaluation shows a resonance like structure not observed in the present investigation. The analysis procedure and the involved corrections of the acquired data will be presented together with the preliminary results obtained so far.
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PR 50

Neutron Capture Measurements and Resonance Analysis of Dysprosium

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Neutron capture measurements of dysprosium were performed at the electron linear accelerator facility of the Rensselaer Polytechnic Institute by using the time-of-flight technique in the energy region from 10 eV to 1 keV. The neutron capture experiments were made with a 16-section NaI multiplicity detector at a flight path length of 25.5 m. High purity isotopic samples of 161Dy, 162Dy, 163Dy, 164Dy as well as one natural dysprosium sample with thickness of 0.508 mm were prepared for this measurement. Resonance parameters were extracted from the data using simultaneous fit with the multilevel R-matrix Bayesian code SAMMY 8.0. New resonances are proposed, and other resonances previously identified in the literature have been revised. The resonance Integral (RI) was calculated for each dysprosium isotope using the codes NJOY and INTER. The resonance integrals calculated for both present and ENDF/B-VII.0 parameters within the energy region of 0.5 to 20 MeV. The present results are compared with other evaluated values of ENDF/B-VII.0 and JENDL 4.0.

PR 51

Neutron Yields from the Thick Targets Bombarded with Deuterons Above 20 MeV

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The reliable thick target neutron yields (TTNYs) data of the deuteron incident nuclear reactions are important for various applications, especially for the deuteron-energy range of 20-40 MeV, which will be used in the safety design of the IFMIF. From the literatures, the data on these subjects have been measured and simulated by some laboratories in the past years. But the data are still scarce such as the outgoing neutron angles and the kinds of target materials. Meanwhile, there are discrepancies between the measured and calculated results which used the Monte Carlo code directly. To improve the understanding of the experimental data, a hybrid method is proposed to estimate the TTNYs bombarded with deuterons above 20 MeV, by including the nuclear models for deuteron breakup reactions. To estimate completely the thick target yield of deuteron induced reaction, it is necessary to incorporate the theoretical studies between the nuclear models and the particle transportation methods. At first, a model calculation is employed to produce the data file, which analyzes the nucleon production from deuteron breakup reaction by the continuum discretized coupled-channels method and the Glauber model. Next, we simulate the deuteron and neutron transport processes in the thick samples, and give the output neutron flux.

PR 52

Transmission and Capture Yield Calculations in the Nuclear Data Evaluation Code Conrad

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This paper deals with the verification and validation of the nuclear reaction models developed in the Conrad code [1] for the modelling of the neutron induced reactions in the Resolved Resonance energy Range (RRR). First, this work demonstrates the capability of CONRAD code to calculate cross sections compared with NJOY [2] code (release 99-259). For both Multi-Level-Breit-Wigner and Reich-Moore approximations of the R-Matrix theory the average discrepancies between the two codes is lower than 0.003% if the precision criteria for the reconstruction of the 293.6 K broadened cross sections is set to 0.01% in NJOY. Second, a transmission and a primary capture yield being a simple functional of cross-sections, these observables are analytically checked with NJOY code highlighting there is no bias. Finally, total capture yields are simulated by a Monte Carlo technique inside CONRAD and checked for U238 at 1200K and Mn55 against SAMSMC [3] nuclear data evaluation code. A good agreement can be achieved between the two codes depending on the model used.

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PR 53

$^{10}B(n,Z)$ Measurements

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Four E Delta E telescopes were used at the LANSCE WNR (n,Z) station to investigate the production of charged particles from ^{10}B. The telescope consisted of a gas proportional detector and a silicon surface barrier detector. The flux was determined using a ^{238}U fission chamber. A clear measurement of the ground state alpha group and first excited state was able to be done at these angles. Proton emission was also observed. The proton branch was up to an order of magnitude larger than the ENDF/B-VII evaluation. A simple R-matrix analysis has been performed on the available data.

PR 54

Characterization of a Be(p,xn) Neutron Source for Fission Yields Measurements

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We report on measurements performed at The Svedberg Laboratory (TSL) to characterize a proton-neutron converter for fission yield studies. A 30 MeV proton beam impinged on a 5 mm water-cooled Beryllium target. The setup was designed to reproduce the conditions at the IGISOL-JYFLTRAP facility (University of Jyväskylä), where the neutron source will be used with the new high-intensity cyclotron for neutron induced fission yields measurements of different actinides using a Penning trap [1].
Two independent experimental techniques have been used to measure the neutron spectrum: a Time of Flight (ToF) system used to estimate the high-energy contribution, and a Bonner Sphere Spectrometer able to provide accurate results from thermal energies up to 20 MeV. An overlap between the energy regions covered by the two systems permits a cross-check of the results from the different techniques.
The ToF setup consisted of a liquid scintillator with good properties for n-γ discrimination [2]. Benchmarking of the ToF technique was obtained by performing measurements with a polyethylene-moderated target and with bare Beryllium targets of different thicknesses. Detailed Monte Carlo calculations of the different experimental conditions have been performed and their comparison with the measured data will also be shown.
[1] H. Penttilä, P. Karvonen, T. Eronen et al. Determining isotopic distributions of fission products with a Penning trap. The European Physical Journal A 44 (2010) 147-168. [2] S.E. Arnell, H.A. Roth, Ö. Skeppstedt et al. A 2π neutron and γ-ray multiplicity filter for the NORDBALL detection system. Nucl. Instr. and Meth. in Phys. Res. A 300 (1991) 303-311.

PR 55

Investigations of the ^{nat}Fe(d,x)^{55,56,57,58}Co,^{52,54}Mn Nuclear Reactions

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We investigated the ^{rmnat}Fe(d,x)^{55,56,57,58}Co,^{52,54}Mn nuclear reactions from their respective threshold up to initial deuteron energy of 24 MeV. A well established, stacked foil activation technique combined with HPGe gamma-ray spectrometry were employed to determine the excitation functions. Measured data were compared with the earlier measurements, and theoretical calculations as well. The possible applications of the measured data are discussed elaborately.

PR 56

Cross sections of Neutron Reactions (n,p), (n,α), $(n,2n)$ on Isotopes of Dysprosium, Erbium and Ytterbium at 14 MeV Neutron Energy

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Cross sections of the nuclear reactions (n,p), (n,α), $(n,2n)$ were measured on isotopes of dysprosium, erbium and ytterbium at the neutron energies 14.6 $\pm$ 0.2 MeV by the use of neutron activation method [1,2]. They were compared with available experimental data, evaluated nuclear data and the results of theoretical calculations. Theoretical calculations were performed with the use of EMPIRE and TALYS codes [3,4] as well as by empirical and semiempirical systematics to make solid estimates of reaction cross sections.
Corresponding author: V.A.Plujko

[1] N.R.Dzysiuk, A.O.Kadenko, I.M.Kadenko, G.I.Primenko, Nucl. Phys. and Atomic Energy. 12, No.2, 137 (2011) [2] N.Dzysiuk, I.Kadenko, A.J.Koning, R.Yermolenko, Phys.Rev.C 81, 014610 (2010) [3] M.Herman, R.Capote, B.V.Carlson et al., Nucl.Data Sheets 108, 2655 (2007) [4] A.J.Koning, S.Hilaire, M.C.Duijvestijn, Proc.of Int.Conf.on Nucl. Data for Science and Technology - ND2007, April 22-27, 2007, Nice, France, eds. O. Bersillon, F. Gunsing, E. Bauge, R. Jacqmin and S. Leray, EDP Sciences, 211 (2008)

PR 57

Determination of Partial Gamma-Ray Production Cross-Sections for Chemical Elements (Establishment of an Analytical Database for Prompt Gamma Activation Analysis)

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The establishment of a spectroscopic database for prompt gamma activation analysis was started in Budapest in 1997 after the PGAA facility was put into operation. No database existed earlier that met the requirements of chemical analysis, which restrained the development of the technique. The first version of the analytic database was published in the Handbook of Prompt Gamma Activation Analysis [1] and later a compiled version appeared in a Technical Document of the International Atomic Energy Agency [2]. This dataset is the basis of the Evaluated Gamma-ray Activation File (EGAF) [3]. The catalog contains the spectroscopic data (energies, partial gamma-ray production cross-sections and their uncertainties) for the prompt gamma rays induced by cold neutron capture on every chemical element except helium. Parallel to the establishment of the database, a method was developed to perform reliable chemical analysis based on the comparison of the prompt gamma spectra of unknown samples to the data library. Prompt gamma-ray measurements were initially performed with the low-flux thermal and medium-flux cold neutron beams at the PGAA facility at the Budapest Research reactor and later at the high-flux facility at FRM II, Garching. Three separate spectra were measured for all naturally occurring elements 1) an irradiation in their elemental, oxide, or sometimes other simple-compound form, 2) irradiation together with chlorine (PVC) whose precisely-known prompt gamma lines were used to calibrate the energies of the elemental ones, and 3) irradiation of stoichiometric compounds (e.g. chlorides) or homogeneous mixtures (e.g. water solutions) to determine the partial cross-sections of the lines relative to a comparator (Cl or H). The prompt gamma dataset was validated by a large number of measurements, and it has been frequently improved since its introduction. Similar measurements were performed in a chopped neutron beam to determine the intensity of decay gammas from short-lived nuclides. Revision of the prompt gamma library continues in Garching where many of the previous measurements will also be repeated utilizing the unique conditions of the high-flux PGAA instrument.

[1] Zs. Révay, R.B. Firestone, T. Belgya, G.L. Molnár in G.L. Molnár (ed.) Handbook of Prompt Gamma Activation Analysis with Neutron Beams, Kluwer, Dordrecht, 2004, pp. 173-364. [2] H.D. Choi, R.B. Firestone, R.M. Lindstrom, G.L. Molnár, S.F. Mughabghab, R. Paviotti-Corcuera, Zs. Révay, A. Trkov, V. Zerkin, Z. Chunmei "Database of prompt gamma rays from slow neutron capture for elemental analysis", International Atomic Energy Agency, Vienna, 2007. [3] R.B. Firestone, this conference [4] L. Szentmiklósi, Zs. Révay, T. Belgya, Nucl. Instr. Meth A 564 (2006) 655 and 622 (2010) 468.

PR 58

Measurement of Activation Cross Sections of Erbium Irradiated by Proton Beam

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Erbium is one of the rare earth elements which are used to produce therapeutic radioisotopes by charged particle induced reactions. Charged particles such as proton, deuteron and alpha particle can be used for the production of therapeutic radioisotopes. In this study, activation cross sections were measured for erbium sample irradiated by proton beams. MC-50 cyclotron of KIRAMS (Korea Institute of Radiological and Medical Sciences) was used for the irradiation of proton beams with energy up to 42 MeV. Radioactive nuclides are produced and decay to yield gamma rays with specific energies. A HPGe detector was used to measure gamma ray energies for the activation cross section measurement. A stacked foil technique was adopted to measure the activation cross sections at different proton energies. The thickness of erbium foil was 25 microns. Copper foil was used as a monitor foil to measure proton beam current. SRIM code was used to calculate energies of proton beams penetrating each foil. The measured data was compared with other available experimental data. The measured data was also compared with theoretical cross sections calculated based on TALYS code.

PR 59

Measurement of the ^{54,57}Fe (n,γ) Cross Section in the Resolved Resonance Region at CERN n_TOF

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The accurate measurement of neutron capture cross section of the stable Fe isotopes is important for disentangling the contribution of the s-process and the r-process to the stellar nucleosynthesis of elements in the mass range $60 < A < 120$. At the same time, Fe is an important component of structural materials and improved neutron cross section data is relevant for the reliable design of new nuclear power systems. This contribution presents the final results for ^{54,57}Fe (n,γ) measured at CERN n_TOF in the energy range from 1 eV to 1 MeV using two C_6D_6 detectors in combination with the pulse height weighting technique. A comparison of the n_TOF results versus previous measurements and nuclear data evaluation will be also reported.

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PR 60

Total Neutron Cross Section Measurements of ^{27}Al, ^{12}C and ^{238}U on Filtered Neutron Beams of 54 keV and 148 keV

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Neutron filter technique was used to produce quasi-monoenergetic neutrons of 54 keV and 148 keV on horizontal channel of Dalat Research Reactor. Total neutron cross sections of ^{27}Al, ^{12}C and ^{238}U have been measured on those neutron energies by transmission technique using a gas-filled proton-recoil spectrometer. Simulations of total neutron cross sections and self shielding effect with different target thicknesses were also taken into account by MCNP code. The obtained data of ^{27}Al, ^{12}C and ^{238}U are in good agreement with experimental ones from other authors and evaluated values of JENDL-4.0 and ENDF/B-VII.0.

PR 61

Nuclear Data Measurements at VERA for Fusion, ADS and Environmental Applications

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Accurate cross sections are the backbones for calculating the production of long-lived radionuclides, which are of interest in a variety of fields. We summarize some recent cross-section measurements using Accelerator Mass Spectrometry (AMS) for counting long-lived radionuclides. Data presented here relate to nuclear fusion and advanced reactor concepts but also to the production of cosmogenic radionuclides for environmental and geological applications. Lack of information exists for a list of nuclides as pointed out by nuclear data requests. AMS represents an ultra-sensitive technique for measuring a limited, but steadily increasing number of longer-lived radionuclides. This method implies a two-step procedure with sample activation and subsequent AMS measurement. Cross section measurements via neutron activations in the fast neutron energy range were performed in cooperation with TU Dresden (TUD), utilizing their neutron generator, i.e. producing 14-MeV neutrons via the (d,t) reaction; and higher energy neutrons were produced via the Van de Graaff facility at IRMM, Geel, with neutron energies between 13 and 22 MeV. After activation the AMS measurements were performed at the VERA laboratory. An overview of recent measurements with reference to the respective application is given and the method is exemplified for some specific neutron-induced reactions leading to longer-lived nuclides: we will present new precise data for ^{58}Ni(n,α) and ^{56}Fe(n,2n), both leading to ^{55}Fe. A systematic study of ^{14}C production from ^{14}N(n,p) and ^{nat}O will be shown. We also continued our studies of ^{26}Al production in a fusion environment. Finally, new results obtained for (n,3n) reactions on ^{70}Ge, ^{204}Pb and actinides will be compared to model calculations.

PR 62

Experimental Measurement of Absolute Gamma-ray Emission Probabilities for ^{138}Xe

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The gamma-ray emission probability is an important factor in the research field of nuclear-reaction products or radioisotope application. ^{138}Xe decays by beta-particle emission with a half-life of 14.08 min[1]. ^{138}Cs is daughter of ^{138}Xe, and decays by beta-particle emission with a half-life of 33.41 min[1] . The ^{138}Xe, with a short half-life, is radioactive gas nuclide. It was therefore difficult to determine the precise gamma-ray emission probability by using the routine method. Reference [1] an [2] gave the results of gamma-ray emission probabilities for ^{138}Xe, but the uncertainties is relatively large. Recently through preparation of the homogeneous sources for ^{138}Xe-^{138}Cs [3], we obtained the activity of ^{138}Xe by using the decay relationship between ^{138}Xe and ^{138}Cs. After the gamma-ray efficiency curve of the HPGe detector was calibrated using many standard sources and self-absorbed effect was corrected [4], the absolute gamma-ray full-energy peak efficiency of ^{138}Xe were determined. Thus, the absolute emission probabilities of three

main gamma-ray for ^{138}Xe were determined , and the results of 258 ,434keV and 1768keV were 34.91(62)%, 22.18(35)% and 18.79(30)%, respectively. The results of the present work were in poor agreement with Ref.[1]. Because the data adopted in the evaluation of Ref[1] were almost determined in the 1970's when the experiment equipment and measuring technology were behind today, we believe that the results gave in the present work are more reliable.

[1] FIRESTONE R B., Table of isotopes, 8th Edition, 1998. [2] J.K.Tuli, Selected Update for A=138*, Nuclear Data Sheets, 74,349, 1995. [3] Z.Y.Chen, F.Xie, Preparation of calibration sources of ^{88}Kr and ^{138}Xe for HPGe detector, Journal of Radioanalytical and Nuclear Chemistry, 273: 257-261, 2007. [4] XIE Feng, The study of self-absorption correction in γ-ray efficiency calibration of fission gas nuclide, Atom Energy Science and Technology, Vol.44, No.10, 2010.

PR 63

Processing with LLNL's New Evaluated Nuclear Data Structure GND and Infrastructure Fudge

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Lawrence Livermore National Laboratory (LLNL) has made an initial effort towards defining a new structure for storing evaluated nuclear reaction data called Generalized Nuclear Data (GND). In addition to the structure, LLNL has developed an infrastructure called FUDGE that allows one to modify, visualize and process (e.g., convert to a form suitable for deterministic transport) data stored in the GND structure. Additionally, the FUDGE infrastructure can convert an ENDF formatted evaluated nuclear data file to and from GND. By converting an ENDF file to GND and processing we can now compare FUDGE's processing results to other ENDF processing codes such as NJOY. In this presentation we will describe the FUDGE processing codes, demonstrate how to obtain FUDGE and use it to process an ENDF file as well as show comparisons between the results of FUDGE and NJOY processing. This work has been supported by Department of Energy contract No. DE-AC52-07NA27344 (Lawrence Livermore National Laboratory).

PR 64

Processing and Validation of JEFF3.1.2 Neutron Cross-Section Library into Various Formats: ACE, PENDF, GENDF, MATXSR and BOXER.

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Following the processing and validation of JEFF-3.1 performed in 2006 and presented in ND2007, and as a consequence of the latest updated of this library (JEFF-3.1.2) in February 2012, a new processing and validation of JEFF-3.1.2 neutron cross-section library is presented in this paper. The nuclides processed are all the evaluations of the General Purpose Library and Thermal Scattering JEFF-3.1.2 Library, including the important light nuclei, structural materials, fission products, control rod materials and burnable poisons, all major and minor actinides. The processed library was generated with NJOY-99.364 nuclear data processing system plus some specific updates. The processed library contains continuous energy neutron cross-section data files at ten different temperatures in ACE format. In addition, NJOY inputs are provided to generate PENDF, GENDF, MATXSR and BOXER formats. The processed library has undergone strict Q & A procedures, being compared with other available libraries (JEFF-3.1.1, ENDF-B/VII.0 or VII.1) using JANIS-3.4 and PREPRO-2000 codes. MCNP5 is used for validation purposes with a set of 119 criticality benchmark experiments taken from ICSBEP-2010. This work has been done with the support of the OECD/NEA Data Bank.

PR 65

Target Characterization of Large Area Minor Actinide Layers for Fast Neutron Induced Fission Cross Section Experiments at nELBE

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The development of Accelerator Driven Systems (ADS) requires accurate nuclear data. Especially neutron induced fission cross sections of Plutonium and minor actinides in part show high uncertainties in the fast energy range. For ^{242}Pu current uncertainties are of around 21 %, the target uncertainties in the order of 7 %. Sensitivity studies ([1], [2]) show that the total uncertainty has to be reduced below 5 %, to enable reliable neutron physical simulations. This challenging task will be performed at the neutron time-of-flight facility of the new German National Center for High Power Radiation Sources at HZDR, Dresden. Improved experimental conditions (low scattering environment) and beam power, paired with the right spectral shape of the nELBE neutron source will provide excellent conditions to achieve this aim. A parallel plate ionization chamber with it's approximately 100 % intrinsic detection efficiency will measure fission fragments from thin minor actinide layers (areal density: 580 and 220 microgram per centimeter^2; total mass: 200 milligram of ^{235}U and 75 milligram of ^{242}Pu). These very homogeneous targets are produced by the institute of radiochemistry of the University of Mainz. To handle the high specific alpha activity of the Pu targets, a combination of fast preamplifiers and digital signal processing has been developed to suppress pile-up effects. It is planned to determine the homogeneity of the minor actinide targets by two different methods. Due to their high specific activity the number of fissionable Pu atoms per unit area will be determined by a spatially resolved alpha spectroscopy. The required setup was optimized using Geant 4 simulations. Results of this simulations and first experimental approaches will be presented. For the uranium targets it is planned to determine the homogeneity in a fission chamber with a collimated neutron beam at PTB Braunschweig. Physical properties (distance between anodes and cathodes, counting gas etc.) of the chamber have also been optimized using the Geant 4 framework. The work is embedded in the TRAKULA project (BMBF 02NUK13A) supported by the Federal Ministry for Education and Research of Germany.

[1] OECD/NEA, Nuclear Data High Priority Request List, (2011), http://www.nea.fr/html/dbdata/hprl/
[2] Working Party on International Evaluation Co-operation of the NEA Nuclear Science Committee, Uncertainty and Target Accuracy Assessment for Innovative Systems Using Recent Covariance Data Evaluations, (2008), http://www.nea.fr/html/science/wpec/volume26/volume26.pdf

PR 66

Monte Carlo Simulation of Prompt Fission Neutron Observables for the Spontaneous Fission of ^{236}Pu, ^{238}Pu,

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Recently, a Monte Carlo code which simulates the fission fragment deexcitation process has been developed at CEA-Cadarache. Our aim is to get a tool capable to predict spectra and multiplicities of prompt particles

and to investigate possible correlations between fission observables. One of the main challenges is to define properly the share of the available excitation energy at scission between the two nascent fission fragments. In a previous work [1], these excitation energies were treated within a Fermi-gas approximation in aT^2 (where a and T stand for the level density parameter and the nuclear temperature) and a mass dependent law of the temperature ratio ($R_T = T_L/T_H$, with T_L and T_H the temperature of the light and heavy fragment) has been proposed. With this R_T-law, the main fission observables of the ^{252}Cf(sf) could be reproduced. Here, in order to take into account the fission modes by which the fissioning nucleus undergoes to fission, we have adopted a specific R_T-law for each fission mode. For actinides, the two main fission modes are called Standard I and Standard II (following the Brosas's terminology [2]). This new procedure has been applied on various spontaneously fissioning Pu-isotopes, since a strong variation of the relative importance of both modes appear for these isotopes [3]. The Pu-isotopes constitute therefore a nice database to investigate the impact of fission modes on the prompt fission neutron observables (multiplicity and spectra).
[1] O. Litaize and O. Serot, Phys. Rev. C 82, **054616** (2010) [2] U. Brosa, S. Grossman and A. Muller, Phys. Rep. 197 (1990) 167 [3] L. Demattè *et al.*, Nucl. Phys. A 617 (1997) 331-346

PR 67

Consistent Modeling of (n, f), (γ, f) and (t, pf) Cross Sections

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An accurate and consistent theoretical prediction of fission cross sections remains a daunting task to this day, as many model parameters are often tuned to accurate experimental data, when known, and crudely extrapolated when data is missing. Chief among those parameters are the fission barrier heights and widths, and the level densities at the saddle points. The specific model used to describe fission probabilities can dramatically change the choice of those parameters and render difficult a clear comparison with experimental fission barriers, for instance. Here we present an attempt to describe several fission cross section data, leading to the same fissioning nucleus, such as (n, f), (γ, f), (t, pf), as well as fission fragment angular distributions, consistently, i.e., within a unified model with a single and common set of model parameters. Fission probabilities are calculated in the R-matrix formalism applied to the main fission channel [1], paying particular attention to the intermediate structures generated by the presence of states in the second-well of the fission path. Treating the specific entrance channel correctly is also very important as it determines which fission transition states are more likely to contribute. For instance, neutron-induced fission and transfer reaction leading to fissions will populate distinct spin and parity sub-spaces in the fissioning nucleus, leading to significant corrections in the fission probabilities. We will present preliminary results in the case of $^{236}U^*$ fissioning system, for which available experimental data on different reaction channels can be used to constrain the model calculations.
[1] J.E. Lynn, J. Phys. A: Math., Nucl. Gen., **6** (1973) 542.

PR 68

Nuclear and Particle Physics Outreach at the Sanford Underground Research Facility

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The Sanford Underground Research Facility in Lead, SD provides the facility and infrastructure for scientists to study some of the most compelling questions about the history and fate of our universe through its major experiments searching for direct evidence of dark matter and exploring the nature of neutrinos. Early experiments currently in the installation phase are LUX, a direct search for dark matter (supported by the U.S. high energy physics program), and the Majorana Demonstrator, a search for neutrinoless double beta decay in Germanium (supported by the U.S. nuclear physics program). The Sanford Center for Science Education (SCSE) is in the planning stages as the education component of the laboratory. The mission of the SCSE is to draw upon the underground science and engineering, its human resources, its unique facility and its setting within the Black Hills to inspire and prepare future generations of scientists, engineers, and science educators. As work proceeds towards design of the building, institution, and the programs and exhibits therein, early work has progressed towards establishing programs that build capacity and partnerships and begin to prototype innovative educational programming and exhibits to meet its educational vision. As the Sanford Lab education team explores innovative ways to convey the excitement of the physics to audiences of all ages, successes and challenges from the first three years of early educational programming will be highlighted in this presentation. Particular attention will be given to those that draw on nuclear physics and chemistry: background radiation, gamma ray counting, cosmic rays, weak interaction physics, etc.

PR 69

Teaching Quantum Mechanics with Single-Photon Experiments

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A common learning goal for instructors of advanced physics is for students to recognize a difference between the experimental uncertainty of classical physics and the fundamental uncertainty of quantum mechanics. We have documented the positive impact on student thinking of incorporating experiments on the foundations of quantum mechanics into the undergraduate physics curriculum. In light of the Advanced Laboratory Physics Association's current efforts to "modernize" undergraduate laboratory courses nationwide (with an emphasis on affordable "single-photon" experiments), it is important for instructors to be conscious of the specific issues students face with the concepts behind such experiments, in particular because of the *black-box* nature of the apparatus. This talk will also stress the importance of semi-classical models of light detection, so that students can properly interpret their experimental data, and engage in a true contrasting of competing theories, instead of simple "confirmation".

PR 70

UMC with Multivariate Lognormal Probability Distributions for Nuclear Data Applications

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Inherently positive parameters with large relative uncertainties (typically $> 30\%$) are often considered to be governed by the lognormal distribution. This assumption has the practical benefit of avoiding the possibility of sampling negative values in stochastic applications. Recently the relations between multivariate lognormal and normal distributions have been revisited. New relations between the correlation coefficients of normal and log-normal distributions have been derived which hold independently of the uncertainty value. The possibility of using the Unified Monte Carlo (UMC) technique for the evaluation of nuclear

reaction data assuming log-normal multivariate distributions is discussed in this paper. The mathematical formalism is described and numerical examples are provided comparing normal and log-normal formulations of the UMC for small and large uncertainties with results obtained using the Generalized Least Squares (GLS) method. Suggestions for nuclear data applications are discussed.
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PR 71

Measurement of ^{243}Am(p,tf) as a Surrogate for ^{240}Am(n,f)

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The cross sections of (n,f) reactions are of interest in reactor modeling, but on short-lived isotopes, such as ^{240}Am, can be very difficult to measure. To avoid the enormous background created by such short-lived isotopes, we use the surrogate ratio method, which allows us to determine the ratio of an unknown cross section relative to a known one. In the case of ^{240}Am(n,f), the ratio is relative to ^{235}U(n,f), and we use (p,t) reactions to populate the relevant compound nuclei. We present preliminary results for measurements of ^{243}Am(p,tf) and ^{238}U(p,tf) using the STARLiTe detector system at the Texas A & M University Cyclotron Institute. The performance of the recently commissioned data acquisition system will also be presented. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

PR 72

Neutron Cross Section Covariances for Np-237 in the Resolved Resonance Region

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Neutron elastic scattering, radiative capture and fission cross section covariances for Np-237 are evaluated in the resolved resonance region. Analytical expressions describing the sensitivities of cross sections with respect to the resonance parameters at certain energy point are derived from the Multi-level Breit-Wigner formula. Then they are numerically integrated to obtain the sensitivities of average cross sections to the resonance parameters in an arbitrary energy bin. The full covariance matrix is constructed with a thermal region based directly on experimental data, and a resonance region using the resonance parameter uncertainties from Atlas of Neutron Resonances. Scattering radius uncertainty is handled explicitly, and by using ENDF file 33 we bypass the possible file 32 processing issue which may lead to discrepancies between the multigroup covariances by the different processing codes.

PR 73

D-T Fusion Neutron Irradiations at AWE

Matt Gardner, Andrew Simons, Ben Williams, Mike Rubery, *AWE*.

A team at AWE has conducted a 2-year feasibility study to determine the suitability of ASP, its 300 keV deuteron accelerator, for the measurement of neutron-induced reaction cross-sections. Decay gammas resulting from 89Y(n,n')89mY and 89Y(n,2n)88Y reactions have been collected using high-purity germanium and various different irradiation and counting geometries. Modelling of the ASP system and D-T interaction has been carried out using Geant4 in order to determine neutron spectra as a function of source-target angle and distance. Data collected using both analogue and list-mode systems have been analysed via parallel routes and the results compared. Fast extraction for short-lived products and low-background counting for long-lived products have both been employed; results from the data so collected are presented here.
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Commara-3.0 Covariance Library

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The Commara library is a set of covariances for the major reaction channels that are of importance to thermal and fast breeder reactors in addition to sensitivity studies. Version 3.0 will build upon the earlier work of version 2.0, released in March, 2011, which contained covariances for 110 materials in the AFCI 33-group energy structure. The new version will refer to the central values of ENDF/B-VII.1, released December, 2011, and will incorporate covariances included in this release of the ENDF library, increasing the number of materials in Commara 3.0 to approximately 190. In addition to covariances for the 4-5 major reaction channels, version 3.0 will also expand the number of materials with covariances for prompt fission neutron spectra, mubar (P_1 elastic) and nubar (average number of neutrons/fission), where available. Covariances for cross-reaction channels present in ENDF/B-VII.1 will also be included. The energy weighting will be modified from the pure 1/E weighting used with Commara 2.0 to 1/E + fission spectrum.

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Study of Various Potentials in Heavy-Ion Collisions at Intermediate Energies

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Heavy-ion collisions have always captured a central place in nuclear physics mainly due to the wider domain of physics it caters. Right from low energy to the ultra-relativistic energies, a large number of new phenomena have been predicted. The reaction dynamics in heavy-ion collisions at intermediate energies has been used extensively during the last three decades to understand the nature of nuclear matter at extreme conditions of temperature and density. The phenomena that are mainly observed in this energy range are multi-fragmentation, collective flow and nuclear stopping etc. Among these observables, collective transverse in-plane flow has been found to be of immense importance [1, 2]. Lots of experiments have been performed and number of theoretical attempts have also been employed to explain and understand transverse in-plane flow. Collective flow is negative at low incident energies whereas it is positive at a reasonable higher incident energies. At a particular energy, however, a transition occurs. This transition energy is known as balance energy. This balance energy has been subjected to intensive theoretical calculations using variety of equations of state as well as NN cross-sections [1, 2]. Interestingly none of these studies take the effect of various potentials such as Skryme potential (density dependent), Yukawa potential (surface dependent), Coulomb potential, symmetry potential, and momentum dependent interactions etc. into account. Here, our aim is to pin down the contribution of various potentials in transverse in-plane flow and hence balance energy by using the reactions of Ni58 + Ni58 and Fe58 + Fe58 between the incident energy range from 50 MeV/nucleon to 150 MeV/nucleon. The study has been performed within the framework of Isospin-dependent Quantum Molecular Dynamics (IQMD) model [3]. The impact parameters are guided by the experimental study of R. Pak et al. [4].

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Study of Neutron-Induced Fission Resonances in ^{234}U Measured at the CERN n_TOF Facility

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We present the resolved resonance region analysis of the high resolution ^{234}U(n,f) cross section data obtained using a reaction chamber based on parallel-plate avalanche counters (PPACs) at the CERN Neutron Time-of-Flight n_TOF facility extending the work performed at reference [1]. Current evaluations [2], [3] are based on G. D. James et al. data obtained in the 70's decade [4]. Hence, this study will allow us to improve the knowledge of the ^{234}U fission cross section in the resolved resonance region of interest for reactor studies in the thorium fuel cycle. The resonance parameters in the energy range from 1 eV to 1500 eV, corresponding to the resolved resonance region (RRR) have been studied with the Multilevel Multichannel R-matrix code (SAMMY) [5] using the Multilevel Breit-Wigner approximation of the R-matrix. Corrections of Doppler broadening due to the thermal motion of the nuclei in the sample, resolution broadening of the neutron beam, self-shielding, multiple scattering, normalization and background were included in the SAMMY analysis. The resonance parameters in the JENDL 3.3 evaluation, which were adopted from reference [4] after modification of an average radiative width to 0.026 eV, were used as initial parameters to make the fit. In addition, the statistical analysis has been accomplished with the SAMDIST code [6] in order to study the level spacing, the reduced fission width and the Mehta-Dyson correlation.

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Interaction of Fast Nucleons with Actinide Nuclei Studied with Geant4

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We model interactions of protons and neutrons with energies from 1 to 1000 MeV with uranium and americium nuclei, as well as with extended targets made of such fissile materials. The calculations are

performed with the Monte Carlo model for Accelerator Driven Systems (MCADS) [1, 2] which is based on the Geant4 toolkit [3] version 9.4. This toolkit is widely used for Monte Carlo simulations in particle and nuclear physics already for a decade. Previously it was applied to transport particles in materials containing nuclei not heavier than uranium ($Z <= 92$). After several fixes we apply the toolkit to model proton and neutron-induced reactions on Am nuclei. The fission and radiative capture cross sections, neutron multiplicities and distributions of fission fragments were calculated for thin targets made of uranium and americium and compared with recent experimental data from the EXFOR database. As demonstrated, with the Intra-Nuclear Cascade Liege (INCL) model combined with deexcitation fission-evaporation model ABLA available in Geant4 one is able to describe data on proton-induced fission of uranium and americium. The calculated average numbers of fission neutrons and mass distributions of fission products agree well with the data. At the same time some deviations between theory and experiment are seen for proton-induced fission below 50 MeV. This is expected due to limitations of the cascade model of nuclear reactions at low incident energies.
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PR 78

The Structure and Lowest Energy States of ^{152,154}Sm Isotopes

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The isotopes are classified as deformed nuclei. The phenomenological model [1,2] is presented to describe the complete structure and the lowest energy states of isotopes by taking into account the Coriolis mixing between states. The parameters fitted to the model are calculated. The inertial parameters are defined and rotational angular frequencies are calculated [3]. The energy spectra of positive-parity states which are in good agreement with the experimental data are presented. It is found that the non-adiabaticity of rotational energy bands occurred at high spin due to the Coriolis effect. Few new states are predicted.
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PR 79

A New Formulation for the Doppler Broadening Function Relaxing the Approximations of Beth-Plackzec

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In all nuclear reactors some neutrons can be absorbed in the resonance region and, in the design of these reactors, an accurate treatment of the resonant absorptions is essential. Apart from that, the resonant absorption varies with fuel temperature, due to the Doppler broadening of the resonances. The thermal agitation movement of the reactor core is adequately represented in microscopic cross-section of the

neutron-core interaction through the Doppler broadening function. This function is calculated numerically in modern systems for the calculation of macro-group constants, necessary to determine the power distribution of a nuclear reactor. It can also be applied to the calculation of self-shielding factors to correct the measurements of the microscopic cross-sections through the activation technique and used for the approximate calculations of the resonance integrals in heterogeneous fuel cells. In these types of application we can point the need to develop precise analytical approximations for the Doppler broadening function to be used in the calculation codes that calculates the values of this function. However, the Doppler broadening function is based on a series of approximations proposed by Beth-Plackzec. In this work a relaxation of these approximations is proposed, generating an additional term in the form of an integral. Analytical solutions of this additional term are discussed. The results obtained showed that the new term is important for high temperatures, typical in the centreline of fuel rods operating in nuclear power plants.

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Reaction Data Assimilation Phase 1: Model Based Files and Parameter Covariances

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Assimilation is a refinement of the usual data adjustment procedure. It links results of integral experiments to the parameters of nuclear reaction theory, so that it is the reaction model parameters that are adjusted rather than energy-averaged group cross sections. This novel approach should make adjustment independent from the target application and should account for the physics constraints imposed by the nuclear reaction models, differential, and integral measurements. The resulting covariances should reflect our cumulative knowledge leading to the reduction of the uncertainty margins in the final data. Cross sections and covariances for the model parameters for 239,242Pu, and 235,238U nuclei fully based on the EMPIRE-3.1 code [1] calculations were produced (starting with values from the RIPL database [2]). The Kalman filter technique was used for adjusting selected input model parameters to reproduce differential experimental data and for the production of these covariances. In addition, for the first time, sensitivities of the Prompt Fission Neutron Spectra (PFNS), the nu-bar, and mu-bar (elastic), along with the respective covariances, were consistently incorporated into EMPIRE and into the assimilation procedure. These along with the sensitivities of the cross sections to perturbation of model parameters were used to perform actual assimilation (reported in a separate contribution). These results should shed some light on the issue of the shape of PFNS, which is not well known experimentally, as well as on cross-correlations among cross sections, PFNS, nu-bars and possibly also mu-bars. Details of the EMPIRE calculations, including choice of reaction models and experimental data will be discussed.
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PR 81

The Angular Distribution of Neutrons Scattered from Deuterium below 1 Mev

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A re-evaluation of the angular distribution of elastic scattering of neutrons off deuterium at energies below 1 MeV is one of the high priority requests featured on the High Priority Request List for nuclear data maintained by the OECD-NEA. The request is due to changes in C/E for the effective multiplication factor k and, more importantly, for the coolant void reactivity in heavy water critical benchmarks. These changes came about through the change from ENDF/B-VI.4 to ENDF/B-VI.5 in the angular distribution of n+d scattering. This request has led to several efforts to pin-down the angular distribution with nuclear theory model calculations, but the point is still open and accurate measurements are required to arbitrate between different evaluations and model calculations. On the other hand, measurements of this angular distribution are scarce and discrepant, and the few that are reported in the literature date from the fifties and sixties. Neutron elastic scattering measurements were made at the nELBE neutron time-of-flight facility at a 6 m flight path. Energies below 1 MeV were studied using a setup consisting of eight ^{6}Li-glass detectors placed at nominal angles of 15 and 165 degrees with respect to the incident neutron beam. These angles were chosen since an earlier study showed that the ratio of the scattered neutron currents at theses angles has a large sensitivity to differences between the various data evaluations for deuterium, while still allowing a practical experimental setup. A polyethylene (CD_2) sample enriched to 99.999% in deuterium was used. In the experimental data analysis contributions from time-uncorrelated room-return and time-correlated air-scatter are subtracted using the time-of-flight spectrum and the sample-out measurements, respectively. Monte Carlo calculations are needed to correct for the carbon contribution, sample multiple scattering, air scatter and the energy dependence of the detection efficiency. The high repetition rate and shorter flight path of the nELBE experiment offer clear advantages compared with a similar attempt with the same setup at GELINA at a long flight path (300m). Accurate 165/15 degree angle signal ratios were obtained that will be compared with the various proposed angular distributions. Simultaneously, the early-day experiments using a proportional counter to infer angular distributions from deuterium-recoil pulse-height distributions are being studied through a new experiment with such a device at PTB. The status of this work will be presented and compared to the earlier work and the results of the nELBE experiment.

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ANDES Measurements for Advanced Reactor Systems

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Advanced reactor systems are of interest to minimizing high level waste and maximizing utilization of resources while implementing the highest standards of safety and security. Recent sensitivity studies demonstrate the need for very tight nuclear data uncertainties to enable reliable and accurate estimates of key reactor and fuel cycle parameters. Such needs were prioritized and are advertised by the OECD Nuclear Energy Agency. Many of these needs require a combination of accurate measurements and dedicated new nuclear data evaluations to take optimal advantage of this new work. A significant number of new measurements was undertaken by the ANDES "Measurements for advanced reactor systems" initiative.

ANDES (Accurate Nuclear Data for nuclear Energy Sustainability) is an integrated project co-sponsored by the seventh framework programme (FP7) of the European Commission. These new measurements include neutron inelastic scattering off ^{238}U, ^{23}Na, Mo, and Zr, neutron capture cross sections of ^{238}U, ^{241}Am, neutron-induced fission cross sections of ^{240}Pu, ^{242}Pu, ^{241}Am, ^{243}Am and ^{245}Cm, and measurements that explore the limits of the surrogate technique. The latter study the feasibility of inferring neutron capture cross sections for Cm isotopes, the neutron-induced fission cross section of ^{238}Pu and fission yields and fission probabilities through full Z and A identification in inverse kinematics for isotopes of Pu, Am, Cm and Cf. Finally, four isotopes are studied which are important to improve predictions for delayed neutron precursors and decay heat by total absorption gamma-ray spectrometry (^{88}Br, ^{94}Rb, ^{95}Rb, ^{137}I). The measurements which are performed at state-of-the-art European facilities (CENBG, CERN n_TOF, GANIL, IRMM, Jyväskylä University, Oslo Cyclotron Laboratory) have the ambition to achieve the lowest possible uncertainty, and to come as close as is reasonably achievable to the target uncertainties established by the above mentioned sensitivity studies. An overview will be presented of the activities and achievements of this initiative leaving detailed expositions to the various parties contributing to the conference.

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Neutron Inelastic Scattering Measurements for Na, Cu, Mo, Zr, Ge, Th and U

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Studies for advanced reactor systems such as sodium-cooled fast reactors designed for recycling of high level waste, accelerator driven systems for transmutation, and systems envisioning the use of the Th/U fuel cycle impose tight requirements on nuclear data for accurate predictions of their operation and safety characteristics. Among the identified needs established by sensitivity studies, neutron inelastic scattering on the main structural materials and actinides and some (n,xn) cross sections for actinides feature prominently. Neutron inelastic scattering measurements using the (n,n'g)-technique are carried out at two measurement setups at the GELINA neutron time-of-flight facility of IRMM. The GAINS setup has 12 high purity coaxial germanium detectors of 8 cm diameter and length and is placed at 200 m from the neutron source for a 1 keV neutron energy resolution at 1 MeV. It is readily applied for elemental and enriched samples of stable isotopes for which sizeable samples are easily obtained. The GRAPHEME setup, established by CNRS/IN2P3/IPHC has 4 high purity planar detectors and is placed at 30 m from the neutron source for optimal intensity in studies of actinide samples. The latter samples need to be thin (0.2 mm) to minimize the self-absorption of the low-energy gamma-rays characteristic for the decay of the low-lying levels in actinide targets. Recent progress of the measurements will be shown for ^{23}Na, ^{63,65}Cu, Mo, Zr, ^{76}Ge, ^{232}Th and ^{235,238}U. Modeling and evaluation of the data is essential for advancing the use of these data in applications. This requires a close collaboration with the theoretical and evaluation communities thus enabling our results to be compared with state-of-the-art model calculations. Studies for Na, Mo, Zr, and ^{238}U are co-sponsored by the European Commission's FP7 programme via the ANDES project. The work for ^{76}Ge supports the GERDA and similar experiments searching for evidence of neutrinoless double-beta decay.

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Light-Ion Production in 175 MeV Neutron-Induced Reactions on Oxygen

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Over the past years several applications involving high-energy neutrons (E>20 MeV) have been developed or are under consideration, e.g., radiation treatment of cancer, neutron dosimetry at commercial aircraft altitudes, soft-error effects in computer memories, accelerator-driven transmutation of nuclear waste and energy production. Data on light-ion production in light nuclei such as carbon, nitrogen and oxygen are particularly important in calculations of dose distributions in human tissue for radiation therapy at neutron beams, and for dosimetry of high energy neutrons produced by high-energy cosmic radiation interacting with nuclei (nitrogen and oxygen) in the atmosphere. When studying neutron dose effects, it is especially important to consider carbon and oxygen, since they are, by weight, the most abundant elements in human tissue. Such data have been measured with the MEDLEY setup based at The Svedberg Laboratory (TSL), Uppsala, Sweden. It has been used to measure differential cross sections for elastic nd scattering and double-differential cross sections for the (n,xp), (n,xd), (n,xt), (n,x^{3}He), and (n,xα) reactions from C, O, Si, Ca, Fe, Pb, and U around 96 MeV [1]. In the new Uppsala neutron beam facility the available energy range of quasi mono-energetic neutron beams is extended up to 175 MeV. The detector setup used in MEDLEY [2] consists of eight so-called telescopes mounted at different angles inside an evacuated reaction chamber. Each of the telescopes consists of two fully depleted ΔE silicon surface barrier detectors (SSBD) and a CsI(Tl) crystal. To allow for measurements at this higher neutron energy some changes in the detector setup compared to the campaign at 96 MeV had to be made. The second ΔE detectors have been replaced by 1000 μm thick SSBDs and the size of the crystals used as E detectors was increased to a total length of 100 mm and a diameter of 50 mm. The $\Delta E - E$ technique is used to identify the light ions, and cutoff energies as low as 2.5 MeV for protons and 4.0 MeV for alpha particles are achieved. Suppression of events induced by neutrons in the low-energy tail of the neutron field is achieved by time-of-flight techniques. The data are normalised relative to elastic np scattering measured in one of the telescopes at 20 degrees. Preliminary double-differential cross sections for oxygen are presented and compared with theoretical reaction model calculations.

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PR 85

The New Approach to Analysis and Evaluation of Reliable Partial Photoneutron Reactions Cross Sections

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Accurate and reliable information on cross sections of partial photoneutron reactions primarily (γ,n), (γ,2n) and (γ,3n) is very important for both basic research and many applications. The most modern and actual now of those is monitoring of the beam luminosity in ultra-relativistic heavy-ion colliders by measuring neutron emission (in (γ,n) and (γ,2n) reactions) rates in mutual electromagnetic dissociation of colliding nuclei. The majority of such kind data were obtained using quasimonoenergetic annihilation photons at Livermore (USA) and Saclay (France). Data are included into various reviews, atlases and databases, are used in many modern codes (GEANT, IMPIRE, TALYS). Unfortunately there are significant (till 100 %) systematical disagreements between those data - generally (γ,n) reaction cross sections are larger at Saclay, but (γ,2n) reaction cross sections vice versa at Livermore. In various investigations (for example, [1, 2]) it was shown that the main reasons are shortcomings of neutron multiplicity sorting methods used at Saclay and the method was proposed for overcoming of those disagreements - recalculation of unreliable Saclay data putting them into accordance with reliable Livermore data. But at the same time there are many doubts that Livermore data are reliable because in many cases behavior of (γ,n) reaction cross section is very strange - above the Giant Dipole Resonance (GDR) maximum it falls rapidly going into the region of negative values, then returns back to positive values showing clear positive maxima and after that again goes to negative values. That means that the task of investigation of those cross sections reliability and authenticity remains till now very actual and important. To solve it the simple, objective and absolute criteria were proposed at the first time - transitional photoneutron multiplicity functions $F_i(\gamma,in) = \sigma(\gamma,in)/\sigma(\gamma,xn)$ equal correspondingly to ratios of cross sections of (γ,n), (γ,2n) and (γ,3n) reactions to that of total photoneutron yield reaction (γ,xn) = (γ,n) + 2(γ,2n) + 3(γ,3n) + ... Follow their definitions those functions F_i could not have absolute values higher than 1.00, 0.50, 0.33,... correspondingly. Larger values mean definite incorrectness of neutron multiplicity sorting and therefore - non-reliability and non-authenticity of data. The main consequence of that is appearing of non-physical negative values in cross section. Systematic analysis of experimental data for (γ,n), (γ,2n) and (γ,3n) reaction cross sections obtained at Livermore for nuclei ^{90}Zr, ^{115}In, ^{112,114,116,117,118,119,120,122,124}Sn, ^{159}Tb, ^{165}Ho, ^{181}Ta, ^{197}Au, ^{208}Pb revealed that majority of those data are not reliable and authentic because in many energy ranges they do not satisfy (for example, because of $F_2 > 0.50$) objective criteria. The successful descriptions of various GDR decay channels were achieved in the frames of various advanced theoretical models (for example, [3 - 5]). So the new experimentally-theoretical treatment to the evaluation of partial photoneutron reaction cross sections was proposed [6]. That uses both the results of modern preequilibrium calculations based on the Fermi-gas densities equations and taking into account the effects of nuclear deformation and GDR isospin splitting [4, 5] and experimental data for only (γ,xn) reaction cross section, free from outgoing neutrons multiplicity sorting uncertainties and errors. Theoretically calculated transitional multiplicity functions F_i^{theor} were used for partial reaction cross section $\sigma^{eval}(\gamma,in)$ evaluation of by the way - $\sigma^{eval}(\gamma,in) = F_i^{theor}(\gamma,in)$ x $\sigma^{exp}(\gamma,xn)$. New reliable and authentic data on partial and total photoneutron reaction ((γ,sn) = (γ,n) + (γ,2n) + (γ,3n) + ...) cross sections were evaluated for nuclei mentioned above. It was shown that those are in contradiction to data obtained using the neutron multiplicity sorting method but are in agreement with data obtained using the method of induced activity - direct method of partial reaction cross section determination free of neutron multiplicity problems. Various physical consequences of "evaluated-experimental" distinctions of data are discussed. The work was supported by Russia Grant of Scientific Schools Supporting 02.120.21.485-SS, MINOBRNAUKA Contract 02.740.11.0242 and RFBR Grant N 09-02-00368.

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The Systematics of (n,2n) Reaction Excitation Function

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Based on the constant temperature evaporation model taking the competition of (n,3n) reaction and the contribution of preequilibrium emission into account, the systematics formulae of (n,2n) reaction excitation function have been established. The systematics behaviours of (n,2n) reaction excitation function have been studied. There are two systematics parameters T and $\sigma_{n,M}$, and can be adjusted in the formulae. For getting the two parameters, the new evaluated data of (n,2n) reactions were adopted and fitted by means of the nonlinear least squares method. The fitted results agree fairly well with the measured data at $45 < A < 210$ below 30 MeV. Based on a body of new measurements, the reliability to predict (n,2n) reaction excitation function is improved. Hence more accurate systematics prediction for unmeasured nucleus or energy range may be provided.

PR 87

Analysis of Deuteron Induced Reactions from Threshold

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Deuteron breakup reactions have recently caught considerable attention in association with not only the development of neutron sources, such as those used in the International Fusion Materials Irradiation Facility (IFMIF) and Accelerator Driven Systems (ADS), but also the study of projectile breakup of exotic and halo nuclei. Although neutron production from inclusive (d,xn) reaction is essentially important in the design of neutron sources, inclusive (d,xp) reactions are also helpful to understand the mechanism of deuteron breakup reactions and have an advantage that the experimental data are more available than (d,xn) data. Deuteron induced reactions on many nuclei are studied by using the modified Glauber model with trajectory modifications on Coulomb and nuclear interactions. The total deuteron and proton reaction cross sections are calculated down to the threshold energy and compared with experimental data and optical model calculations. Then, the modified Glauber model is incorporated into a model calculation for analyses of nucleon production from deuteron breakup reactions, in which the elastic breakup process and the inelastic breakup process are described by the continuum discretized coupled-channels method and the Glauber model, respectively. In addition to these two direct processes, the evaporation and pre-equilibrium processes are described by the Hauser-Feshbach theory and the Exiton model. Target mass number and incident energy dependences on deuteron breakup reactions are investigated systematically through the present analyses.

PR 88

Extraction Behavior of Polonium-210 from HCl and HNO_3 Solution Using Tributyl Phosphate

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A new route for the production of purified Po-210 (Polonium) was accomplished by irradiating Bi-209 (Bismuth) foil for two hours by a 38 MeV alpha external beam delivered by the ARRONAX cyclotron in Nantes with an average beam current of 0.1 μA. The separation of the radiotracer of Po-210 (2.10^{-13} mol) from the macroscopic quantity of Bi-209 (3.10^{-2} mol) were performed by extraction of Po-210 to an organic phase (10% TBP in para-Xylene) from a 7M HCl solution and back-extracted to a 9M HNO_3 phase after studying different parameters (TBP dilution degree, solvent , acid nature). The current investigation aimed in explaining the mechanism of extraction and back-extraction of Po-210 from hydrochloric and nitric acid respectively. In the present study, we determine the distribution ratios in solvent extraction (in tributyl phosphate-hydrochloric acid and tributyl phosphate-nitric acid systems) and the distribution coefficients in ion exchange (anionic resin AG1_X8 and cationic resin AG50_X8) at different acidic range. From these results, we discussed the polonium - chloride / nitrate complexation and the chemical species extracted and back-extracted at different acid concentration, and determined the best experimental conditions for polonium extraction. Based on our results and by comparing with previous data, we confirm the formation of a strong neutral polonium chloride complexes (H_aPoCl_{4+a}; a=0, 2) that can be extracted in tributyl phosphate, and a complete non-extraction of bismuth nuclides which have a high tendency to form anionic complexes ($BiCl_5^{-2}$, or $[Bi(H_2O)Cl_5]^{2-}$, and BiCl6 $^{3-}$) that have high affinity toward aqueous phase. For back-extraction, our results allow us to confirm the presence of weak polonium-nitrate complexes; upon using a high concentration of nitric acid, a degradation mechanism of TBP occurred, thus releasing Po-210 into the 9M HNO_3 phase from the previously extracted organic phase.

PR 89

Differential Cross Sections for the ^{40}Ca(n,α)^{37}Ar Reaction in the MeV Neutron Energy Region

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Differential cross sections and angle integrated cross sections for the ^{40}Ca(n,α_0)^{37}Ar, ^{40}Ca(n,$\alpha_{1,2}$)^{37}Ar and ^{40}Ca(n,$\alpha_{3,4,5}$)^{37}Ar reactions are measured in the neutron energy range of 4.0   6.5 MeV using a double-section gridded ionization chamber and two back-to-back CaF_2 samples. Experiments were performed at the 4.5 MV Van de Graaff Accelerator of Peking University. Monoenergetic neutrons were produced through the ^{2}H(d,n)^{3}He reaction with a deuterium gas target. Foreground and background were measured in separate runs. A ^{238}U sample set on the sample changer in the gridded ionization chamber and a BF_3 long counter were utilized for absolute neutron flux calibration and for neutron flux normalization, respectively. Present results are compared with existing measurements and evaluations. Model calculations are performed using the TALYS code and reasonable agreements are achieved between measurements and calculations. The present work was financially supported by the National Natural Science Foundation of China (11175005) and the Russian Foundation for Basic Research (RFBR-NSFC 07-02-92104).

PR 90

Alpha Decay Measurement of ^{144}Nd

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To improve the value of the half life of long living ^{144}Nd a Frisch grid ionisation chamber was build. These devices are generally used for measurements on large areas samples and provide a good energy resolution for alpha spectroscopy. A new approach with digital pulse shape combined with charge production in different volumes in the chamber and the signature of different particles allow a better signal to background ratio. Some results of the new background suppressing method and the status and results of the current measurement on ^{144}Nd will be presented.

PR 91

Analysis of Three Body Resonances in the Complex Scaled Orthogonal Condition Model

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During the last four decades a resonance problem has emerged as a crucial and useful research area in nuclear structure. Several extensions of the basic problem have been studied, where, for instance, a unified treatment of nuclear scattering and structure has been developed. Furthermore, the interactions between composite particles have extensively been studied, and the role of the Pauli exclusion principle in scattering and reaction processes has been understood considerably. The complex scaling method (CSM) [1-2] and the orthogonal condition model (OCM) [3] have been successfully utilized to describe the resonance states of light and middle mass nuclei. Although many problems have been solved so far, but further researches are required still. In this study, the complex scaled orthogonal condition model (CSOCM) [4] is applied to the light nuclei for ^{9}Be and three-body resonances of α+α+n is investigated. The data on resonance states of nuclei are of interest to basic and applied research. Although resonance structures of α+α+n have been studied, experimentally [5-6] and theoretically [7-9], there are still need more accurate and comprehensive calculations in the structure and decay of the low-lying excited states. The nucleus ^{9}Be is created in the universe when cosmic rays induced fission in heavier elements found in interstellar gas and dust. According to this idea, ^{9}Be is one of the especial interest system in astrophysics, where formation of ^{9}Be can proceed through the reaction ^{4}He(αn,γ)^{9}Be. In addition, the beryllium can be used as a moderator and reflector for the nuclear facilities, but also it is applicable to isotopic neutron sources, such as plutonium-beryllium and americium-beryllium source. Due to this interest, the investigation of beryllium isotopic structure is still important. The main objective of our study is to investigate the resonance states of ^{9}Be by using CSOCM for a three-cluster system. Therefore, certainly understanding of α+α and α+n subsystems is needed in order to perform calculations of an α+α+n system.

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PR 92

B(E2) Evaluation for $0_1^+ \rightarrow 2_1^+$ Transitions in Even-Even Nuclei for Z=2-56

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The results of B(E2)↑ evaluation for even-even Z=2-56 nuclei will be presented. This work is a continuation of S. Raman work [1] on B(E2) values and was motivated by a large number of recent measurements. It extends the previous evaluation and includes comprehensive shell model analysis when possible. Evaluation policies of experimental data and systematics will be discussed. Future plans for completion of the B(E2;$0_1^+ \rightarrow 2_1^+$) evaluation project will be outlined.

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PR 93

Measurements of High Energy Excited States and γ-rays of Fission Products with 4π Clover Detector

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Decay schemes are essential information in nuclear decay data for studies on nuclear physics and engineering. To construct high energy excited states of fission products and γ-rays populating from the states is important with respect to the decay heat evaluation in nuclear power plant, and also meaningful to know the nuclear structure of neutron-rich nuclei. We have developed a clover detector which consists of four large HPGe crystals (80 mm$^{\Phi}$ x 90 mm) to measure β-decay energy (Q_β) [1]. Radioactive sources are put into a through hole along the central axis of the detector. Therefore, we can measure the sources with almost 4π solid angle. Energy signals from each Ge crystal are independently stored together with the corresponding time information in an event-by-event mode. Two spectra, a singles and an add-back spectrum, were obtained through an off-line sorting. In the singles spectrum, four individual spectra of Ge crystals were summed and stored. Gamma-ray intensities are determined from the singles spectrum using experimentally determined peak efficiencies with an accuracy of 5% [2]. In the add-back spectrum, energy signals from the different crystals corresponding to coincident events were summed and stored. High energy excited levels are assigned in the add-back spectrum compared with the singles one because cascade γ-rays are identified as cross-over γ-rays. We have reported the level scheme of the fission product ^{147}Ce up to 3.5 MeV including newly identified 56 levels and 160 γ-rays [3]. ^{147}La isotopes, which are the precursor of ^{147}Ce, were produced with the neutron-induced fission of ^{235}U, and separated using the on-line mass separator installed at the Kyoto University Reactor. We have also measured γ-rays following the β-decay of neutron-rich ^{145}Ba and ^{149}Ce, for which the excited levels up to 1.0 MeV were reported [4]. Note that ^{145}Ba is one of the radionuclides recommended to measure high energy excited states for precise decay heat calculations [5]. We successfully observed the γ-rays and excited levels up to 3.0 and 2.5 MeV in the daughter nuclei ^{145}La and ^{149}Pr, respectively. In this conference, we will report the decay schemes of ^{145}Ba and ^{149}Ce as well as new findings of ^{147}La. This study is partially supported by "Study on nuclear data by using a high intensity pulsed neutron source for advanced nuclear system" entrusted to Hokkaido University by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

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PR 94

Development Status and Perspectives on the CONRAD Evaluation Code

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The CONRAD code is an object-oriented software tool developed at CEA Cadarache since 2005 to deal with problems arising during the evaluation process (data assimilation and analysis, physical modeling, propagation of uncertainties, etc. . .).
This paper will present the most recent developments concerning the experimental and theoretical aspects as well as the improvements in term of interface. The experimental descriptions capabilities have been enhanced thanks to the implementation of both analytical (Chi-Square, Gaussian) and Monte-Carlo resolution functions which are required for neutron resonance shape analysis. On the theoretical aspects, efforts have been focused on the continuum energy part with the wrapping of the ECIS and TALYS codes and the management of optical model/statistical parameters. These new features make possible for Conrad to currently perform evaluations from 0eV to 20MeV.
Concerning the interfacing developments, a multigroup cross-sections generating tool and an ENDF parser have been recently improved to produce multigroup cross-section covariance matrices in the frame of the JEFF project.
Each development aspect is illustrated with several examples and comparisons with other codes (SAMMY, REFIT) and some forecasted features are detailed as well.

PR 95

Zirconium Evaluations for ENDF/B-VII.2 for the Fast Region

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We have performed a new combined set of evaluations for 90-96Zr, including new resolved resonance parameterizations from Said Mughabghab for ^{90,91,92,94,96}Zr and fast region calculations made with EMPIRE-3.1. Because ^{90}Zr is a magic nucleus, ^{90}Zr is nearly spherical. Therefore, all even-even nuclei in the evaluation set were evaluated using EMPIRE's OPTMAN coupled channels code and a new soft-rotor optical model potential. This then led to improved (n,el) angular distributions, helping to resolve improper leakage in the older ENDF/B-VII.1β evaluation in KAPL proprietary, ZPR and TRIGA benchmarks. Another consequence of ^{90}Zr being a magic nucleus is that the level densities in both ^{90}Zr and ^{91}Zr are unusually low causing the (n,el) and (n,tot) cross sections to exhibit large fluctuations above the resolved resonance region. To accomodate these fluctuations, we performed a simultaneous constrained generalized least-square fit to (n,tot) for all isotopic and elemental Zr data in EXFOR, using EMPIRE's TOTRED scaling factor. TOTRED rescales reaction cross sections so that the optical model calculations are unaltered by the rescaling and the correct competition between channels is maintained. In this fit, all (n,tot) data in EXFOR was used for E_{in} ¿ 100 keV, provided the target isotopic makeup could be correctly understood, including spectrum averaged data and data with broad energy resolution. As a result of our fitting procedure, we have full cross material and cross reaction covariance for all Zr isotopes and reactions.

PR 96

Updated and Revised Neutron Reaction Data for ^{233}U

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The updated and revised evaluation of a complete set of n+^{233}U nuclear data from 10^{-5} eV $\sim$ 20 MeV were carried out and recommended based on the evaluated experimental data and the feedback information of various benchmark tests. The mainly revised quantities are the resonance parameters, fission cross sections, inelastic and elastic scattering cross sections as well as angular distributions etc. The benchmark tests indicate that the promising results were obtained when the renewal evaluated data of ^{233}U and will be used to instead of the ^{233}U evaluated data in CENDL-3.1.
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PR 97

Updated and Revised Neutron Reaction Data for Np

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The updated and revised evaluation of a complete set of n + $^{236-239}$Np nuclear data from 10^{-5} eV $\sim$ 20 MeV were carried out and recommended based on the evaluated experimental data. The mainly revised quantities are the resonance parameters, fission cross sections, inelastic and elastic scattering cross sections as well as angular distributions etc. The promising results were obtained when the renewal evaluated data of $^{236-239}$Np will be used to instead of the Np evaluated data in CENDL-3.1.

PR 98

Microscopic Optical Potential of Nucleon, Deuteron, Helium-3 and Alpha Based on Skyrme Interactions

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The optical model has a significant impact on many branches of nuclear reaction physics. The central assumption of that model is that the complicated interaction between an incident particle and a nucleus can be represented by a complex mean-field potential. An important feature of a good optical model potential is that it can be used to reliably predict these observables for energies and nuclides for which no experimental measurement data exist, while the ingredients of the model, either microscopic or phenomenological, are physically well-behaved. From the view of the many-body theory the nucleon optical potential can be identified with the mass operator of the one-particle Green function. The first and second order mass operators of one particle Green function in nuclear matter are obtained, and the real and imaginary parts of the optical potential for finite nuclei are obtained by applying a local density approximation. With certain versions of the Skyrme interactions we have obtained the microscopic optical potential for finite nuclei which shows that for certain energy regions the potential depth, shape, relative contributions of the surface and volume parts, as well as the energy dependences are in reasonable agreement with the phenomenological

optical potentials and those based on realistic nucleon-nucleon interaction. The calculated results, such as the total, nonelastic and differential cross sections and analyzing powers are in good agreement with the experimental data and to certain extent comparable with the phenomenological optical potentials up to 100 MeV. The microscopic optical potentials for deuteron, helium-3 and alpha are obtained by the two-particle, the three-particle and four-particle Green function method through nuclear matter approximation and local density approximation based on the effective Skyrme interaction. The radial dependence, the volume integral per nucleon and the root mean square (rms) radii of the microscopic optical potential are calculated. The reaction cross sections and elastic scattering angular distributions for nuclides in the mass range $12 \leq A \leq 208$ with incident deuteron, helium-3 and alpha energies from threshold up to 100 MeV per nucleon are calculated, and the calculated results are compared with the experimental data. The calculated results of reaction cross sections and elastic scattering angular distributions are generally in good agreement with the experimental data in most cases.

PR 99

Evaluations for n+^{54,56,57,58,nat}Fe Reactions Below 20MeV

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Based on the evaluated experimental data of total, nonelastic scattering cross sections and elastic scattering angular distributions, a set of neutron optical model potential parameters were obtained by APMN code. All cross sections of neutron induced reactions, angular distributions, energy spectra, double differential cross sections and γ production data were consistently calculated and analyzed for ^{54,56,57,58,nat}Fe at incident neutron energies below 20 MeV with theory codes DWUCK and UNF which are based on the nuclear theoretical models. Evaluated results were compared with available experimental data and evaluated data from ENDF/B-VII.0 and JENDL-3.3. Especially, consistence adjusting was done between natural elememt and its isotopes in order to make the cross section of natural Fe equal to the weight sum of its isotopes. Furthermore, experimental data of ^{54}Fe(n, 2n) cross sections below 20MeV were analyzed and evaluated with corrections and normalization. The data were processed in terms of a fitting by a spline code with the consideration of correlation errors. The corresponding covariance matrixes of experimental data were constructed with the information on experimental errors and correlation errors.

PR 100

Evaluated Activation Cross Section Data for Proton Induced Nuclear Reactions on W up to 3 Gev Incidence Energy

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The target of the European Spallation Source ESS will consist of solid tungsten that will be bombarded by 2.5 GeV protons. During operation numerous hazardous radio-nuclides will be produced in the tungsten target. These can be assessed by means of inventory calculations provided reliable production data are available. To this end, a full set of data files has been prepared containing yields of radionuclides produced in proton induced reactions on tungsten with energies up to 3 GeV. The data were obtained from the analysis of nuclear model calculations, available experimental data and systematics. The calculations of cross-sections were performed using the intranuclear cascade model combined with the Hauser-Feshbach model. The CASCADE code [1] and the TALYS code [2] were applied for numerical calculations. At

relative low projectile energies the pre-equilibrium exciton model and the Hauser-Feshbach model implemented in TALYS were used for the cross-section calculations. The transition between CASCADE-TALYS and TALYS calculations was achieved by employing a "hybrid" approach similar to the one discussed in Ref.[3]. The available experimental information, results of calculations and systematics were applied for the evaluation of yields of residual nuclei using statistical methods implemented in computer code package BEKED elaborated in KIT. Evaluated data were obtained for tungsten isotopes with the mass number 180, 182, 183, 184, and 186.
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PR 101

The *np* Cross Section Determination below 1000 MeV

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The absolute cross section for *np* scattering below 1000 MeV are determined based on partial-wave analyses (PWAs) of nucleon-nucleon scattering data along with that for pp scattering [1]. These cross sections are compared with most recent ENDF/B and JENDL data files, and experimental data. Systematic deviations from the ENDF/B and JENDL evaluations in both total and angular differential cross sections are found to exist in the low-energy region.
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PR 102

Extensions of GENEUS Towards a Mature Evaluation Tool

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The evaluation tool GENEUS (General Nuclear Data Evaluation and Uncertainty System) is a program package which provides evaluated cross sections and associated covariance matrices above the resonance range. It is based on the Full Bayesian Evaluation Technique [1] which consistently combines a-priori knowledge and experimental data. Much care is devoted to generate a proper prior resulting in a method well suited for evaluations strongly relying on modelling. The first version was focused on evaluations of angle-integrated cross sections and associated uncertainties of structural materials and was presented at the ND2010 [2]. With regard to routine applications, improvements concerning the stability of the algorithms were performed first [3]. In this contribution recent extensions of GENEUS are presented: (a) inclusion of fissionable nuclei, (b) generation of a more complete output with additional MF-numbers and (c) transfer of the smoothness of nuclear models to evaluated data. The progress achieved by these extensions is also discussed. Work supported in part by EURATOM via the project ANDES and F4E within the FPA-168.
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PR 103

Charge-exchange QRPA with the Gogny Force for Axially-Symmetric Deformed Nuclei

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In recent years fully consistent quasiparticle random-phase approximation (QRPA) calculations using finite range Gogny force have been performed to study electromagnetic excitations of several axially-symmetric deformed nuclei [1] up to the ^{238}U [2]. Here we present the generalization of this approach to the charge-exchange nuclear excitations. In particular we focus on the Isobaric Analog and Gamow-Teller resonances. A comparison of the results with existing experimental data, as well as predictions for some short-lived neutron-rich nuclei are presented.

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PR 104

Recent LAQGSM Developments and Benchmarking in the 1-10 GeV Energy Region

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The Los Alamos version of the Quark-Gluon String Model (LAQGSM) code system, used as a default event generator to simulate heavy-ion-induced and other high-energy nuclear reactions in the MARS15, MCNP6, and MCNPX transport codes, has been further developed. Simulation of the hadron-hadron inelasic interactions were substantially improved in the crucial for numerous applications, but difficult from a theoretical standpoint, projectile energy region 1-10 GeV. Several channels have been implemented for an explicit description: $N + N \to N + N + m\pi$, $\pi + N \to m\pi$ $(m < 5)$, $B + B \to B + Y + K$, $\pi + N \to K + Y$, $\overline{K} + B \to Y + \pi$, $\pi + \pi \to K + \overline{K}$, and production of $N - \overline{N}$ pairs in $N + N$ and $\pi + N$ interactions. The particle production for these channels is now based on a combination of the phase-space and isobar models using the available experimental data for the production cross sections. At higher energies, inelastic interactions are still simulated in the framework of the Quark-Gluon String Model (QGSM) developed originally in Dubna and Moscow, Russia. Descriptions of pion, kaon, and strange particle production and propagation in nuclear media are improved. Calculated with the new LAQGSM model double differential cross sections of pions, protons, and kaons produced in interactions of protons with various nuclei are compared with experimental data obtained by the LANL, ITEP, HARP, and ANKE collaborations. Agreement is very good in the entire experimentally accessible phase space.

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PR 105

MCNP6 Study of Fragmentation Products from ^{112}Sn+ ^{112}Sn and ^{124}Sn+ ^{124}Sn at 1 GeV/nucleon

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Production cross sections from ^{112}Sn + ^{112}Sn and ^{124}Sn + ^{124}Sn at 1 GeV/nucleon, measured recently at GSI using the heavy-ion accelerator SIS18 and the Fragment Separator (FRS), have been analyzed with the latest Los Alamos Monte Carlo transport code MCNP6 using the LAQGSM03.03 event generator. MCNP6 reproduces reasonably well all the measured cross sections. Comparison of our MCNP6 results with the measured data and with calculations by a modification of the Los Alamos version of the Quark-Gluon String Model allowing for multifragmentation processes in the framework of the Statistical Multifragmentation Model (SMM) by Botvina and coauthors, as realized in the code LAQGSM03.S1, does not suggest unambiguously any evidence of a multifragmentation signature.

PR 106

Fitting Prompt Fission Neutron Spectra Using Kalman Filter Integrated with Empire Code

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Prompt fission neutron spectra (PFNS) have proven to have a significant effect in some critical benchmarks, in some cases as important as cross-section uncertainties. Therefore, a precise determination of uncertainties in PFNS is largely desired. Existing PFNS evaluations in nuclear data libraries relied so far almost exclusively on the Los Alamos model [1]. However, deviations of evaluated data from available experiments have been noticed at both low and high neutron emission energies. Existing experimental database for PFNS in EXFOR has been revisited and covariance information of selected experimental sets have been proposed [2]. New experimental measurements have been recently published. The use of the Bayesian Kalman filter has successfully proven to be a powerful tool to improve and refine evaluations by fitting cross-section data. It therefore represents a natural path for fitting fission spectra using all available experimental data. The goal is to derive realistic values for PFNS model parameters and corresponding uncertainties and correlations. The present work describes the effort of integrating Kalman and EMPIRE codes in such a way to allow for parameter fitting of PFNS models. The first results are shown for the major actinides for two different models (Kornilov [3] and Los Alamos [1]). This represents the first step towards consistent fitting of both cross-section and fission spectra data considering both microscopic and integral experimental data.
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PR 107

Modelling of Spallation Source for the Myrrha Reactor Using the MCNPX and Geant4 Codes for Sensitivity Analysis of Reactivity

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In an accelerator driven nuclear reactor (ADS) neutrons are produced from spallation reactions providing an external source to the core and sustaining its operation. Although there are different approaches to describe the kinetic behaviour of these reactors, the complete picture of its functioning still need to be addressed as there is no commercial ADS reactor in operation. In order to provide a better understanding on this matter one can take advantage of Monte Carlo techniques which allow to simulate the whole system in three dimensions considering time dependence and with realistic details of the complicated geometries involved. In this work a simulation of the time evolution for the MYRRHA conceptual reactor was developed. The SERPENT code was used allowing to simulate the nuclear fuel depletion. The spallation source which drives the system was simulated using both MCNPX and GEANT4 codes. These two packages can run

assuming a number of models to describe hadronic interactions. The obtained results for the neutron energy spectrum from the spallation are coherent with each other and were used as input for the SERPENT code which simulated the constant power operation regime and also a linear variation of power. The obtained results show that the criticality of the system is sensitive to the model employed, but keeping relative small deviations with respect to the results obtained from the inverse kinetic model which comes from the point kinetic equations proposed by Gandini.
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PR 108

Nuclear Level Density within Extended Superfluid Model with Collective State Enhancement

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For nuclear level densities, a new variant of extended superfluid model [1,2] with collective state enhancement factor [3,4] is proposed and tested. An effect of collective states on the temperature of the intrinsic states is taken into account [3,4]. The ready-to-use table of the asymptotic values of level density parameter a and addition shift to excitation energy are prepared by the chi-square fit of the theoretical values of neutron resonance spacing and cumulative number of low-energy levels to experimental values. The systematic expressions for these parameters as a function of neutron excess are obtained too. The collective state effect on gamma-ray spectra and cross sections of neutron-induced nuclear reactions is investigated by the use of EMPIRE code[5] with modified level density parameters. The best expressions for collective state enhancement factor of nuclear level density are recommended.

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PR 109

Rotational-vibrational Description of Nucleon Scattering on Actinide Nuclei Using a Dispersive Coupled-Channel Optical Model

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Tamura coupling model (reference [1]) has been extended to consider low-lying bands of vibrational and non-axial nature observed in even-even actinides. Low-lying bands of vibrational nature present in odd actinides are also described in the present work. These additional excitations are introduced as a perturbation to the underlying rigid rotor structure that is known to describe well the ground state rotational band of major actinides. A coupled-channel optical model potential (OMP) containing a dispersive term is used to fit simultaneously all the available optical experimental databases (including neutron strength functions) for nucleon scattering on ^{238}U and ^{232}Th nuclei. Quasi-elastic (p,n) scattering data to the isobaric analogue states of the target nucleus are also used to constrain the isovector part of the optical potential. Derived Lane-consistent OMP is based on 15+ low-lying coupled levels that include the ground state, octupole, beta and gamma rotational bands. OMP parameters show a smooth energy dependence and energy independent geometry. Fitted deformations are in reasonable agreement with FRDM deformations theoretically derived by Moller and Nix (reference [2]). Preliminary results of the extension ofthe derived potential to odd fissile actinides (e.g. ^{239}Pu and ^{235}U) are being discussed. This work was partially supported by the Spanish Ministry of Economy and Competitivity under Contract FPA2011-28770-C03-02 and the International Science and Technology Center under contract B-1804.

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PR 110

Influence of projectile energy and target mass on the production of Light Charged Particles and Intermediate Mass Fragments in proton induced reactions

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Calculations were performed for proton induced spallation reactions over wide range of atomic masses of the targets; 12C,27Al, Ni,108Ag and197Au using the Intra-nuclear Cascade Model (4.6) with coalescence which includes the emission of light clusters(d 4He) and intermediate mass fragments formed by the nucleons during first stage of reaction. The emissions of particles from excited cascade residua were described using the codes SMM, ABLA07 and GEMINI++. A comparison of calculations with experimental double differential cross sections d2/ddE for light charged particles and IMF's obtained by PISA collaboration was studied at proton beam energies between 1.2 GeV 2.5 GeV. The shape and magnitude of the experimental spectra are reasonably well reproduced by all computer codes. However, systematic deviations of theoretical

cross sections from the experimental data are observed for light charged particles, especially at forward angles and higher beam energies. This situation points to the need to check the shortcomings of used parameterizations and lacking of some important physical processes which are not taken under consideration in models

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PR 111

Monte Carlo Predictions of Prompt Fission Neutrons and Gamma Rays: a Code Comparison

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In recent years, Monte Carlo techniques have been implemented successfully to predict prompt fission neutron and gamma-ray data, calculate average quantities such as the average prompt fission neutron spectrum and multiplicity, as well as distributions such as the neutron multiplicity distribution $P(\nu)$ and correlations, e.g., *n*-*n* energy and angular correlations. Several codes are being developed worldwide to perform such calculations. At LANL, the `CGMF` code implements in full the Hauser-Feshbach formalism that describes the statistical de-excitation of the primary fission fragments by the emission of neutrons and gamma rays. `CGMF` combines two previously developed codes, the `CGM` Hauser-Feshbach code [1] and the `FFD` code [2] that describes the initial conditions of the fission fragment yields in mass, charge and kinetic energy, and the initial distribution of excitation energies and spins of the fragments. At LBNL and LLNL, the `FREYA` code [3,4] has been developed in the last few years. It simulates the emission of prompt neutrons from a Weisskopf-Ewing spectrum, following in detail the sequence of neutron emissions until it reaches a lower energy limit below which only gamma rays can be emitted. Also, recent efforts have been put into modeling the prompt gamma-ray emissions into `FREYA` [5]. Both codes use very similar, although distinct, physics models as well as input parameters. In this work, we present an inter-comparison of the `FREYA` and `CGMF` codes by studying their results predicted for the neutron-induced fission reaction of ^{239}Pu. In particular, we focus on differing physical assumptions, e.g., the partitioning of excitation energy between the two fragments, Hauser-Feshbach vs. Weisskopf-Ewing, etc., and how they impact the final results.
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PR 112

Systematics of Neutron Radiative Capture Cross Section

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Base on the Breit-Wigner resonance theory, a systematics function is given to describe the average cross section of 25keV. Cross sections of 148 nuclei are used for fitting. Considering the process of compound nucleus and the contribution of direct-semi-direct process, a total systematics function is used for describing the excitation functions for (n, γ) in the energy range of 1keV- 20MeV. There are 2 parameters in this

function, and the 2 parameters systematics functions are given. One is defined the shape of excitation functions for (n, γ) in low energy range, and the cross section of 25keV is used to confirm the absolute value. The other parameter is defined the absolute value of excitation functions for (n, γ) in high energy range. At the same time, a new set of parameters for systematics function of energy density parameters is obtained. The experimental data used in this work are gained from EXFOR database.

PR 113

Coupled-channels Calculation of Isobaric Analog Resonances

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The position and width of isobaric analogue resonances in nucleon-nucleus scattering are accurate and detailed indicators of the positions of resonances and bound states with good single-particle characters [1]. Since determining the positions of shells and shell gaps has often been the objective of experiments with unstable isotopes, measuring isobaric analogue resonances (IAR) should be modeled as well as possible by theorists in relation to proposed experiments. These IAR have the great virtue that *neutron* bound states, both occupied and unoccupied, can be determined in experiments that react *protons* on nuclei. Proton targets can be made with hydrogen. The best information about levels is determined by (p,p$'\gamma$) coincidence experiments [2]. The displacement energies of IAR also depend critically on neutron-proton density differences, so can be used to probe those densities in the surface. We therefore implemented within our coupled-channels code FRESCO [3] the main Lane coupling term [4]: the charge-exchange interaction that transforms an incident proton into a neutron. Because of Coulomb shifts, the neutron will be at a lower energy, such as a sub-threshold energy near an unoccupied single-particle state. We see isobaric analog resonances when the neutron energy is near a bound state. At the same time, a target neutron must have changed to a proton, so it must have been in an occupied neutron state with quantum numbers such that a proton with those parameters is not Pauli blocked. We therefore extended the Lane coupled-channels formalism to follow the non-orthogonality of this neutron channel with that configuration of an inelastic outgoing proton, and the target being left in a particle-hole excited state. This is being tested for ^{208}Pb, for which good (p,p$'\gamma$) coincidence data exists [2], and we make predictions for the equivalent processes for ^{132}Sn. Experiments such as [5] show the methods are also useful for light nuclei. Prepared by LLNL under Contract DE-AC52-07NA27344, through the topical collaboration TORUS.
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PR 114

Coupled-Channel Models of Direct+Semidirect Capture via Giant-Dipole Resonances

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It was recognized in the 1970's that semidirect capture, a two-step process that excites a giant-dipole resonance in the first step, followed by its radiative de-excitation in the second step, is a dominant process near giant-dipole resonances in the neutron energy range 5–20 MeV. At lower energies such processes may affect neutron capture rates that are relevant to astrophysical nucleosynthesis models. We therefore

implemented a semidirect capture in a coupled-channel code FRESCO [1] and validated it by computing direct-semidirect capture ^{208}Pb(n,γ)^{209}Pb into the ground and excited states of ^{209}Pb for which experimental data exist [2]. We use a conventional single-particle direct-semidirect capture code CUPIDO [3,4] for comparisons. Furthermore, we present and discuss our computations of direct+semidirect capture cross section ^{130}Sn(n,γ)^{131}Sn [5] whose effect on nucleosynthesis models is known to be large [6]. Prepared by LLNL under Contract DE-AC52-07NA27344, through the topical collaboration TORUS.
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PR 115

Using R-matrix Parameters to Describe One-Nucleon Transfers to Resonances

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Deuteron-induced reactions, in particular (d,p) one-neutron transfer reactions, have been used for decades to investigate the structure of nuclei. These reactions, carried out in inverse kinematics, will play a central role in the study of weakly-bound systems at modern radioactive beam facilities. While the theoretical framework and its computational implementation for describing (d,p) reactions have seen much progress over the decades, open questions remain and need to be addressed, including the proper treatment of transfers to resonance states. Recently, Mukhamedzhanov [1] proposed a novel approach that describes transfers to both bound and resonance states. The new formalism, which is general enough to include deuteron breakup, formulates the cross section in terms of a dominant surface term that can be expressed in terms of R-matrix parameters. Here we test some of the ideas underlying the proposed formalism, compare calculations to measured cross sections, and discuss implications. Prepared by LLNL under Contract DE-AC52-07NA27344, through the topical collaboration TORUS.
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PR 116

Isospin-dependent Microscopic Nucleon Optical Potential within Relativistic Brueckner Hartree-Fock Framework

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The optical model potential (OMP) is an essential tool in nuclear reaction studies. The investigations of OMP based on a fundamental microscopic theory provide a reliable basis to explore nuclear reaction mechanisms in particular for cases without experimental data. In this work, the microscopic OMP is investigated in the Dirac-Brueckner-Hartree-Fock (DBHF) framework with Bonn B meson exchange interaction. Both real and imaginary parts of isospin-dependent self-energies are uniformly derived from a projection on Lorentz invariant amplitudes Ref.[1,2]. Due to the rigorous deterministic approaches in the present DBHF theory, the many body calculation does not contain any adjustable parameter both for the symmetric nuclear matter(N.M.) and the asymmetric N.M.; therefore, the isospin-dependent OMP based on such theory should have a larger predictive power when applied in the study of unstable nuclei. We construct the Dirac potentials (scalar and vector potentials) according to the self-energies, and the potentials of equivalent Schrödinger equation for finite nuclei are determined correspondingly through an improved local density approximation (ILDA) method. We systematically analyze the scattering reactions of n, p $+^{12}$C-^{208}Pb in terms of this RMOP within incident energy 100keV <= E <=; 200MeV. The total neutron cross sections, the reaction cross sections, differential elastic scattering cross sections, analyzing powers and spin-rotation functions are calculated and compared with the experimental data, as well as the result of Koning phenomenological OMP Ref.[3]. It is shown that the present relativistic OMP can yield a good prediction of nucleon-nucleus scattering reaction with only one adjusted parameter in ILDA for various nuclei and incident energies.

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PR 117

Calculation of Pre-Equilibrium Effects in Neutron-Induced Cross Sections on ^{59}Co Using the Talys 1.4 Code

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Neutron-induced reactions on medium-weight targets as: iron, cobalt and lead are interest not only for basic physics but also for applications in the accelerator-driven systems (ADS). Double differential cross sections for protons emission on cobalt are calculated for 6 incident neutron energies between 25 and 40 MeV and compared with the neutron-induced experimental data of [1]. In our calculations, pre-equilibrium emission has been based on exciton model at two components by using the Talys 1.4 code [2]. The squared matrix element M2 input in the semi-empirical expression of exciton model has been adjusted for good agreement with the experimental data [1]. Also, the optical model potentials used are the local parameterizations in Eq. (7) of Koning and Delaroche [3] for neutrons and protons. Deuterons, tritons, helions and alpha particles transmission coefficients obtained from Watanabe [4,5] are included. On the other hand, the constant temperature model and the Fermi gas model with level density parameters used for the level density [6] and the damping of shell effects with excitation energy in single particle level densities are shown to be important for our calculations.

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PR 118

20 years of calibration standards production in the Czech Metrology Institute,Inspectorate for Ionizing Radiation (CMI-IIR)

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The beginnings of radiation metrology in the Czech Republic date back to 1919 when the State Institute of Radiology (SIR) was established. As this scientific discipline went through its radical progress and evolution, so grew the extent of the SIR. After 40 years of its existence, in 1959 the Institute was renamed

the Institute for Research, Production and Application of Radioisotopes (UVVVR) and its administration passed from the Ministry of Health to the Ministry of Chemical Industry.
After the Velvet Revolution in 1989, the UVVVR was privatized and divided into many private companies, some of which had a major foreign capital share. The activities in the field of metrology were decided to be secured by the Inspectorate for Ionizing Radiation a new part of the State Metrology Institute which became the Czech Metrology Institute (CMI) after the division of the Czechoslovakia in 1993. The current full name of the institution is Czech Metrology Institute, Inspectorate for Ionizing Radiation and unlike the headquarters of the CMI based in Brno, CMI-IIR resides in Prague, the capital of the Czech Republic. The main three tasks of this body is the Fundamental metrology (including regular participation in the international comparative measurements), Legal Metrology (with around 400 devices calibrated and certified each year) and production of the radionuclide standards mainly for calibration purposes.
Nowadays (2013) there are 25 type-approved standards produced by the CMI-IIR. These are produced with various nuclides and their respective combinations. The number of produced calibration standards for commercial and metrology use has a rising tendency from 417 in 1995 to 750 during 2012. The export administration is managed by the Eurostandard CZ Company created in 1994 for this purpose and the international network of customers currently reads more than 200 clients from 58 countries over the world.

PR 119

Nuclear Data Evaluation and the NNDC

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In the late nineteenth century, natural philosophers looked for future discoveries in the sixth place of decimals, since most important fundamental laws had already been discovered. We start our review of nuclear data from the discoveries of radioactivity, of the neutron, of nuclear fission, and the wartime Manhattan District Project (development of the "atomic bomb") into the post-war (large government funding and big science) era. The detailed examination begins with the creation of the Brookhaven National Laboratory (BNL) to house an "East Coast" nuclear reactor for peaceful purposes by the nine large academic institutions in the northeast USA. We examine the effort to determine "best values" for neutron cross sections (and later non-neutron nuclear data) at the precursors of the National Nuclear Data Center (NNDC) at BNL and a major effort in development of computerized systems for neutron data storage and retrieval. We will include the U.S. Atomic Energy Commission's (USAEC) creation of the Cross Section Evaluation Working Group (CSEWG) to develop (for reactor applications) a consistent evaluated digitized neutron data system, the Evaluated Nuclear Data File (ENDF). We review the work of the "BNL Study Group", which helped to centralize the nuclear structure data evaluation within the USA and eventually world-wide. We discuss the development of the Evaluated Nuclear Structure Data File (ENSDF) and the Recent References File.

PR 120

Neutron Resonance Densitometry for Particle-like Debris of Melted Fuel

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Feasibility study of neutron resonance densitometry (NRD) has been started to quantify of nuclear materials in particle-like debris of melted fuel formed in severe accidents of nuclear reactor such as Fukushima Daiich nuclear power plants. The NRD here is a combined method of NRTA (neutron resonance transmission analysis) and NRCA (neutron resonance capture analysis) using a pulsed neutron generator and TOF (time of flight) measurement. The presentation includes the proposed compact NRD system, the spectrometer design for NRCA using $LaBr_3$ detectors by Monte Carlo simulations, and analytical studies on achievable accuracies. The experimental results using particle-like Cu samples measured at the GELINA facility in IRMM are also shown in comparison with analytical studies. Required nuclear data for the NRD will be also discussed. This work was done under the agreement between JAEA and EURATOM in the field of nuclear materials safeguards research and development. This research was supported by JSGO/MEXT.

PR 121

Neutron Spectrum Simulation at Flight Altitude in the South Atlantic Magnetic Anomaly

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A large part of Brazil and thus of South America is subject to the South Atlantic Magnetic Anomaly (SAMA), which may modify the behavior of cosmic radiation showers as a function of altitude. High-energy neutrons are produced by primary cosmic ray interactions with atoms in the atmosphere through spallation reactions and intranuclear cascade processes. These neutrons can produce secondary neutrons and also undergo moderation due to atmospheric interactions, resulting in a wide energy spectrum, which ranges from thermal energies (0.025 eV) to energies of several hundreds of MeV. The resulting cosmic-ray induced neutron spectrum (CRINS) is essential for evaluating the dose accumulated in aircraft crew members at flight altitude and the soft-error rates of semiconductor devices. It is thus very important to understand the cosmic-ray induced neutron spectrum in the atmosphere. The goal of this study is to assess the CRINS using the Monte Carlo computational codes MCNPX [1] and GEANT4 [2,3]. To do so, it is necessary to reproduce the physical situation of a wide energy spectrum of protons incident from all angles at the top of the atmosphere and propagating into it. The simulations were performed using physics models at energies above those available in nuclear data libraries and tabulated evaluations of nuclear data at lower energies.

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PR 122

Statistical Building of a Hierarchy of Numerical Models with Deterministic Parameters for Cross Section Uncertainty Evaluations

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Nuclear reaction models play a crucial role in today's nuclear data evaluations. However, there are difficulties associated with evaluating data uncertainties, both in performing the experimental measurements as well as in building them from nuclear models. In this general context, our interest is targeted towards the study of the propagation of uncertainties within nuclear models, and in particular the evaluation of nuclear cross sections. Current approaches (Sensitivity propagation, Inverse Approach, Mean Squared Error, Bayesian Estimation, ...) envisaged for the study of cross sections uncertainties introduce numerous modelization biases whose impact on the announced uncertainty is unknown (parametric approaches, bayesian presuppositions, artificial alea). Keeping the cross section uncertainties under control requires to take into account two types of knowledge: a) the physical theory (and its implementation through the numerical codes) and b) the experiment. In front of the variability observed in the experimental measures and the sensibility of the numerical models with regards to their parameters, the statistical methods can supply a support for the quantification of the uncertainties. In this paper, we propose a new global approach intended to supply instruments for the comparison of the candidate cross sections. The basic hypothesis consists in not modelling the physical and numerical code parameters as random quantities. The idea is to sort the choices of modelling in a numerical code by level of adequacy (named score) with a set of preset measures. We can also see this approach as an attempt to produce a score associated with every theoretical model of cross section. We can also see our approach as a protocol to refute cross section evaluation or experimental measure. Regression models used for a statistical approximation of the cross sections allow in particular to take into account the constraint of regularity of the corresponding curves. Our approach bases itself on the following presuppositions: - The selection of "relevant" points of measures (in other words, compatible with a theoretical model) can be automated while conforming to the criteria of the physicist. - There is no perfect set of model parameters but there are sets better than the others, the best selected by their score values. - The quantification of the uncertainty can be approached in a global way by applying a shape of the statistical error around a reference cross section calculated using the selected sets.

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Fast Neutron Laboratory of the NPI Řež: Quality Assurance of Neutron Fields from p+Li/C Target

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The production of quasi-monoenergetic neutron beams at the NPI Řež is provided with a thin (2mm) ^{7}Li foil with 2 cm C backing to stop the proton beam (cyclotron U-120M, 20-38 MeV, up to 5 μA). The measured activation samples can be placed as close as 5 cm from the Li target. At this sample position the flux density of up to 10^8 n/cm^2/s of neutrons in the peak region is routinely provided. Using the MCNPX simulations, several aspects of the experimental setup affecting the flux in the peak- and low-energy part of spectrum at sample positions were studied (eg. precise positioning, absorption of neutrons in samples, contribution from scattered neutrons, angular distribution of the neutron beam, etc.). In the simulations, neutron libraries for ^{7}Li and C were validated against TOF data measured at similar Li/C neutron source at CYRIC (EXFOR database [1]). It is shown that for peak neutrons the flux density at the sample positions could be predicted with an overall uncertainty of 10% by the MCNPX simulation. The other sources of uncertainties as the measurement of the proton beam current, the thickness of the Li foil, and uncertainties at the gamma-spectroscopy of the activated samples are also discussed.
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[1] Y. Uwamino, NIM **A389** (1997) 463-473, EXFOR Accession # E1826

PR 124

Adequate Treatment of Correlated Experimental Data in Nuclear Data Evaluations Avoiding Pelle's Pertinent Puzzle

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Peelle's Pertinent Puzzle is a long-standing problem of nuclear data evaluation: Namely, one obtains unexpected mean values and variances when combining experimental data affected by statistical and systematic uncertainties by weighing with an experimental covariance matrix. This occurs for non-linear functions of statistical quantities, e.g. for a product. In [1], it was shown in terms of Bayesian Statistics that Peelle's Pertinent Puzzle is primarily caused by an improper estimate of the experimental covariance matrix. However, this was only demonstrated by means of two experimental data points for the same theoretical quantity. In this contribution, the solution is tested for more than one theoretical quantity and is applied to a typical nuclear data problem.
[1] "Peelle's Pertinent Puzzle and its Solution," R. Fruehwirth, D. Neudecker, H. Leeb, EPJ Web of Conferences 00008, **27** (2012)

PR 125

Documentation of Uncertainties in Experimental Neutron Cross Sections for EXFOR

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Detailed documentation of uncertainties in neutron-induced reaction cross sections has been urged by nuclear data evaluators who want to incorporate experimental information of cross sections and their uncertainties properly. Though this request has been discussed between nuclear data centres in the past, there are few EXFOR entries which satisfy the data evaluators, regardless of the existence of some text books of error analysis specialized for nuclear data [1,2]. Following a number of recommendations from the IAEA Technical Meeting on Neutron Cross Section Covariances [3], we have prepared practical guidance on experimental neutron cross section uncertainties with various examples and also extended the EXFOR format to accommodate a wide range of uncertainty information, in order to encourage experimentalists to provide a full description of partial and total uncertainties to data evaluators through the EXFOR library. The paper will review the flow of data from experiment to users, and present several new options of the EXFOR formats for uncertainties and covariances with sample EXFOR entries. A full report of the guidance is also under preparation [4].
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PR 126

Application of GRS Method to Evaluation of Uncertainties of Calculation Parameters of Perspective Sodium-Cooled Fast Reactor

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A number of recent studies have been devoted to the estimation of errors of reactor calculation parameters by the GRS (Generation Random Sampled) method. This method is based on direct sampling input data resulting in formation of random sets of input parameters which are used for multiple calculations. Once these calculations are performed, statistical processing of the calculation results is carried out to determine the mean value and the variance of each calculation parameter of interest. In our study this method is used for estimation of errors of calculation parameters (Keff, power density, dose rate) of a perspective sodium-cooled fast reactor. Neutron transport calculations were performed by the nodal diffusion code TRIGEX and Monte Carlo code. Key Words: GRS-method, uncertainty analysis, covariance matrix, Keff, power density, dose rate, TRIGEX, MMK.

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PR 127

Propagating Correlated Uncertainties in the Prompt Fission Neutron Spectra

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The most modern nuclear data libraries, including the ENDF/B-VII.1 library in the US [1], have recently focussed much of the evaluation efforts not only on obtaining the best possible mean values for important nuclear reactions but also the uncertainties associated with the mean values [2]. With many of the neutron-induced reaction uncertainties becoming available to the nuclear applications community, there is a large need to propagate the evaluated uncertainties through neutron transport calculations to better understand the effect on the integral quantities computed in the neutron transport simulations and observed in selected experiments. Recently, the prompt fission neutron spectrum (PFNS) uncertainties have been systematically quantified across a suite of isotopes [3] using a Kalman filter and a modified version of the Los Alamos model [4]. A covariance matrix with cross-isotope correlations describing the PFNS uncertainties resulted along with new evaluated PFNS mean values across each suite of isotopes. The benefit of the systematic approach to evaluating the PFNS in this manner is that the minor actinides, which have extremely scarce differential experimental measurements, have now been evaluated using the differential experimental measurements available for the major actinides in an indirect but very reasonable and coherent fashion. First, we propose to use the newly evaluated PFNS mean values in some selected transport benchmarks and compare the integral quantities obtained against the integral quantities computed using the ENDF/B-VII.1 data library [1]. To obtain the uncertainties associated with the computed integral quantities of the transport benchmarks, several uncertainty propagation methods are explored, including the first-order "sandwich" rule, brute force Monte Carlo and polynomial chaos expansion methods. Finally, the impact the cross-isotope correlations have on the selected transport benchmarks are studied by comparing the differences when propagating the PFNS uncertainties through the transport solution separately (assuming no cross-isotope correlation exists) and propagating the correlated PFNS uncertainties.

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PR 128

Evaluation of the Covariance Matrix of Estimated Resonance Parameters

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In the resolved resonance region nuclear resonance parameters are mostly deduced from experimental measurements using a least squares adjustment. Derived parameters can be mutually correlated through the adjustment procedure as well as through common experimental or model uncertainties. In this contribution we investigate four different methods to propagate the additional covariance caused by experimental or model uncertainties into the evaluation of the covariance matrix of the estimated parameters: (1) including the additional covariance into the experimental covariance matrix based on calculated or theoretical estimates of the data; (2) include the common uncertainty affected parameter as additional experimental data input and model parameter; (3) evaluation of the full covariance matrix by Monte Carlo sampling of the common parameter; and (4) retroactively including the additional covariance by marginalization proposed by Habert et al. [1]. These different methods are investigated based on simulated data and based on experimental data resulting from transmission and capture measurements on ^{197}Au covering the resolved and unresolved resonance region. Using the simulated data the impact of different components are investigated: counting statistics, the self-shielding term in the yield expression, and the inclusion of a thermal cross section on the deduced covariance matrix is demonstrated. The impact of the different procedures on the covariance of the final cross section calculated is shown.

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[1] Habert et al., Nucl. Sci. Eng. **166**, 276 – 287 (2010)

PR 129

Comparison of Two Approaches for Nuclear Data Uncertainty Propagation In MCNP(X) for Selected Fast Spectrum Critical Benchmarks

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Nuclear data uncertainty propagation based on stochastic sampling (SS) is becoming more attractive while leveraging the huge increase in modern computer power. Two variants of the SS approach are compared in this study. The Total Monte Carlo (TMC) method [1] developed at the Nuclear Research Consultancy

Group (NRG) prescribes probability density functions to theoretic parameters of nuclear reaction models and uses them to create random ENDF nuclear data files, which are translated subsequently into the ACE-formatted nuclear data files by NJOY. At the Paul Scherrer Institut (PSI), the Nuclear data Uncertainty Stochastic Sampling (NUSS) system is under development and based on the concept of generating the randomly perturbed ACE-formatted nuclear data files directly from applying groupwise nuclear data covariances onto the original pointwise ACE-formatted nuclear data [2]. Both the TMC and PSI-NUSS methods are applied with the Monte-Carlo code MCNP(X) for the well-studied Jezebel and Godiva fast spectrum critical benchmarks in this paper. At first, using TENDL-2012 libraries and associated covariance matrices, uncertainty assessments for k_{eff} and spectral parameters are carried out and compared. The propagated uncertainties due to various reactions of ^{239}Pu, ^{235}U and ^{238}U are crosschecked between the two methods. Furthermore, with the PSI-NUSS method, an examination of applying different groupwise perturbations onto continuous nuclear data and the effect of using ENDF/B-VII.1 with its covariance library versus the SCALE6 44-group covariance library are assessed. With the latter, the results obtained by PSI-NUSS are compared to those calculated by the Sensitivity and Uncertainty (S/U) methodology of the SCALE6 package. Generated under different principles, the uncertainty results from the deterministic S/U method serve as a separate verification for the two SS-based methods. The observed differences in the propagated uncertainties of nuclear data among the considered methods and covariance files are discussed.
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PR 130

Validation of Evaluated Nuclear Data Libraries for Calculation of Fast Reactors

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Given that integral data plays a key role in the validation of neutronics simulations for safety assessment, a collection of integral benchmarks is being created at IRSN. It includes measurements of K_{eff}, reactivity coefficients, β_{eff}, reaction rates, power distributions and other reactor-type parameters for dozens of configurations which originate mostly from the Handbook of the International Reactor Physics Experiment Evaluation Project (IRPhEP Handbook). For fast reactor neutronics code validation, the benchmarks are selected from independent facilities in a way to cover a range of plutonium enrichments, 240Pu contents, core sizes and diluents. The collection includes ZEBRA-22, ZEBRA-23, ZEBRA-24, ZEBRA-25, MZA, MZB, ZPR-6/7-12, ZPR-6/7-99, SNEAK-7A, SNEAK-7B, BFS-62.3a, Joyo and other fast benchmarks. For the purpose of validation, it is important to ensure that the uncertainties for the benchmark experiments are well evaluated and correlations between the uncertainties are well established. Previous studies demonstrate that the experimental correlations may not be negligible in a validation study. The correlations between the experimental uncertainties (also called experiment correlations) arise from the use of the same fuel and structural materials, the same container tank or cladding, and common methods for measurements and instrumentation. The efforts are being mounted at IRSN to identify, quantify and document the experimental correlations for the selected fast benchmarks. JEFF-3.1, ENDF/B-VI.8, ENDF/B-VII.0 and ENDF/B-VII.1 libraries will be validated against the above benchmarks computed with MCNP. The validation study will be performed with and without the experimental correlations. The full paper will describe the validation method. The validation results will be presented and analyzed in order to understand how the advances in new libraries improve performance in integral validation reactor-type benchmark tests. The analysis will be supported by K_{eff} sensitivities to nuclear data calculated with

SCALE TSUNAMI-3D sequence for some benchmarks.
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PR 131

MCNP6 Simulation of Quasi-Monoenergetic ^{7}Li(p,n) Neutron Sources below 150 MeV

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The applicability of MCNP6 to simulate quasi-monoenergetic neutron sources from interactions of proton beams with energies below 150 MeV on thick ^{7}Li targets have been studied. Neutron spectra at zero degrees from a 2-mm ^{7}Li layer backed by a 12-mm carbon beam stopper in an Al flange bombarded with protons of 20, 25, 30, 35, and 40 MeV have been calculated with MCNP6 using the recent Los Alamos 3007.00h data library as well as using the Bertini+Dresner and CEM03.03 event generators. A comparison with the experimental neutron spectra shows that the event generators do not do well in describing such reactions, while MCNP6 using the LANL 3007.00h data library simulates production of neutrons from p + ^{7}Li in good agreement with the measured data.

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Benchmarking the Latest Evaluated Nuclear Data Libraries with Criticality Benchmarks

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To improve the CENDL library and also considering about recommending a set of international evaluated nuclear data library in the future, hundreds of criticality benchmarks from ICSBEP covering thermal, intermediate and fast spectra were selected and calculated with the MCNP code to test CENDL-3.1, ENDF/B-VII.1, JEFF-3.1.2 and JENDL-4.0 library. The C/E values of k_{eff} for selected benchmarks were analyzed with the trends breaking down to different kind of materials against energy spectra index EALF. Several common problems existed in tested libraries shown in comparisons were discussed. The evaluations and improvement need to be done in the next step were suggested.

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