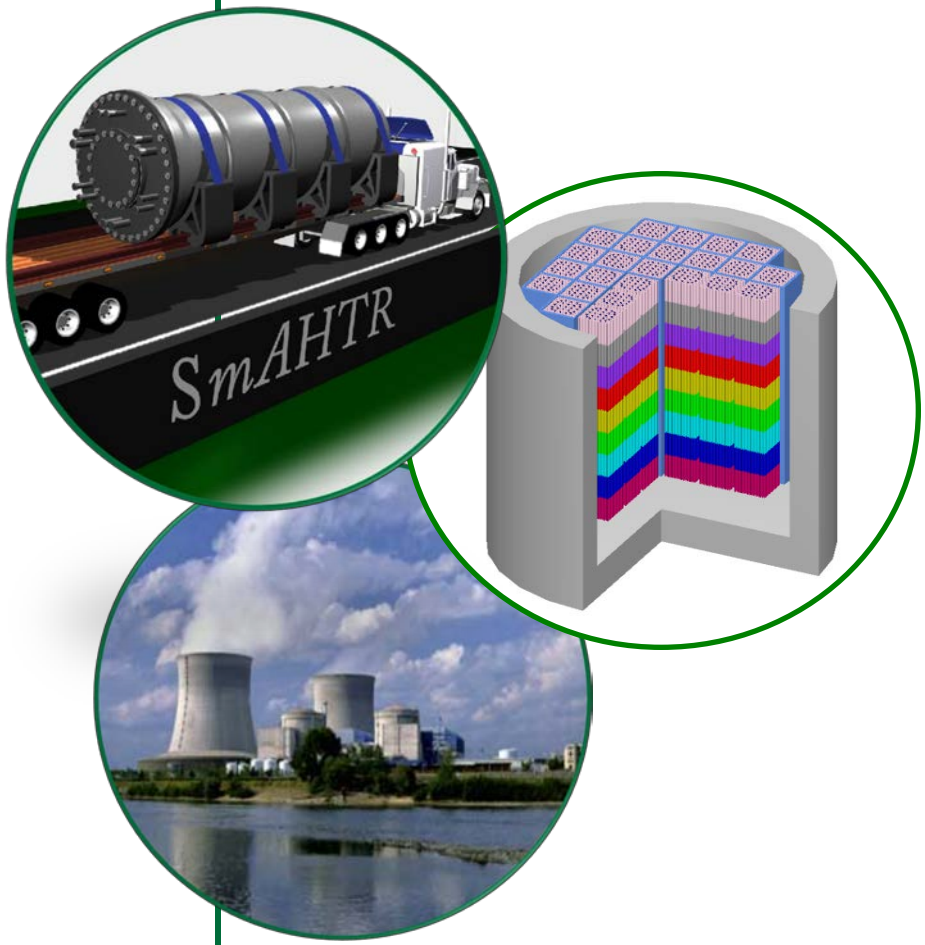
Overview of Reactor and Nuclear Systems Division

Cecil Parks

RNS Division Director

parkscv@ornl.gov

865-574-5267

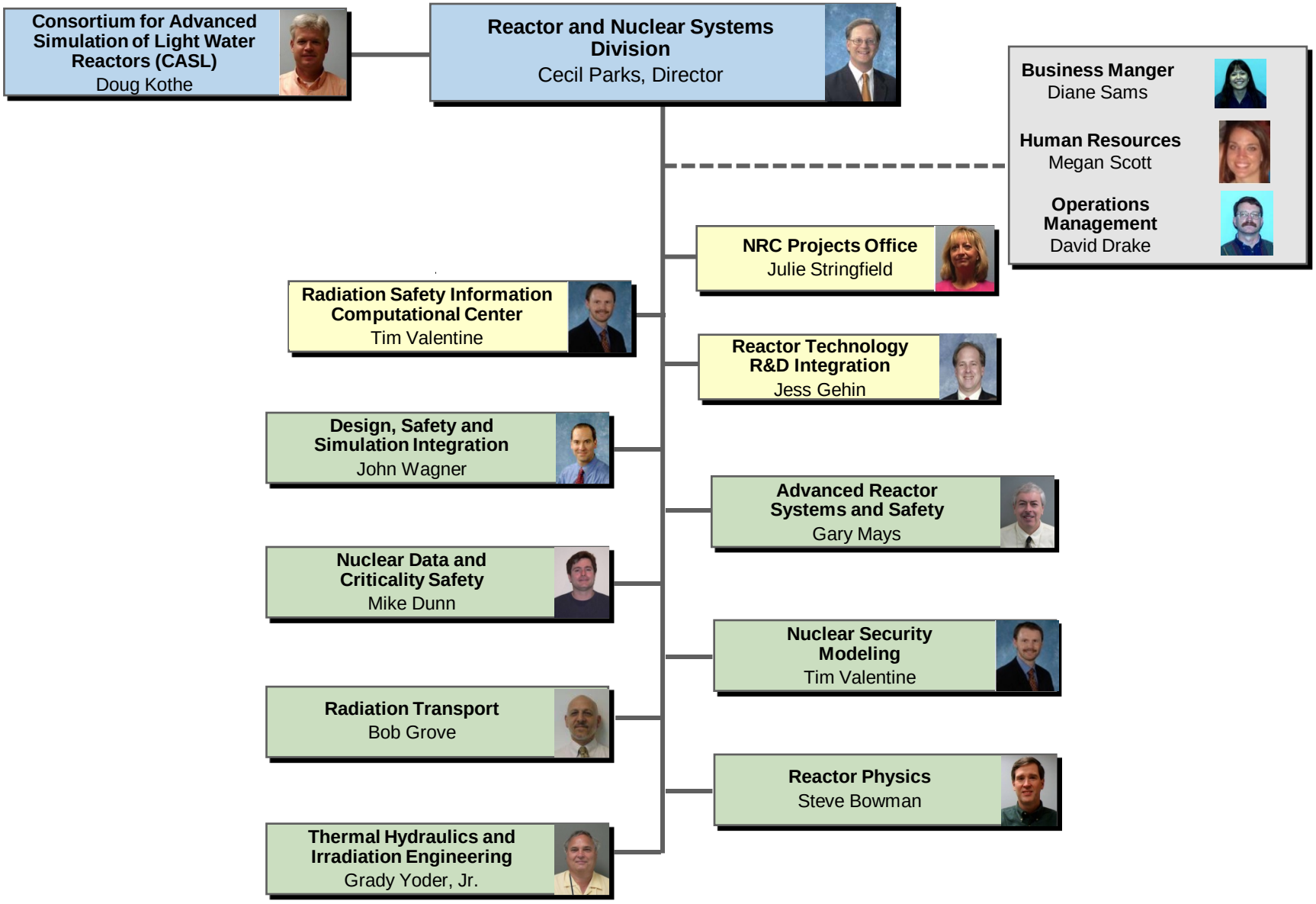


U.S. DEPARTMENT OF ENERGY

RNSD Reactor and Nuclear Systems Division

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

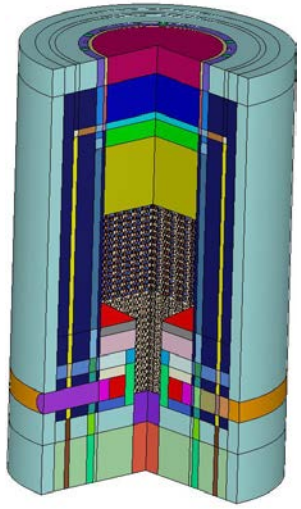

Consortium for Advanced Simulation of Light Water Reactors (CASL)
Doug Kothe
Reactor and Nuclear Systems Division
Cecil Parks, Director
Business Manger
Diane Sams
Human Resources
Megan Scott
Operations Management
David Drake
NRC Projects Office
Julie Stringfield
Radiation Safety Information Computational Center
Tim Valentine
Reactor Technology R&D Integration
Jess Gehin
Design, Safety and Simulation Integration
John Wagner
Advanced Reactor Systems and Safety
Gary Mays
Nuclear Data and Criticality Safety
Mike Dunn
Nuclear Security Modeling
Tim Valentine
Radiation Transport
Bob Grove
Reactor Physics
Steve Bowman
Thermal Hydraulics and Irradiation Engineering
Grady Yoder, Jr.

RNSD is a leader in developing and providing nuclear science and technology to a vast array of internal and external customers:

- Department of Energy (DOE)
  - Office of Science
  - Office of Nuclear Energy
  - Office of Environmental Management
  - Office of Intelligence
- National Nuclear Security Administration
  - NA-10: Program Readiness, Infrastructure
  - NA-20: Nonproliferation and Safeguards
  - NA-40: Emergency Response
- Nuclear Regulatory Commission (NRC)
- National Aeronautics and Space Administration
- Defense Threat Reduction Agency
- Department of Homeland Security
- Industry (AECL, EPRI, Westinghouse, etc.)

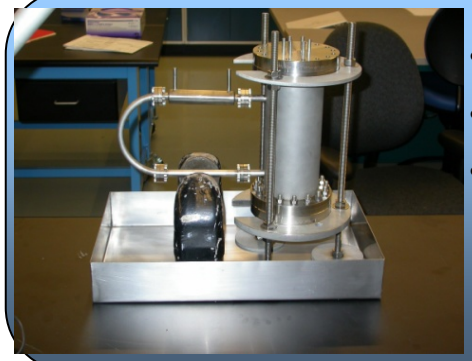
Reactor and Nuclear Systems Division

- Software and data development for nuclear analysis
  - SCALE software system
  - Consortium for Advanced Simulation of LWRs (CASL)
  - Cross section data measurement, evaluation, and processing (AMPX code system)
  - Radiation Safety Information Computational Center
- Application of nuclear analysis software to address national agenda
  - Used fuel transport, storage, and disposition
  - Nuclear nonproliferation, safeguards, and consequence management
  - Reactor and nuclear system evaluation (e.g., safety, performance, etc.)
  - Fuel cycle systems
- Technology R&D
  - Irradiation experiment design
  - Space fission power
  - Advanced reactor concepts
  - Safety and regulatory expertise
  - Small modular reactors
  - Thermal hydraulics experimentation



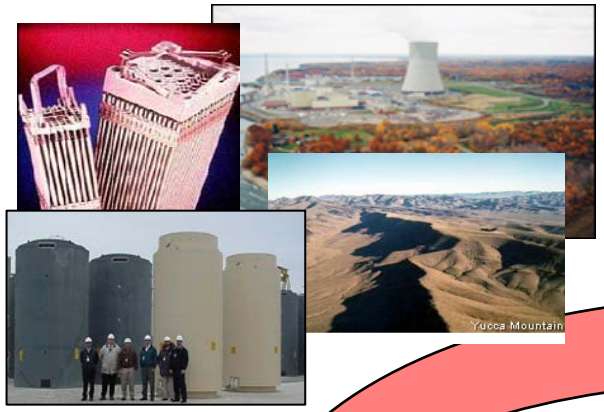
HTR-10 Pebble Bed Reactor Benchmark

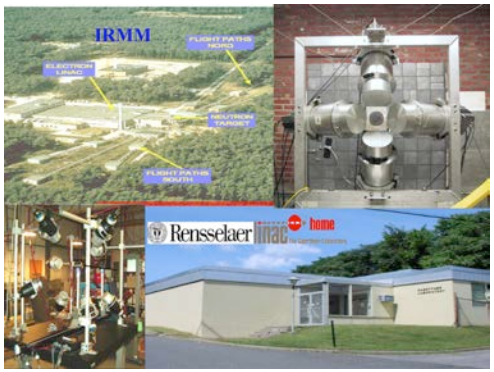
Reactor Technology Lab – R&D for Reactor Power Systems



- Liquid metal systems
- Bench-scale flow testing
- Simulate generation, acquisition, & processing of signals by control system

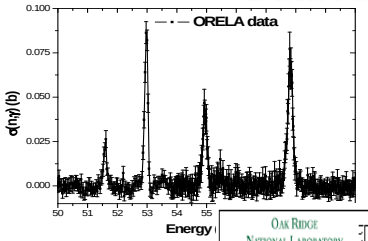
Applications



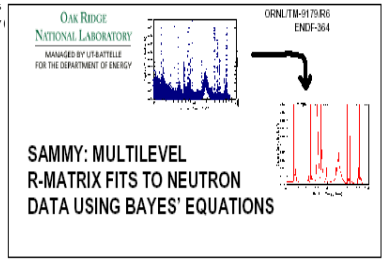


Measurements

Data Analyses

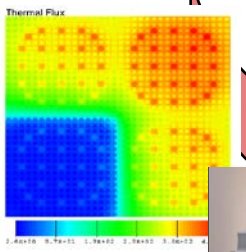


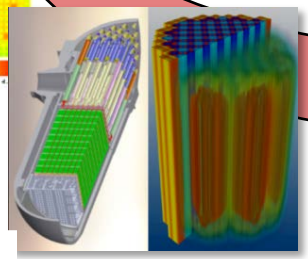
SAMMY



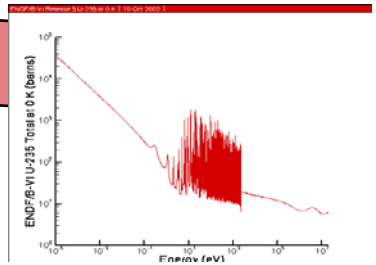
ORNL integrates experience in nuclear data, computational modeling, and nuclear technology to support span of nuclear science and technology

Cross-Section Evaluations

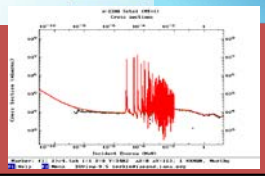




Computational Modeling



Evaluated Nuclear Data Files (ENDF/B)



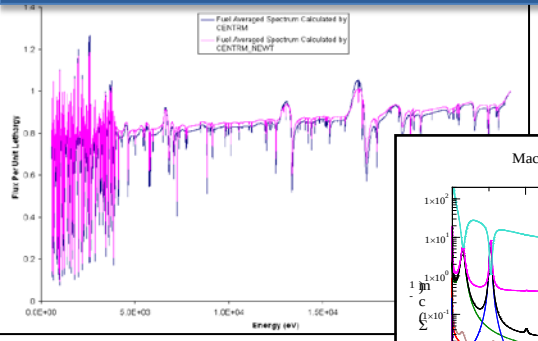
scale

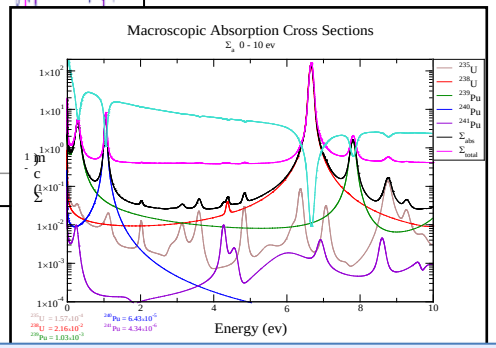
CASL

AMPX

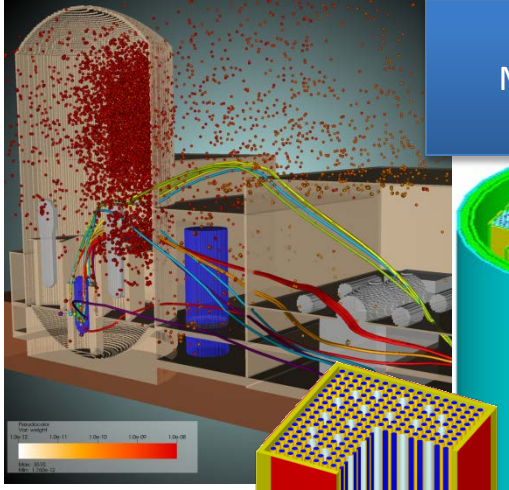
Cross-Section Processing

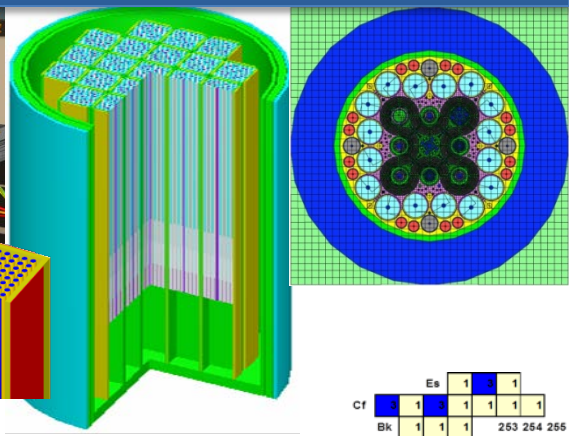
Convenient Material Input and Current Nuclear Data with Continuous-Energy Resonance Processing





High-Resolution Geometry Modeling in Monte Carlo and Deterministic Transport

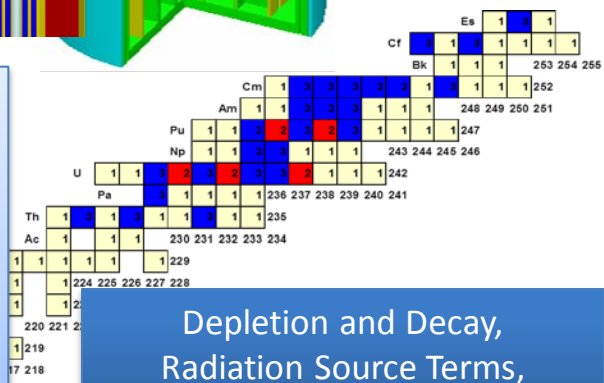




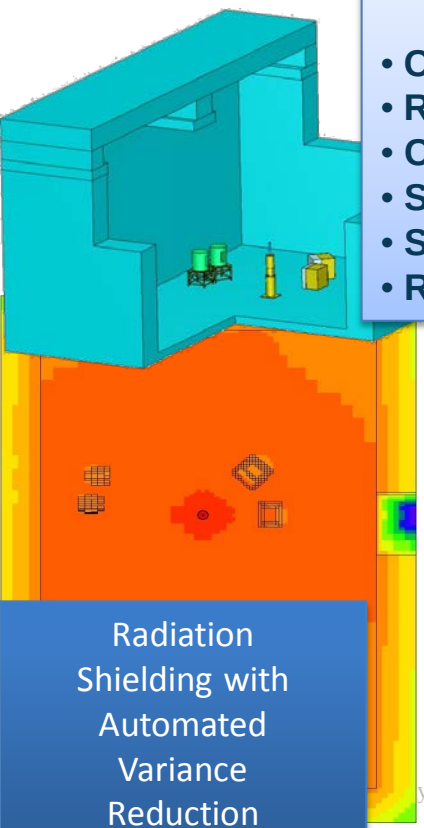
SCALE Capabilities

- Criticality safety
- Radiation shielding
- Cross-section processing
- Spent fuel and HLW characterization
- Sensitivity and uncertainty analysis
- Reactor physics

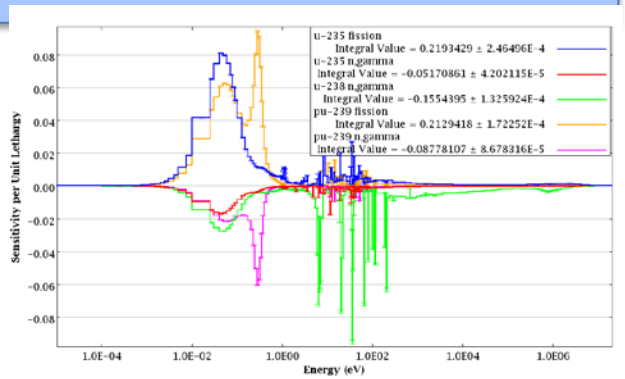
scale



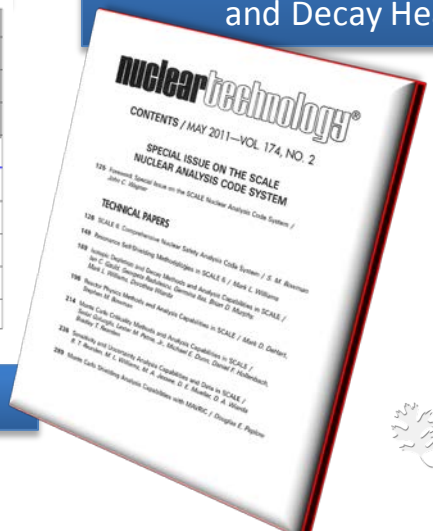
Depletion and Decay, Radiation Source Terms, and Decay Heat



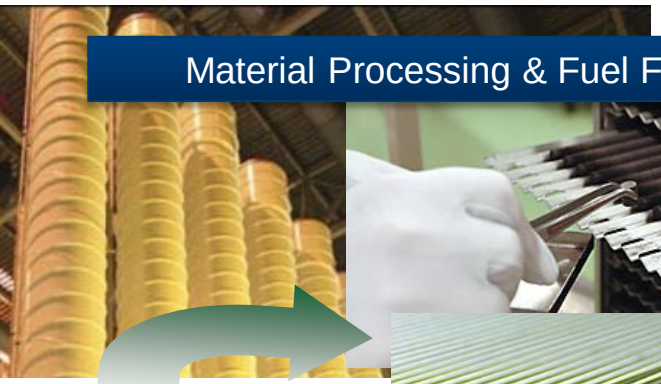
Radiation Shielding with Automated Variance Reduction



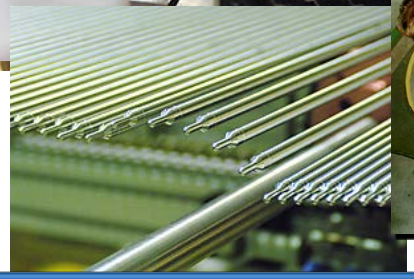
Sensitivity and Uncertainty Analysis



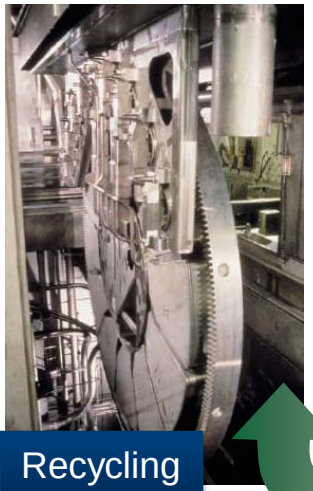
OAK RIDGE National Laboratory



Material Processing & Fuel Fabrication

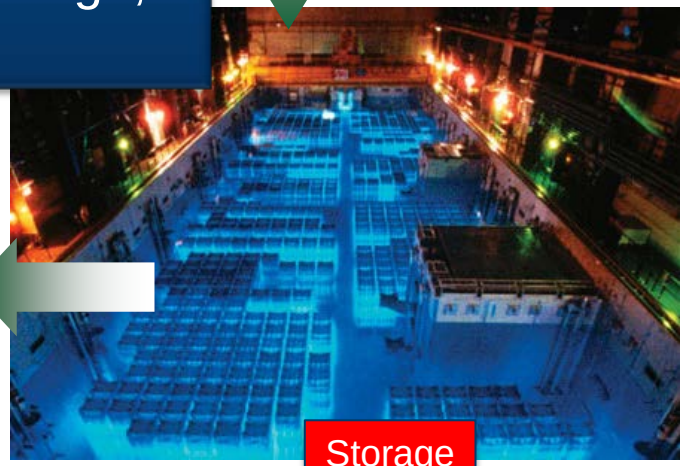


Commercial and Research Reactors



Recycling

Applications of SCALE:
The Nuclear Fuel Cycle,
Historical focus on transport and storage,
extended to reactor physics



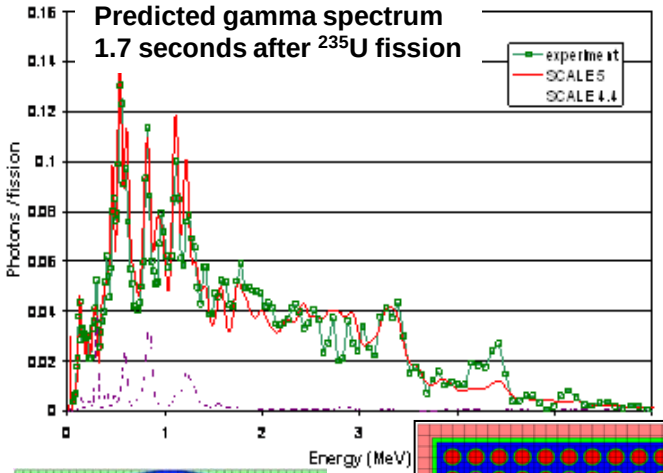
Storage

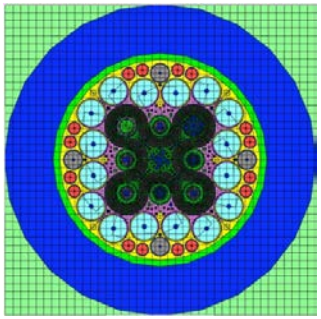
Transportation

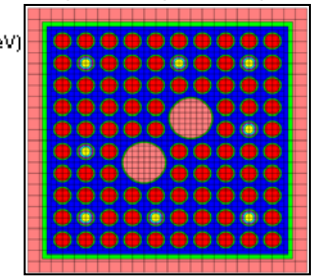
Disposal

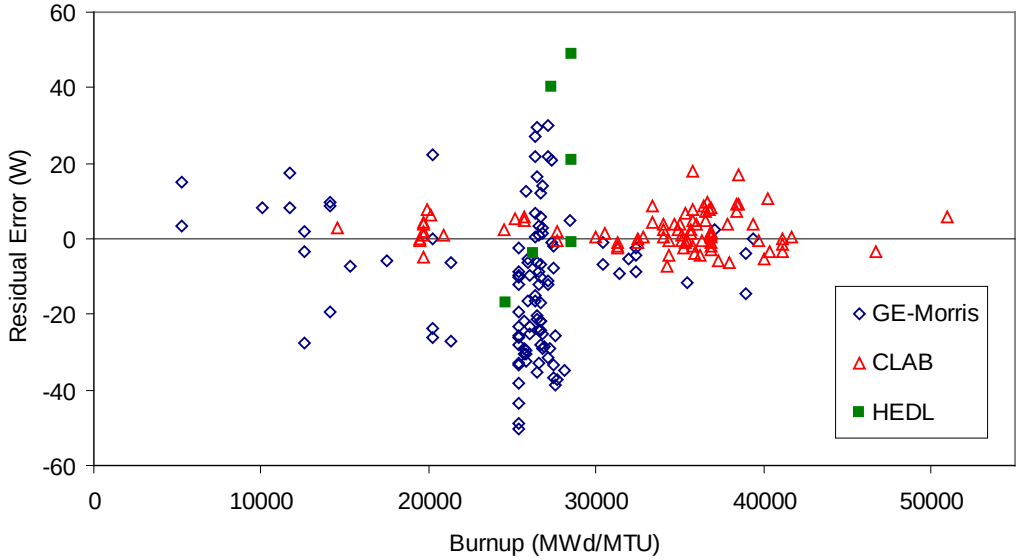
Reactor physics and source terms

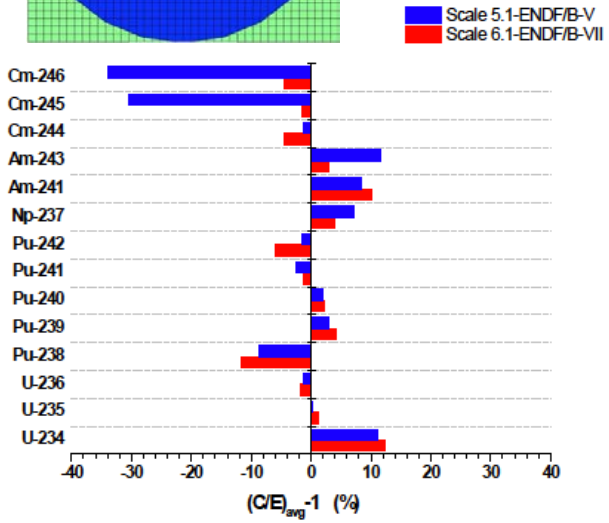
- 2D lattice physics and 3D Monte Carlo depletion coupled with ORIGEN
- ORIGEN: Oak Ridge Isotope GENeration and Depletion code
  - Irradiation and decay calculations
  - Explicit simulation of 2226 nuclides
  - Isotopic inventories validated against destructive radiochemical assay experiments
  - Decay heat results validated against measured data







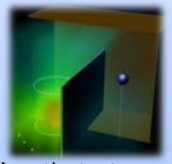




Denovo – massively parallel deterministic radiation transport code enabling solutions to enormous nuclear energy applications

- State of the Art Transport Methods
  - 3-D Discrete Ordinates (SN)
  - Multigroup energy, anisotropic PN scattering
  - 6 spatial discretization algorithms to choose from
- High Performance, Modern, Innovative Solvers
  - GMRES, BiCGStab. or Source Iteration options on within-group solves
  - DSA-preconditioning (SuperLU/ML-preconditioned CG)
  - Transport Two-Grid up-scatter acceleration of Gauss-Seidel MG iteration
  - Parallel first collision approximation
  - Eigenvalue (k_{eff}) and fixed-source problem modes
  - Krylov solvers provided by Trilinos Library

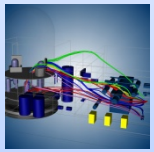
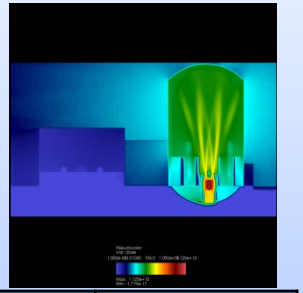
- Parallel Algorithms
  - Koch-Baker-Alcouffe (KBA) wavefront solve
  - Domain replicated & decomposed options for parallel first-collision source
  - Multi-level decompositions in energy and angle under development
  - Parallel I/O for massive problems



- Advanced Visualization and Run-Time Environment
  - Python front-end allows high-degree of flexibility in prescribing input/output
  - Direct connection to SCALE geometry and data
  - HDF5 output directly interfaced with Visit

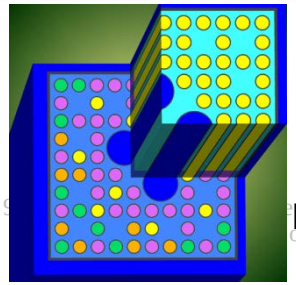
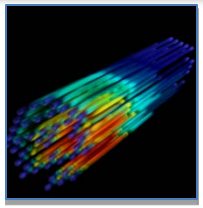
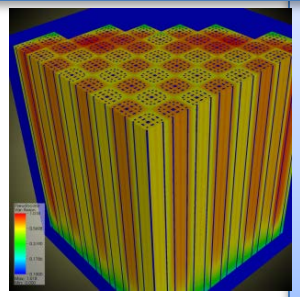
PWR Facility Modeling



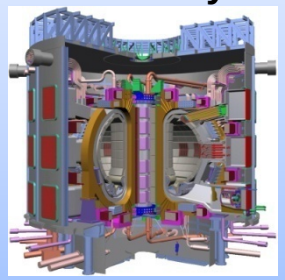
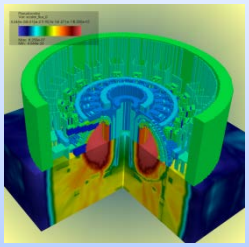
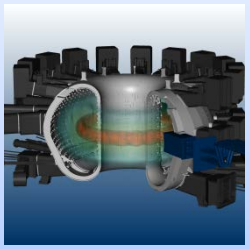
Zones	Angles	Groups	State Size (GB)	Output (GB)	Time (m)
103.7M	S_{24}/P_3	27	568.741	83.457	46.97
1,047.8M	S_{24}/P_3	27	5,746.180	843.189	79.43

- **Highlights**
  - **Routinely running > 100M cell problems on Cray XT5**
  - **FY10 ASCR JOULE code**
  - **Key component of ORNL hybrid (Monte Carlo/deterministic) code/methods development**
- **On-going and Future Directions**
  - **Neutronics solver for DOE NE NEAMS integrate fuel project**
  - **ORNL LDRD support for development of explicit full-core reactor analyses**
  - **ORNL LDRD development for hybrid reactor analysis**
  - **Electron transport for home land security applications**

Nuclear Energy: LWR analyses

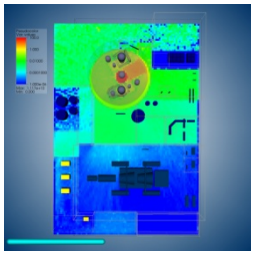
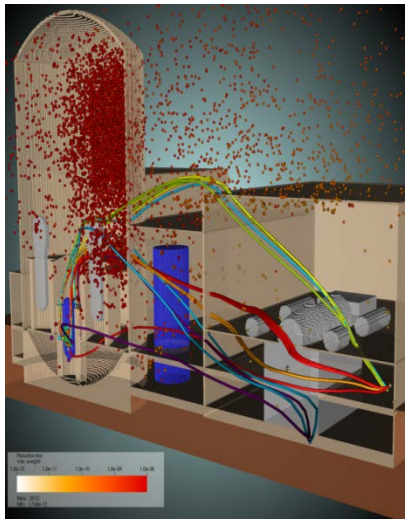
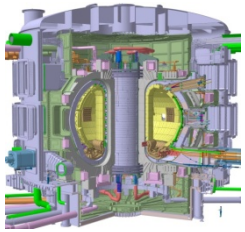
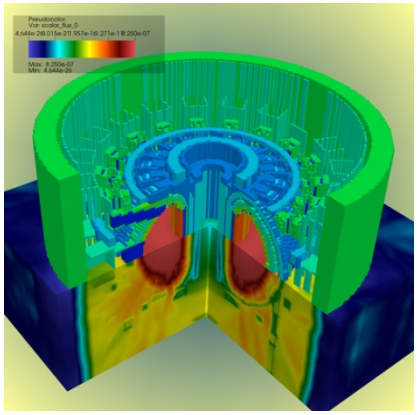
Fusion: ITER analyses

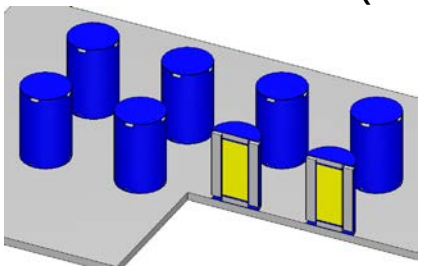




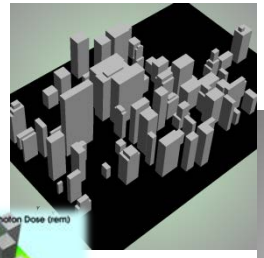
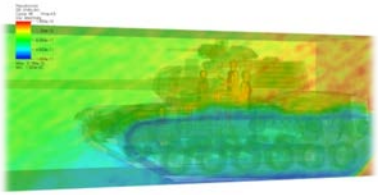
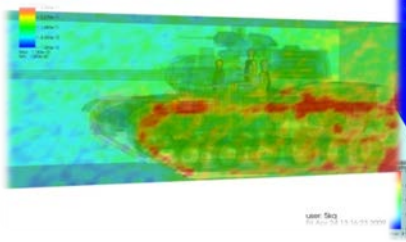
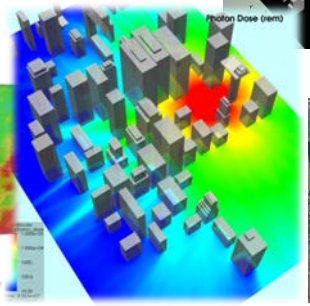
285M cell, S_{24}/P_3 model of the International Thermonuclear Experimental Reactor (ITER)

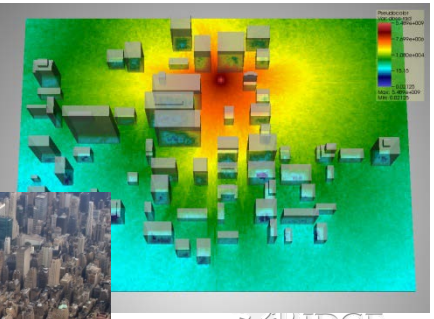
Radiation transport capabilities have been enhanced for advanced applications

- Hybrid (deterministic and Monte Carlo) computational radiation transport tools expand potential for solving large, complex real-world problems
  - Radiation from a nuclear detonation
  - Monte Carlo reactor simulation
  - Cargo interrogation
  - Facility safety and safeguards
  - Fusion (ITER)

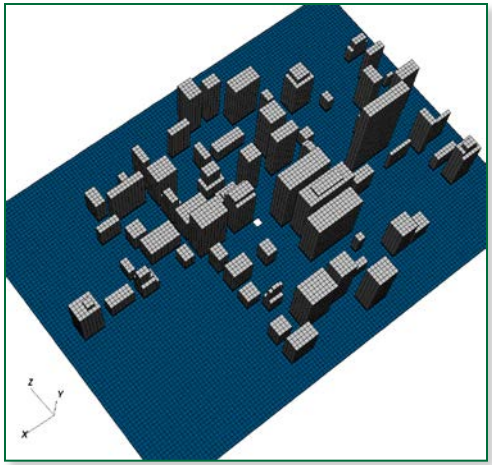


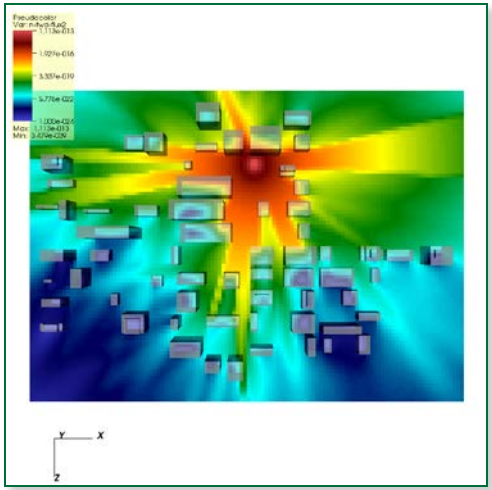


Problem: 25 mrem/y dose limit at controlled area boundary for ISFSI

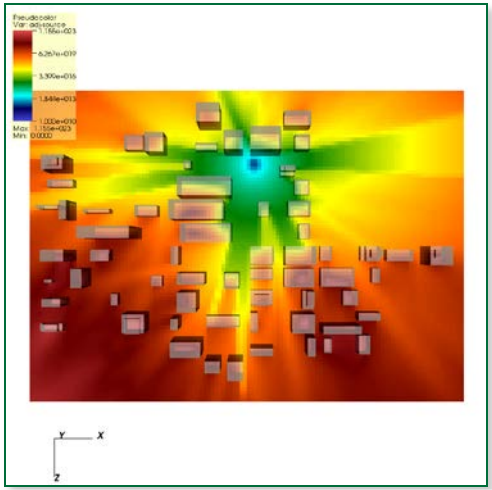
The FW-CADIS Method



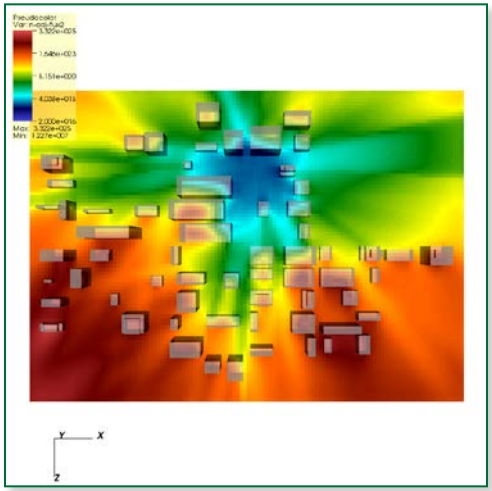
1: construct DX model



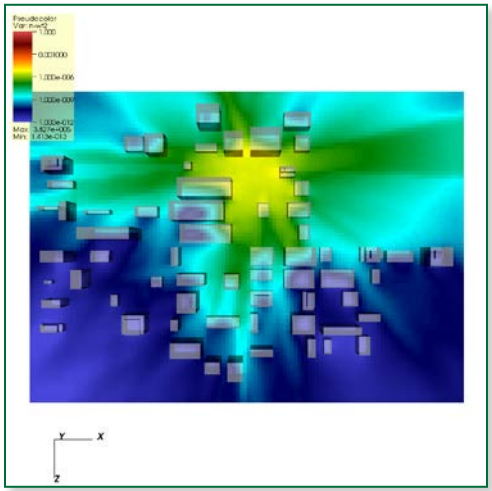
2: solve DX transport equation



3: construct importance source



4: solve DX importance equation



5: construct weight windows

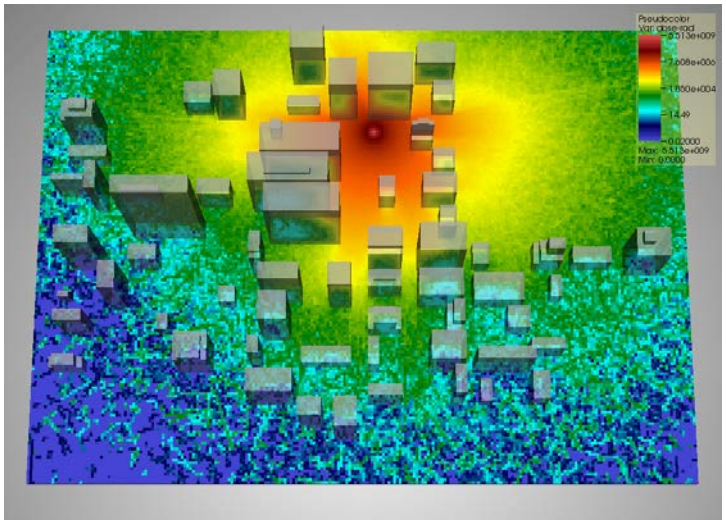
RNSD Reactor and Nuclear Systems Division

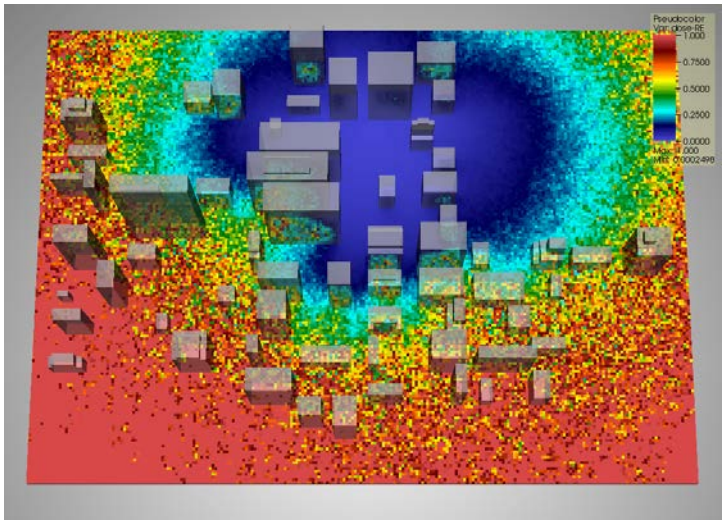
OAK RIDGE National Laboratory

ADVANTG Hybrid Results

24-hr Monte Carlo simulation of a 20kT Hiroshima-like weapon

conventional

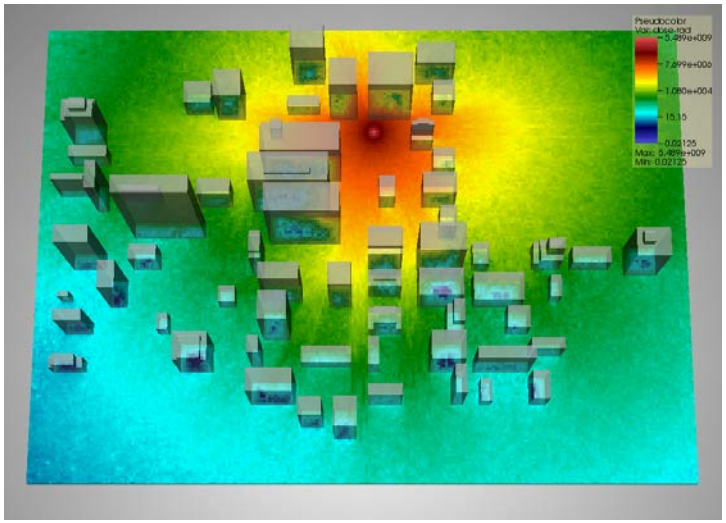


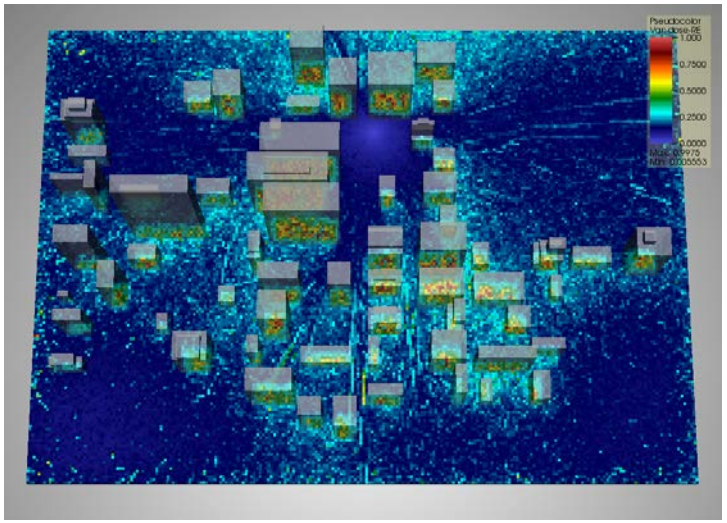


25% of cells have RE < 20%

48% of cells have RE < 50%

Hybrid





77% of cells have RE < 20%

97% of cells have RE < 50%

neutron dose (rad)

relative uncertainty

RNSD

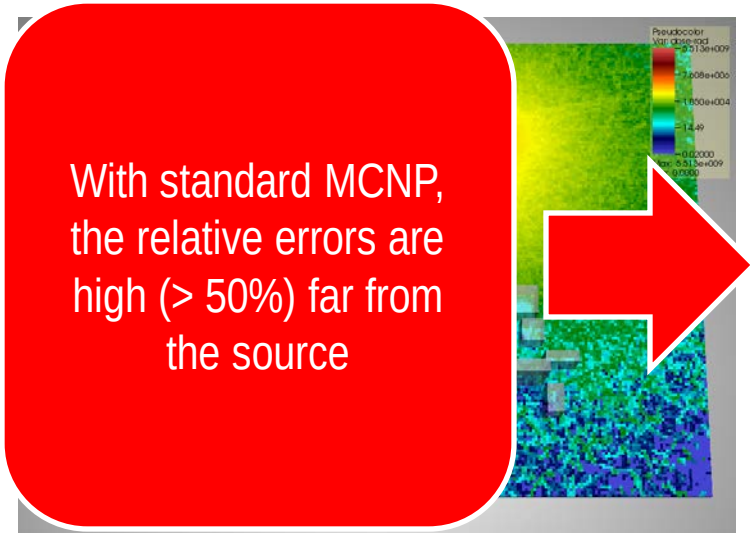
OAK RIDGE National Laboratory

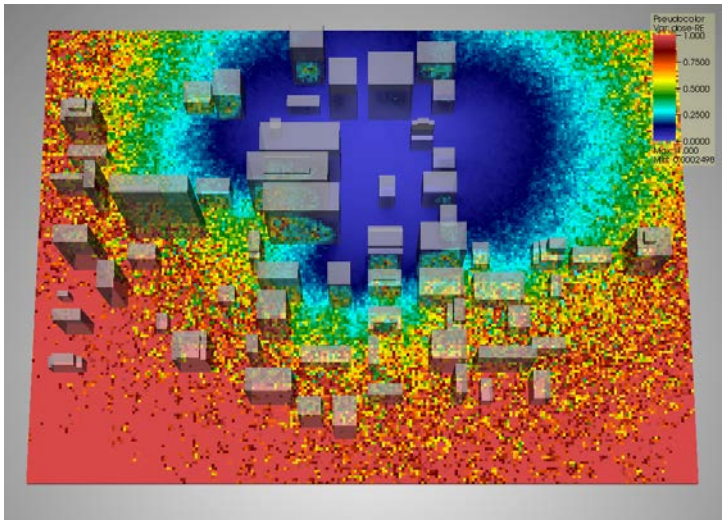
ADVANTG Hybrid Results

24-hr Monte Carlo simulation of a 20kT Hiroshima-like weapon

conventional

With standard MCNP, the relative errors are high (> 50%) far from the source



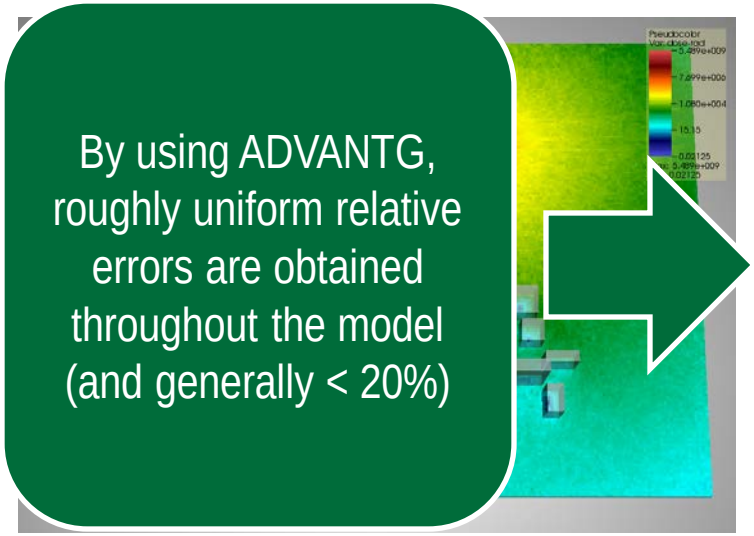


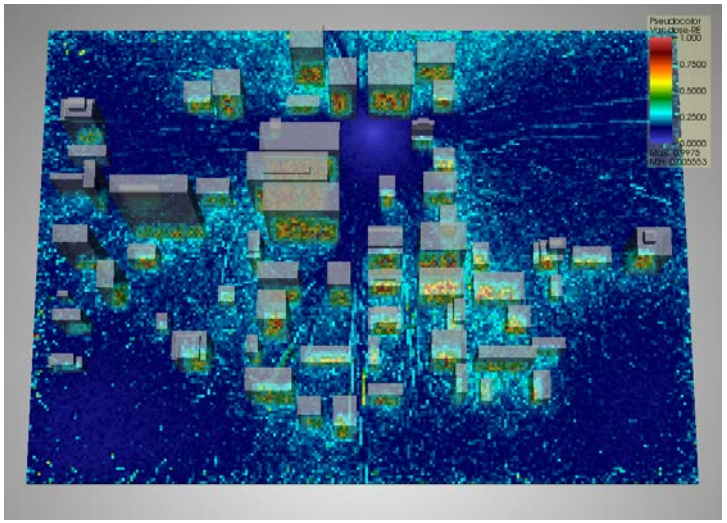
25% of cells have RE < 20%

48% of cells have RE < 50%

Hybrid

By using ADVANTG, roughly uniform relative errors are obtained throughout the model (and generally < 20%)





77% of cells have RE < 20%

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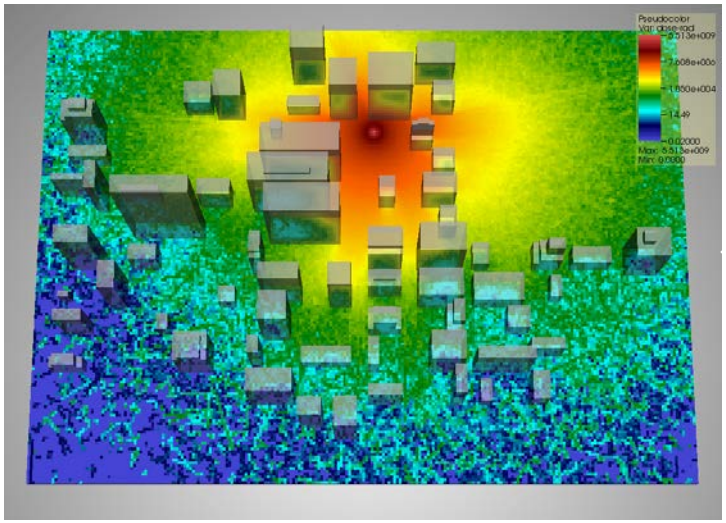
neutron dose (rad)

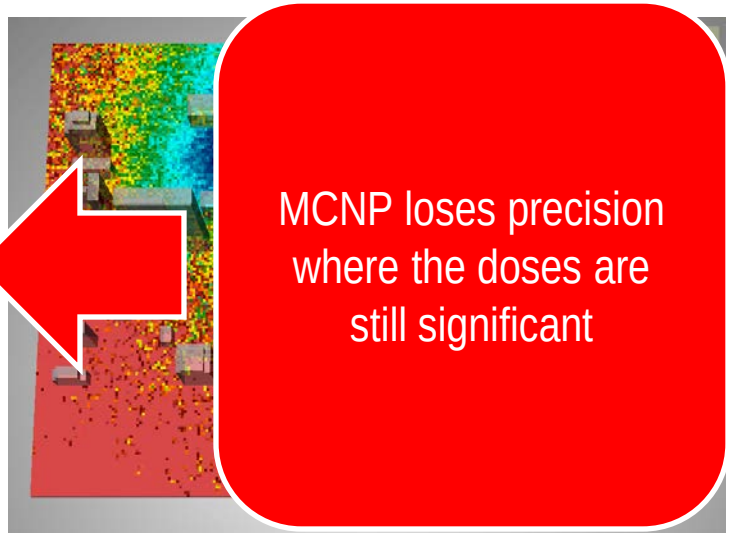
relative uncertainty

ADVANTG Hybrid Results

24-hr Monte Carlo simulation of a 20kT Hiroshima-like weapon

conventional



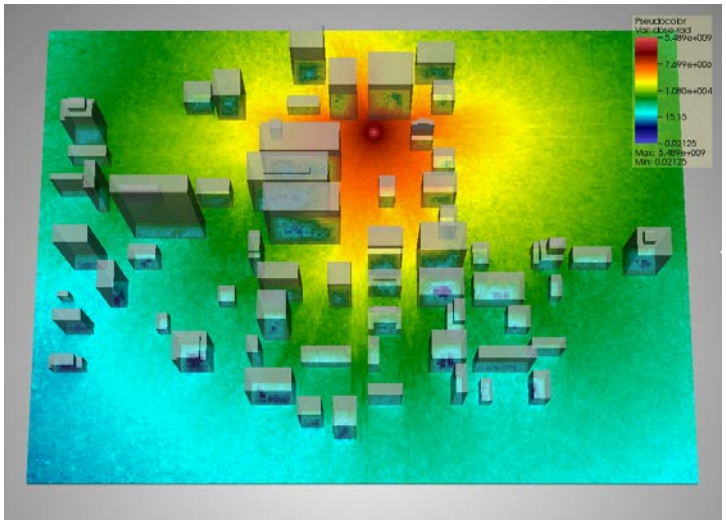


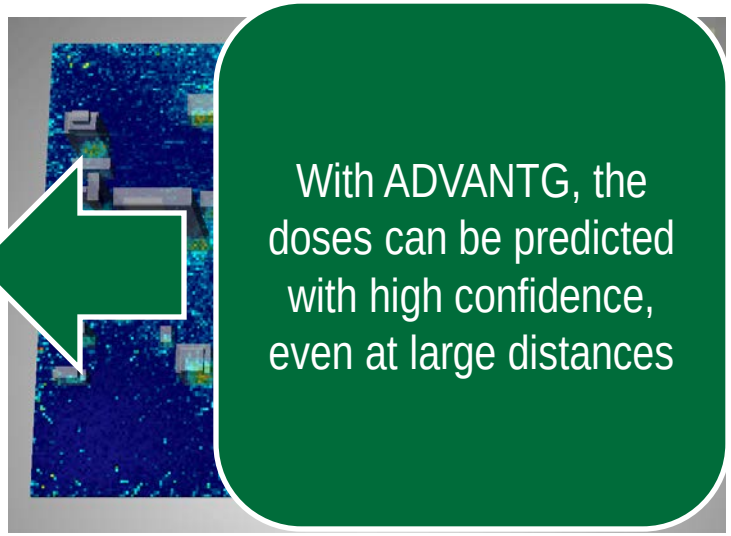
MCNP loses precision where the doses are still significant

25% of cells have RE < 20%

48% of cells have RE < 50%

Hybrid





With ADVANTG, the doses can be predicted with high confidence, even at large distances

77% of cells have RE < 20%

97% of cells have RE < 50%

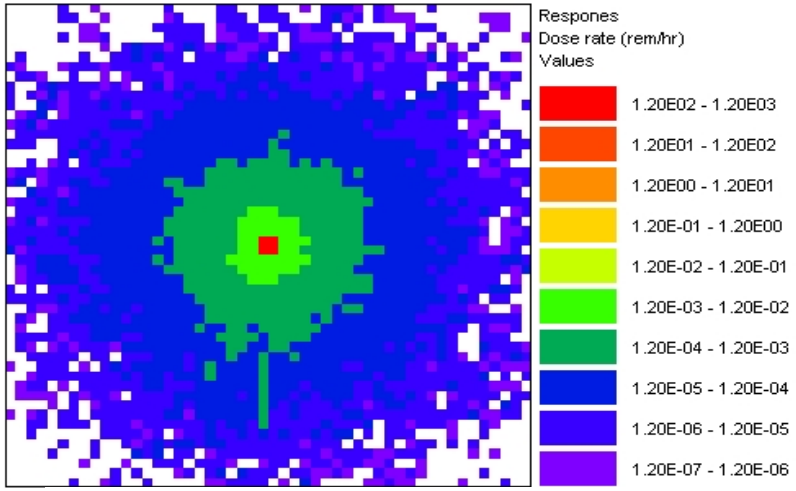
neutron dose (rad)

relative uncertainty

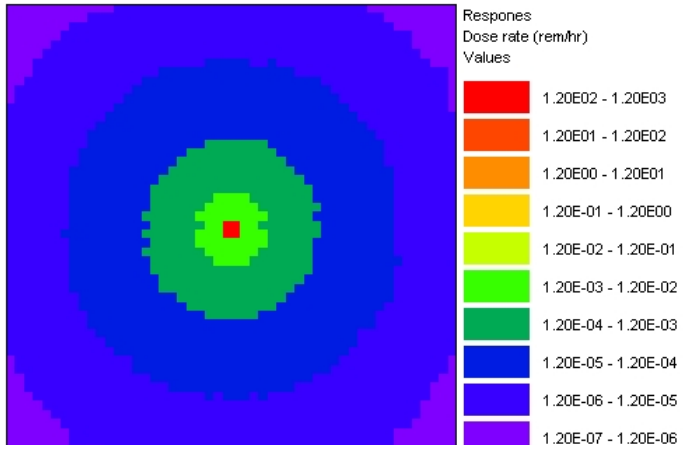
RNSD

OAK RIDGE National Laboratory

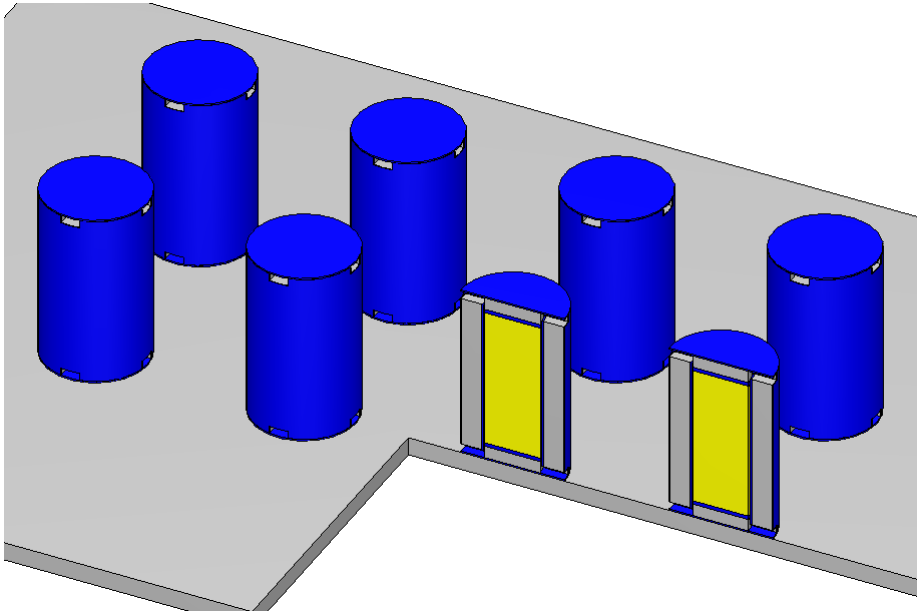
MAVRIC: Dose Rates from Cask Array



Analog calculation:
560 hours, poor resolution in mesh tally



Automated variance reduction: 109 hours,
80% voxels < 5% rel unc
97% voxels < 10% rel unc



Revolutionize radiation transport for reactor analyses

LDRD project 05424 initiated in FY10

Renewed for FY11

- Goal: Enable Monte Carlo for "real" reactor analyses

- Main thrusts:
  - Address prohibitive computational TIME through extension of ORNL's hybrid (deterministic/Monte Carlo) transport methods
  - Address prohibitive MEMORY requirements through development of a new domain-decomposition algorithm and code

- Y1 Accomplishments:
  - Developed & tested new hybrid method
  - Developed novel domain decomposition algorithm
  - Publications: Nov. ANS, MC2010
  - Linkage with CASL

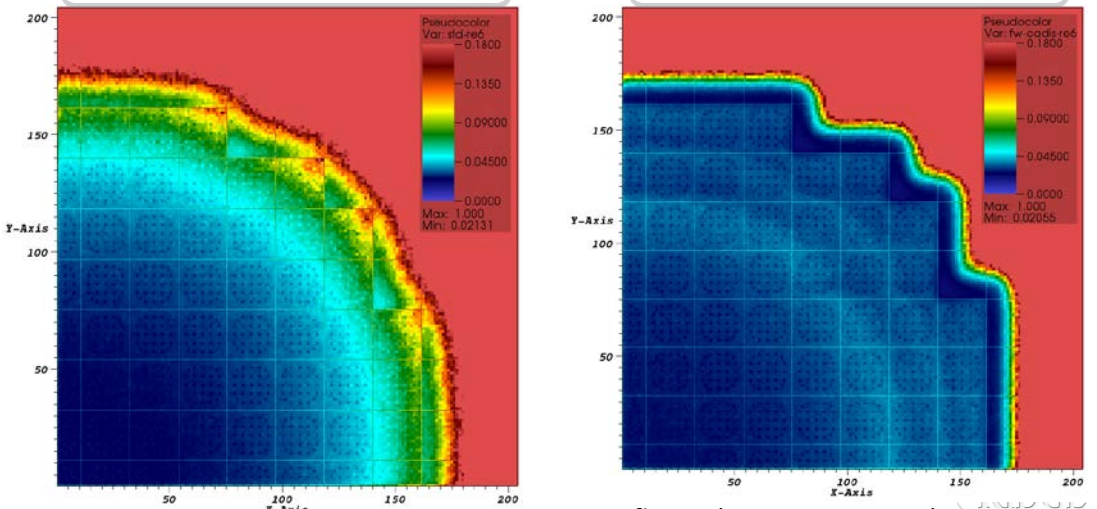
LDRD Team

Tom Evans, Scott Mosher, Douglas Peplow, John Turner, John Wagner

Ivan Maldonado, Brenden Mervin (UT JDRD)

Conventional MC simulation

MC w/new hybrid method

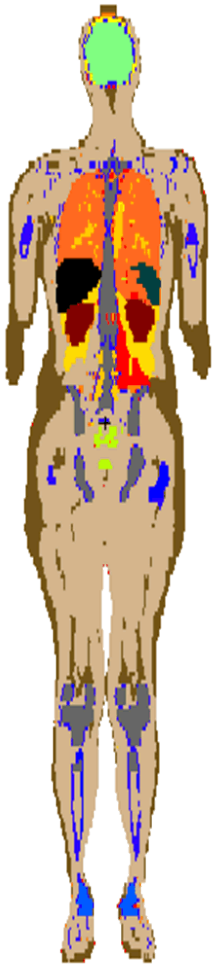


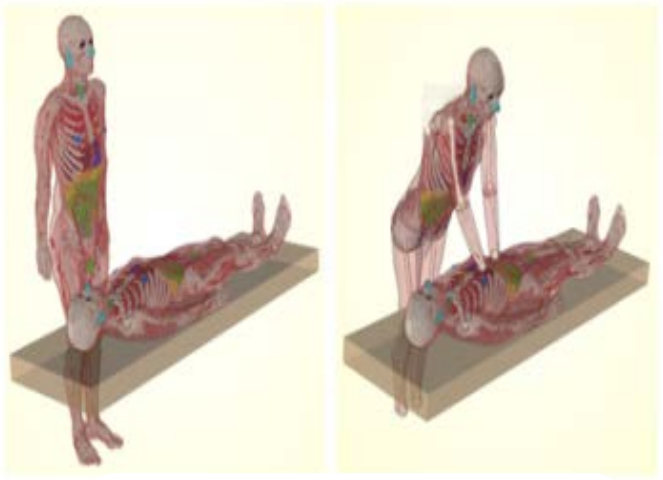
Statistical uncertainties in group 6 fluxes (0.15 to 0.275eV)

Researchers continue to improve ability to predict radiation dose to workers in the nuclear field

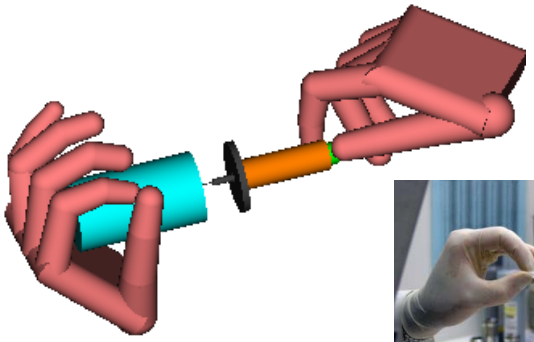
- Computationally efficient, yet realistic human models
  - Accurate representation of anatomy for vital area (torso and head)
  - User interface enables realistic positioning of arms and legs consistent with actual worker posture
  - Development of gender and age-specific models underway

Historical phantom model experiments are being replaced with detailed M&S



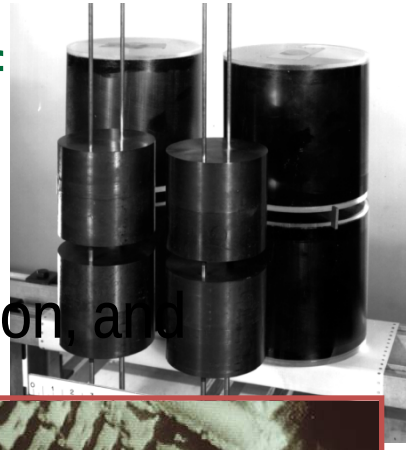


Physician Dose

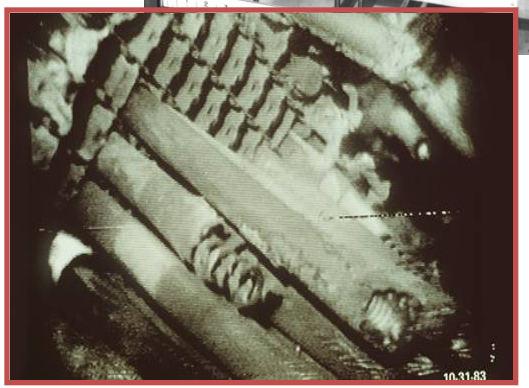


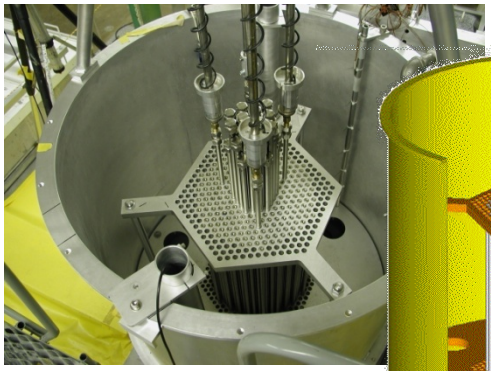
RNSD
Reactor and Nuclear Systems Division

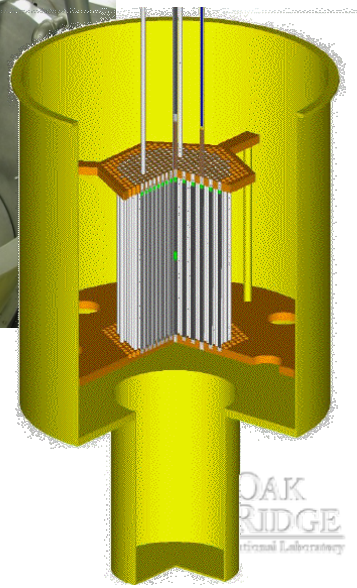
ORNL has rich heritage in area of nuclear criticality safety

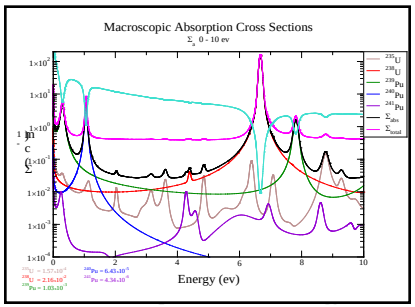


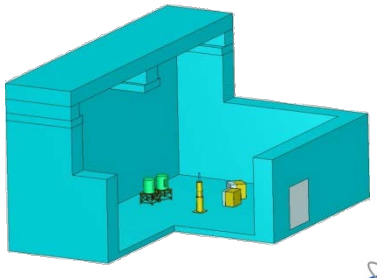
- Operations support for enrichment, fabrication, production, and research
- Critical experiment facility at Y-12
- Leadership in standards development
- Support and consultation to DOE and NRC
  - Development of regulatory guidance
  - Development of training programs
  - Technology advancements

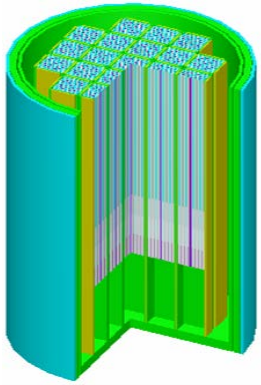










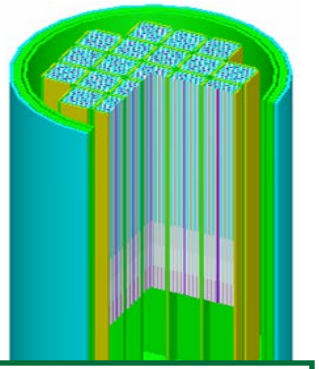


RNSD

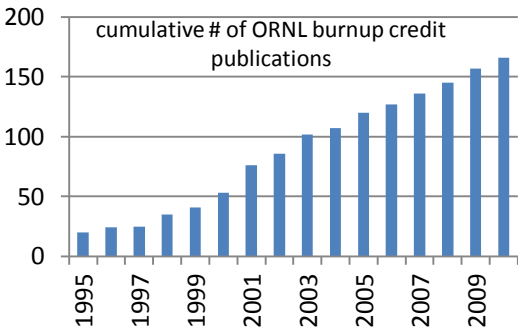
ORNL provides leadership to assure safe and secure storage, transport, and disposal of used nuclear fuel (UNF)

- Supporting NRC on regulatory safety requirements, license reviews, and resolution of important issues
- Predictive characterization of UNF for criticality and radiation safety
- Recognized international leader in burnup credit
- Supporting DOE NE Used Fuel Disposition Campaign

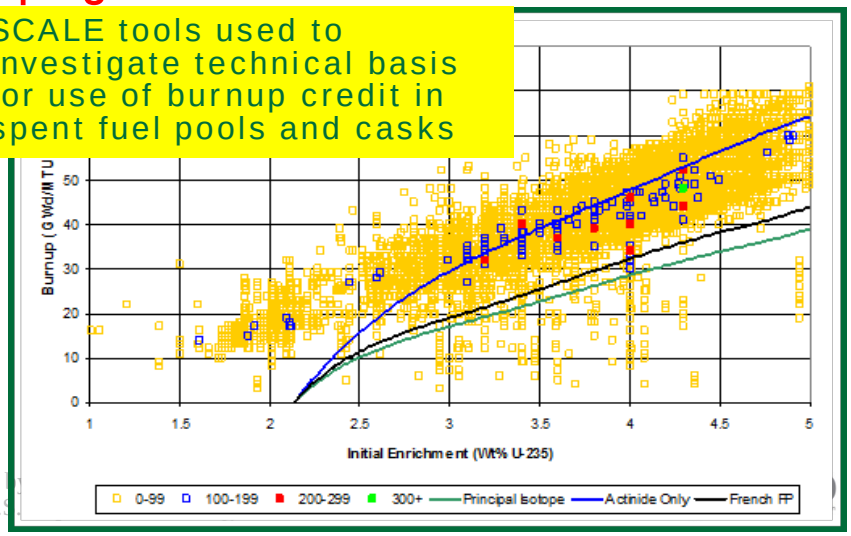
- International leader for criticality safety and radiation safety of UNF
- YMP lead for post-closure criticality
- Supporting UNF VLTS issues



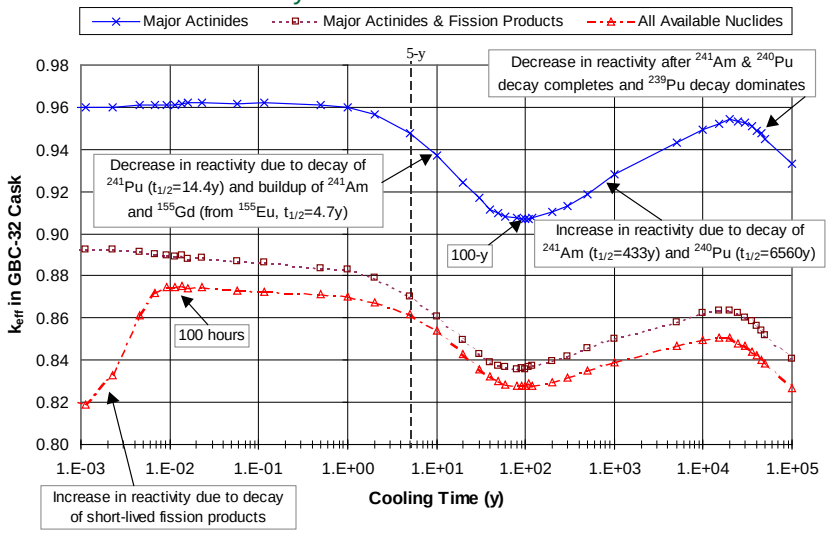
21-assembly Transport, Age, and Dispose (TAD) canister system in a Waste Package



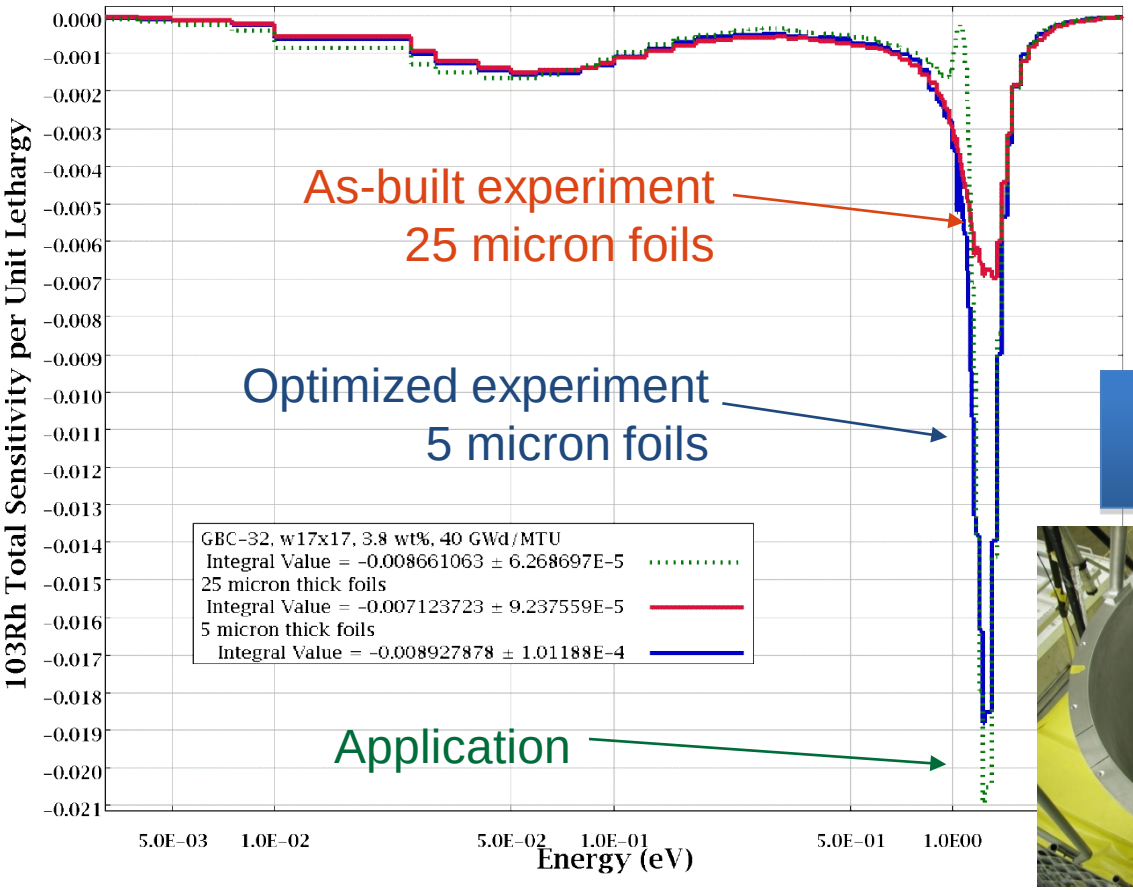
SCALE tools used to investigate technical basis for use of burnup credit in spent fuel pools and casks

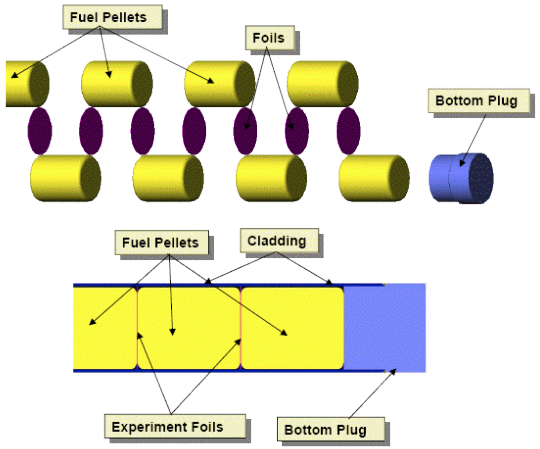


Reactivity of UNF as a function of time

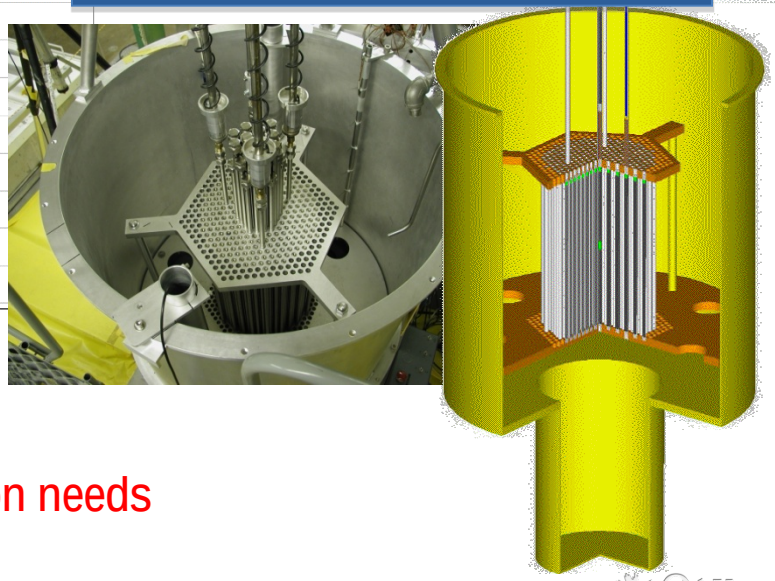


SCALE technology used to help design critical experiments in US and France





Rh-103 Critical Experiment Design for Burnup Credit



Sensitivity/uncertainty analysis used to obtain

- experiment designs optimized to meet application needs
- Improved estimates of subcritical margins

Leading measurements in France to support safety analysis validation

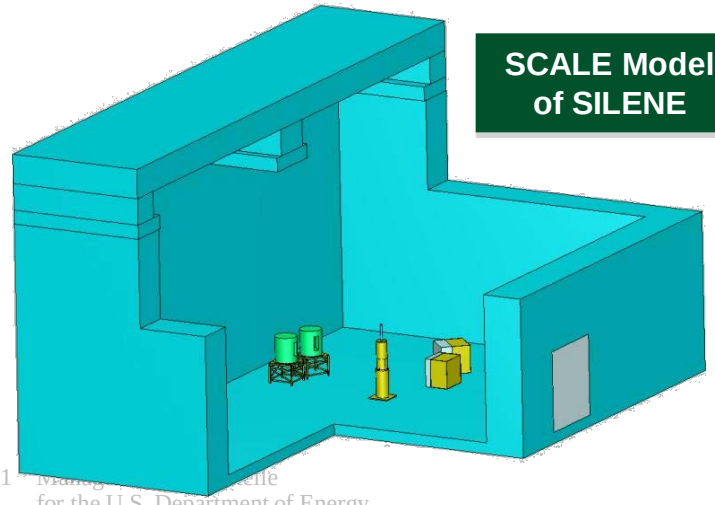
Supported by DOE Nuclear Criticality Safety Program

- OBJECTIVE: *Develop, evaluate and document measurement data for benchmarking Criticality Accident Alarm System (CAAS) analyses codes/data*
- Address needs for benchmark data for CAAS analyses
- ORNL leading multi-organizational effort to perform the measurements at CEA's Valduc Facility (Dijon, France)
- Measurements performed Oct. 11 – 22, 2010
- Measurements to be evaluated and included in ICSBEP Handbook

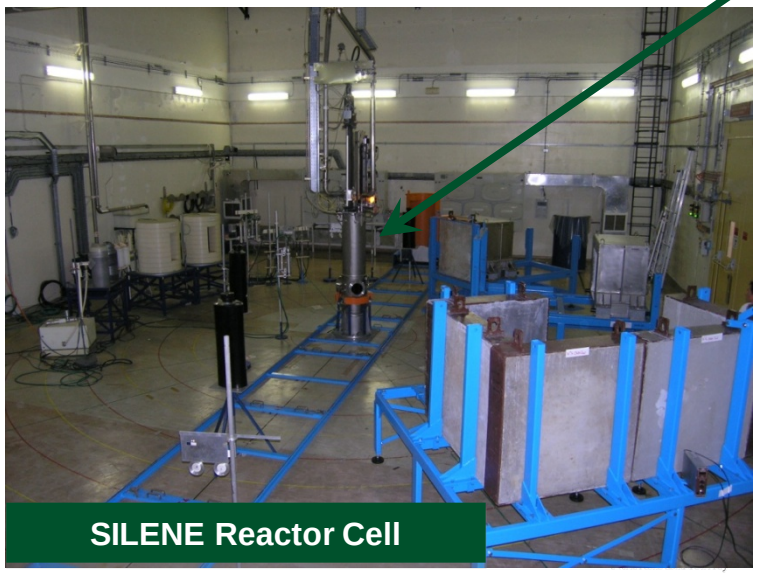
Team

ORNL (lead), CEA Valduc, CEA Saclay, LLNL, Y12, Babcock Int., LANL

SILENE Reactor



SCALE Model of SILENE



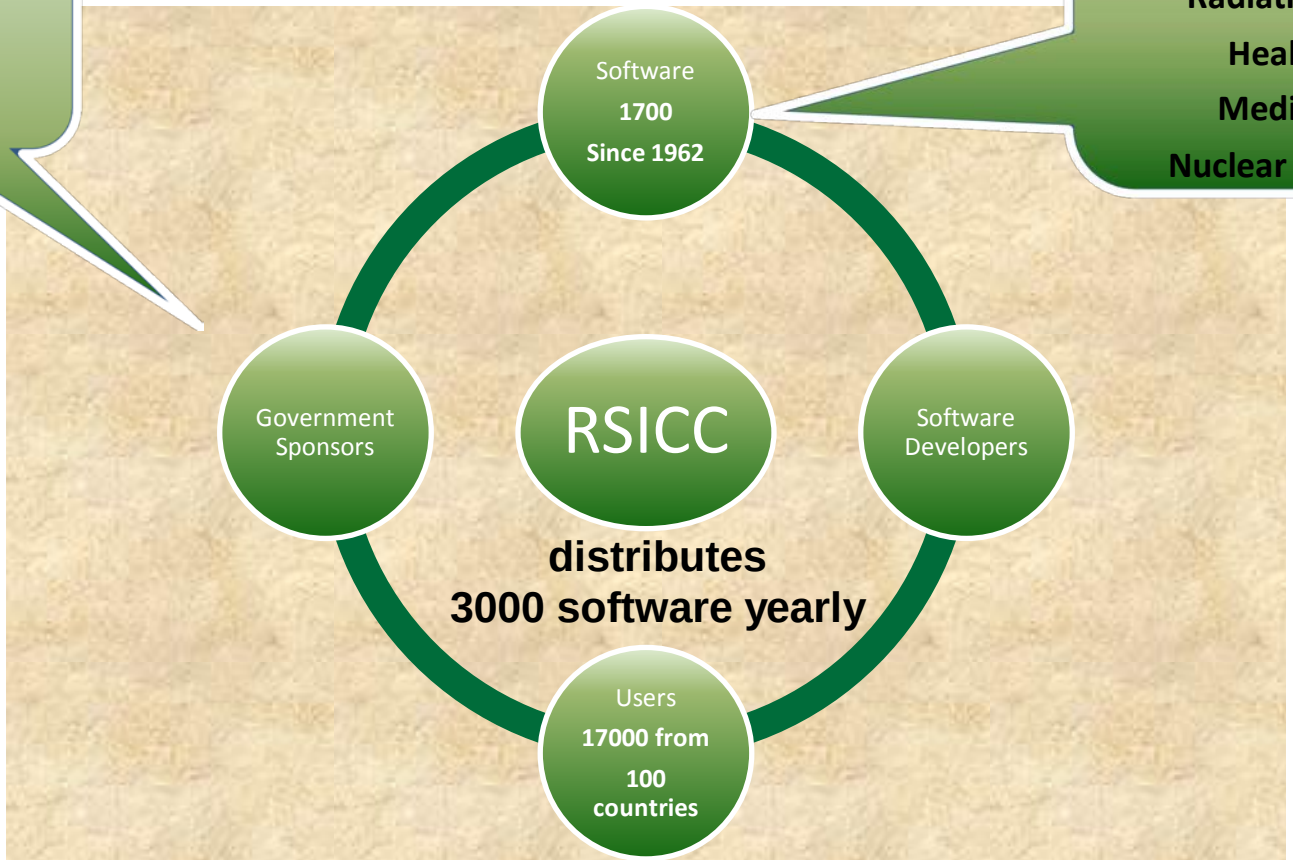
SILENE Reactor Cell

RNSD Reactor and Nuclear Systems Division

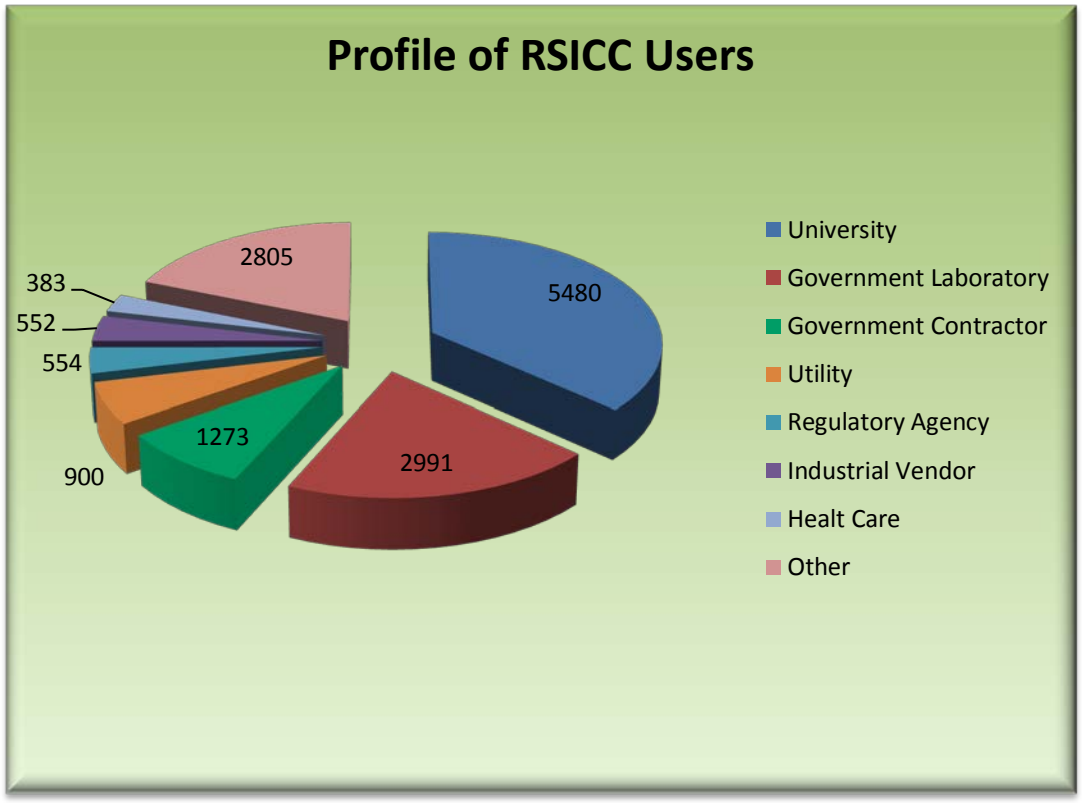
Who we are
The RSICC Environment

DOE
DHS
NRC

Criticality safety
Reactor physics
Radiation shielding
Radiation detection
Health physics
Medical Physics
Nuclear cross sections



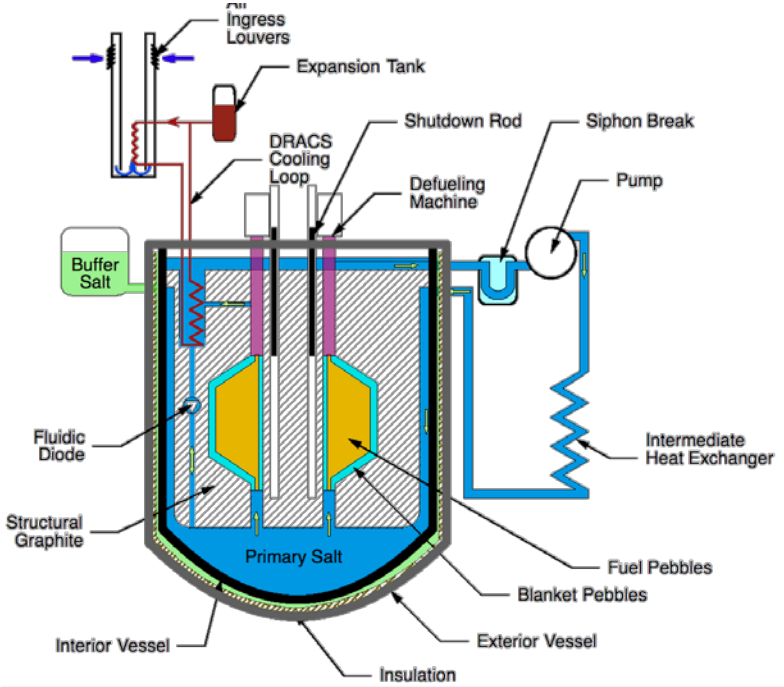
What we do
RSICC Profile of Users Fiscal Year 2011



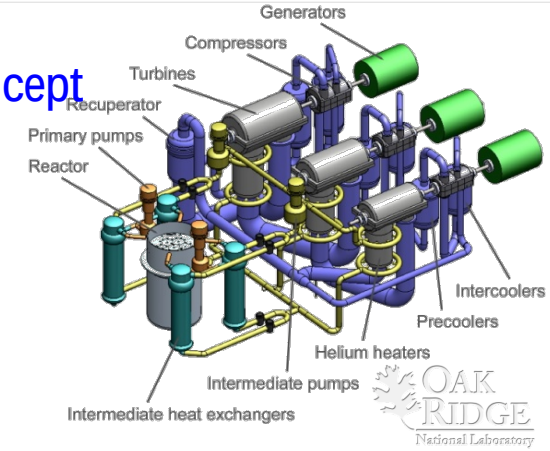
ORNL is leading development of an advanced reactor concept for DOE Office of Nuclear Energy

- **Fluoride salt-cooled high temperature reactors (FHRs) are emerging class of reactors**
  - **High-temperature heat for efficient energy production**
  - **Uses a single phase, low-pressure, liquid coolant for enhanced heat transfer and transport**
  - **Uses coated particle fuel design**
  - **Builds on ORNL molten-salt reactor experience**
- **Developing a liquid fluoride salt flow loop to test high temperature components and systems**
- **Completed report analyzing testing requirements for FHR components – prelude to test-scale reactor**
- **ORNL teaming with UC-Berkeley**
  - **Experimental facilities – low temps / salt simulants**
  - **Integration in nuclear engineering coursework**

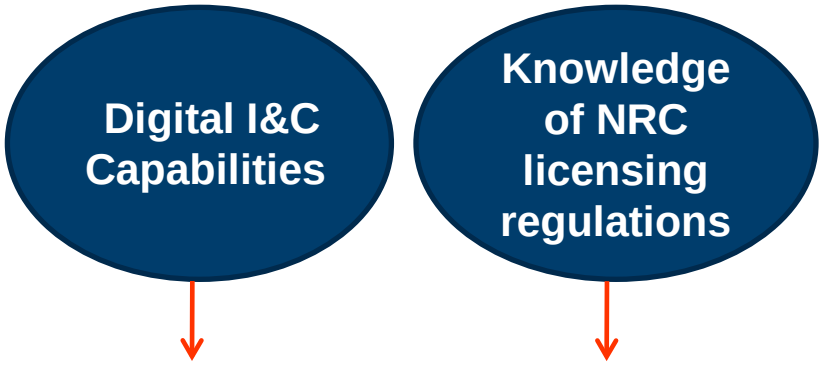
FHR Schematic



UC-B FHR Concept



Ongoing NRC support to develop framework for electronic tool for DI&C reviews – extend to all NRC regulations and guidance documents



Relevant ORNL Projects for NRC

- APWR DCD Chapter 7 Review (NRO)
- HFC Digital Platform Review (NRR)
- DIC Diversity Strategies (RES)
- Design Guidelines for FPGAs (RES)
- Design Practices for Highly Integrated Control Rooms (RES)
- Review Guidance for DIC systems for Research/Test Reactors (RES)
- Updating software related RG's (RES/NRR)

ORNL well positioned to support this new project

Background:

- **Familiarization of existing guidance challenge for new staff**
  - **Large number of NRC documents and industry standards**
  - **Regulatory Guides**
  - **Recent Interim Staff Guidance for digital systems**

Project Objective:

- **Develop framework that organizes licensing requirements and guidance for I&C systems**
  - **Inform and facilitate licensing reviews by new NRC staff**
  - **Framework is basis for NRC developing electronic system to guide reviewers**
- **ORNL staff to engage NRR and NRO staff for input**
- **NRC info systems staff to be involved from start**

This project represents a test case for addressing "patchwork regulations issue cited in NRC Fukushima report"

Staff supported NRC in developing new risk-informed approach for licensing Small Modular Reactors

- Approved unanimously by NRC Commissioners
- Represents a significant change for NRC in licensing future reactors
- Provides a framework for a graded approach to review systems, structures, and components (SSCs)
  - Safety-related
  - Nonsafety-related
- RNSD contribution
  - Led intra-DOE lab team in evaluating the two leading iPWR SMR designs to categorize SSCs
  - Successfully applied new approach for selected SSCs

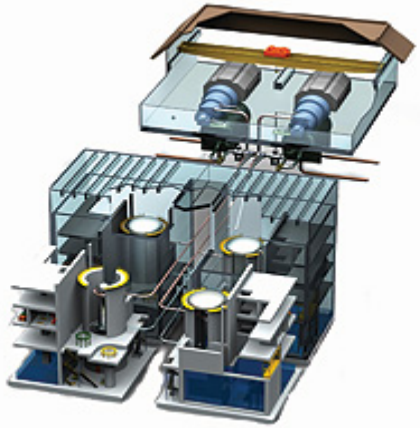
May 11, 2011

MEMORANDUM TO: R. W. Borchardt
Executive Director for Operations

FROM: Annette L. Vietti-Cook, Secretary /RA/

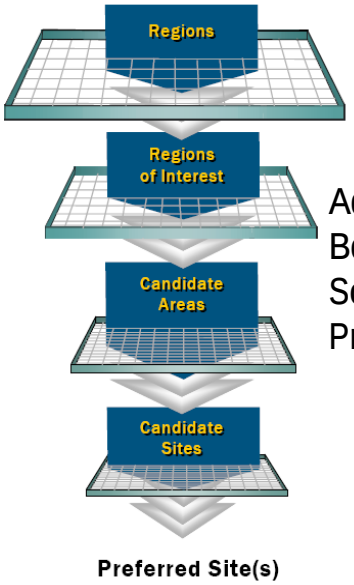
SUBJECT: STAFF REQUIREMENTS – SECY-11-0024 – USE OF RISK INSIGHTS TO ENHANCE THE SAFETY FOCUS OF SMALL MODULAR REACTOR REVIEWS

The Commission has approved the staff's use of the risk-informed and integrated review framework for staff pre-application and application review activities pertaining to integral pressurized-water (iPWR) design applications; and the consolidation of staff activities currently underway regarding a risk-informed regulatory structure into the staff's plan discussed in SECY-11-0024 for the longer term development of a recommendation related to a new risk-informed regulatory structure.



B&W m-Power 125 MWe iPWR design

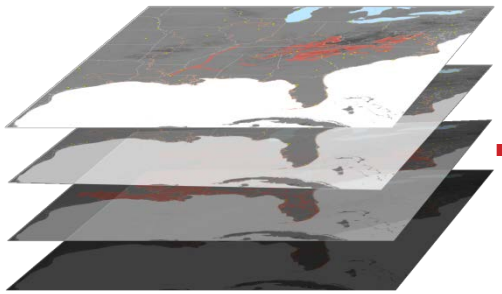
ORNL is examining siting options for new nuclear plants using GIS data as screening criteria



Adapted/Extended Bechtel -EPRI Screening Processes

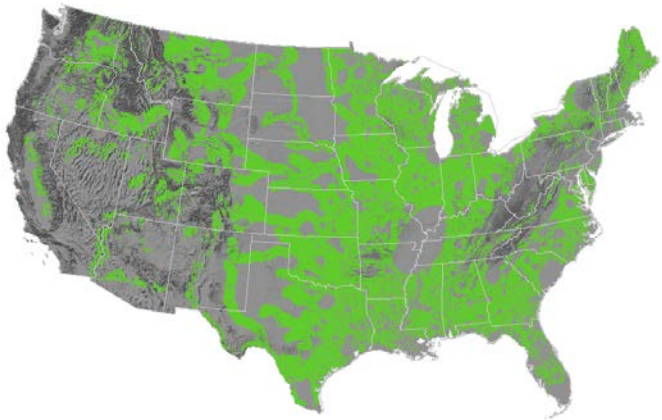
Environmental Design Data (Plant Parameter Envelope – PPE) – Used for NRC Approved Early Site Permits

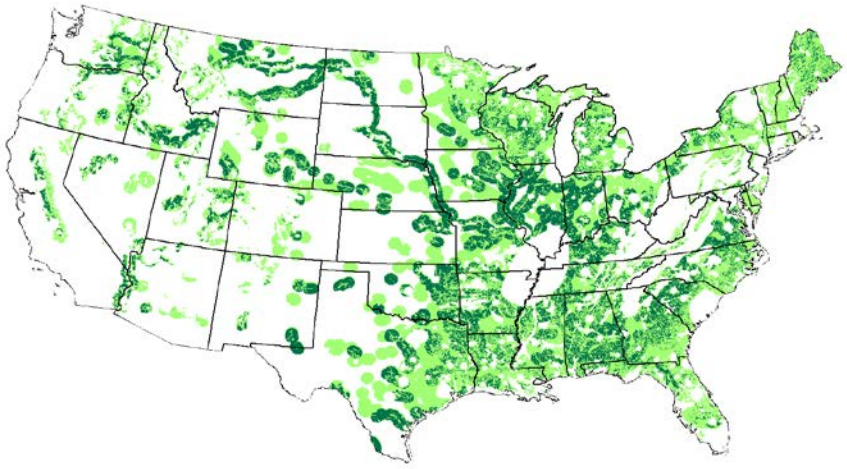
+



Sum of GIS Exclusion Layers

Candidate Site Areas for Small-Medium Size Reactors

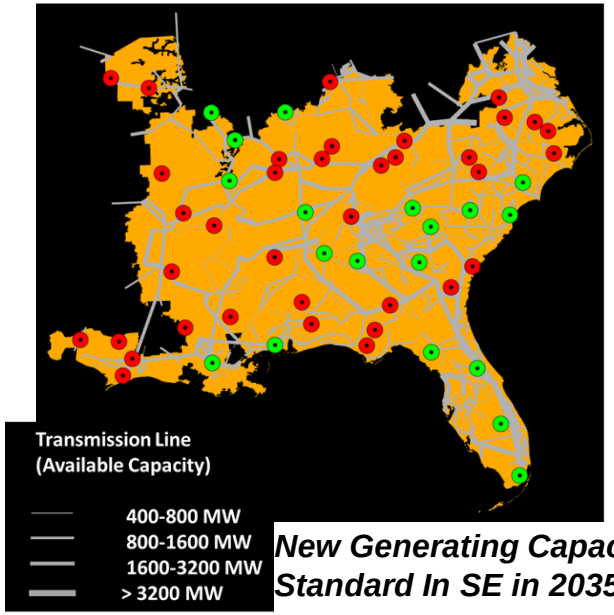




- Completed proof-of-principle approach analyzing siting of new nuclear power plants
- Initiated new project (EPRI) to look at optimizing siting of nuclear, renewables, clean coal and incorporation of electrical grid
- Supporting DOE-NE to identify candidate areas for SMRs for early site permit applications

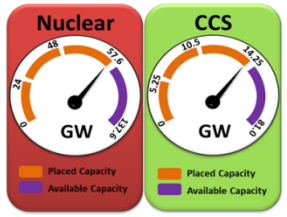
ORNL developing interactive decision support tool for energy policy planning

- **Integrate requisite models, data, and visualization resources into one tool**
- **Assist energy policy makers in seeing potential impacts of legislative actions**
- **Optimize deployment of new electrical generation capacity based upon demand and areas of country more suitable for clean coal, solar, geothermal, nuclear, etc.**
- **Evaluate options for**
  - **Clean energy standard**
  - **Carbon Tax**
  - **Economic factors**
- **Based on GIS approach for relating energy needs w/energy resources**



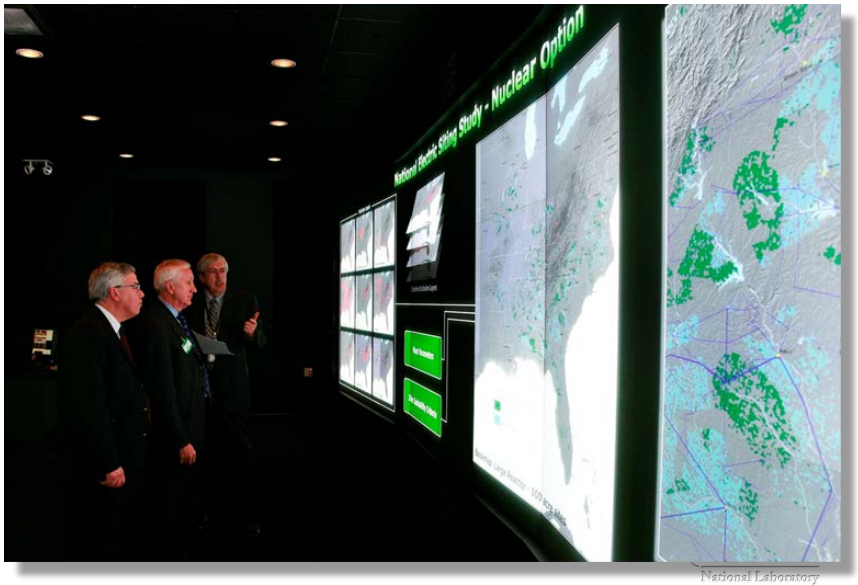
Southeast Region Achieves 81% Clean Energy Mix

SOUTHEAST REGION	Nuclear	Clean Coal	Concentrated Solar
Capacity (GWe) to Meet Presidential 80% Clean Energy Goal	57	14	0



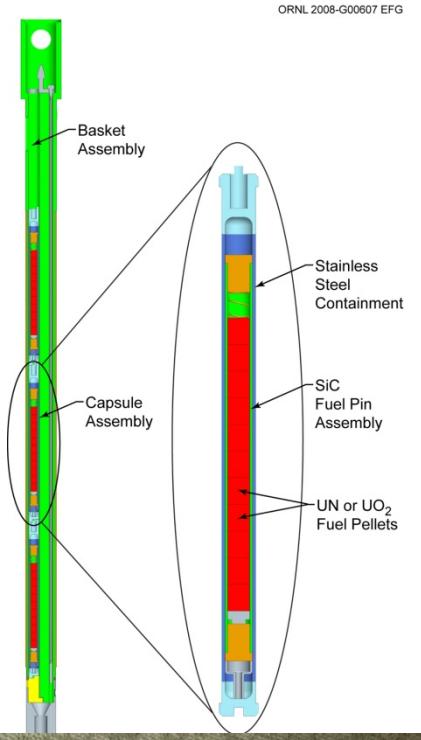
New Generating Capacity to Meet Clean Energy Standard In SE in 2035 using nuclear & clean coal

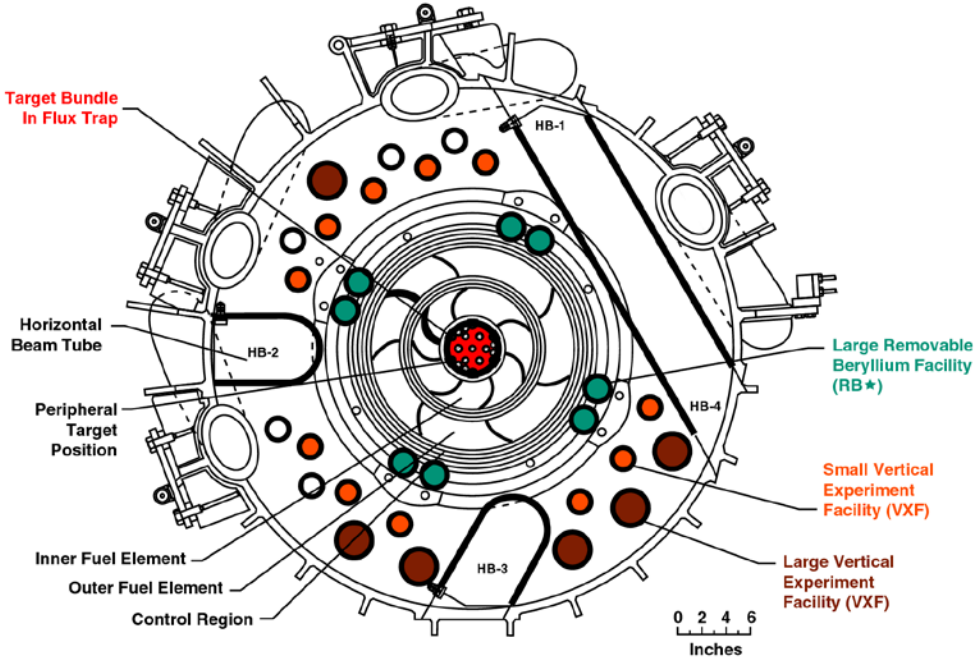
Results for siting large and small reactors in ORNL's Visualization Facility, EVEREST

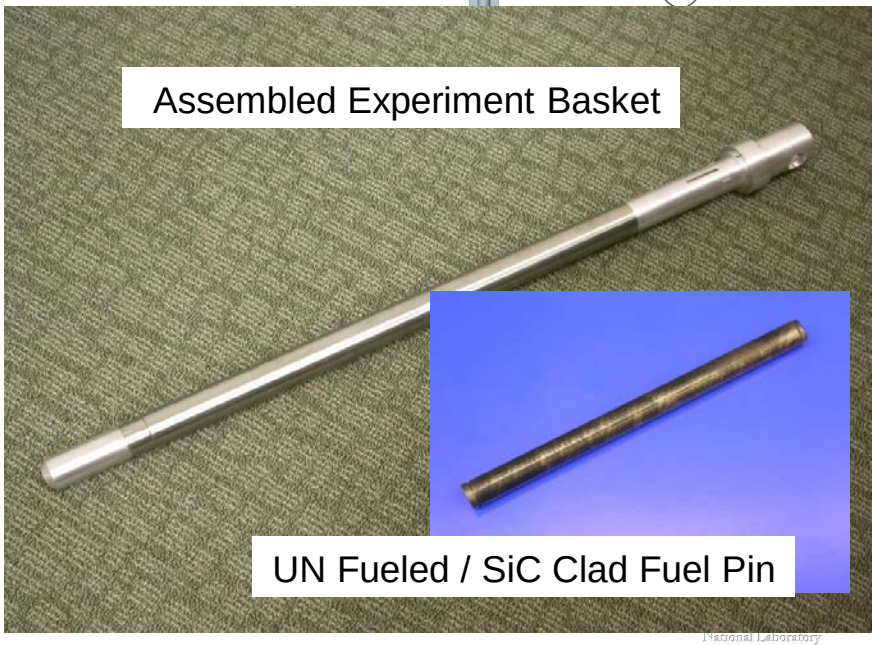


ORNL fuel irradiation capabilities supporting advanced fuel and clad design

- Facilities allow testing of advanced reactor fuels and clad at prototypic reactor conditions and fuel/cladding dimensions
- Initial tests with UO_2 and UN fuel inside an SiC clad
- Fuel power density is held relatively constant throughout the experiment by matching fuel and neutron shield burnout
- Multiple fuel types can be tested concurrently; fuel pins can be removed & replaced



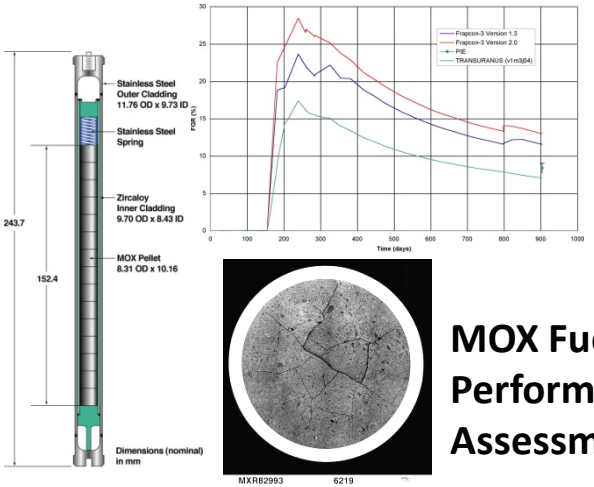




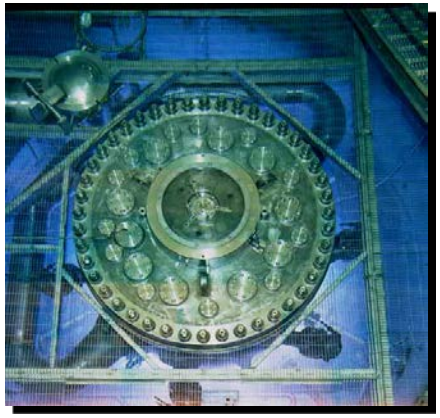
Design of irradiation experiments requires coupling of wide variety of staff expertise

Fuel/Clad Irradiations For US Commercial Vendor

DOE and Japanese Fusion Energy Programs



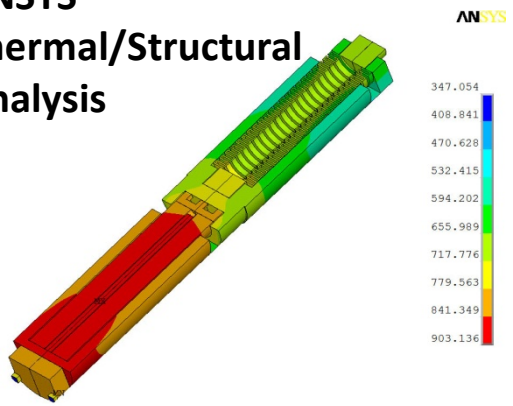
MOX Fuel Performance Assessment



Close integration with HFIR staff and operations

Fuel and Materials Experiment Design, Assembly And Irradiation

ANSYS Thermal/Structural Analysis



RNSD
Reactor and Nuclear Systems Division

OAK RIDGE National Laboratory

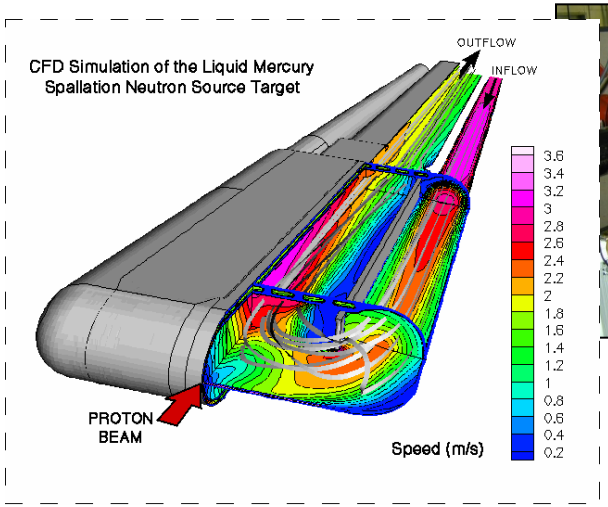
Benchmark experiments performed to:

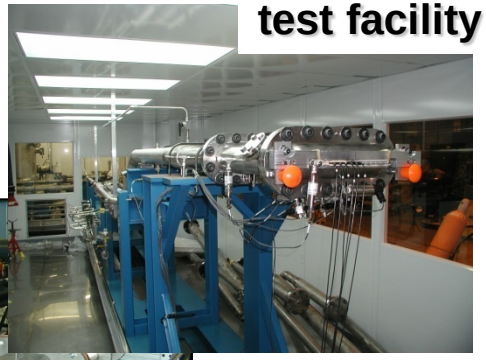
- Characterize thermal and fluid behavior
- Develop correlations and validate codes

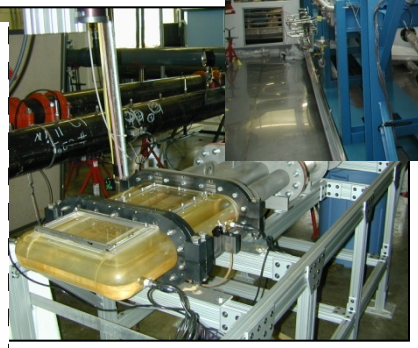
Full scale Hg target test facility

SNS Mercury and Water loops

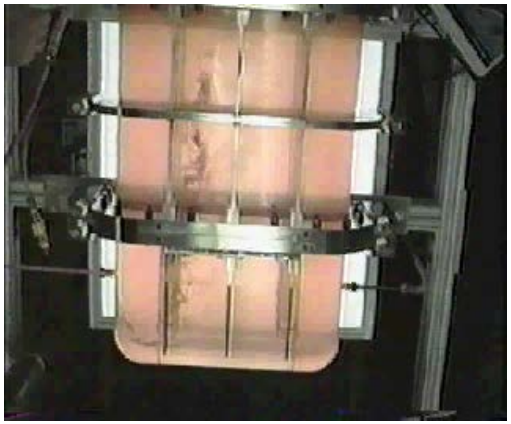
Hg heat transfer loop



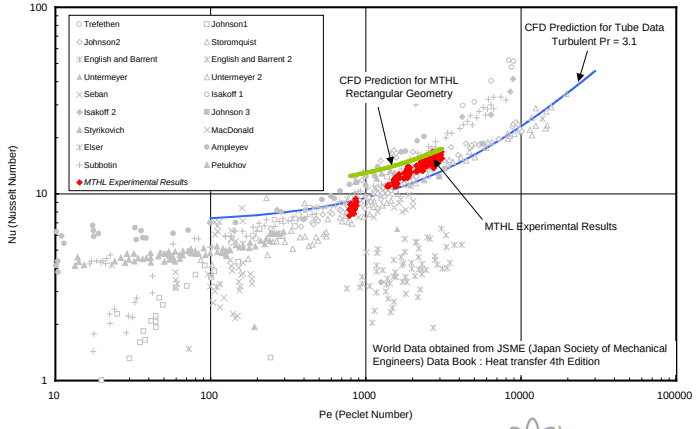




Target flow simulated using water



Mercury Heat Transfer



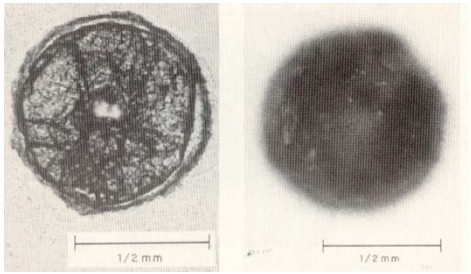
CFD Predicted and Experimental Streamlines

RNSD

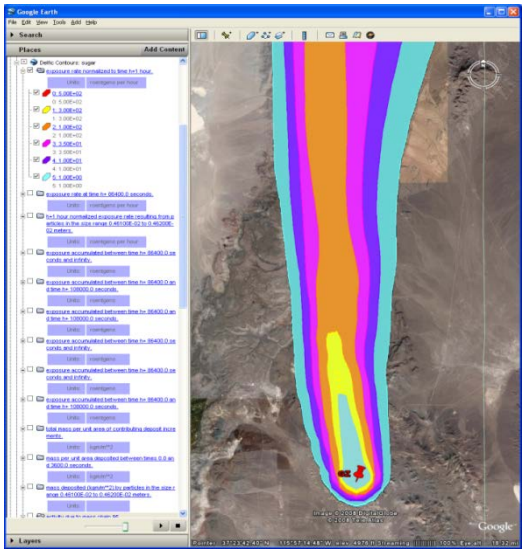
OAK RIDGE National Laboratory

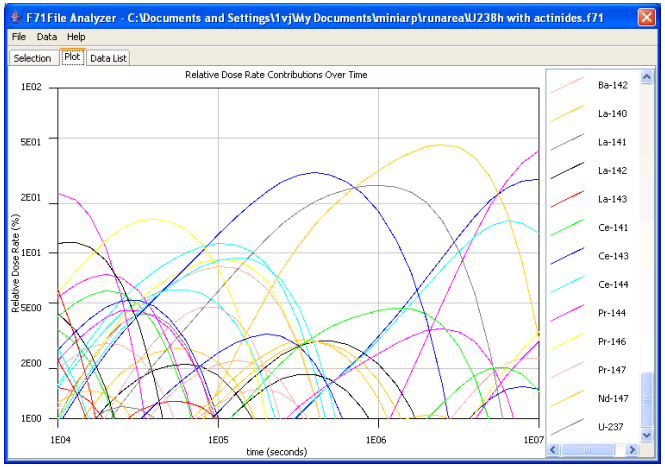
ORNL's Fallout Research Program

- Supports: DOE, DOD, DHS, FBI & EPA
  - forensics, emergency response & defense needs
- Physical, chemical, & radiological properties of fallout
  - Nevada Test Site, urban, and water surface bursts
- New software interfaces for 2 existing codes:
  - Defense Land Fallout Interpretive Code (DELFIC)
  - Oak Ridge Isotope Generation (ORIGEN) code

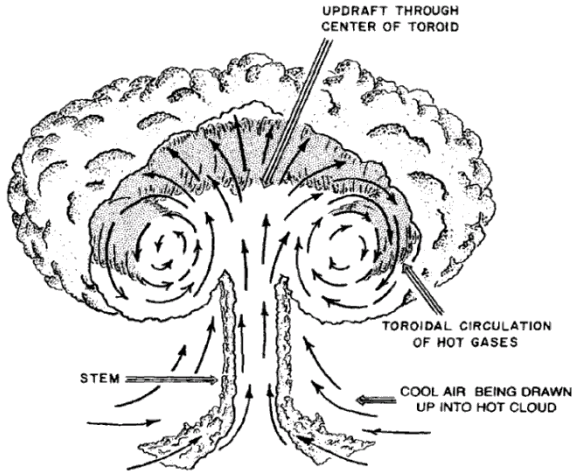


Activity distribution within/on fallout particles due to radiochemical fractionation.





ORIGEN tracks all the nuclides all the time and provides source term spectra.



Source terms from different burst environments.

DELFIC interface tracks dose rates, integrated dose, times of arrival, particle sizes, and activity concentrations.

QUESTIONS?