Neutron Activation Data for Neutron Interrogation Applications

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Neutron Interrogation

- Various technologies have been proposed for neutron interrogation of packages, luggage, or containers with the intent of locating concealed contraband items such as conventional explosives, drugs, or restricted special nuclear materials.
- These schemes generally involve using intense sources of neutrons with energies in the range thermal – 14 MeV, so the possibility that unacceptable levels of unintended residual radioactivity might be generated in interrogated objects must be explored.

The Issues

- Identification of problem areas (if any) can be made only via detailed Monte Carlo simulations of the irradiation apparatus and interrogated target objects, coupled with the consideration of half lives, decay radiations, and biological impact
- Such analyses will require accurate and comprehensive knowledge of neutron cross sections as well as radioactive decay properties

Scope

- The present investigation (in progress) focuses on surveying the status of neutron cross section data for potentially important reactions involved in neutron interrogation
- In most cases, radioactive decay data are likely to be adequate for this application
- Simulation studies to determine exposure doses for various interrogation scenarios are topics for separate investigations and these are not considered here

Materials and Reactions

- The list of elements being considered in this study has been developed from several sources, the most extensive one being that included in a 2002 report to the National Council on Radiation Protection and Measurements (NCRP)
- This list of elements includes: H, Li, B, C, N, O, F, Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Br, Rb, Zr, Nb, Mo, Ag, Sn, Sb, Lu, Ta, W, Ir, Pt, Au, Hg, Pb, and Bi
- The reactions considered are: (n,γ), (n,inel), (n,p), (n,d), (n,t), (n,^{3}He), (n,α), (n,2n), (n,np), (n,nd), (n,nt), (n,n^{3}He), and (n,nα)

A "Short" List

- Consideration of the elements and reactions listed on the previous slide, along with energetic and decay properties, resulted in a list of nearly 2000 possible neutron activation reactions
- A "short" list of approximately 100 reactions has also been prepared by considering only C, N, O, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Fe, Co, Ni, Cu, Ag, Sn, Pt, and Au, half lives from 1 m – 10 y, isotopic abundances > 5%, gamma emitters, threshold energies < 10 MeV, and no tritium or ^{3}He emitting reactions … the choices are based on identifying those processes that are perceived to likely be the most hazardous to the public in realistic interrogation scenarios

Sources of Information

- The information for this survey is retrieved from databases found at the NNDC and IAEA Nuclear Data Section
- Information on radioactive decay properties is obtained from the NNDC based on the ENSDF library (included for completeness only)
- CINDA provides an index to all compiled references dealing with these reactions
- Experimental data are retrieved from the EXFOR system for plotting
- Evaluated data are obtained from the ENDF, JENDL, JEF, CENDL, and BROND GP libraries as well as from the fusion library FENDL

Status for Some Important Reactions

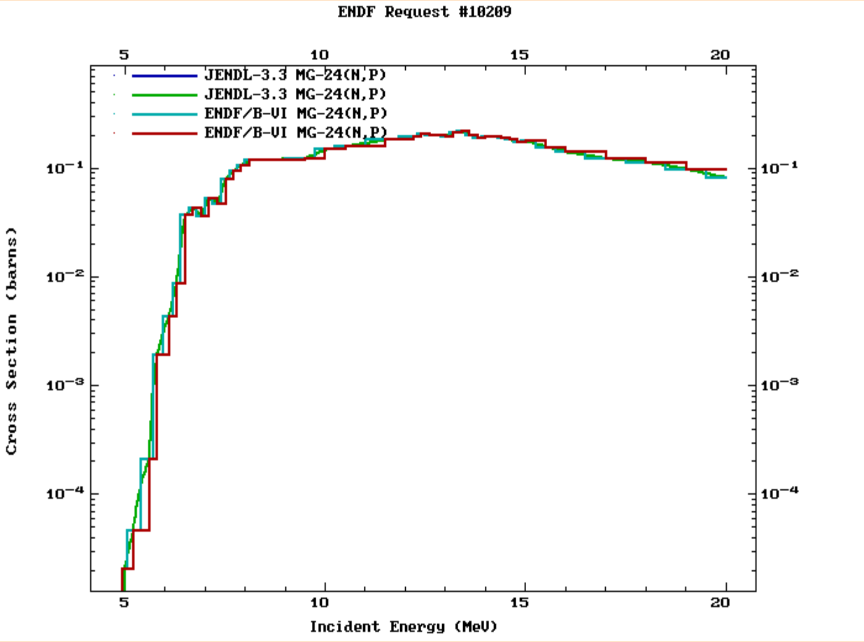
Isotope	Reaction	Product	Et (MeV)	T1/2	Decay	γ-ray's (MeV)	CINDA	EXFOR	E	Je	Jf	C	B	F	Status
Mg-24	(n,p)	Na-24	4.933	14.9512 h	β-	1.37, 2.75	286	66							
Al-27	(n,a)	Na-24	3.250	14.9512 h	β-	1.37, 2.75	595	123							
K-41	(n,g)	K-42	0.000	12.360 h	β-	1.52	94	22							
Ti-46	(n,p)	Sc-46	1.619	83.79 d	β-	0.14	340	73							
Ti-47	(n,p)	Sc-47	0.000	3.3492 d	β-	0.16	288	59							
Ti-48	(n,p)	Sc-48	3.279	43.67 h	β-	1.31, 0.98, …	342	74							
Fe-54	(n,p)	Mn-54	0.000	312.11 d	ε, β-	0.83	440	83							
Fe-56	(n,p)	Mn-56	2.966	2.5789 h	β-	0.85, 1.81, …	578	116							
Co-59	(n,g)	Co-60	0.000	1925.1 d	β-	1.33, 1.17	406*	53*							
	(n,a)	Mn-56	0.000	2.5789 h	β-	0.85, 1.81, …	314	66							
	(n,p)	Fe-59	0.796	44.472 d	β-	1.10, 1.29	246	47							
Ni-58	(n,p)	Co-58	0.000	70.86 d	ε	0.81, 0.51	658*	168*							
Cu-63	(n,g)	Cu-64	0.000	12.700 h	ε, β-	0.51	262	32							
	(n,a)	Co-60	0.000	1925.1 d	β-	1.33, 1.17	240*	46*							
Ag-109	(n,g)	Ag-110m	0.000	249.76 d	β-, IT	0.66, 0.88, …	283*	45*							

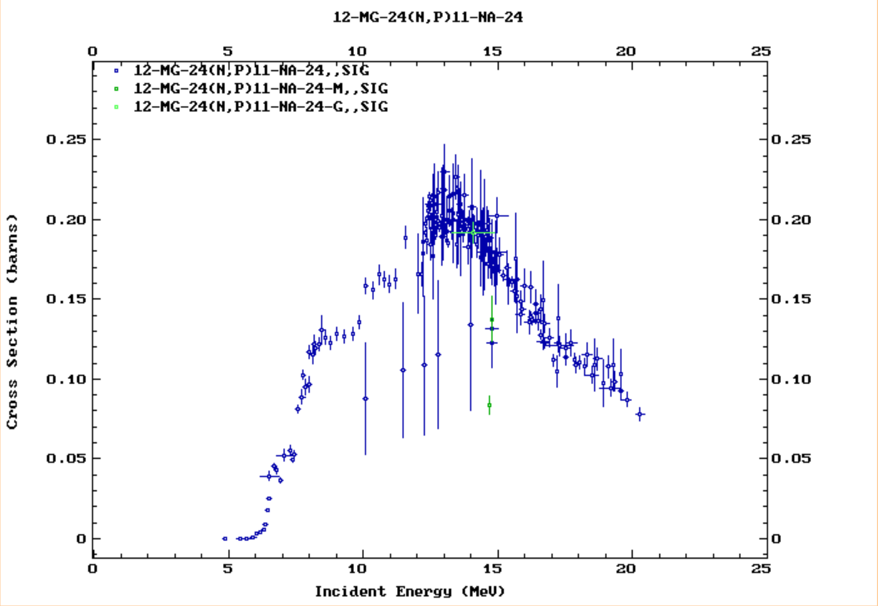
- Status of cross section data for reactions flagged in 2002 NCRP report as being important for interrogation is generally good (green = adequate; yellow = marginal)

Slide Show

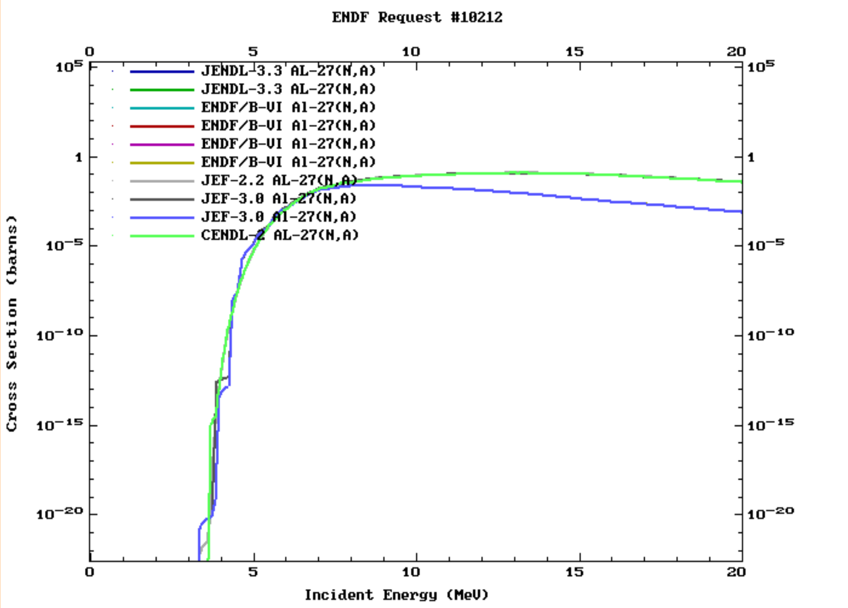
- The following slides provide a flavor of the status of cross section data for some of the reactions listed in the previous table
- The slides show experimental data from EXFOR and evaluated data from the GP files (or FENDL)
- These represent the “cream of the crop” … in many other cases of potential interest for interrogation the status is far worse

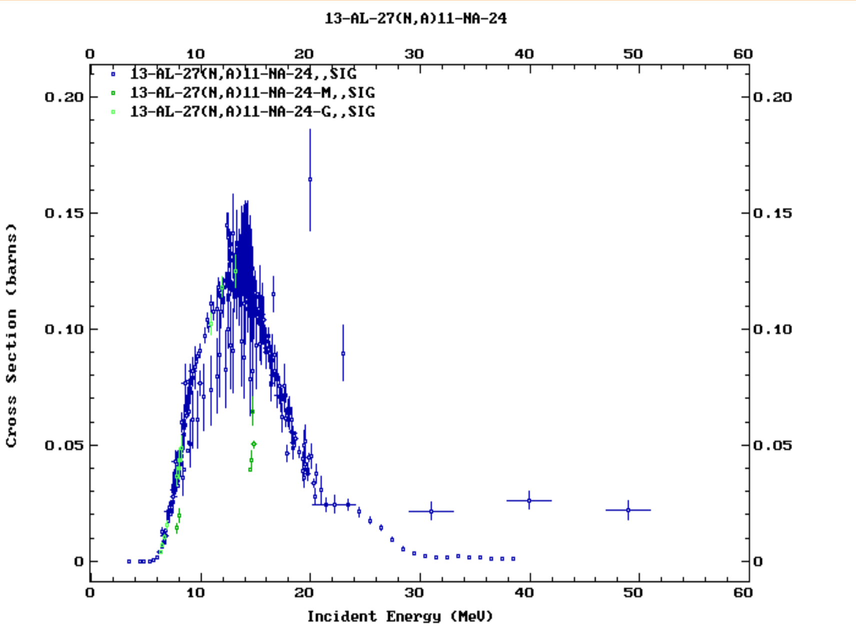
$^{24}Mg(n,p)$ Reaction



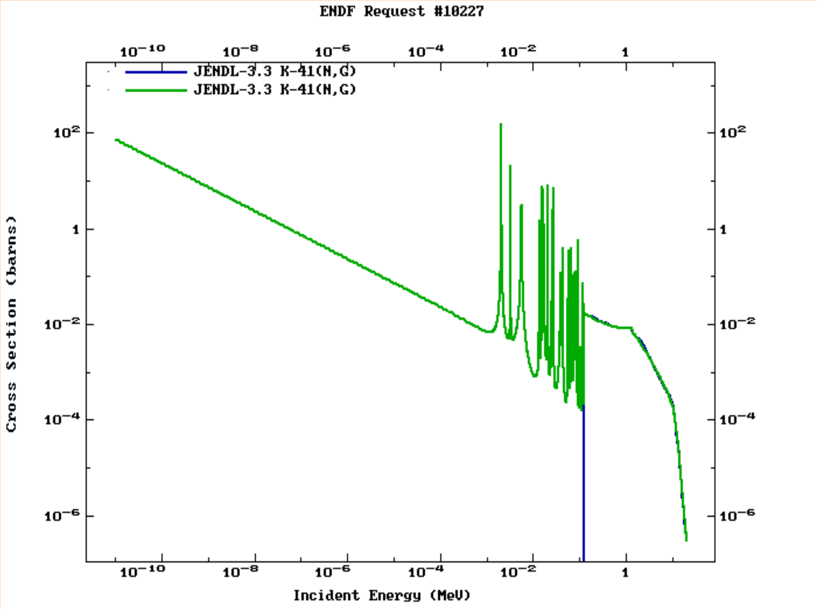


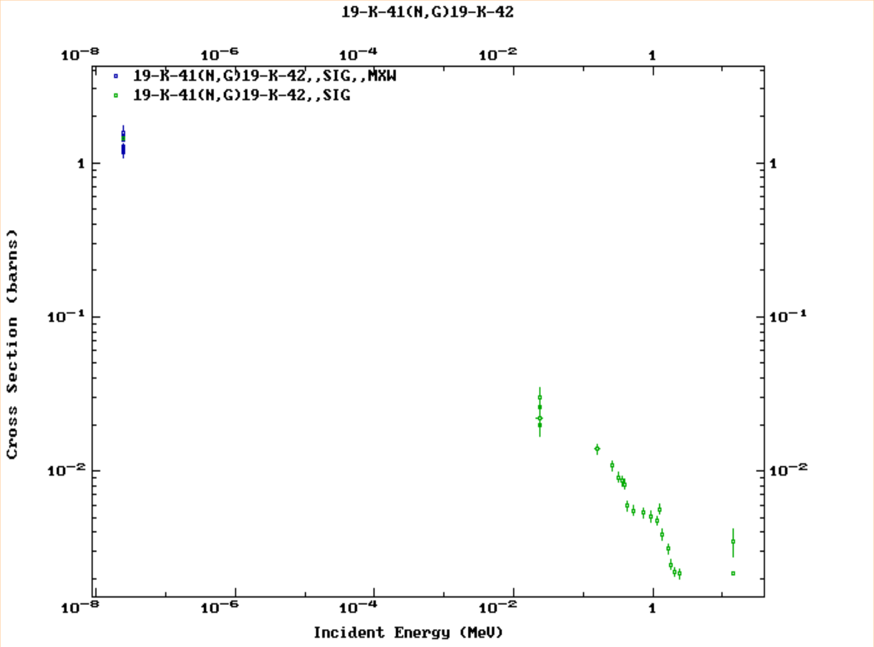
$^{27}Al(n,\alpha)$ Reaction



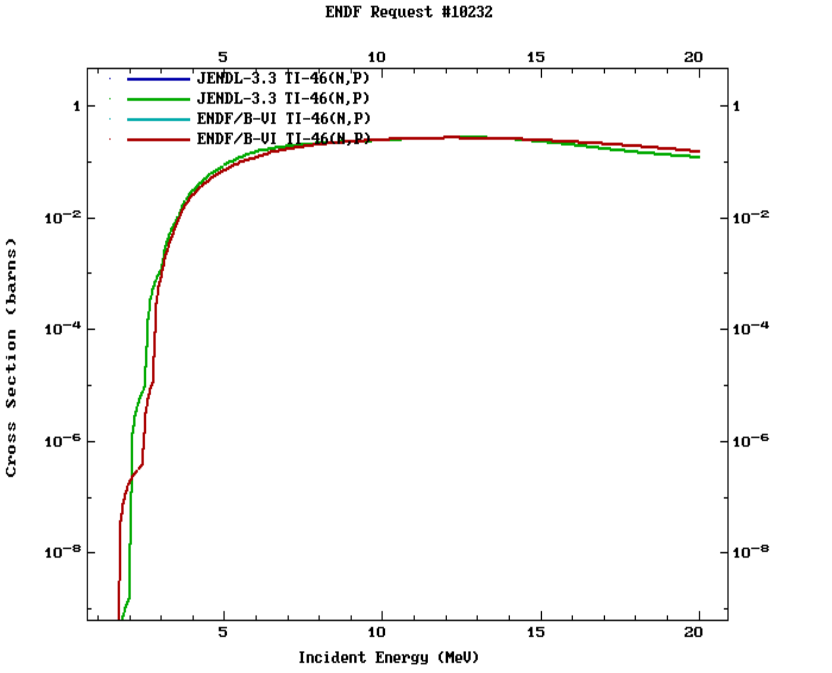


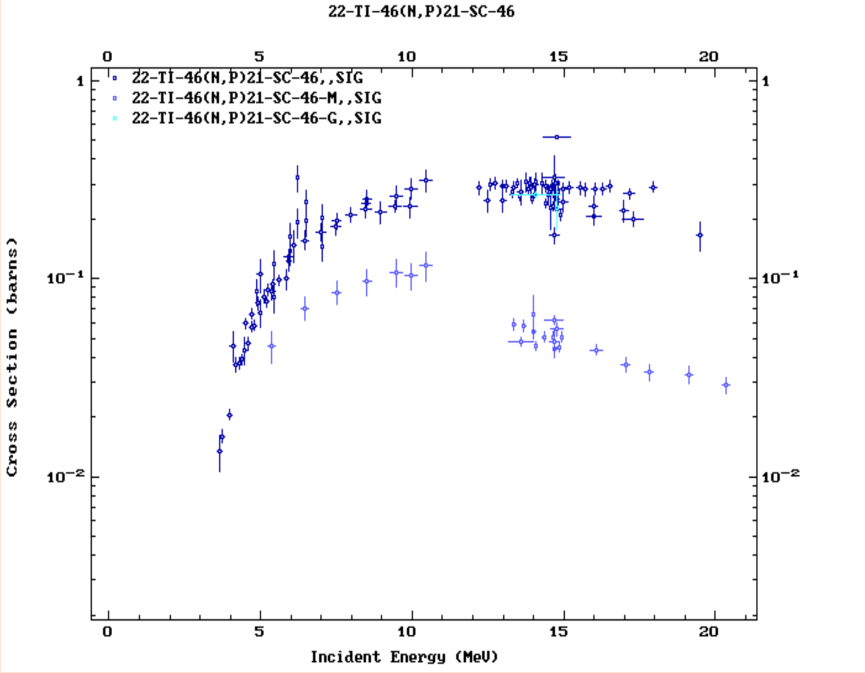
$^{41}K(n,\gamma)$ Reaction



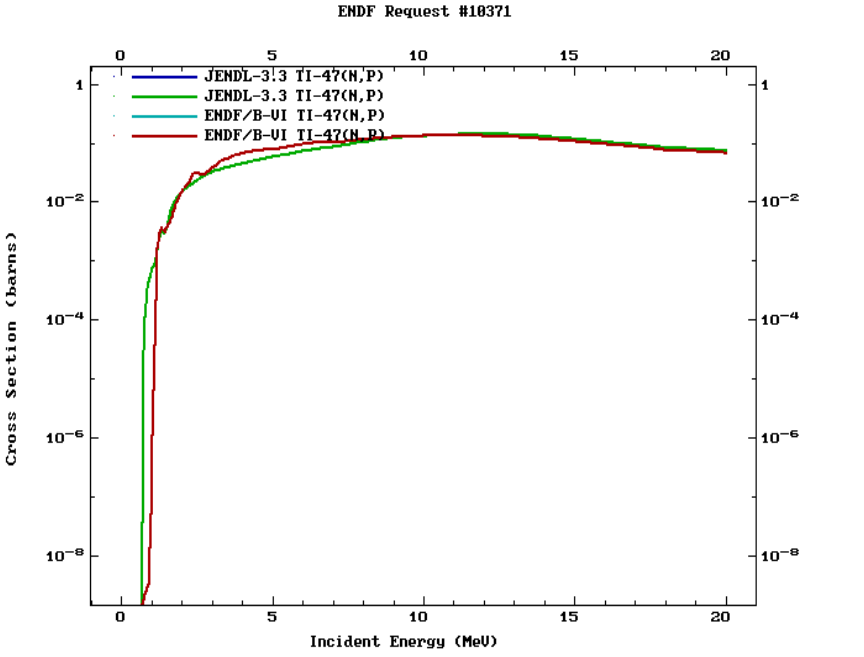


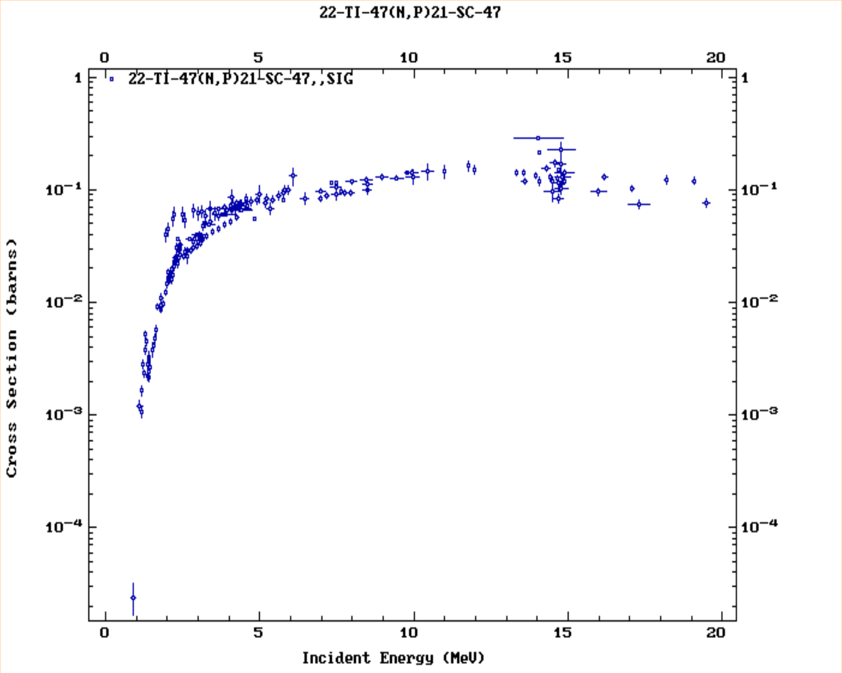
^{46}Ti(n,p) Reaction



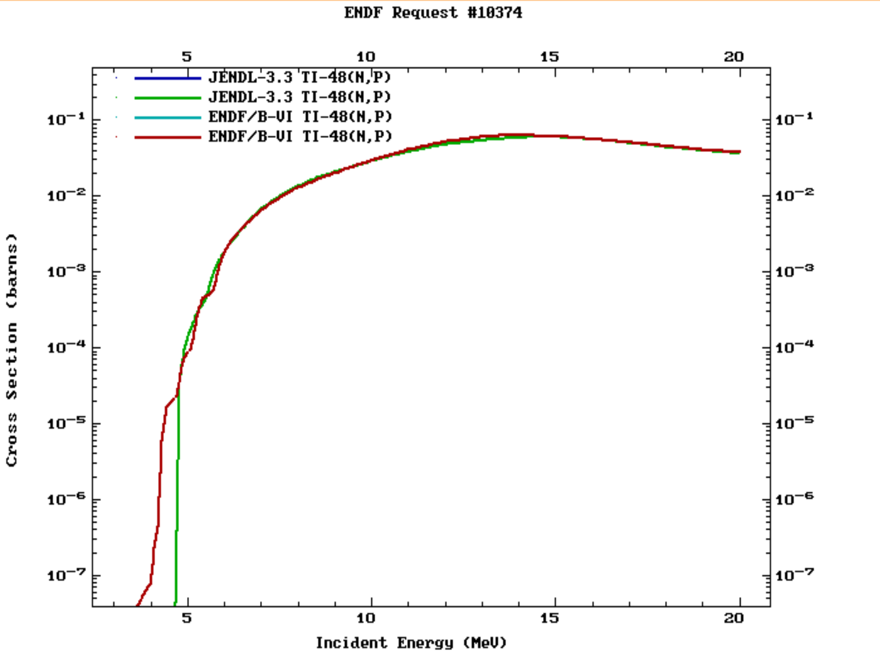


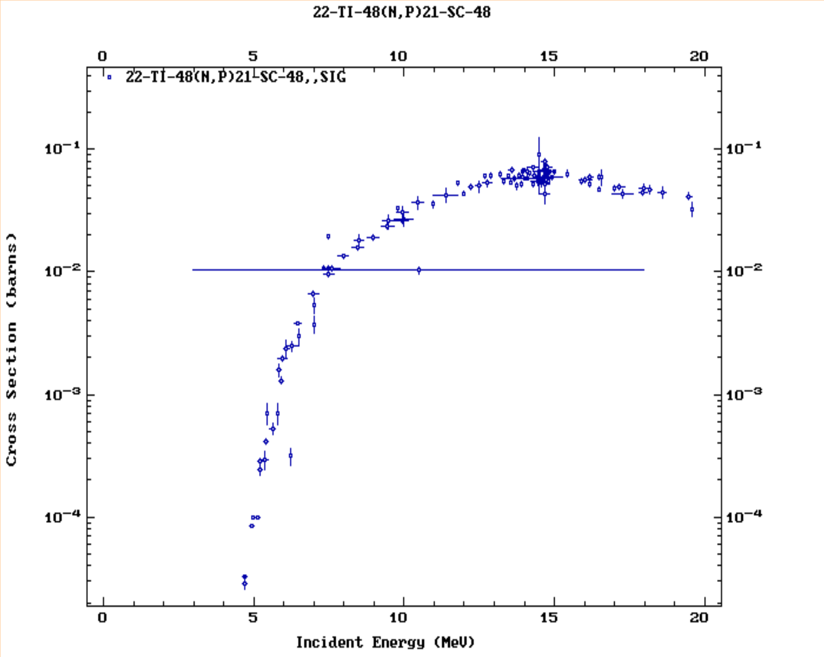
^{47}Ti(n,p) Reaction



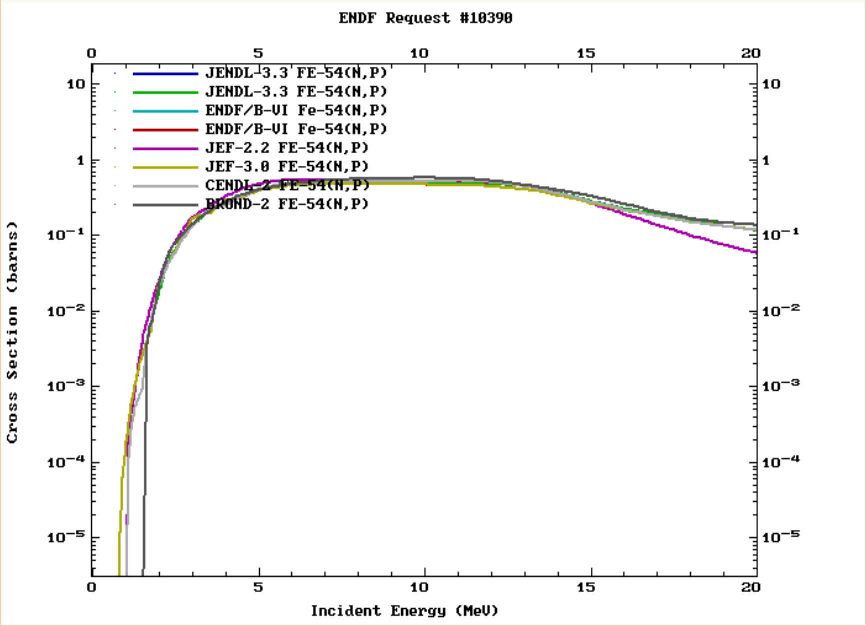


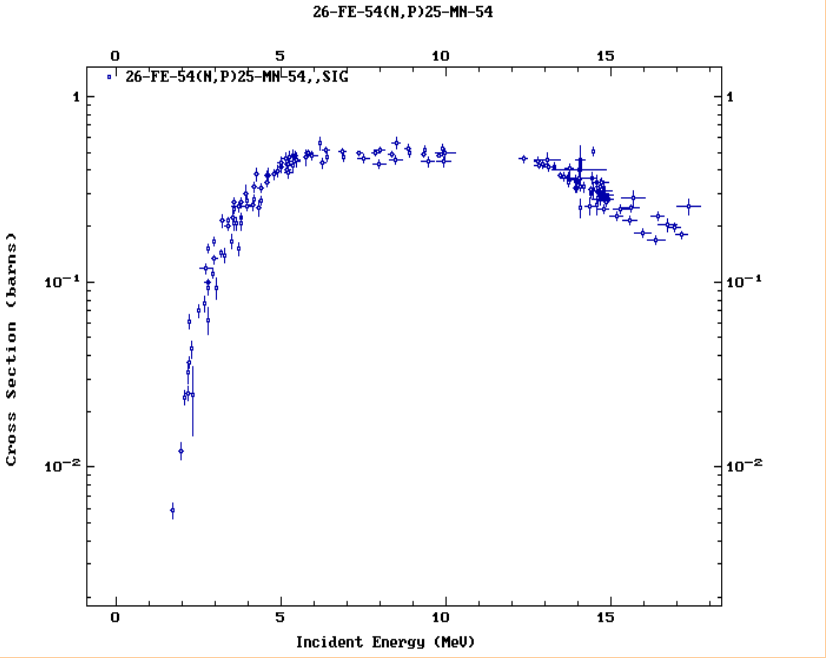
$^{48}Ti(n,p)$ Reaction



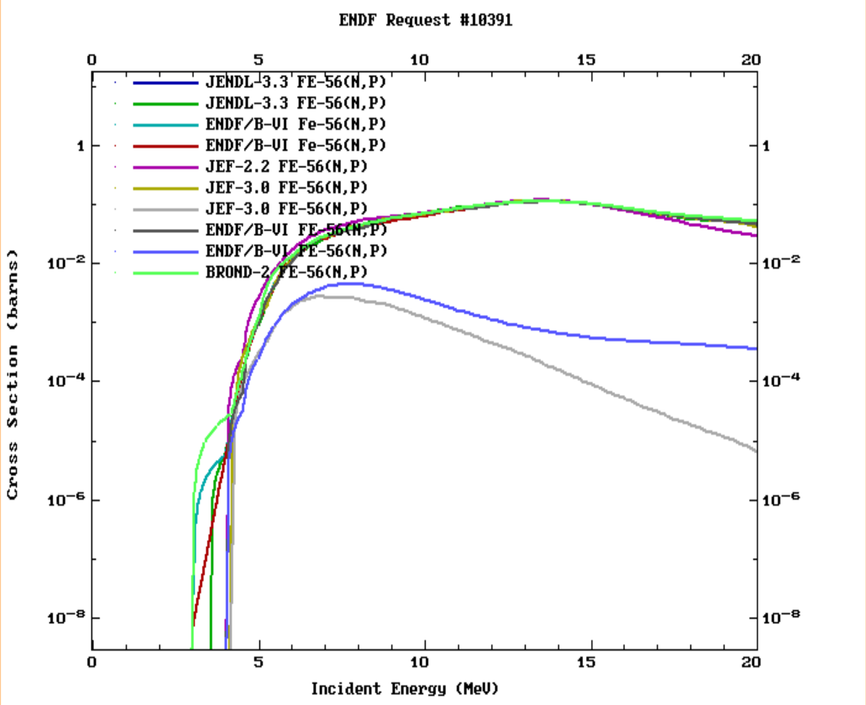


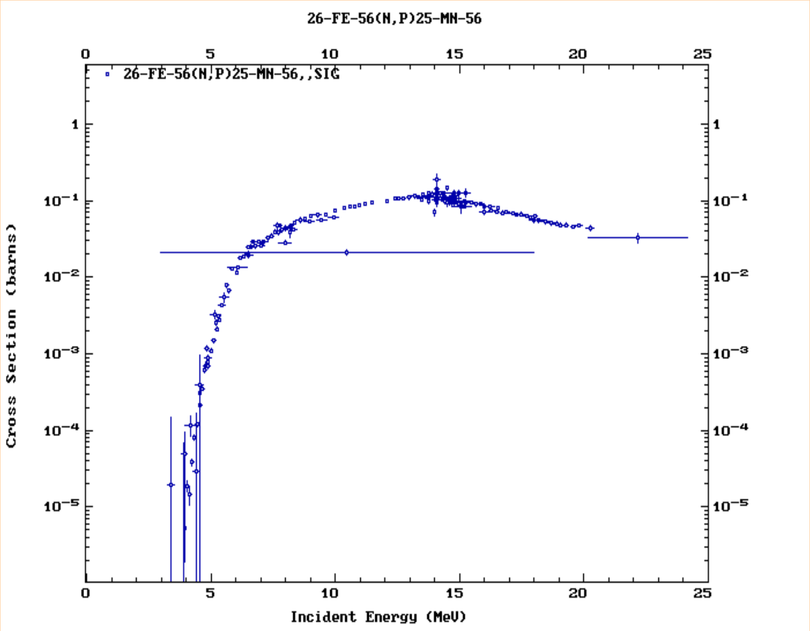
$^{54}Fe(n,p)$ Reaction



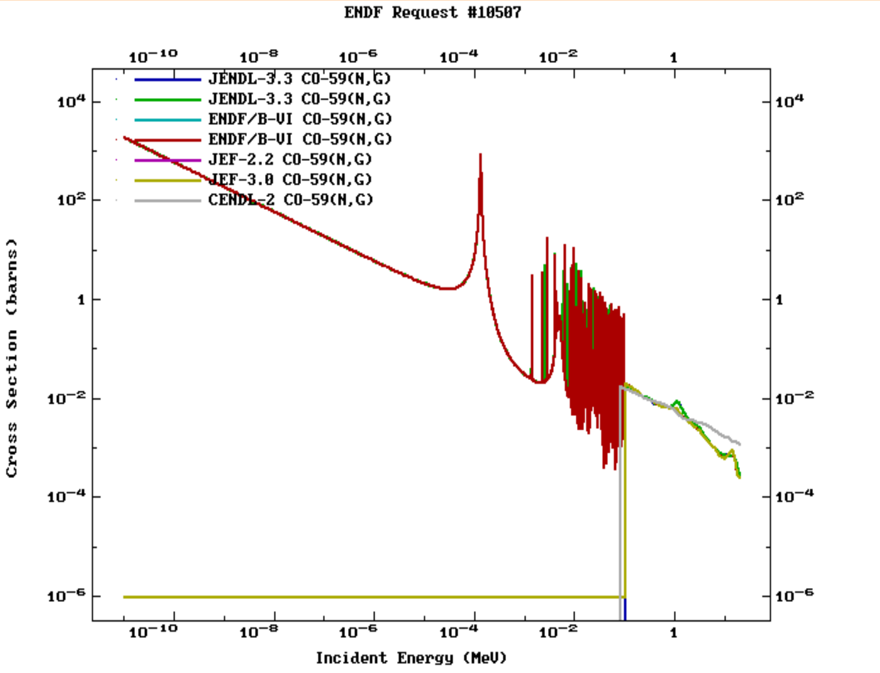


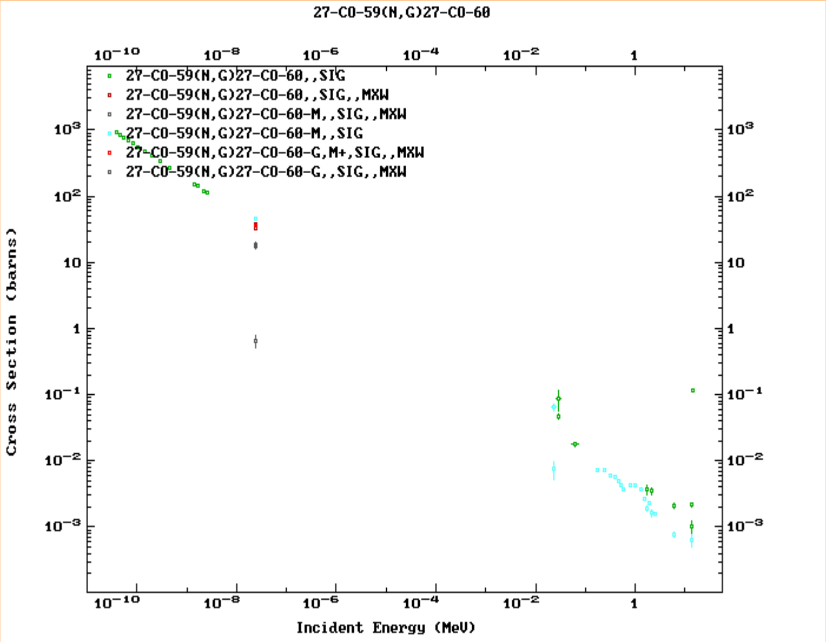
$^{56}Fe(n,p)$ Reaction



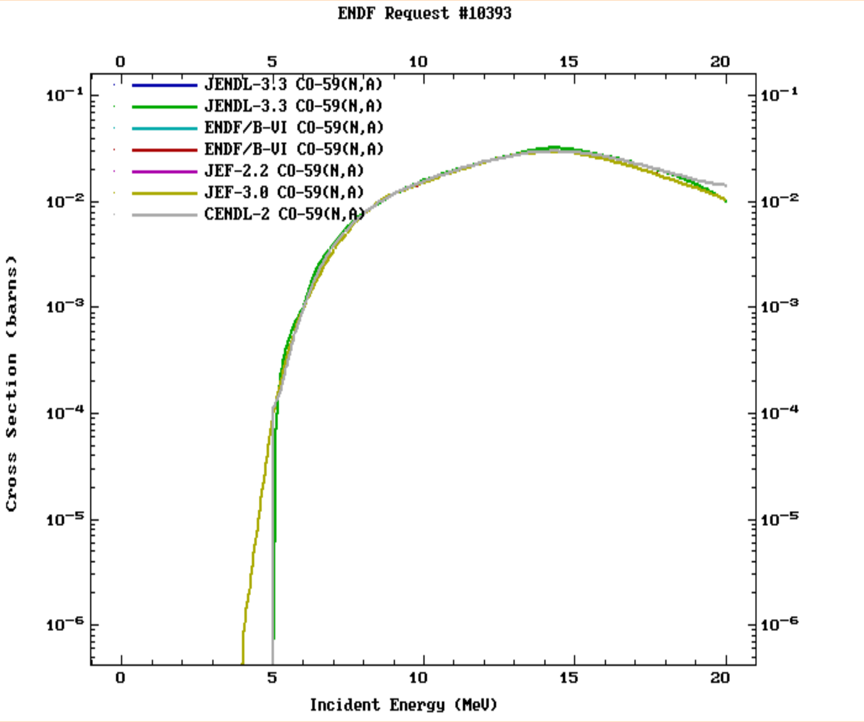


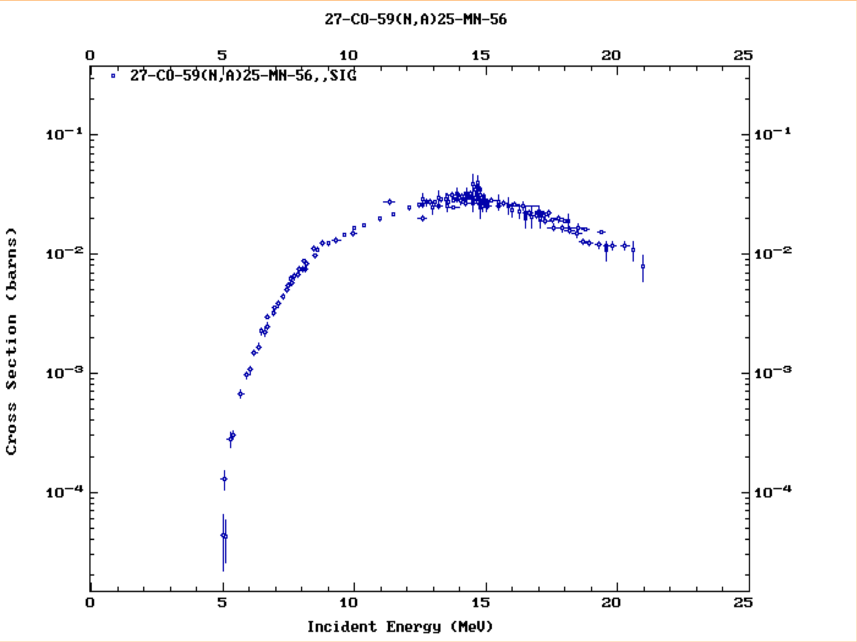
$^{59}Co(n,\gamma)$ Reaction



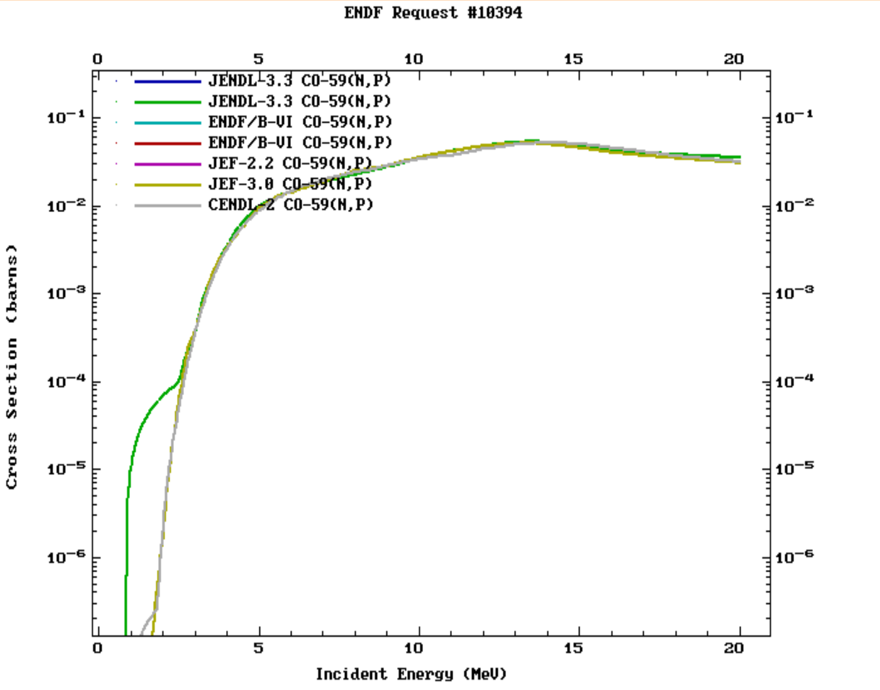


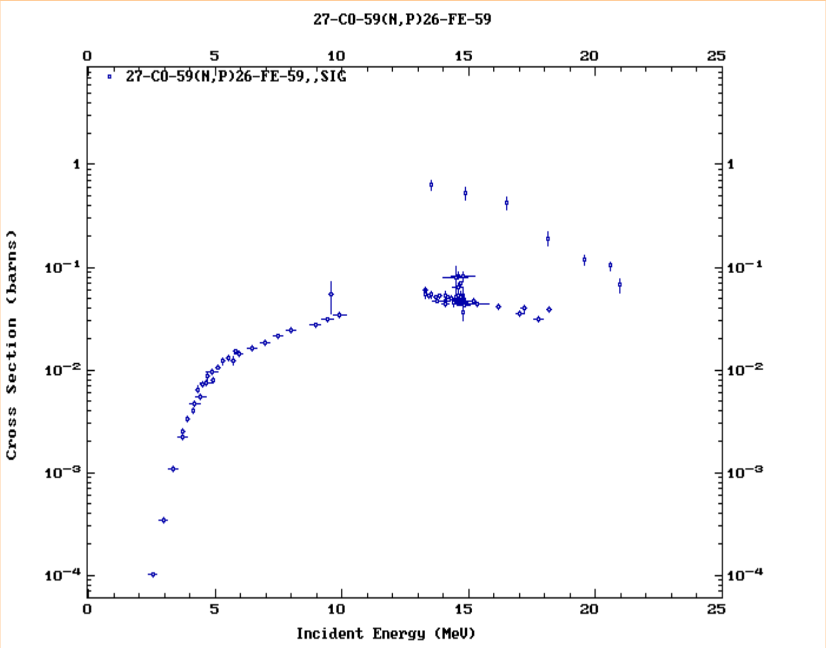
$^{59}Co(n,\alpha)$ Reaction



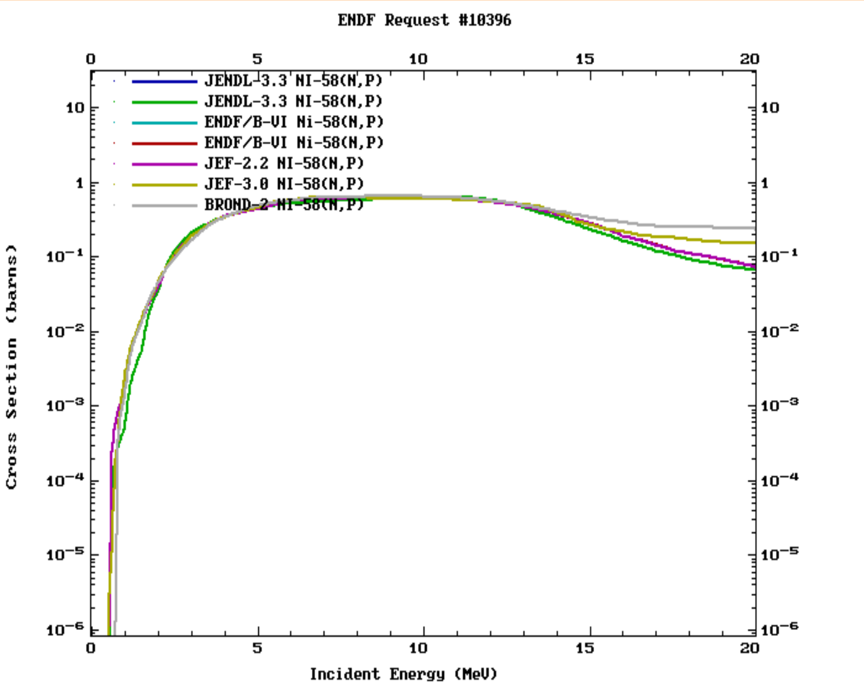


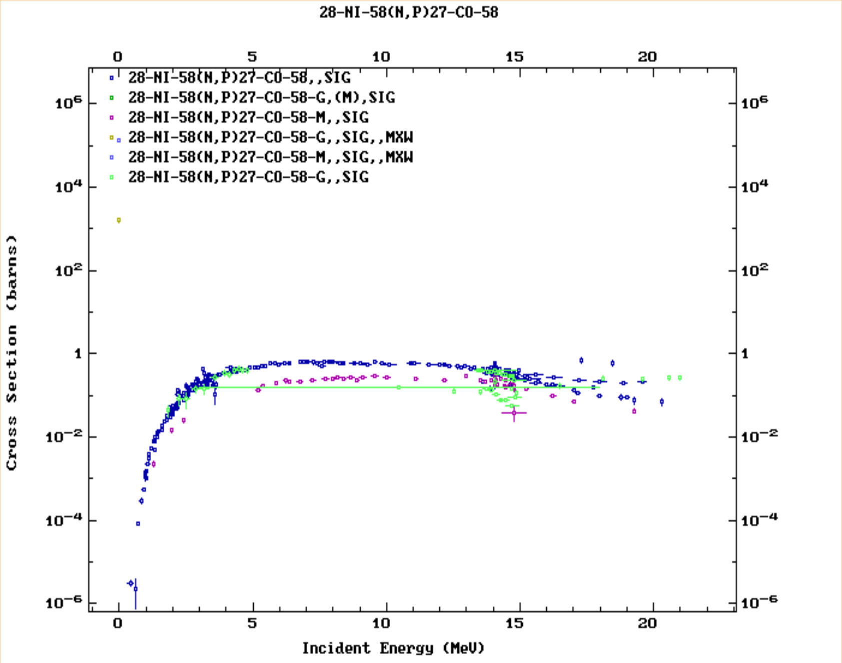
^{59}Co(n,p) Reaction



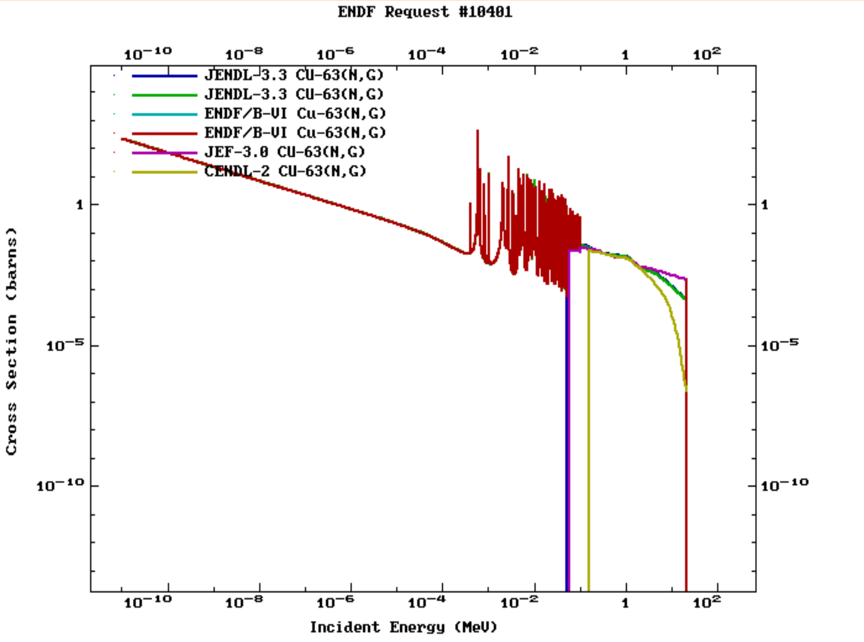


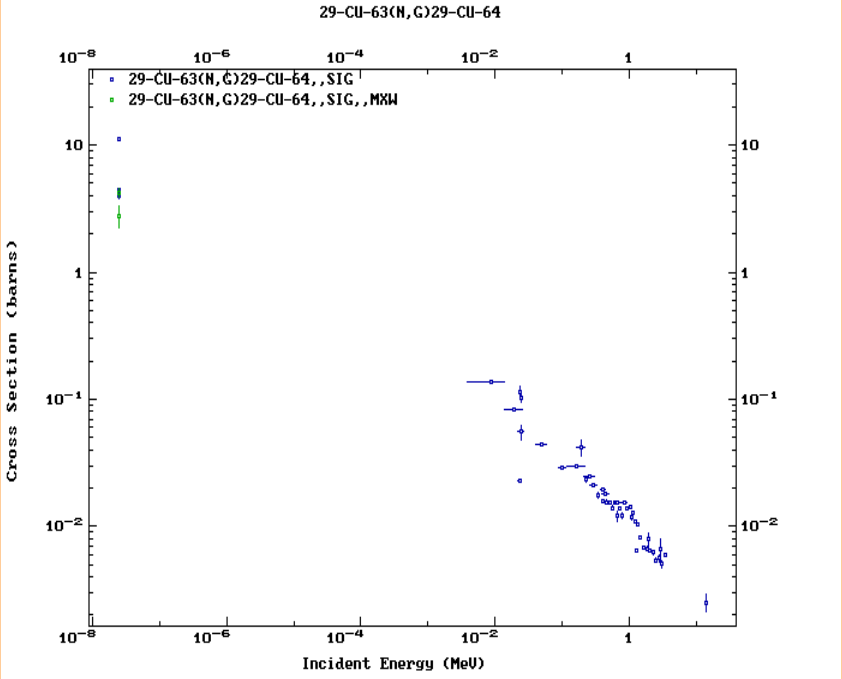
^{58}Ni(n,p) Reaction



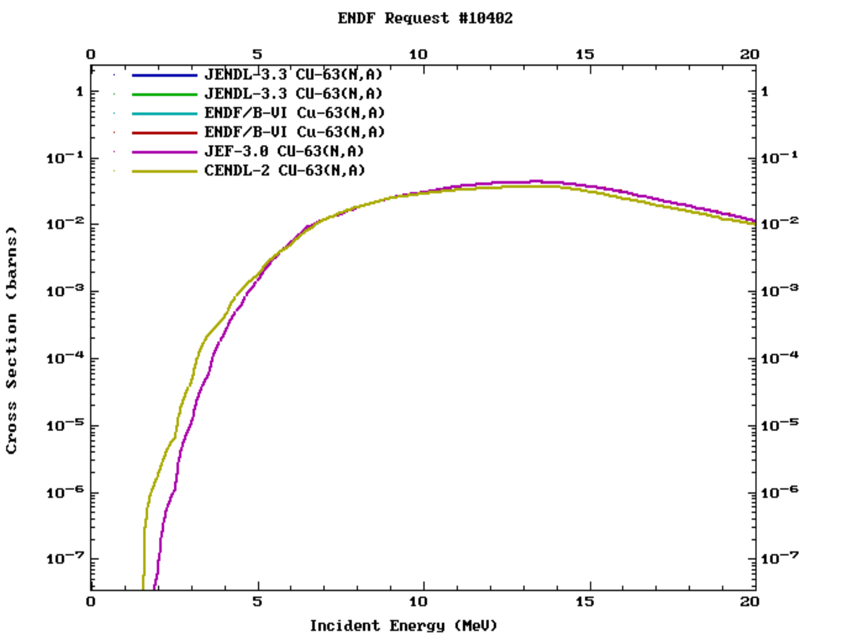


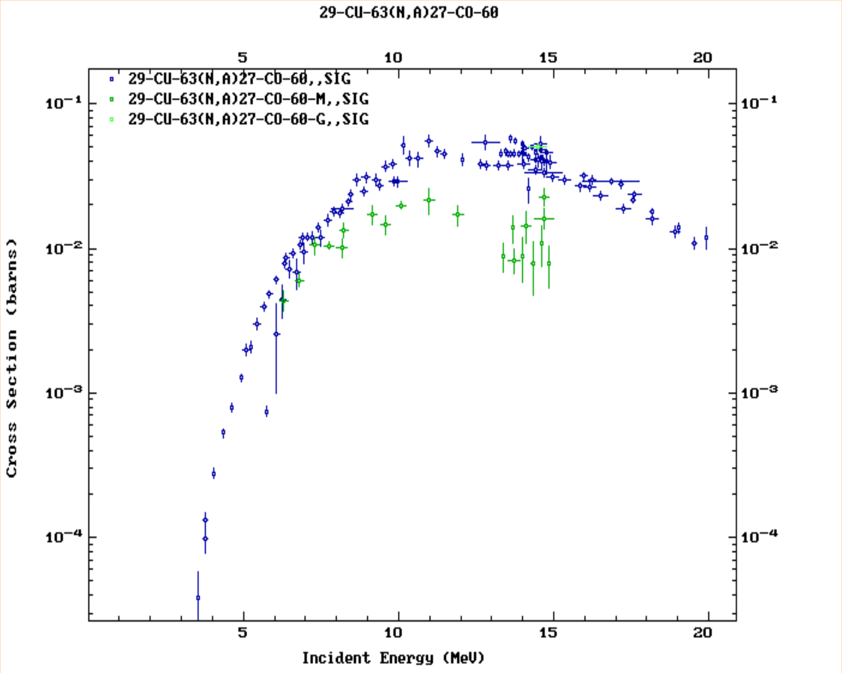
$^{63}Cu(n,\gamma)$ Reaction



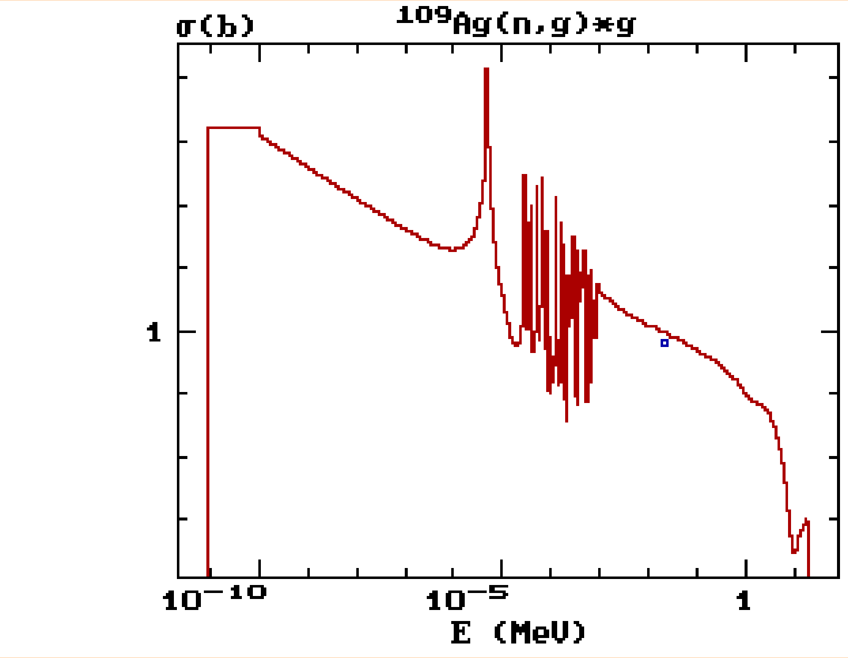


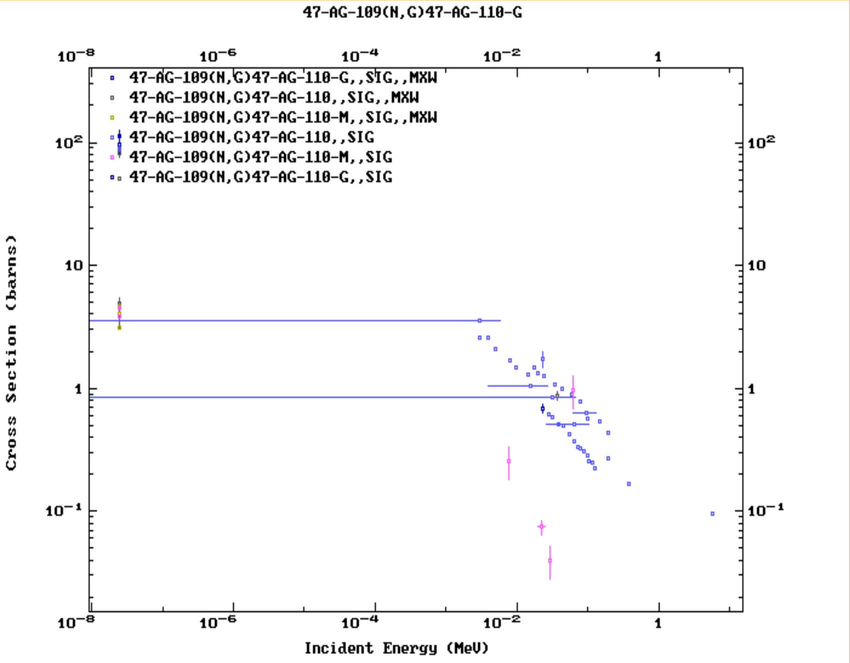
$^{63}Cu(n,\alpha)$ Reaction





^{109}Ag(n,γ) Reaction





Conclusions

- Reactions considered to be the most important for interrogation tend to be ones for which the data are well known for a similar reason – large cross sections and easily detected radiations
- This survey is ongoing, but the conclusion to date is that there is no overwhelming justification for mounting a major program now to improve neutron activation cross sections for neutron interrogation … however, as the technologies improve requirements for more accurate data are likely to become more stringent
- Monte Carlo simulation studies should be carried out to investigate the issue of residual radioactivity from neutron interrogation