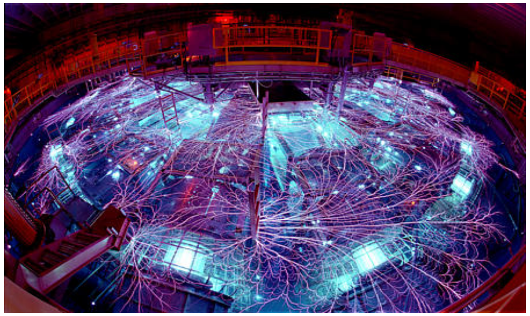
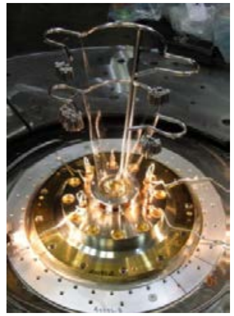
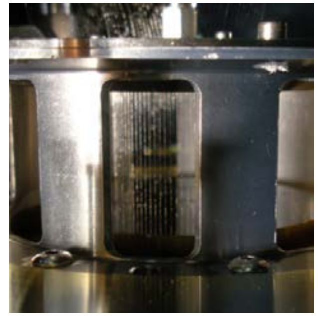
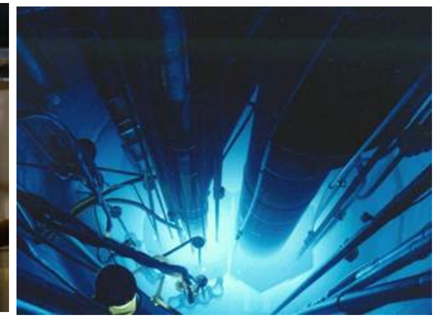
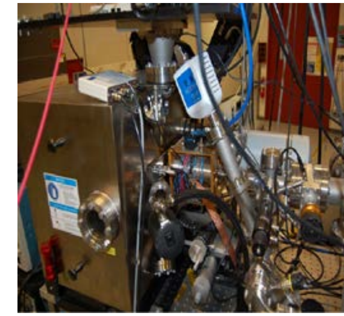










"Nuclear Data Needs for Understanding Material Damage"

Presented at: Nuclear Data Needs and Capabilities for Applications (NDNCA) Workshop sponsored by US Nuclear Data Program (USNDP)

Patrick J. Griffin
Senior Scientist
Org. 1300, Radiation and Electrical Sciences

Date: May 27 – May 29, 2015

SAND2015-3772 PE

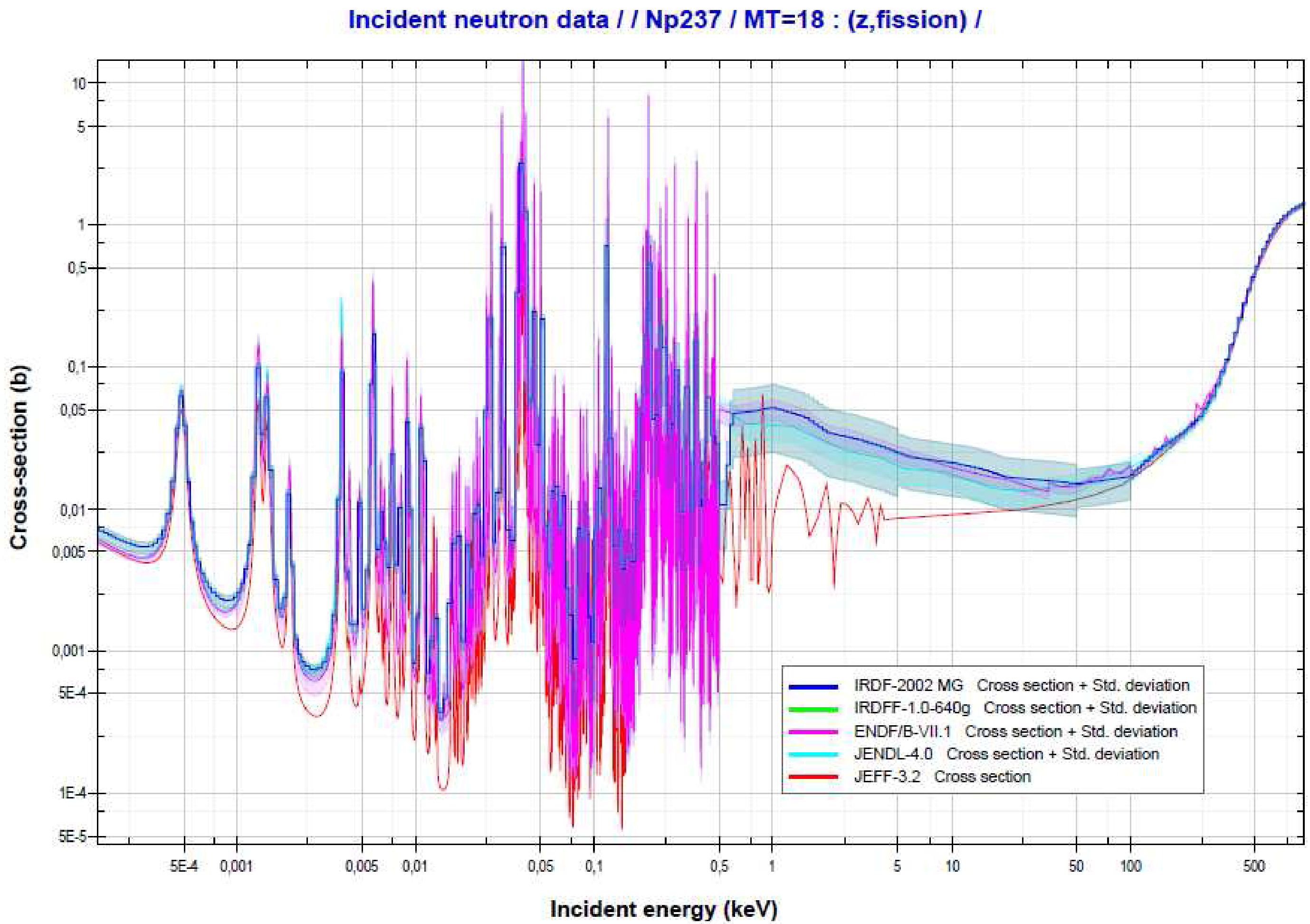
AGENDA:

a) Dosimetry cross sections
b) Validation data in benchmark neutron fields
c) Gamma emission probabilities
d) Uncertainty in cross section
e) Fission product yields
f) Other considerations

Dosimetry Cross Sections

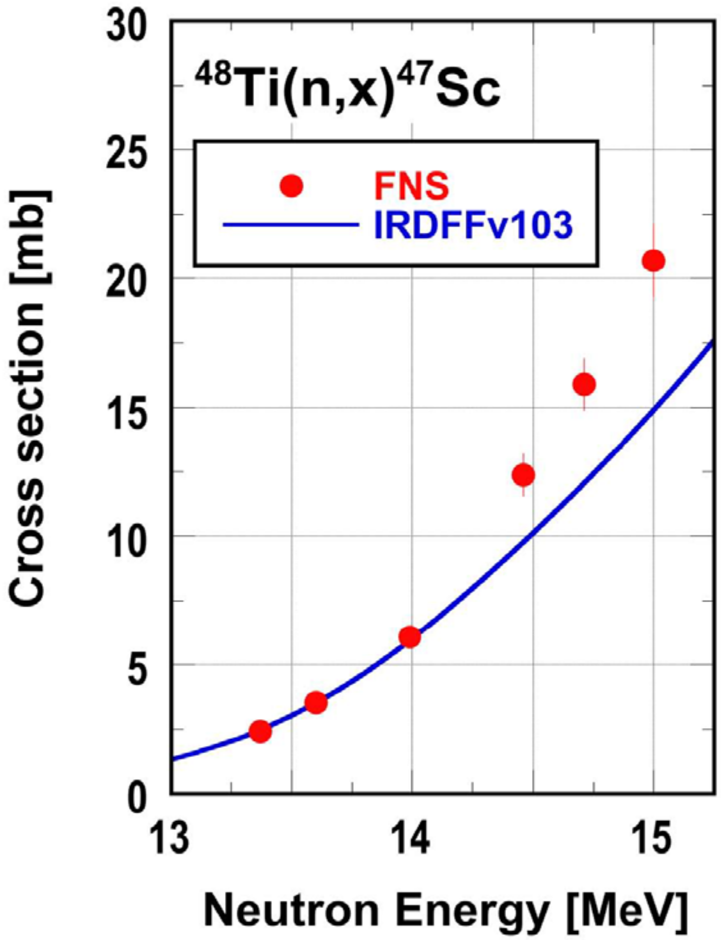
- $^{117}Sn(n,n')$
  - Cover energy response 0.3 – 3.0 MeV
- Data to support new evaluations
  - $^{23}Na(n,\gamma)$
    - Discrepant in fast neutron region, > 100 keV
  - $^{23}Na(n,2n)$
  - $^{27}Al(n,2n)$
- Address discrepancies:
  - $^{55}Mn(n,\gamma)$ cross section from 10 keV to 1 MeV
  - $^{58}Fe(n,\gamma)$ reaction in the 10 keV to 1 MeV energy region for fast reactor
  - ^{237}Np(n,fission) and ^{241}Am(n,fission) measurements between LANL and n-TOF (CERN) on the plateau [
  - Some 14-MeV dosimetry reactions

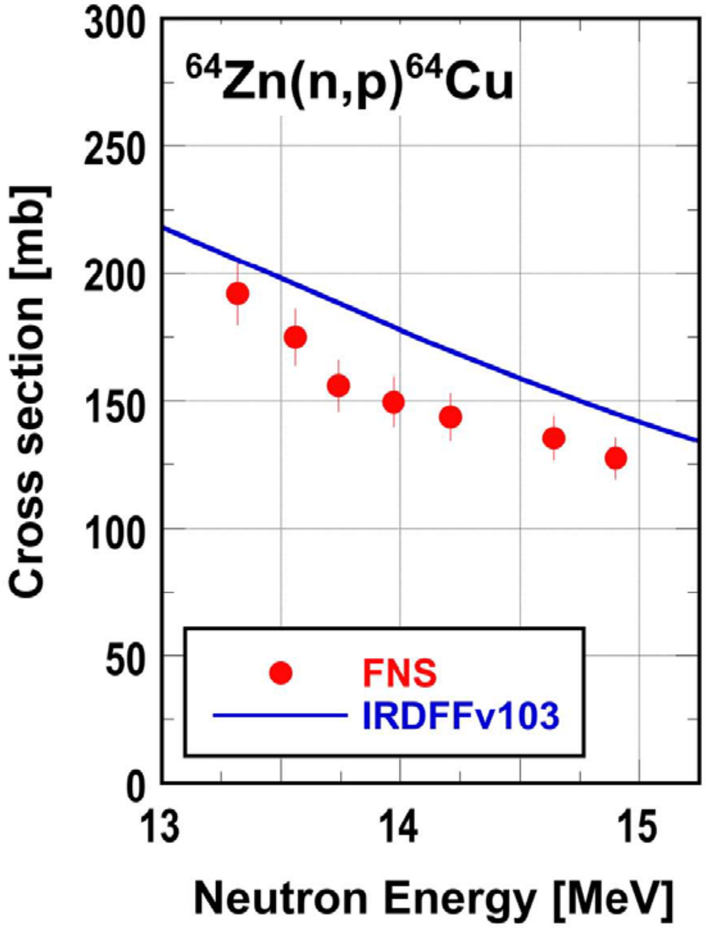
^{237}Np(n,f): Energies 1 – 100 keV



Plot from Dextouches, CEA

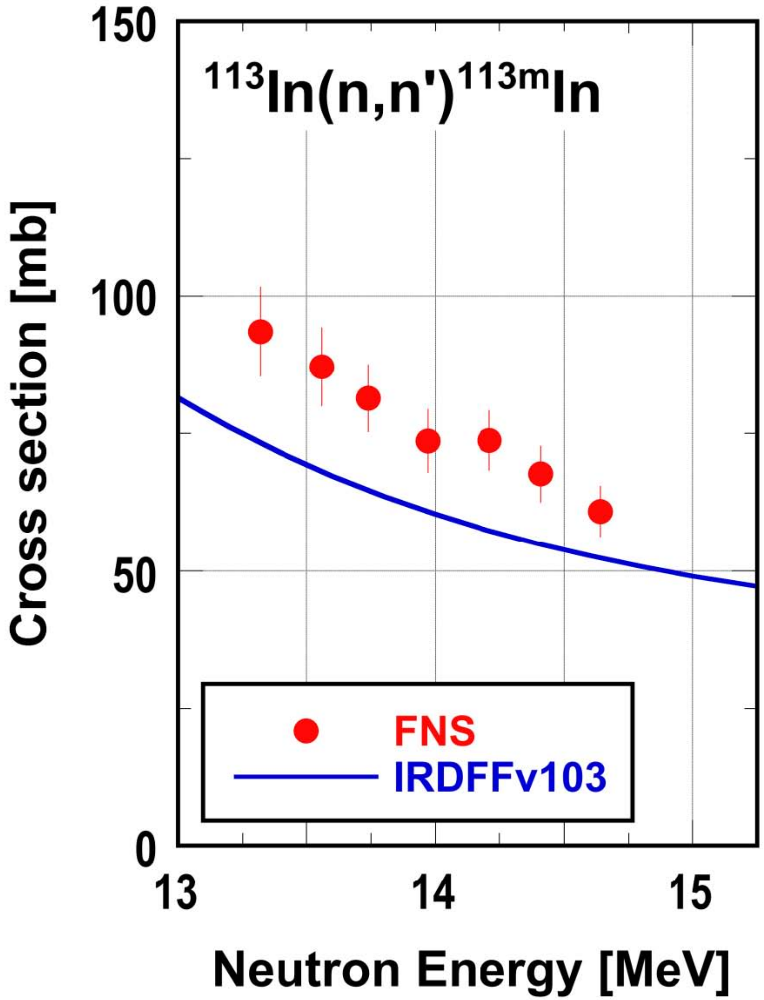
Dosimetry data Near 14-MeV where discrepancies are seen (1/2)

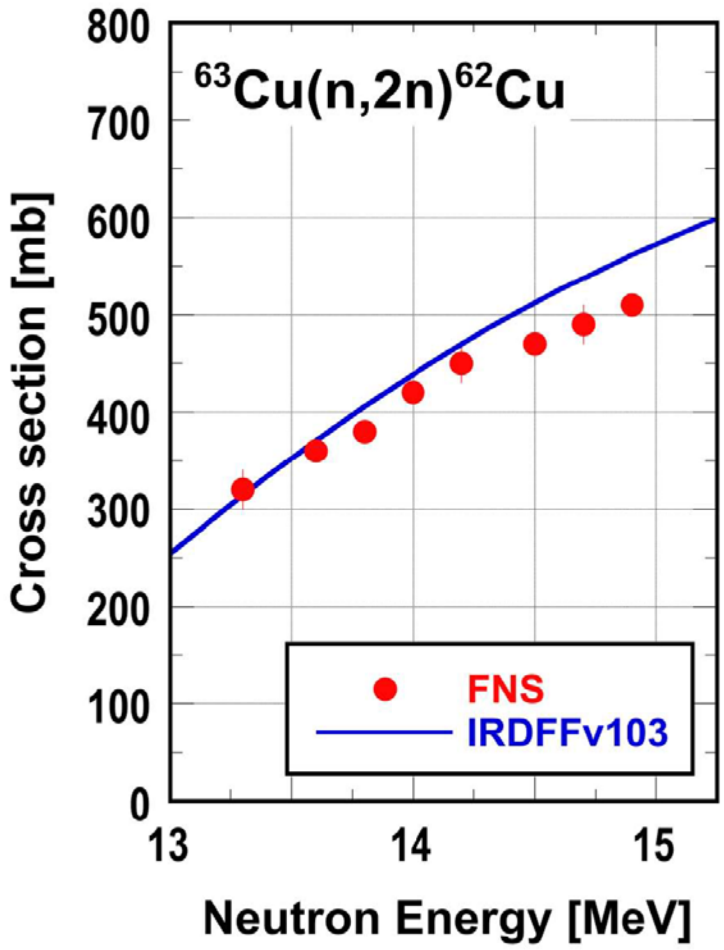




Plot from Konno, JAEA

Dosimetry data Near 14-MeV where discrepancies are seen (2/2)





Plot from Konno, JAEA

Thermal capture for ^{93}Nb(n,γ); ^{115}In(n,γ); K_o conflict with Mughabghab

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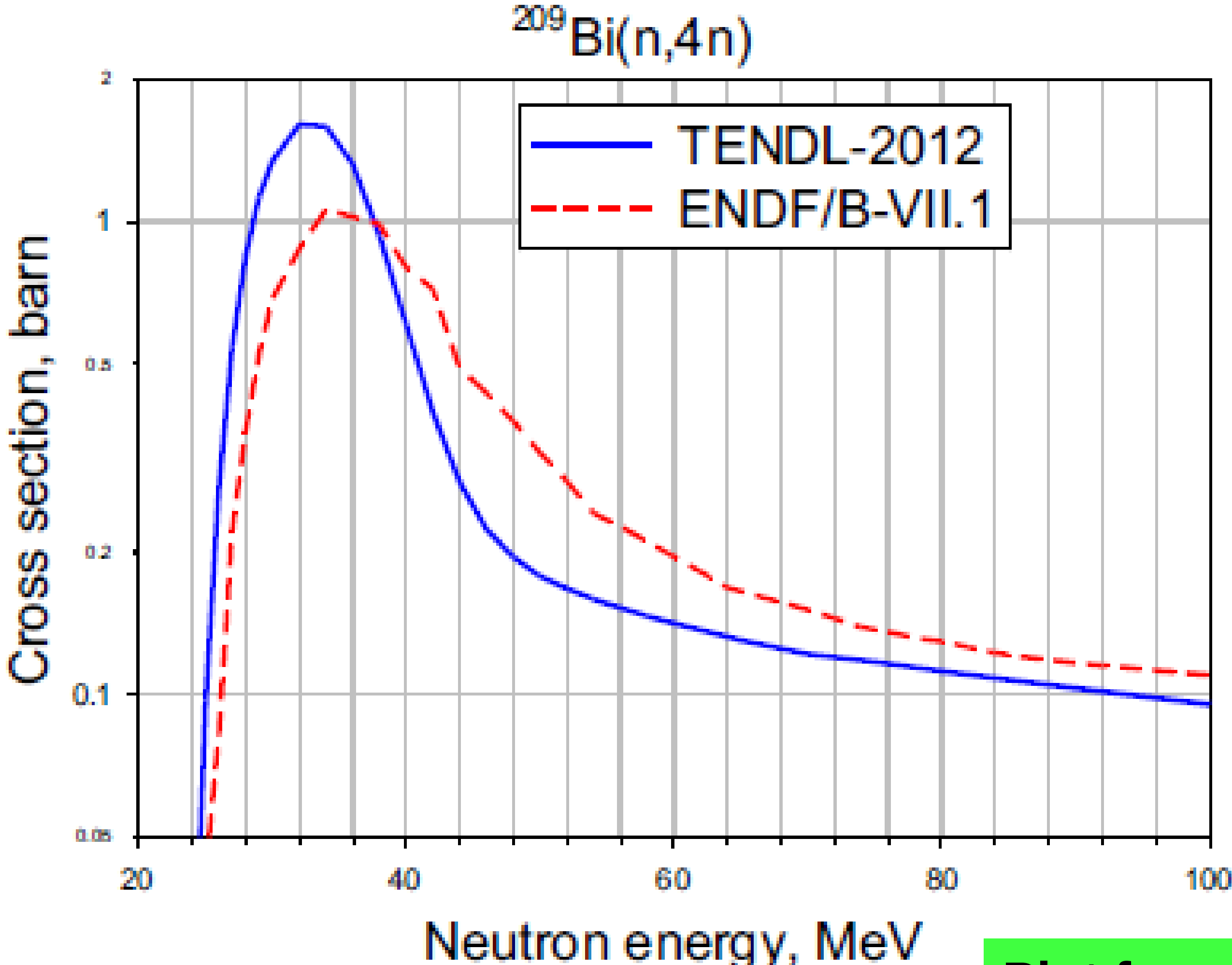
		Mughabghab [1]			Kayzero/Nudat [2]		IRDFF		IRDF-2002		IRDF-90/V2	
Target	Product	σ_0 [b]	$\Delta\sigma_0$ [%]	Diff [%]	σ_0 [b]	$\Delta\sigma_0$ [%]	σ_0 [barns]	Diff [%]	σ_0 [barns]	Diff [%]	σ_0 [barn]	Diff [%]
Na-23	Na-24	0.53	0.9	3.3	0.513	0.57	0.528	2.9	0.528	2.9	0.528	2.9
Sc-45	Sc-46	27.2	0.7	3.6	26.26	0.40	27.208	3.6	27.21	3.6	27.22	3.7
Mn-55	Mn-56	13.36	0.4	1.3	13.18	0.92	13.278	0.7	13.42	1.8	13.42	1.8
Fe-58	Fe-59	1.316	1.9	1.0	1.30	2.66	1.315	1.2	1.301	-0.1	1.15	-12
Co-59	Co-60	37.18	0.2				37.18		37.18		37.24	
Cu-63	Cu-64	4.52	0.4	-2.4	4.63	0.90	4.471	-3.4	4.471	-3.4	4.473	-3.4
Nb-93	Nb-94m	1.15	4.3		0.86		1.156	34	1.156	34	1.156	34
Ag-109	Ag-110m	3.91	1.1		3.94	2.88	4.214	7.0	4.214	7.0	4.689	19.0
In-115	In-116m	202	1.0		160.24	6.23	159.8	-0.3	166.5	3.9	166.5	3.9
La-139	La-140	9.04	0.4	-4.1	9.42	1.78	9.042	-4.0	9.042	-4.0		
Ta-181	Ta-182	20.5	2.4	-0.4	20.59	7.59	20.68	0.4	20.68	0.5		
W-186	W-187	38.5	1.3	-8.2	41.92	2.67	38.095	-9.1	38.49	-8.2		
Au-197	Au-198	98.65	0.1	0.0	98.65	0.09	98.70	0.1	98.77	0.1	98.79	0.1
Th-232	Th-233	7.35	0.4	-0.3	7.37	0.34	7.338	-0.4	7.405	0.4	7.401	0.4
U-238	U-239	2.68	0.7	-0.1	2.68	0.43	2.686	0.2	2.718	1.3	2.710	1.0

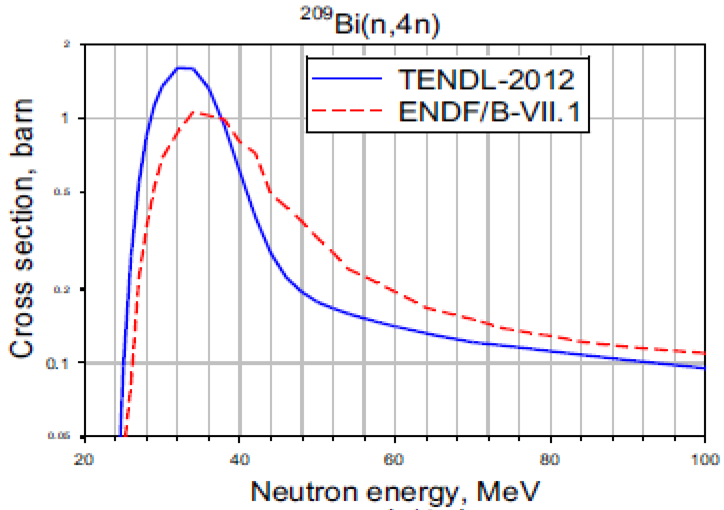
Table from Kodeli, Jozef Stefan Institute, Slovenia

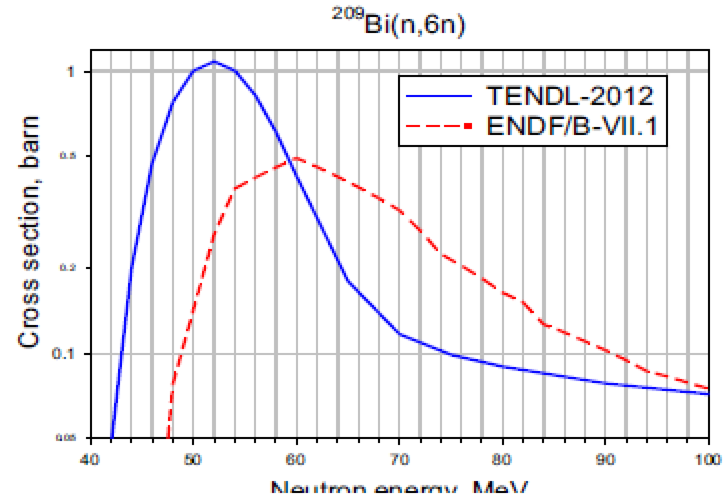
High Threshold Reactions, e.g. ^{209}Bi(n,4n)

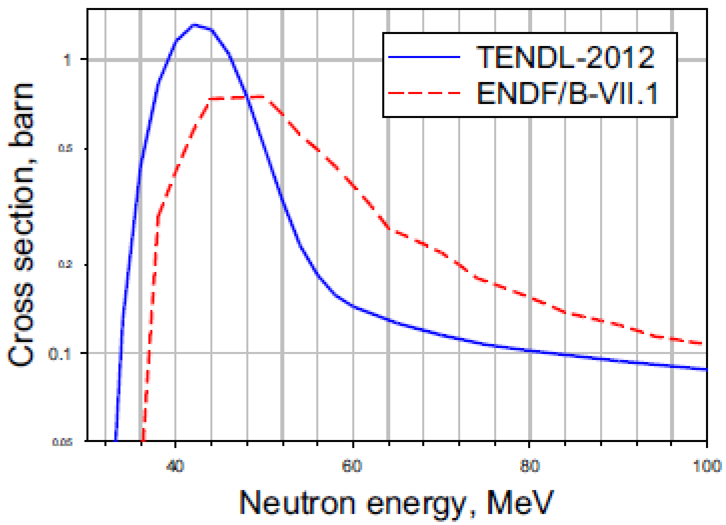


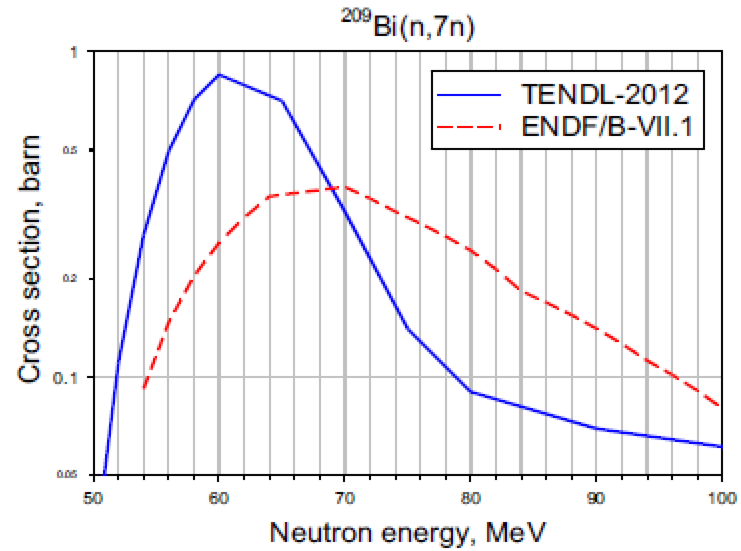
Plot from Pronyaev

^{209}Bi(n,xn) discrepancy increases with “x”



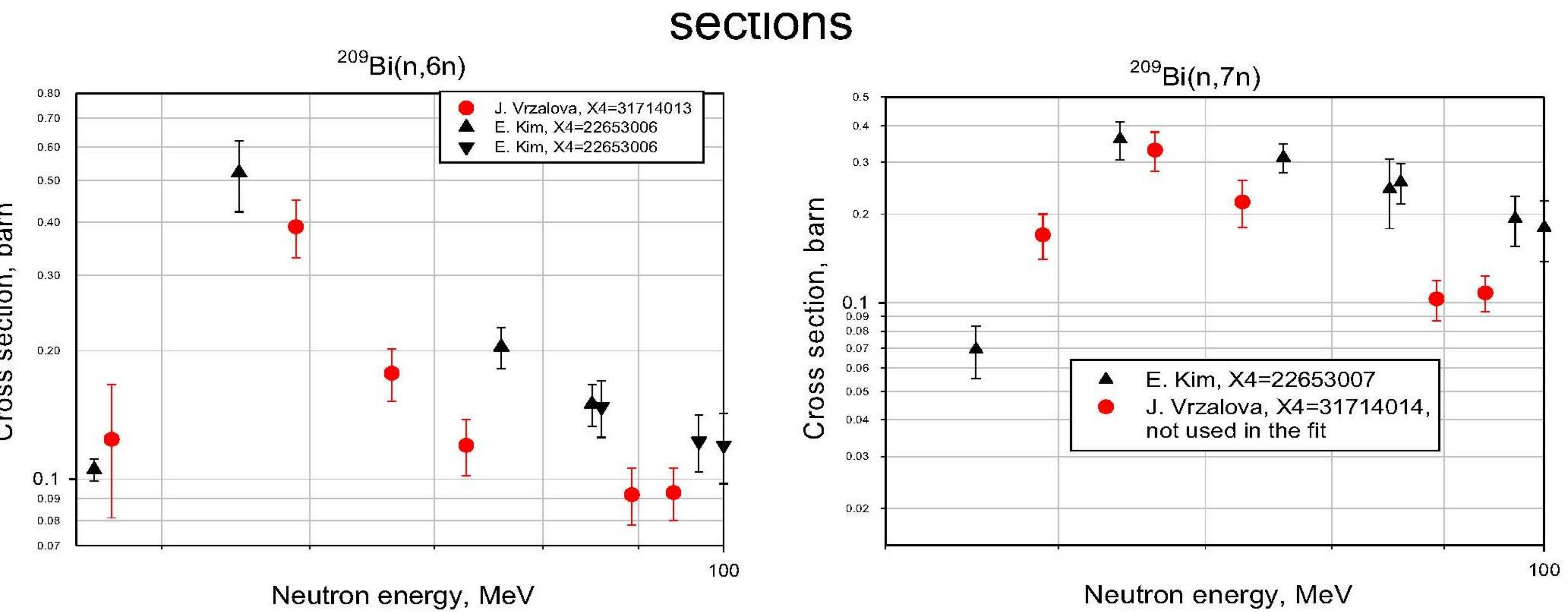






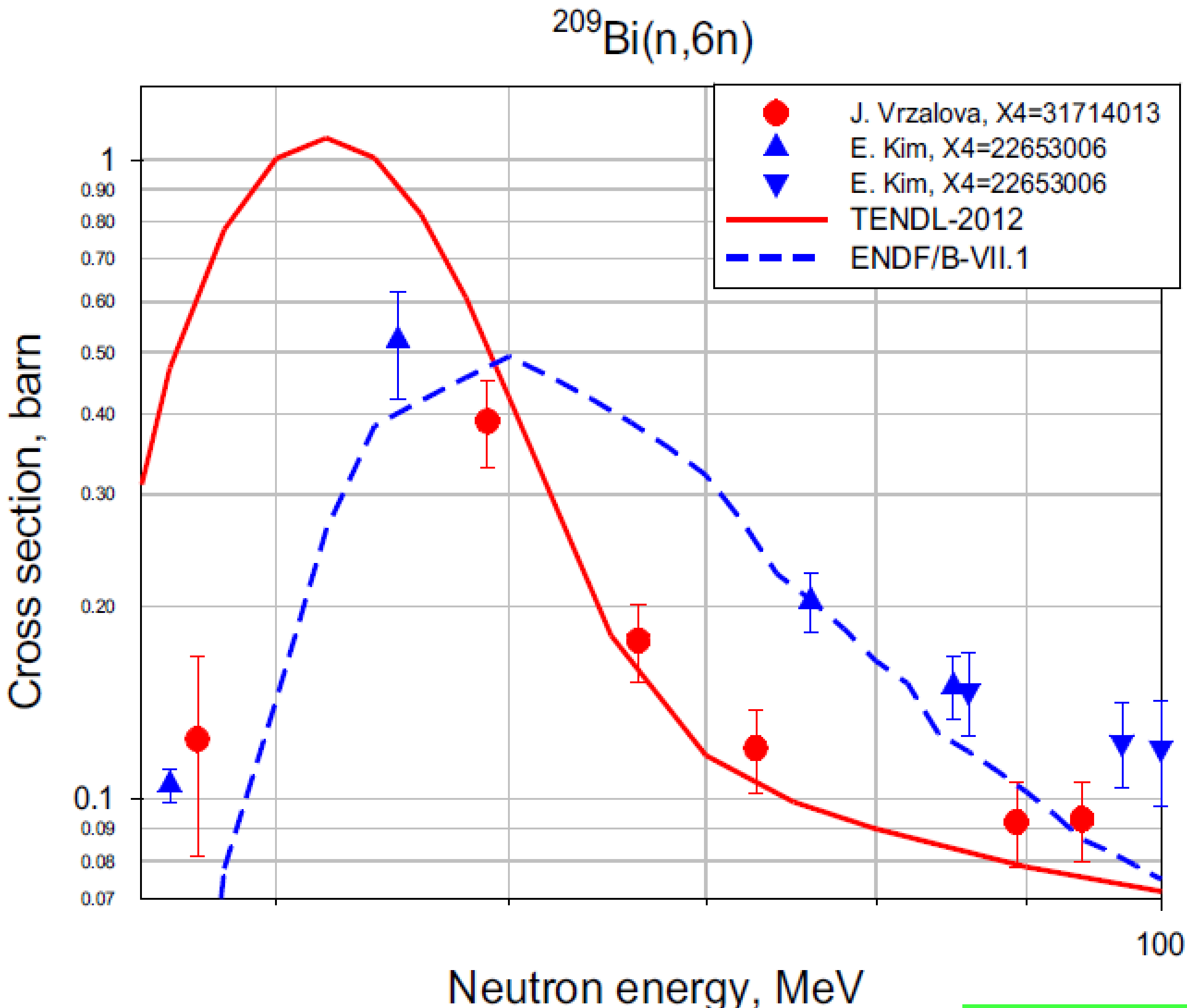
Plot from Pronyaev

Existing experimental data for $^{209}Bi(n,xn)$



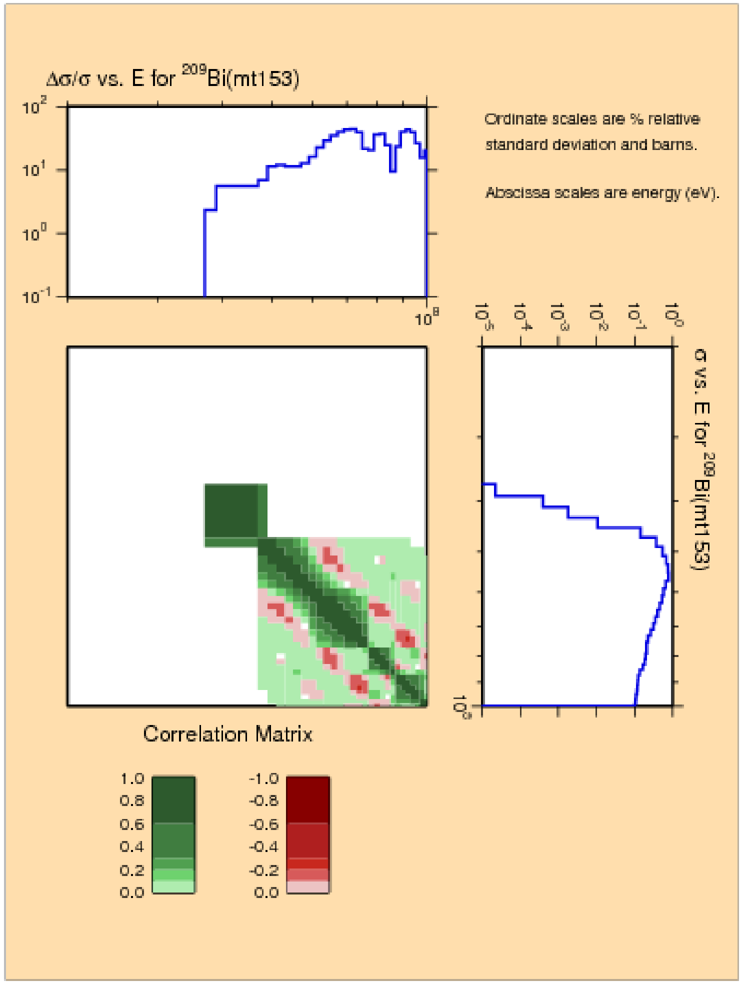
Plot from Pronyaev

How this variation affects data evaluations?



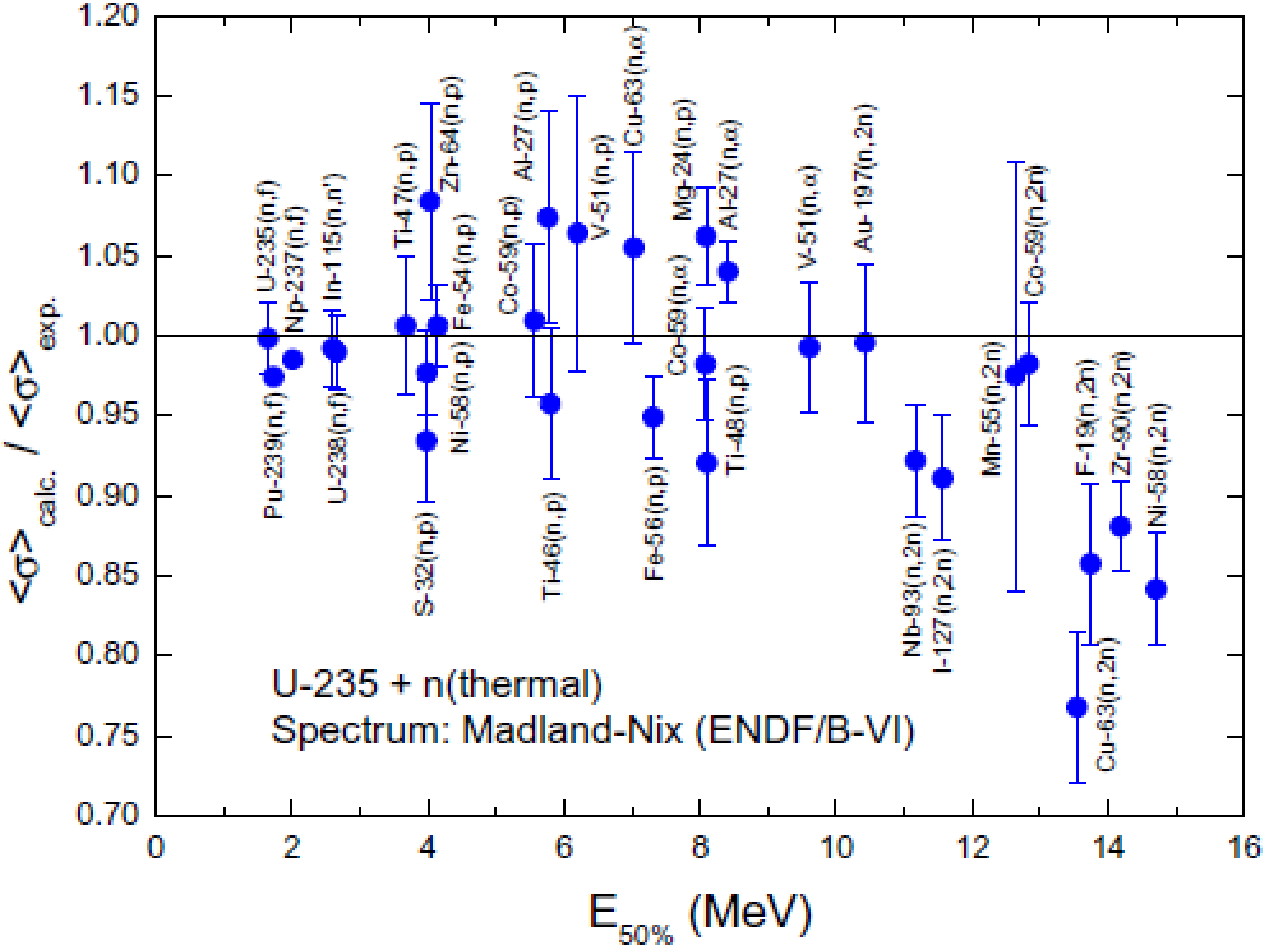
Plot from Pronyaev

The experimental data also affects the covariance data. Dosimetry reactions require small uncertainty.



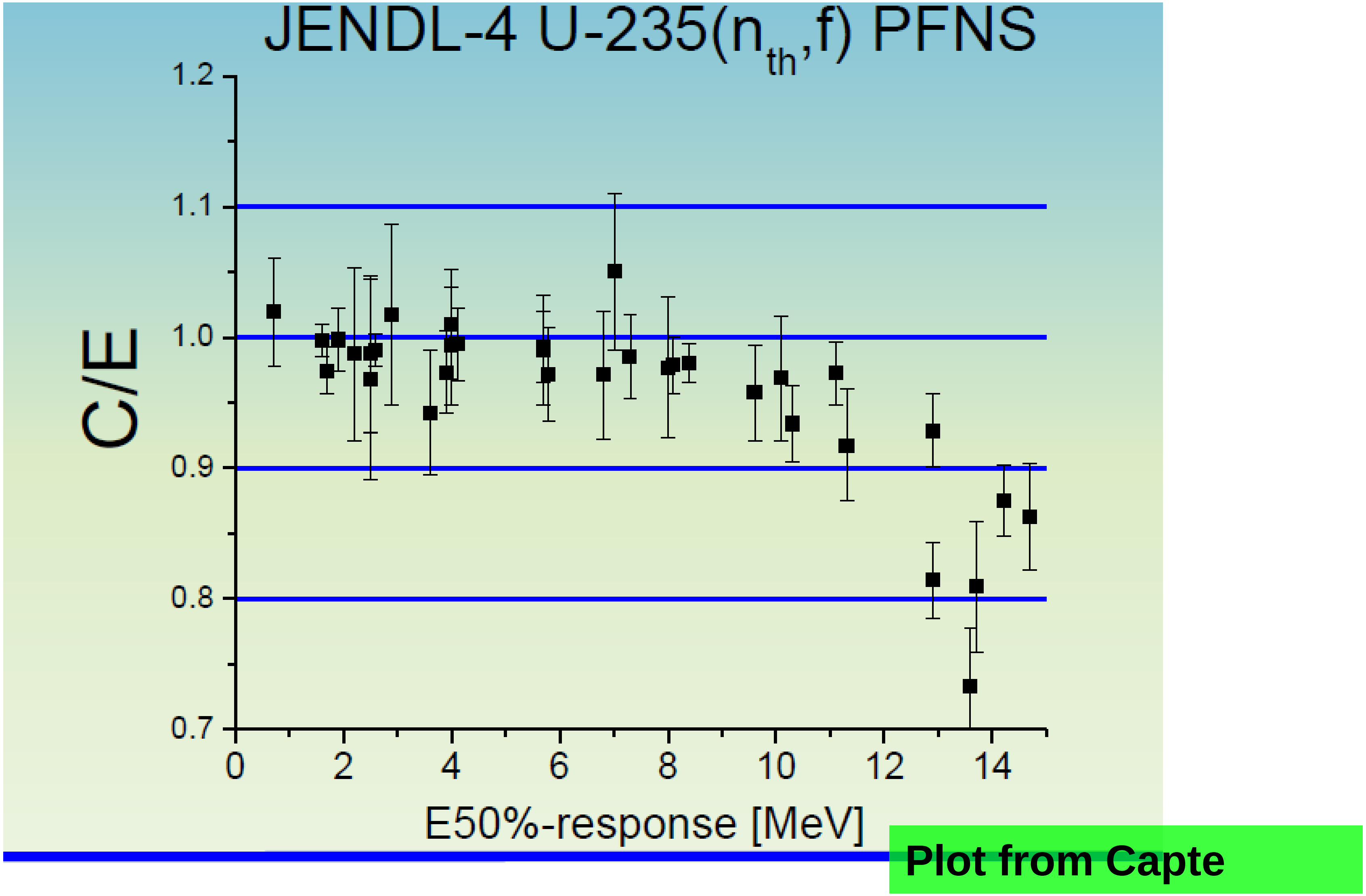
High threshold reactions in ^{235}U(th) reference neutron benchmark field

Sandia National Laboratories



Plot from Mannhart

High threshold reactions in ^{235}U(th) reference neutron benchmark field



Validation data in ^{252}Cf spontaneous fission standard benchmark neutron field

- **Data lacking**
  - $^{238}U(n,\gamma)$ — $^{31}P(n,p)$ — $^{186}W(n,\gamma)$
  - $^{58}Fe(n,\gamma)$ — $^{10}B(n,X)\alpha$ — $^{115}In(n,n')$
  - $^{45}Sc(n,\gamma)$ — $^{54}Fe(n,\alpha)$ — $^{54}Fe(n,2n)$
  - $^{64}Zn(n,p)$ — $^{23}Na(n,2n)$ — $^{75}As(n,2n)$
  - 14 other reactions from IRDFF library
- **Data with large discrepancy**
  - $^{232}Th(n,f)$
  - $^{238}U(n,2n)$
- **Data with outliers (4 reactions)**

IRMM Exploratory Study of Validation Data in ^{252}Cf Standard Neutron Benchmark Field

- **Issues with existing $^{197}Au(n,\gamma)$ due to room return**
- **Issues with existing $^{90}Zr(n,2n)$ due to Th contamination**
- **Issue with existing $^{96}Zr(n,2n)$ due to $^{94}Zr(n,\gamma)$ contribution**

Validation data in ^{235}U thermal fission reference benchmark neutron field

- **Data lacking**
  - **$^{45}Sc(n,\gamma)$ $^{115}In(n,2n)$ $^{46}Ti(n,2n)$**
  - **$^{93}Nb(n,\gamma)$ $^{65}Cu(n,2n)$ $^{54}Fe(n,2n)$**
  - **$^{58}Fe(n,\gamma)$ $^{52}Cr(n,2n)$ $^{59}Co(n,3n)$**
  - **$^{109}Ag(n,g)$ $^{23}Na(n,2n)$ $^{186}W(n,\gamma)$**

  6 other reactions from IRDFF library
- **Data with large discrepancy**
  - **$^{103}Rh(n,n')$ $^{63}Cu(n,\gamma)$ $^{58}Ni(n,2n)$**
  - **$^{238}U(n,\gamma)$ $^{169}Tm(n,2n)$ $^{55}Mn(n,2n)$**
- **Data with outliers (5 reactions)**

Validation data in 30 keV MACS neutron field

- **Data lacking**
  - **$^{109}Ag(n,\gamma)$**
  - **$^{232}Th(n,\gamma)$**
  - **$^{235}U(n,\gamma)$**
  - **$^{238}U(n,\gamma)$**

Require consistency between nuclear data used in cross section evaluation and for decay data

- **Test and improve decay characteristics for radionuclides in new IRDFF reactions:**
  - **^{55}Co**
  - **^{56}Co**
  - **^{94}Nb**
  - **^{114m}In**
  - **^{117m}Sn**
  - **^{195}Au**
- **V. Chechev, Khlopin Radium Institute, has been tasked by IARA CRP to do this review**

Gamma Emission Probabilities

- **Rh-103m**
  - **x-ray emission probability around 20 keV**
- **La-140**
  - **gamma intensities for lines below 1596 keV**
- **W-187**
  - **gamma intensities of 2 lines (473.53 keV and 685.81 keV)**
- **Cu-64**
  - **511 keV annihilation gamma line intensity**

Uncertainty in cross sections

- **Scope:**
  - **Need is for data-based nuclear data evaluation to complement/validate computational covariance data found in TALYS.**
  - **Focus on experimental data targeted to support evaluation needs.**
- **Important Isotopes**
  - **^{69}Ga, ^{71}Ga, ^{75}As**
    - **ASTM E722**
  - **^{56}Fe, ^{54}Fe**
    - **ASTM E693**

Uncertainty in recoil spectrum

- **Recoil spectrum characterization in cross sections (MF=6)**
  - **^{69}Ga, ^{71}Ga, ^{75}As**
  - **Fe isotopes**
- **Validate/test use of calculated cross section libraries, e.g. TENDL, to characterize this uncertainty component**
  - **Scope "model defect"**

Material Primary Damage/Displacement

- **Arc-dpa**
  - **Ion mixing experiments for high recoil energy ions**
- **Damage correlation**
  - **Isotopes: Si, Ge, Fe, III-V semiconductors (GaAs, GaN, etc.)**
  - **Neutron energies:**
    - **Thermal neutron equivalence**
    - **14-MeV damage equivalence**
  - **Damage metrics:**
    - **Defect-type sensitive damage modes**

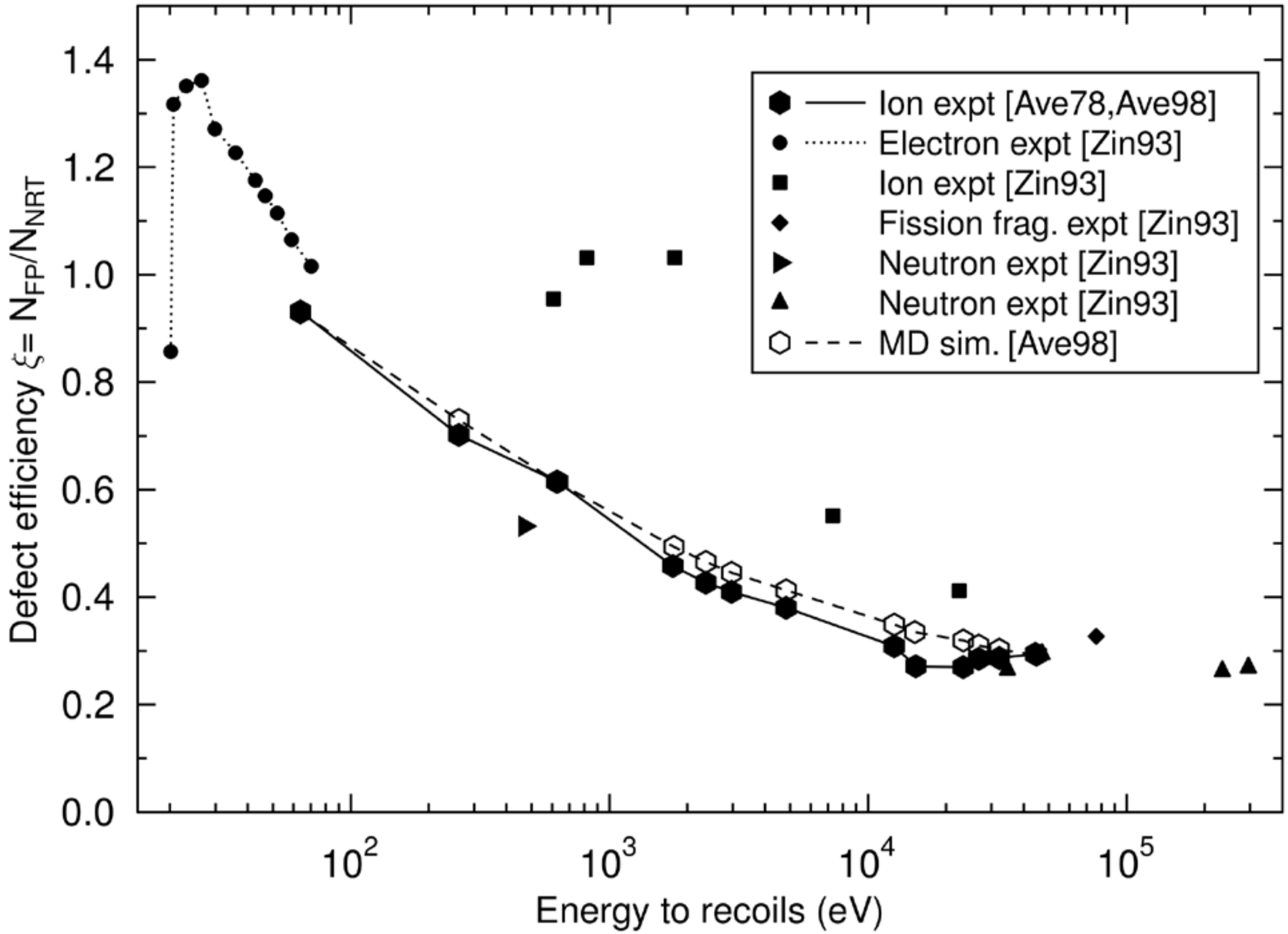
Fission product yield needs

- **Community consensus**
- **Updated uncertainties**
- **Energy-dependence**
- **Photo-induced fission yields**

Some aspects of material damage do not fall within the nuclear data realm

- **Correlation of effects with metric**
  - **Semiconductor gain degradation**
- **Chemistry of impurities (Ni, Cu) in iron material embrittlement**
  - **Radiation-induced temperature transition shift, ASTM E900, NRC Reg. Guide 1.99**
    - **Stable matrix damage (SMD)**
    - **Copper-rich precipitation (CRP)**

Defect efficiency as a function of recoil energy



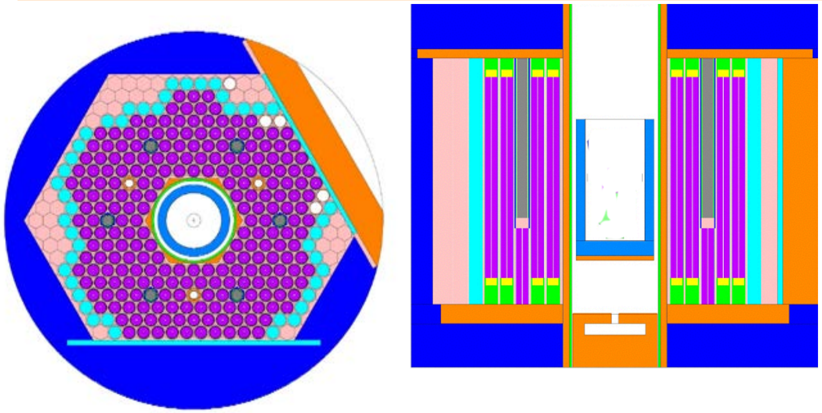
Example for Cu
From OECD "Primary Damage in Materials"

Questions

Annular Core Research Reactor (ACRR) Spectrum

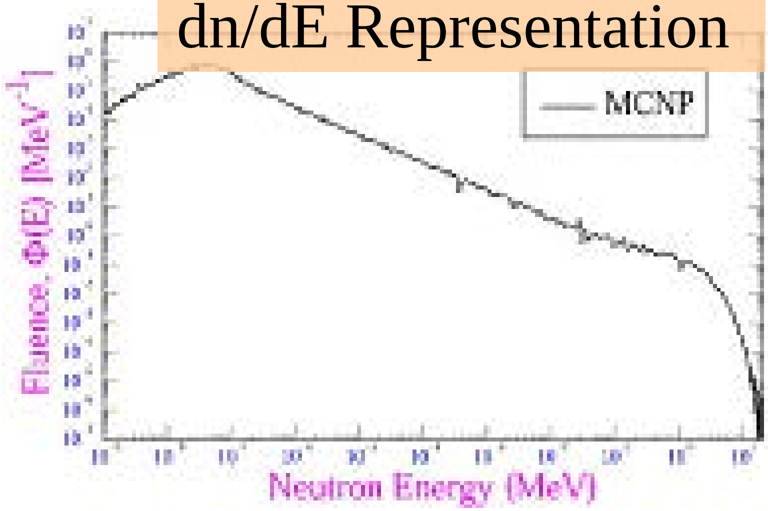
Sandia National Laboratories

Radiation Transport Model

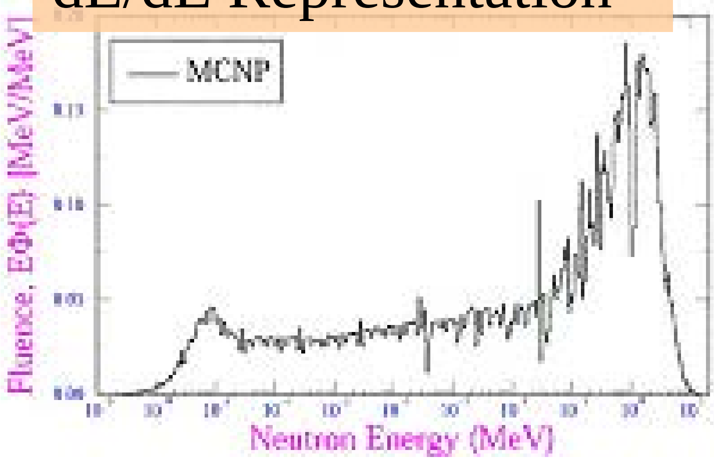


- Calculate *a priori* values
  - <1% statistical unc.

dn/dE Representation



dE/dE Representation

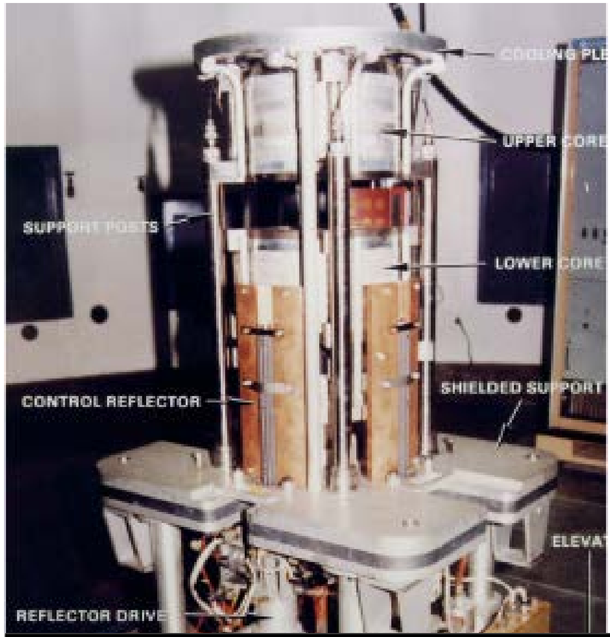


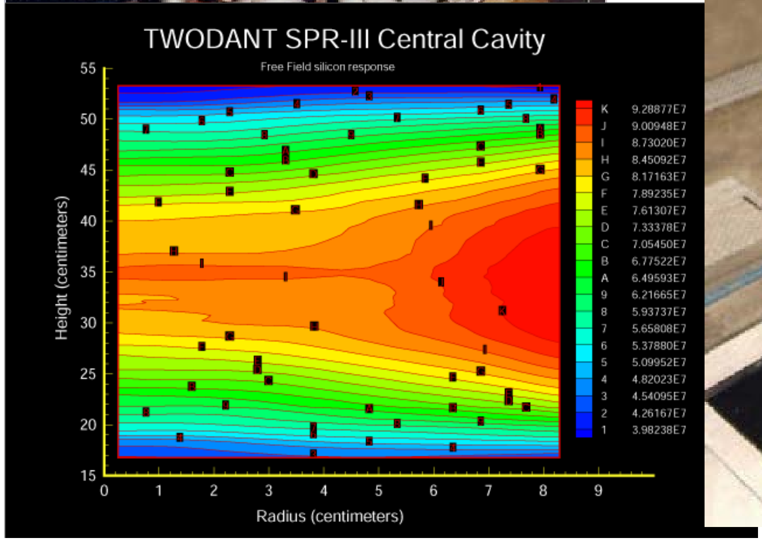
Cover and Self-shielding Corrections

- **640-group adjoint response functions generated using dosimetry response function and fielded configuration.**
  - **Foil self-shielding corrections implicit**
- **Covers are used on many foils**
  - **Cd, nominal, thick**
  - **B_4C**

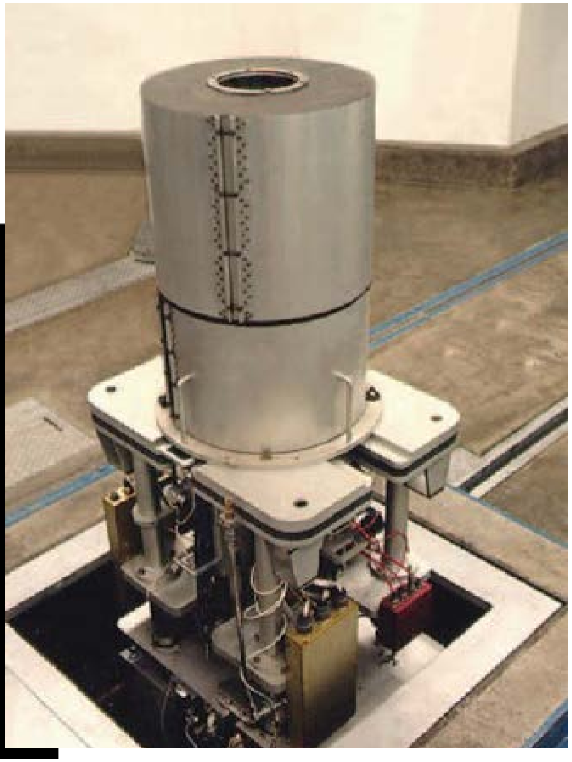
- **See:**
  - **Griffin, "A rigorous treatment of self-shielding and covers in neutron spectra determinations", IEEE TNS, pp. 1878-1885, Vol. 42, 1995**

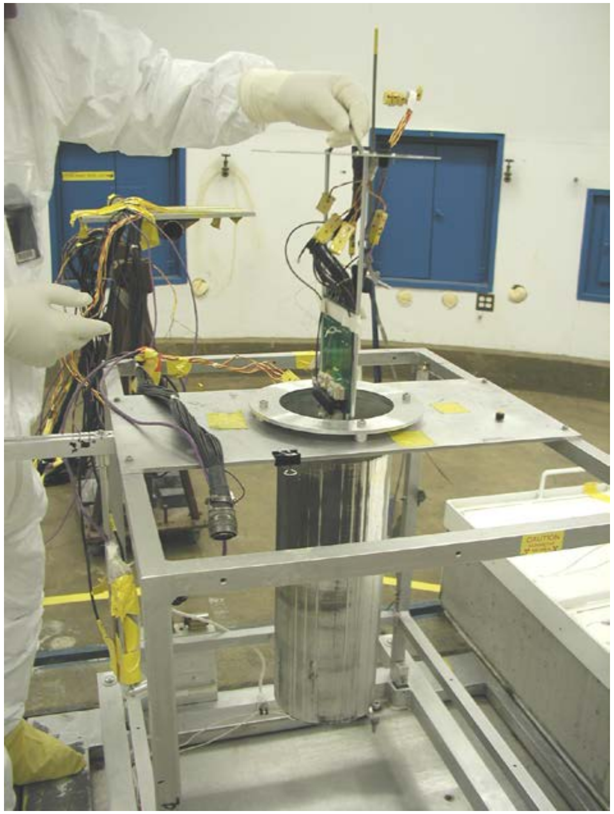
SPR-III Fast Burst Reactor





- **Max. pulse-width, 76 μs**
- **Flux 8×10^{18} n/cm^2-s**
- **1-MeV(Si) Fluence, 5.4×10^{14} n/cm^2**



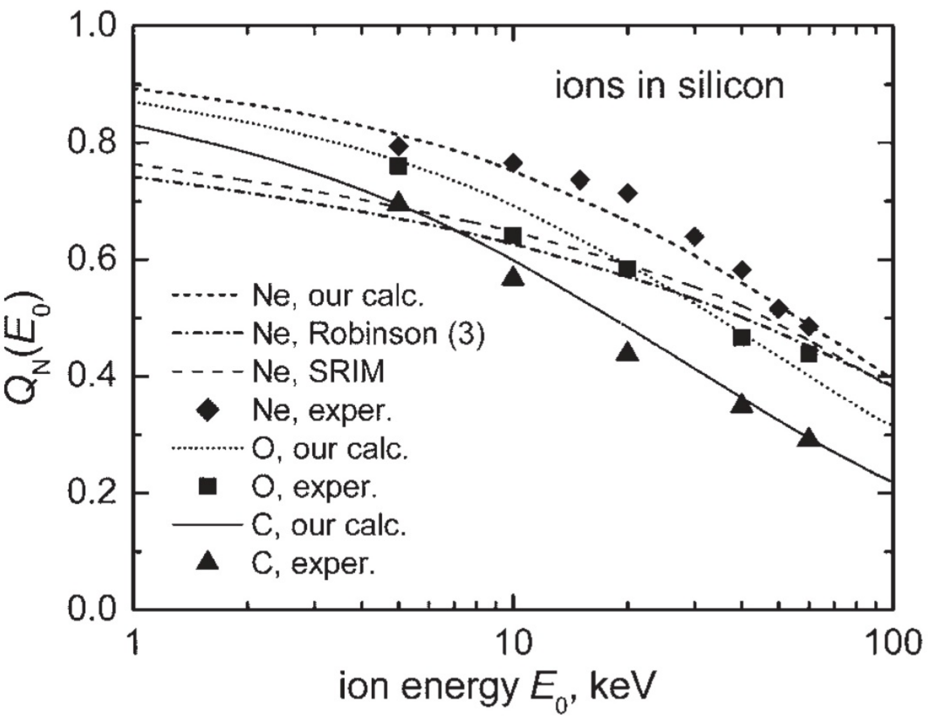


SNLRML Dosimetry

Partition: Robinson vs Akkerman Eqn. for Si

- **Robinson fit for Si in Si**
  - **$g(\varepsilon) = 0.227073\varepsilon + 0.40244\varepsilon^{3/4} + 3.4008\varepsilon^{1/6}$**

- **Akkerman fit (2006)**
  - **$g(\varepsilon) = 0.74422\varepsilon + 2.6812\varepsilon^{3/4} + 0.90565\varepsilon^{1/6}$**



Akkerman vs. Robinson vs. SRIM for Ne/O/C ions in Si

Silicon Displacement Energy Sensitivity