Deterministic 3D Transport, Sensitivity and Uncertainty Analysis of TPR and Reaction Rate Measurements in HCPB Breeder Blanket Mock-up Benchmark

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EFF Meeting, May 22-24, 2006

Calculational tools

Nuclear Data

- Cross-sections: FENDL-2 & -2.1, Be-9 from EFF-3.0; 175-group self-shielded cross sections produced by NJOY/TRANSX
- Covariance matrices: taken from ZZ-VITAMIN-J/COVA libraries, ERROR-J code or processed by NJOY:

  Be-9: EFF-3 & ENDF/B-V

  Li-6: IRDF-90

  Li-7: ENDF/B-VI.8 (some correlation coefficients exceeding 1.0, e.g.: MT=2 (up to -52.2)

  C-12: EFF-2.2

  O-16: JENDL-3.3
- Response functions: IRDF-2002 for Li6(n,t), Nb93(n,2n), Al27(n,α), Ni58(n,p), Au197(n,γ)

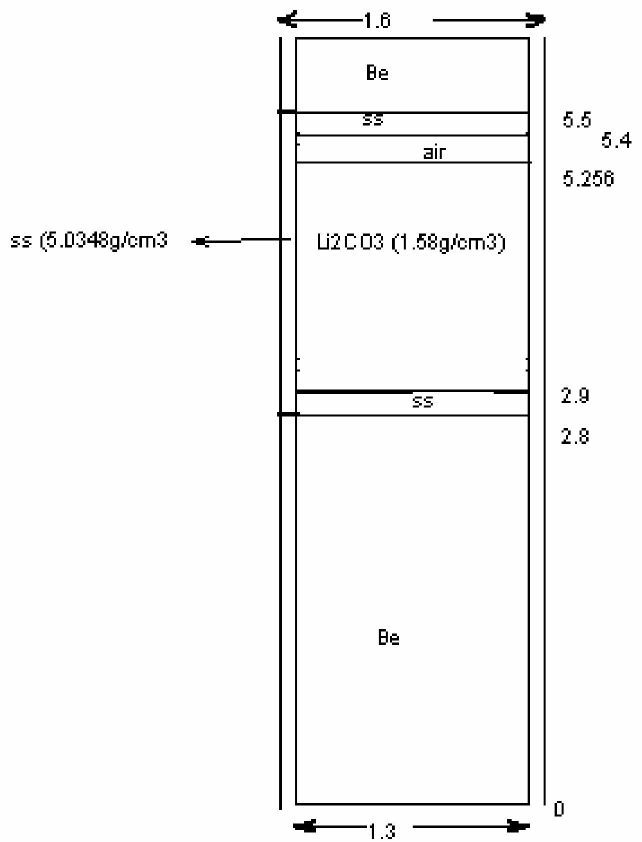
  JEF-2.2 for Li-7(n,t)

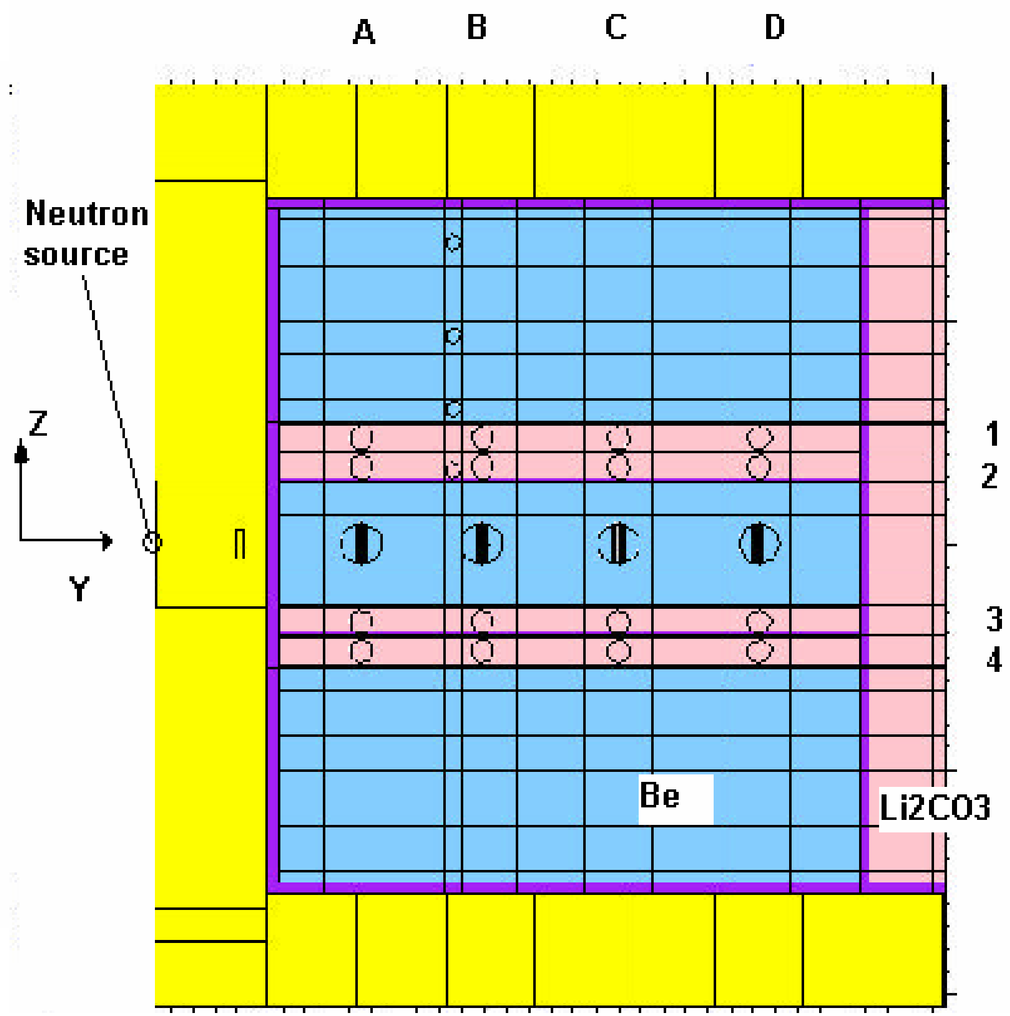
Calculational tools

Discrete ordinates transport computer codes:

- First collision source code GRTUNCL-3D: neutron transport in air
- TORT (S-8 & 16, P-5, 3D X-Y-Z geometry): geometry translated from 3 MCNP inputs (2000 lines each)
- SUSD3D sensitivity & uncertainty package; new version of the code now available from NEA DB

FNG TBM Benchmark



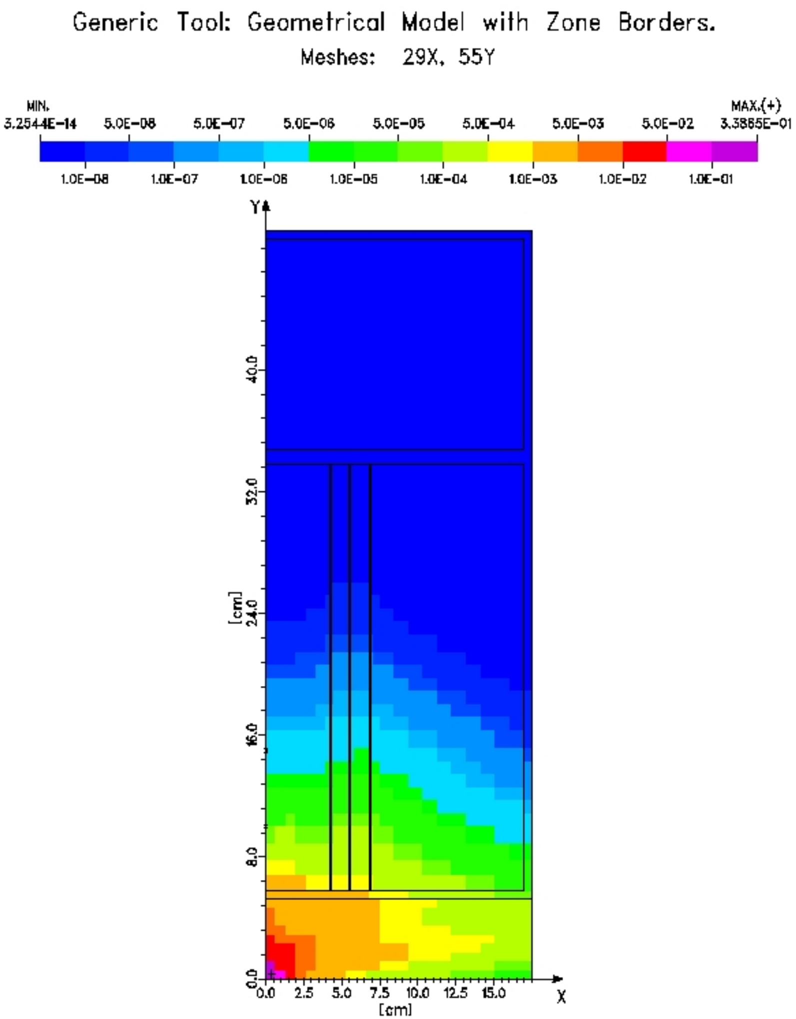


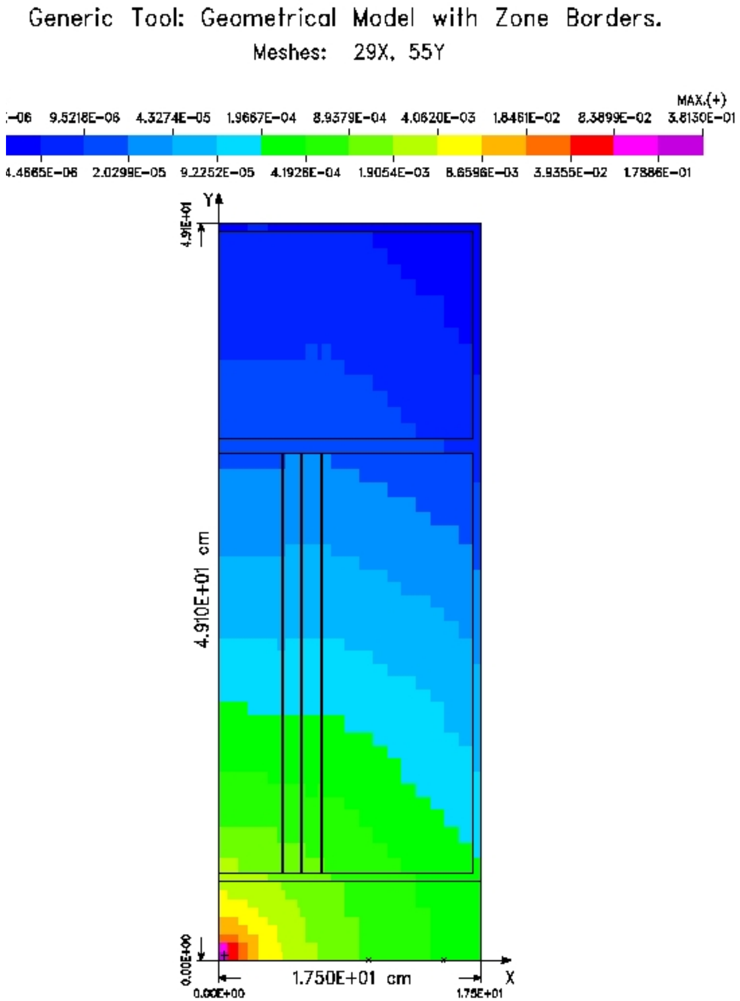
Detector positions:

A: y= 4.2 cm **B**: y= 10.5 cm

C: y= 16.8 cm **D**: y= 23.1 cm

Ray effect mitigation





Contribution of the uncollided flux

TORT/FENDL-2.1: S-16,P5

Uncollided and 1st collision contribution					
Y(cm)	^{27}Al(n,α)	^{58}Ni(n,p)	^{93}Nb(n,2n)	^{197}Au(n,γ)	$^{6+7}$Li(n,t)
4.2 (A)	52.8%	33.7%	57.7%	0.0%	16.6%
10.5 (B)	25.3%	12.3%	29.8%	0.0%	2.4%
16.8(C)	13.4%	5.4%	16.9%	0.0%	0.6%
23.1 (D)	7.5%	2.6%	10.0%	0.0%	0.2%

TORT comparison with measured RR

RR [/(n s)] - C/E (EFF3 / FENDL2.1)				
Posit. [cm]	**^{27}Al(n,α)**	**^{58}Ni(n,p)**	**^{93}Nb(n,2n)**	**^{197}Au(n,γ)**
~4.2 (A)	**1.06**	**1.00 / 1.03**	**1.01**	**1.03 / 1.04**
~10.5 (B)	**1.05**	**0.98 / 1.03**	**0.99 / 0.98**	**1.02 / 1.03**
~16.8 (C)	**1.02 / 1.03**	**0.91 / 0.97**	**0.99 / 0.97**	**1.05 / 1.07**
~23.1 (D)	**0.99 / 1.00**	**0.94 / 1.02**	**1.01 / 0.99**	**1.10 / 1.12**

TORT/S-16, P-5

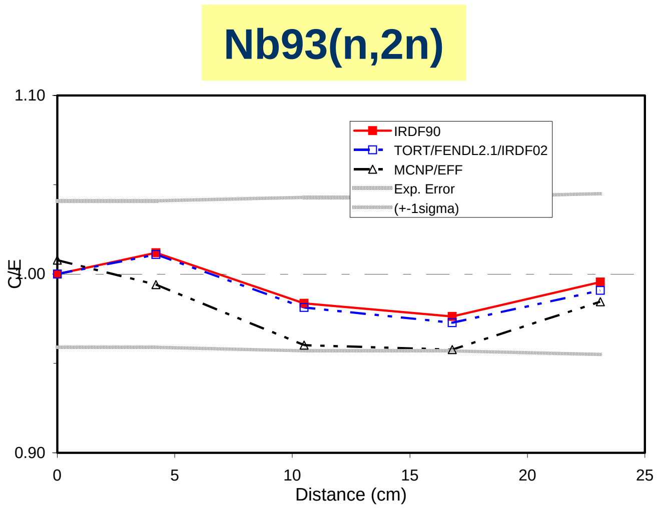
Au-197: d=0.03mm, N=5.895E22 at/cm3

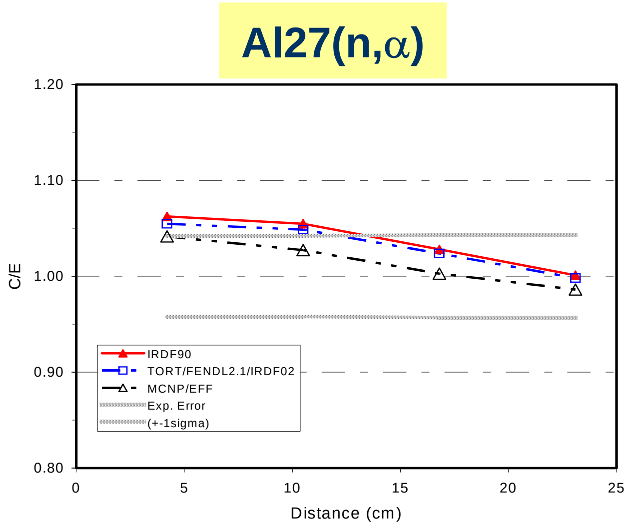
Comparison JEFF-3.1/FENDL2.1 for detector responses and TPR

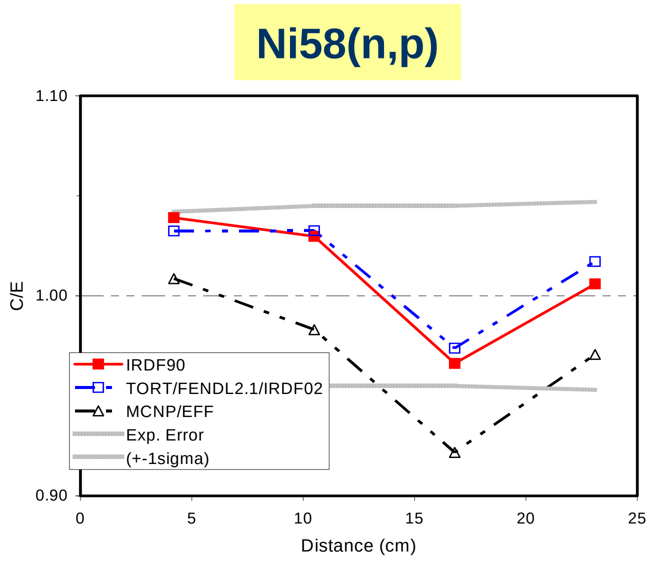
TORT/FENDL-2.1 & EFF-3.0 (Be-9):S-16c, P5

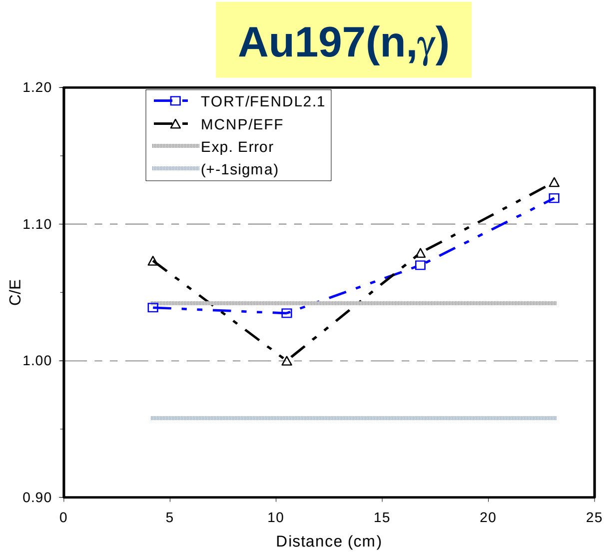
RR [/(n s)] - EFF-3.0 / FENDL-2.1 (TORT)							
Posit. [cm]	$^{27}Al(n,\alpha)$	$^{58}Ni(n,p)$	$^{93}Nb(n,2n)$	$^{197}Au(n,\gamma)$	$^{6}Li(n,t)$	$^{7}Li(n,t)$	$^{6+7}Li(n,t)$
~4.2 (A)	1.00	0.97	1.00	0.99	1.02	0.99	1.01
~10.5 (B)	1.00	0.95	1.01	0.99	1.00	0.98	1.00
~16.8 (C)	1.00	0.93	1.01	0.98	0.99	0.96	0.99
~23.1 (D)	1.00	0.92	1.02	0.98	0.99	0.96	0.99

C/E comparison (TORT)

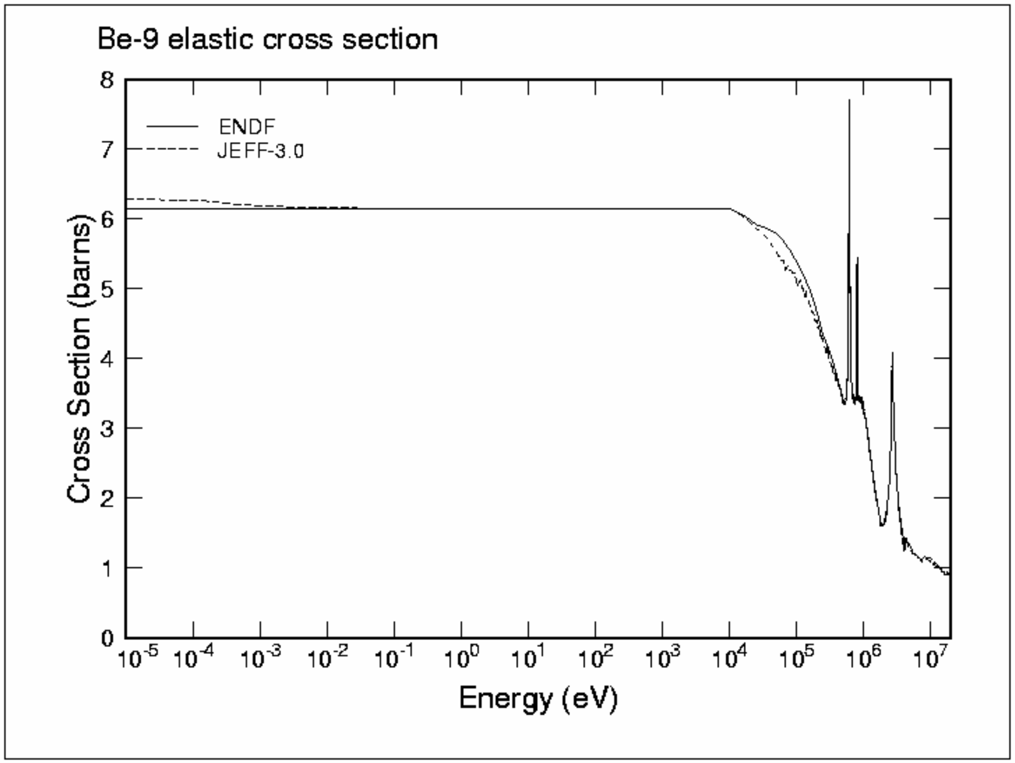


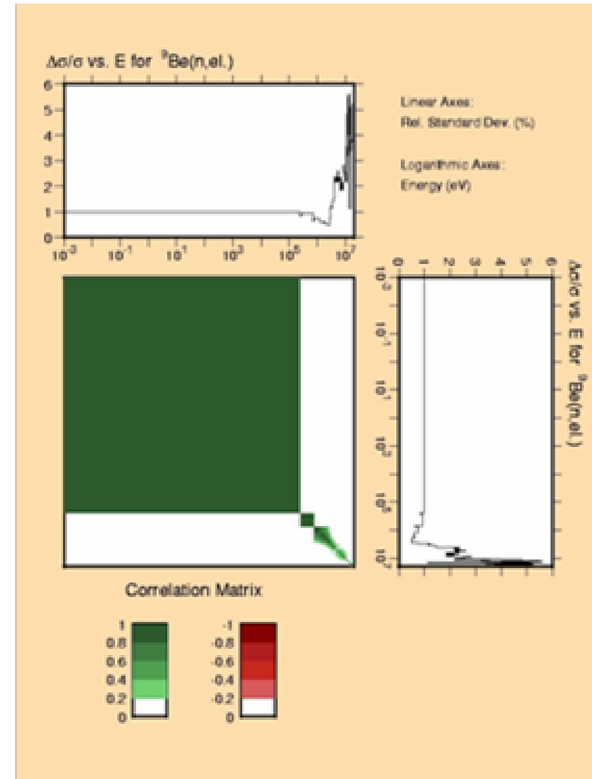




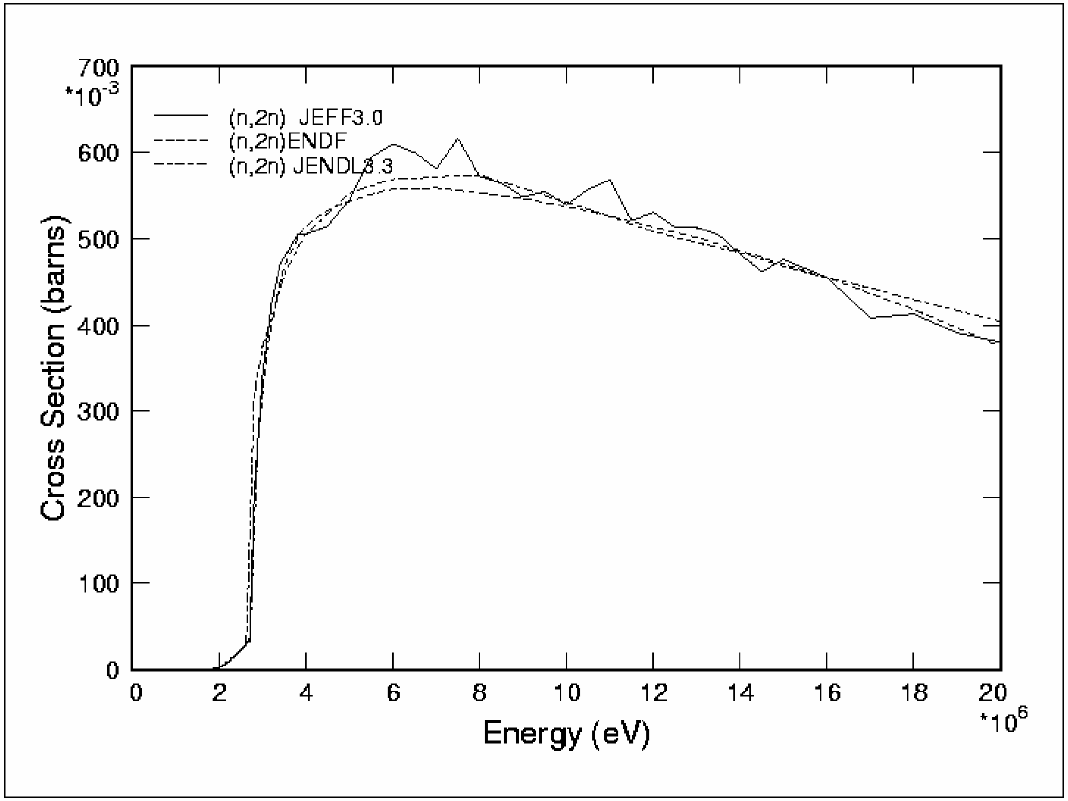


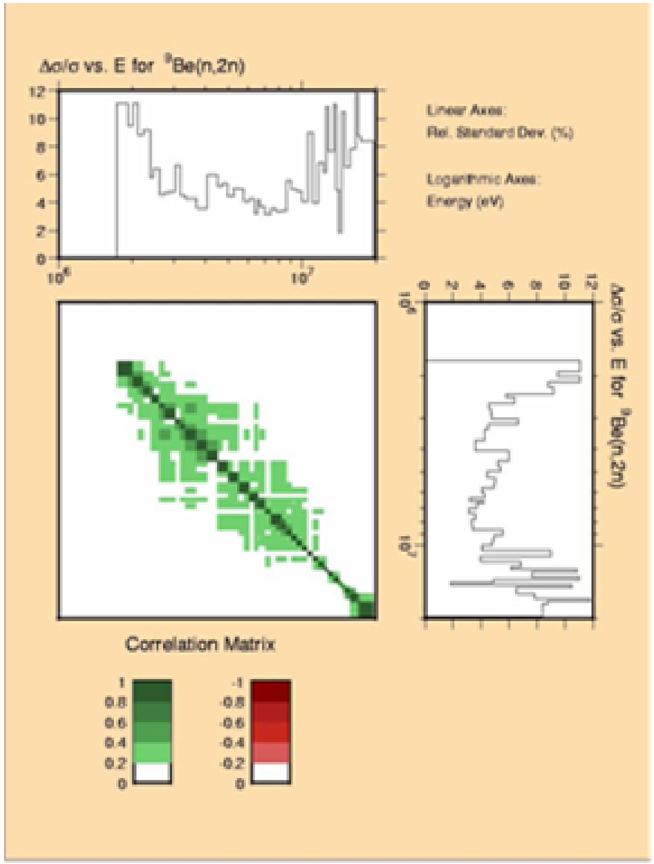
Differences between Be-9 cross section evaluations



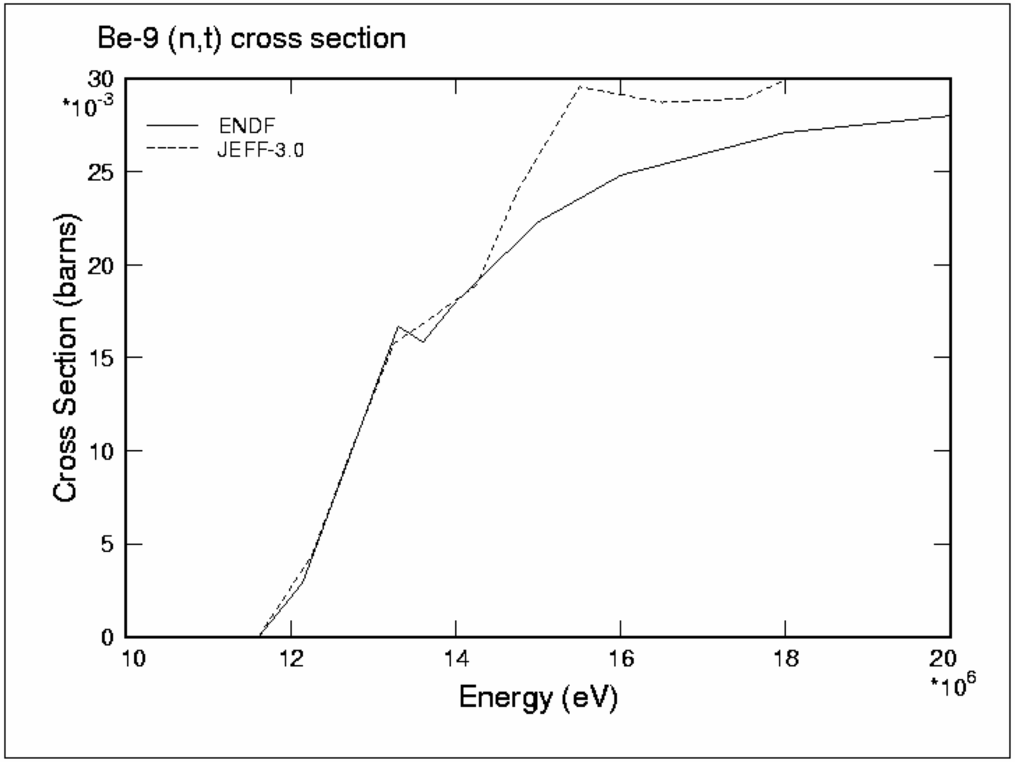


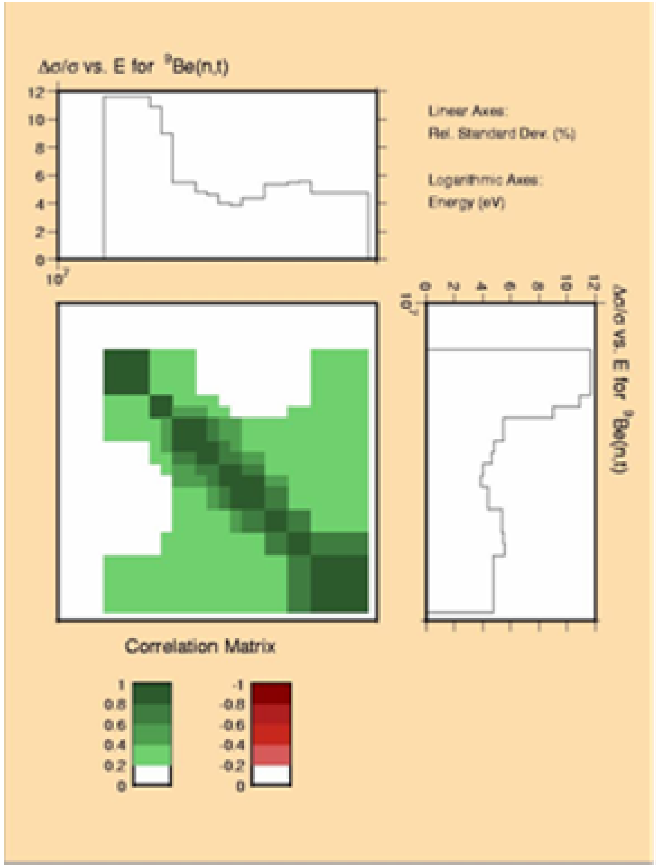
Differences between Be-9 cross section evaluations



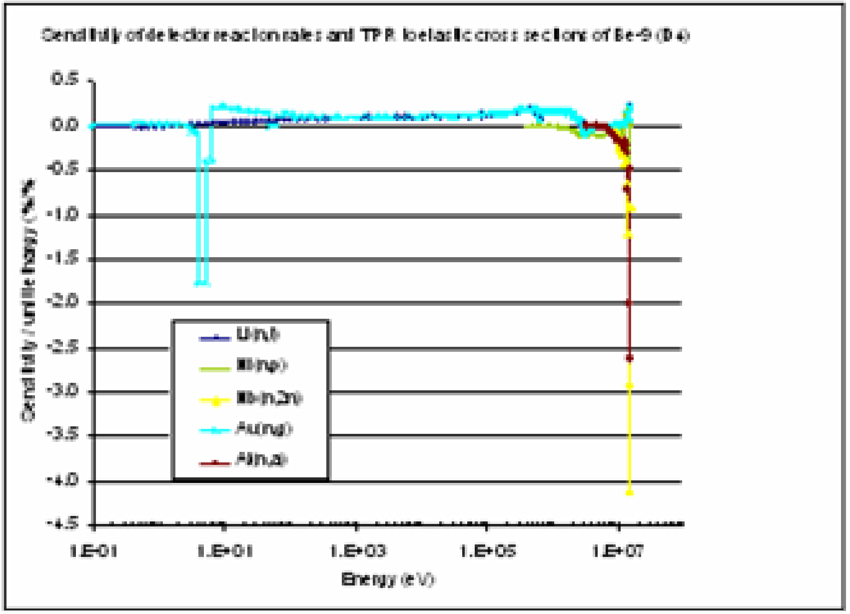


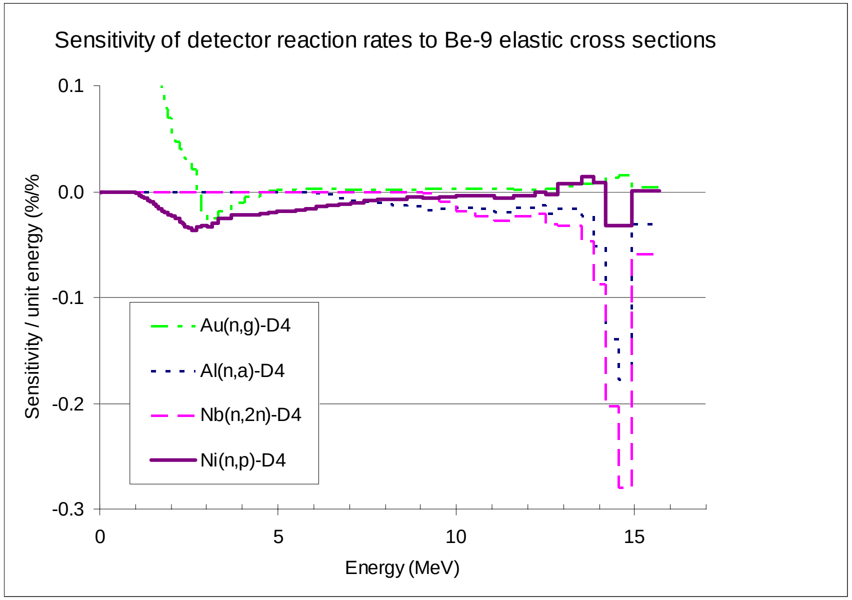
Differences between Be-9 cross section evaluations

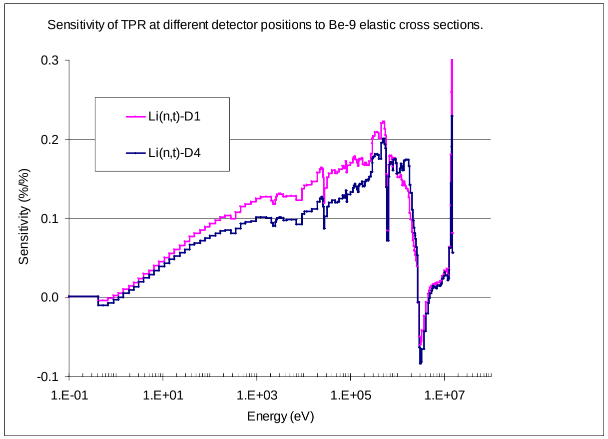




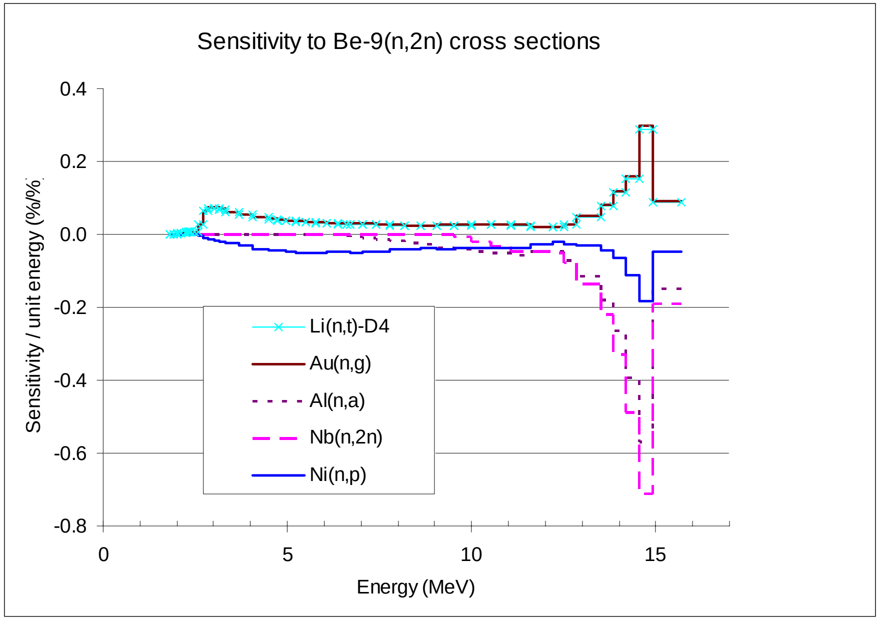
Sensitivity to Be-9 elastic cross-sections (SUSD3D analysis)

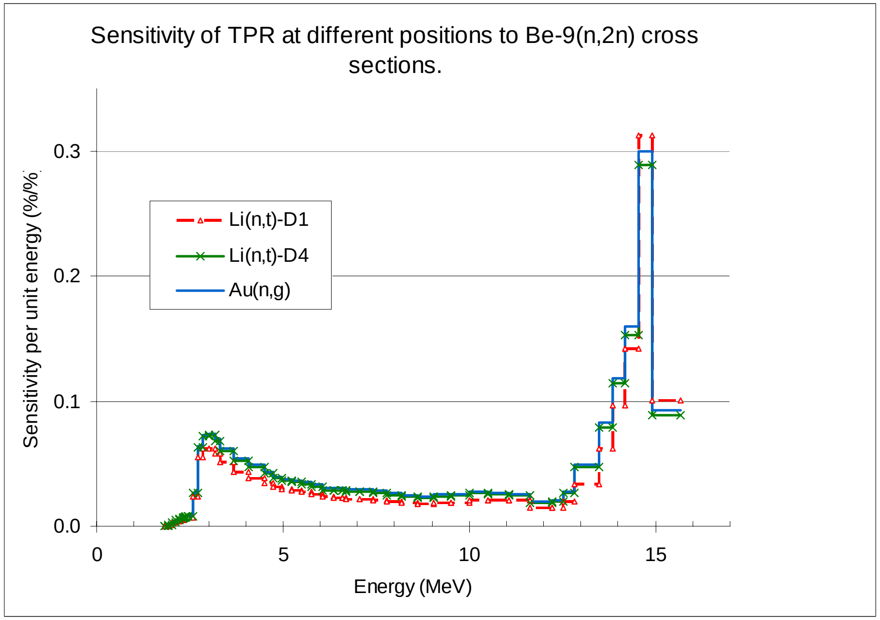






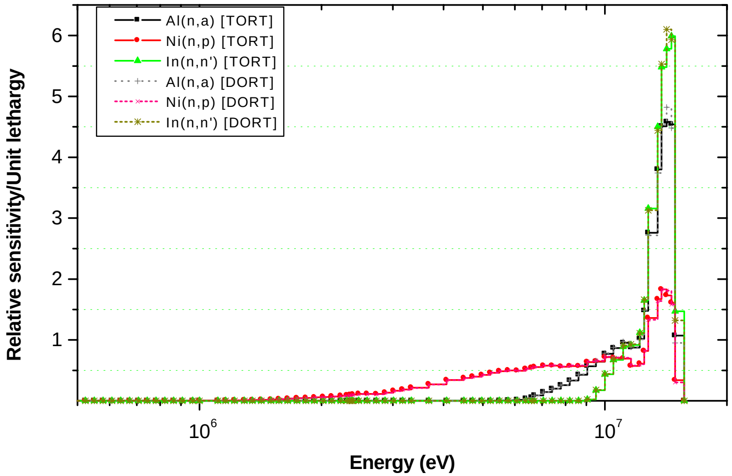
Sensitivity to Be-9 (n,2n) cross-sections (SUSD3D)



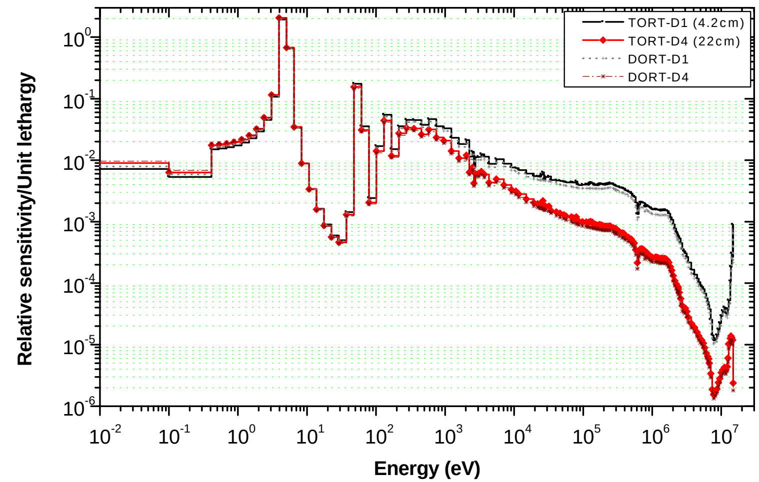


Comparisons 2D/3D sensitivities (SUSD3D)

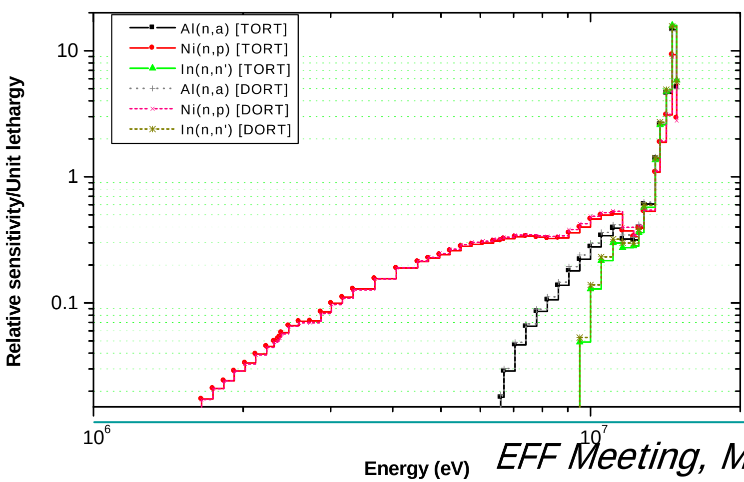
Sensitivity of detector reaction rates to detector response functions (direct sensitivity term) (D4 position ~22cm).

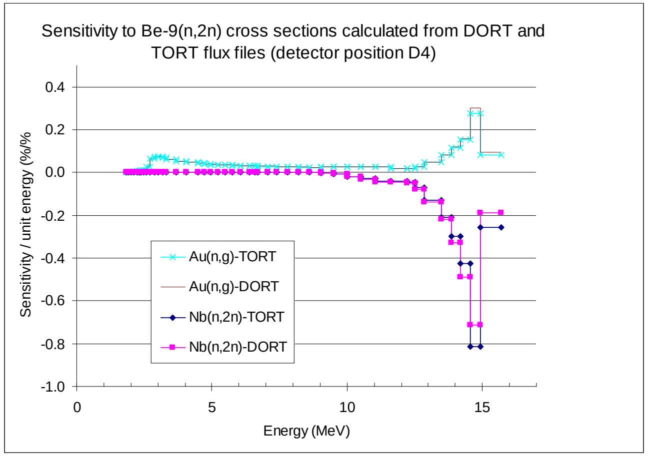


FNG TBM exp.: Sensitivity of Au197(n,g) reaction rate to detector response functions (direct sensitivity term).



Sensitivity of detector reaction rates to detector response functions (direct sensitivity term) (D1 position ~ 4.2 cm).





Sensitivity to cross-sections (SUSD3D analysis)

Elem.	Reaction	Sensitivity (%/%)			2D (3D)		
		TPR Y=23.1 cm	TPR Y=4.2 cm	^{197}Au(n,γ) Y=23.1 cm	^{27}Al(n,α) Y=23.1 cm	^{58}Ni(n,p) Y=23.1 cm	^{93}Nb(n,2n) Y=23.1 cm
^{9}Be	Tot	1.99 (1.95)	2.22	1.90 (1.82)	-1.25	-0.83	-1.41 (-1.48)
	El.	1.40 (1.39)	1.68	1.27 (1.32)	-0.27	-0.17	-0.36 (-0.39)
	(n,2n)	0.66 (0.62)	0.59	0.69 (0.55)	-0.92	-0.58	-0.99 (-1.02)
	(n,t)	-0.02 (-0.02)	-0.01	-0.02 (-0.01)	-0.04	-0.03	-0.04 (-0.04)
	(n,α)	-0.05 (-0.04)	-0.03	-0.05 (-0.04)	-0.03	-0.05	-0.02 (-0.02)
^{6}Li	(n,αt)	0.13 (0.29)	0.22	-0.28 (-0.28)			
	Inel.					-0.002	
^{7}Li	El.	0.02 (0.03)	0.02	0.02		0.005	
	(n,2n)	0.001 (0.001)	0.001	0.001		-0.002	
	Inel.	0.001 (0.001)	0.001	0.001		-0.001	
	(n,n'αt)	0.03 (0.03)	0.24			-0.014	
^{12}C	Tot.	0.02					
	El.	0.02					
	Inel.	-0.001					
	(n,α)	-0.002					
^{16}O	Tot.	0.04					
	El.	0.06					
	Inel.	-0.01					
	(n,p)	-0.002					
	(n,α)	-0.01					

Sensitivity & uncertainty to cross-sections (SUSD3D analysis)

Elem.	Reaction / position	Calculational uncertainty (%) 2D (3D)					
		TPR Y=4.2 cm	TPR Y=23.1 cm	^{27}Al(n,α) Y=23.1 cm	^{197}Au(n,γ) Y=23.1 cm	^{58}Ni(n,p) Y=23.1 cm	^{93}Nb(n,2n) Y=23.1 cm
^{9}Be	EFF-3 ENDF/B-V	2.2 5.6	2.1 5.4	3.0 8.6	2.1 (1.5) 5.3 (4.5)	1.3 3.6	3.5 (4.0) 10.4 (11.2)
^{6}Li	IRDF90 MT105 ENDF/B-V MT2,105	0.04 0.12	0.02 0.06		0.04 0.12	0.002 0.004	< 0.01
^{7}Li	Vitam.J/cova ENDF/B-VI.8	1.0 0.3	 0.1		0.1 0.05		 0.09
^{12}C	Vitam.J/cova		0.02-0.2$				
^{16}O	JENDL3.3		0.2				

Conclusions

- TORT/GRTUNCL-3D computational scheme, new version of SUSD3D.f90.
- Good general C/E agreement, but rather large differences (up to 8%) observed betwwen Ni-58(n,p) RR calculated using FENDL-2.0/-2.1 and JEFF-3.1 Be-9 file. JEFF-3.1 gives up to 4 % lower Li7(n,t) than FENDL-2.1.

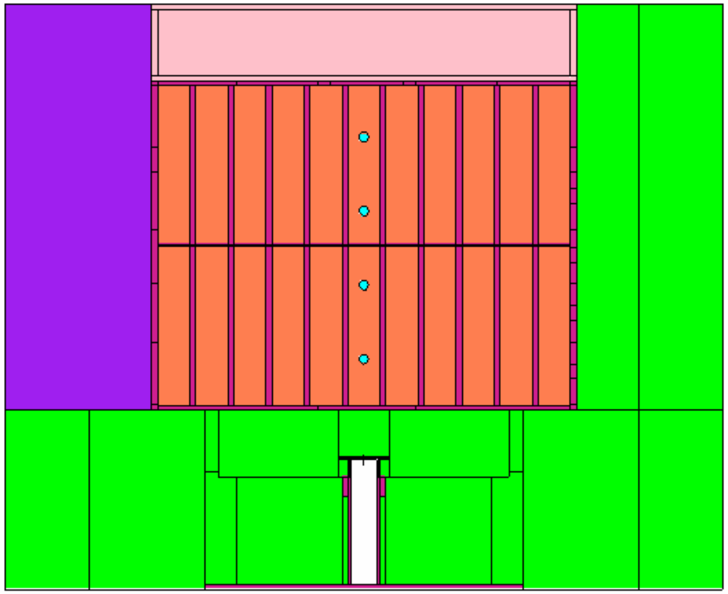
Suggested improvements:

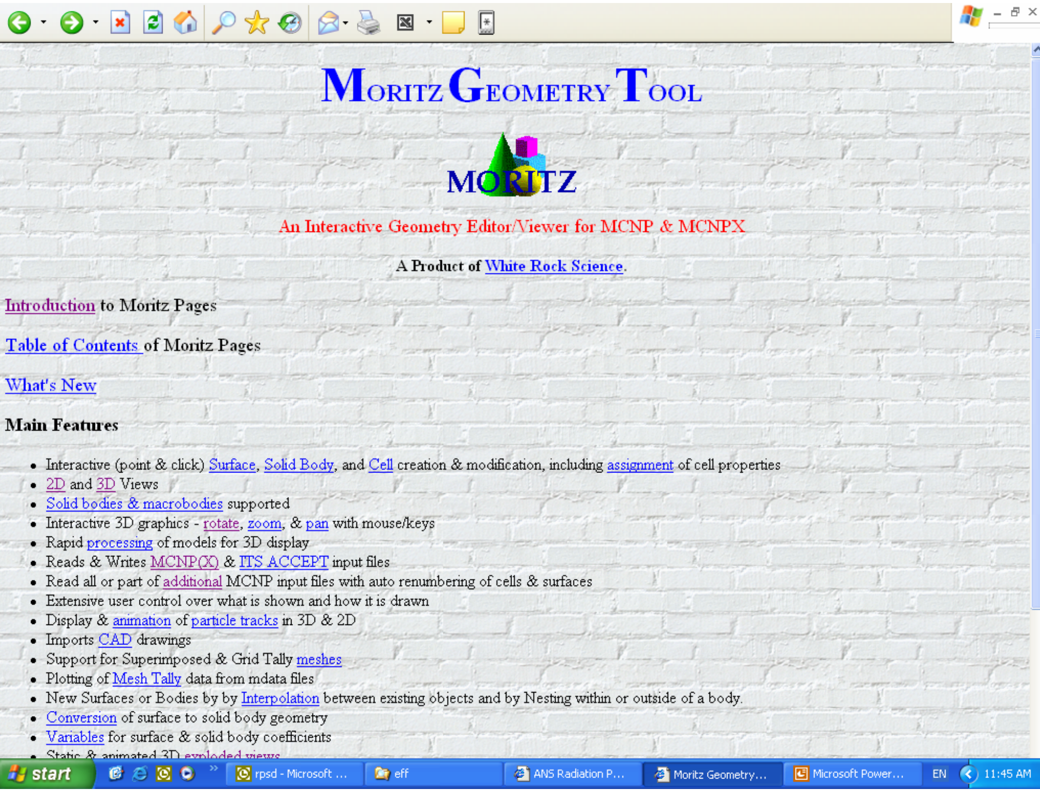
- EFF-3 Be-9 file: (n,2n), elastic XS and covariance matrices should be revisited.
- Li-7 covariances in ENDF/B-VI should be checked (MT=2, 4, (852))

Elem.	Reaction	Li(n,t) TPR		^{197}Au(n,γ)		^{58}Ni(n,p)	
		Sensitivity (%/%)	Δ (%)	Sensitivity (%/%)	Δ (%)	Sensitivity (%/%)	Δ (%)
^{9}Be	Tot El. (n,2n)	1.99 1.40 0.66	2.1^{*} - $5.4^{\#}$	1.90 1.27 0.69	2.1^{*} - $5.3^{\#}$	-0.83 -0.17 -0.58	1.3^{*} - $3.6^{\#}$
^{6}Li	(n,αt)	0.13	<0.1	-0.28	~0.1		< 0.01
^{7}Li	(n,n'αt) El.	0.03 0.02	0.1	0.02	~0.1	-0.01 0.005	0.1
^{12}C	Tot.	0.02	0.2				
^{16}O	Tot.	0.04	0.2				

HCLL Test Blanket module mock-up

Preparation for the design of a HCLL Test Blanket module mock-up for neutronics studies using deterministic analysis, in order to assess the uncertainty on TPR due to uncertainty in the relevant nuclear data.





Moritz user can import blueprints or plans in the form of bitmap images. Any point on the plan can be chosen as the center of the coordinate system and the scale set to the dimensions of the drawing. Using the mouse, one then positions surfaces, such as planes, spheres, cylinders, and cones over the image. Alternatively, one can specify the absolute coordinates of the surface or the distance from another surface. The three orthogonal views allow a complete specification of the geometry.

Additional capabilities include automatic mesh generation, volume fraction calculations in rectangular and cylindrical grids overlying a combinatorial geometry model, and a material library. A material mixing algorithm used with the volume fraction capability can be used to generate a voxelized representation of a model. At present, the voxelized model can only be written in MCNP format; we plan to format the data for use in other codes such as the discrete ordinates PARTISN program.