Introduction

The calculations for the ITER Neutron Streaming Experiment of the Shielding Integral Benchmark Archive and Database (SINBAD 2000), maintained by the Radiation Safety Information Computational Center (RSICC), were performed with Attila. This calculation is a reproduction of a neutronics experiment of the International Thermonuclear Experimental Reactor (ITER) shielding system irradiated with an anisotropic neutron source. Various reaction rates were measured by foils embedded in the shield and along a streaming path.

Problem Summary

Figure 1 shows the quarter symmetric geometry of the neutron streaming experiment assembly. The neutron source is located at (-5.31 cm, 0 cm, 0 cm), shown as the red dot below (on-axis case). Calculations were also performed with an off-axis neutron source (see Ref. 2 for complete source specification).

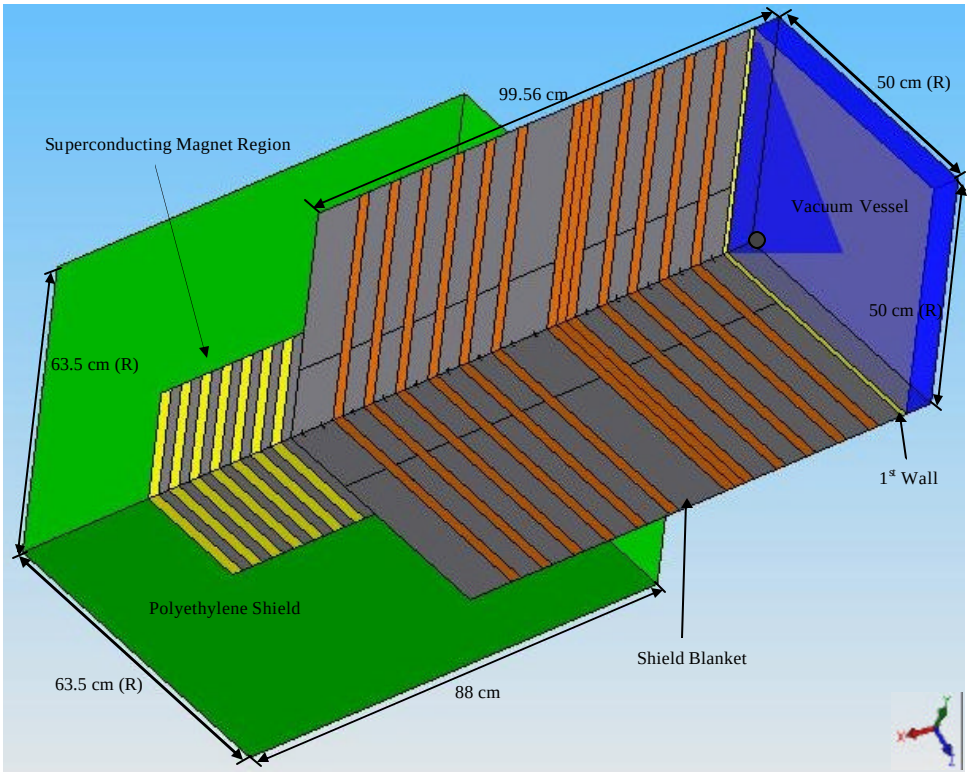

Figure 1: ITER mock-up geometry

This model is exactly like the neutron streaming experiment, except that there is no streaming channel present. The base of the model containing the point source is representative of the ITER vacuum vessel (air - blue) with 1 cm thick copper layer (yellow). This is followed by alternating slabs of AISI-316 stainless steel (grey) and the water equivalent Perspex material (red) representative of the ITER shielding blanket. This is followed by alternating slabs of AISI-316 stainless steel and copper representing the superconducting magnet region. The end of the mock-up is encased by a polyethylene block (green). The material compositions are listed in Ref. [2] and in the Attila input files. A ¼ symmetry model was used in the calculation (as shown in Figure 1). The reflected size of the vacuum vessel / shield blanket assembly is 99.56 cm x 100 cm x 100 cm and the reflected size of the polyethylene shield is 88 cm x 127 cm x 127 cm.

Neutron Source

The neutron source was produced by a 230 keV deuteron beam incident on a T-Ti target as produced by the Frascati Neutron Generator. This source was simulated as an angular dependent anisotropic point source. The energy and angle distribution can be found in Ref [2] and in the Attila anisotropic point source file (eighteen_srcs.ptsrc.inp).

Measurement Locations

Reaction rate measurements were obtained by activation of foils in the channel and shield blanket. These foils were explicitly modeled in the Attila calculation. Figure 2 shows the relative locations of the 14 foils in the mock-up geometry (some of the shield blanket has been made transparent to reveal the foils.

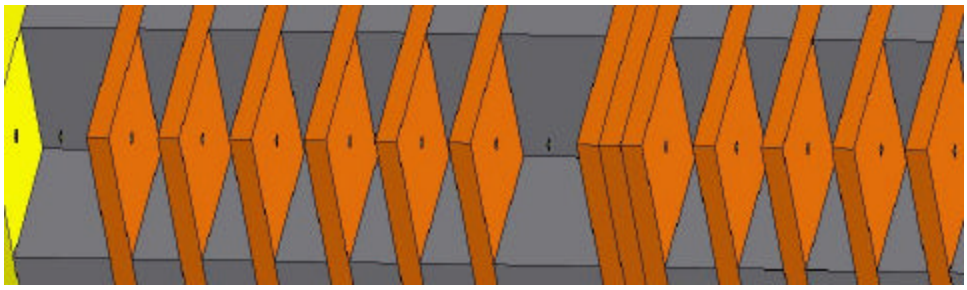

Figure 2: Foil locations in ITER mock-up assembly

Attila Calculation

The following specifies some parameters of the Attila calculation:

- Source: Anisotropic Point
- Geometry:
  - ¼ Symmetry: 35,000 tetrahedral cells
- Cross Section Library:
  - FENDL2.1: 171 neutron groups (15.683 MeV – 1E-11 MeV)
- Quadrature: Triangular Chebychev Legendre, S_{12}, S_{16}
- Scattering Expansion: Galerkin, P_3, P_5
- Response Functions : IRDF-90

Results

Eight different reaction rates were calculated with Attila using the IRDF-90 response function: ^{93}Nb(n,2n), ^{27}Al(n,a), ^{58}Ni(n,p), ^{197}Au(n,?), ^{58}Ni(n,2n), ^{155}In(n,n'), ^{56}Fe(n,p) and ^{55}Mn(n,g). Tables 1 through 8 give the experimentally measured reaction rate values, percent experimental uncertainty (E.U. %), and calculated reaction rate values using MCNP were taken from Ref [2]. The calculated reaction rate values using Attila are given along with the Attila calculated to experimentally measured ratio (Attila C/E) and the Attila / MCNP ratio. Both the MCNP and Attila calculations were performed using FENDL-2 cross sections.

^{93}Nb(n,2n) Reaction Rate							
Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
3.53	3.33E-04	4.0	3.31E-04	3.38E-04	0.12	0.994	0.977
10.42	5.48E-05	4.5	5.19E-05	5.27E-05	0.31	0.946	0.985
17.25	1.34E-05	4.5	1.20E-05	1.22E-05	0.52	0.897	0.985
24.05	3.80E-06	4.5	3.34E-06	3.41E-06	0.78	0.880	0.981
30.9	1.21E-06	4.5	1.06E-06	1.09E-06	1	0.876	0.971
42.15	2.69E-07	6.0	2.05E-07	2.09E-07	1.6	0.763	0.984
47.15	1.04E-07	6.0	8.57E-08	9.02E-08	1.8	0.825	0.950
54.1	3.64E-08	6.0	2.91E-08	3.01E-08	2.4	0.799	0.968
60.85	1.21E-08	7.0	1.04E-08	1.07E-08	2.9	0.856	0.970
67.7	4.51E-09	8.0	3.73E-09	4.40E-09	3.6	0.828	0.848
74.7	1.44E-09	9.0	1.33E-09	1.44E-09	4.1	0.922	0.921
81.4	5.10E-10	10.0	4.99E-10	5.03E-10	5	0.978	0.992
88.3	2.27E-10	15.0	1.95E-10	1.95E-10	5.7	0.858	0.999
92.2	1.44E-10	15.0	9.97E-11	1.01E-10	6	0.692	0.983

Table 1: ^{93}Nb(n,2n) Reaction Rate

^{27}Al(n,a) Reaction Rate							
Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
3.53	8.50E-05	3.5	8.27E-05	8.55E-05	0.12	0.973	0.968
10.42	1.47E-05	3.5	1.36E-05	1.39E-05	0.31	0.923	0.978
17.25	3.60E-06	4.0	3.26E-06	3.32E-06	0.51	0.905	0.981
24.05	1.07E-06	4.0	9.32E-07	9.54E-07	0.75	0.871	0.977
30.9	3.44E-07	4.0	3.02E-07	3.13E-07	0.98	0.879	0.968
42.15	7.06E-08	5.0	6.12E-08	6.22E-08	1.47	0.867	0.983
47.15	2.94E-08	5.0	2.56E-08	2.68E-08	1.7	0.870	0.955
54.1	1.09E-08	6.0	8.80E-09	9.02E-09	2.1	0.808	0.976
60.85	3.71E-09	7.0	3.17E-09	3.27E-09	2.6	0.854	0.968
74.7	4.72E-10	10.0	4.15E-10	4.44E-10	3.7	0.880	0.935
81.4	2.13E-10	15.0	1.58E-10	1.55E-10	4.6	0.743	1.022

Table 2: ^{27}Al(n,a) Reaction Rate

^{58}Ni(n,p) Reaction Rate							
Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
3.43	3.02E-04	3.5	3.03E-04	3.23E-04	0.15	1.004	0.940
10.32	6.42E-05	3.6	6.33E-05	6.58E-05	0.32	0.985	0.962
17.15	1.80E-05	4.0	1.75E-05	1.81E-05	0.49	0.970	0.967
23.95	5.85E-06	4.5	5.48E-06	5.64E-06	0.65	0.937	0.973
30.8	2.02E-06	4.5	1.90E-06	1.96E-06	0.82	0.938	0.969
41.85	4.57E-07	5.0	4.14E-07	4.26E-07	1.2	0.905	0.972
46.85	2.00E-07	8.0	1.79E-07	1.87E-07	1.3	0.896	0.957
53.8	6.15E-08	8.0	6.29E-08	6.48E-08	1.7	1.023	0.970
60.55	2.74E-08	9.0	2.30E-08	2.45E-08	1.9	0.840	0.939
67.4	8.84E-09	8.0	8.54E-09	8.78E-09	2.4	0.966	0.972
74.4	3.58E-09	10.0	3.12E-09	3.31E-09	2.7	0.872	0.944
81.1	1.27E-09	12.0	1.22E-09	1.13E-09	3.2	0.959	1.078
88	6.01E-10	15.0	5.02E-10	4.49E-10	3.5	0.836	1.120
91.9	3.64E-10	15.0	2.67E-10	2.39E-10	3.7	0.735	1.118

Table 3: ^{58}Ni(n,p) Reaction Rate

^{197}Au(n,?) Reaction Rate							
Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
3.53	6.37E-03	4.0	6.32E-03	7.01E-03	0.02	0.992	0.901
10.42	9.72E-03	4.0	1.00E-02	1.03E-02	0.01	1.029	0.971
17.25	5.50E-03	4.0	5.85E-03	6.03E-03	0.01	1.063	0.970
24.05	2.44E-03	4.0	2.68E-03	2.71E-03	0.01	1.096	0.987
30.9	9.47E-04	4.5	1.04E-03	9.94E-04	0.02	1.103	1.051
42.15	1.65E-04	4.5	1.86E-04	1.93E-04	0.03	1.126	0.963
47.15	6.64E-05	4.5	8.14E-05	7.47E-05	0.03	1.225	1.089
54.1	3.76E-05	5.0	4.51E-05	4.10E-05	0.03	1.200	1.100
60.85	1.71E-05	5.0	1.98E-05	1.77E-05	0.03	1.159	1.119
67.7	6.82E-06	5.0	7.65E-06	7.81E-06	0.03	1.121	0.979
74.7	2.68E-06	5.5	3.00E-06	2.45E-06	0.03	1.121	1.226
81.4	1.12E-06	5.5	1.30E-06	1.13E-06	0.05	1.159	1.149
88.3	3.66E-07	6.5	5.61E-07	3.56E-07	0.05	1.532	1.575
92.2	1.71E-07	8.5	2.81E-07	1.65E-07	0.07	1.645	1.704

Table 4: ^{197}Au(n,?) Reaction Rate

^{58}Ni(n,2n) Reaction Rate							
Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
3.53	2.87E-05	3.5	2.82E-05	2.72E-05	0.11	0.981	1.037
10.42	4.15E-06	3.6	4.06E-06	3.93E-06	0.29	0.978	1.033
17.25	9.73E-07	4.0	8.78E-07	8.58E-07	0.52	0.903	1.023
24.05	2.57E-07	4.5	2.30E-07	2.27E-07	0.79	0.894	1.012
30.9	8.18E-08	4.5	6.88E-08	6.90E-08	1.06	0.841	0.997

Table 5: ^{58}Ni(n,2n) Reaction Rate

^{155}In(n,n') Reaction Rate							
Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
3.37	2.15E-04	3.5	1.86E-04	2.01E-04	0.21	0.867	0.926
10.32	5.97E-05	4.0	5.18E-05	5.42E-05	0.34	0.867	0.955
17.15	1.89E-05	4.5	1.62E-05	1.70E-05	0.45	0.859	0.955
23.95	6.59E-06	4.5	5.45E-06	5.62E-06	0.56	0.826	0.970
30.80	2.30E-06	5.0	1.95E-06	2.00E-06	0.7	0.846	0.971
41.85	6.06E-07	6.0	4.04E-07	4.20E-07	1	0.667	0.962
46.85	2.30E-07	6.0	2.02E-07	2.09E-07	1.1	0.877	0.963
53.98	8.87E-08	8.5	7.04E-08	7.20E-08	1.3	0.793	0.977
60.81	3.34E-08	9.0	2.56E-08	2.58E-08	1.4	0.768	0.992
67.68	1.61E-08	10.0	9.58E-09	9.64E-09	1.8	0.595	0.993
74.71	7.00E-09	12.0	3.52E-09	3.59E-09	1.9	0.502	0.979
81.39	2.51E-09	15.0	1.38E-09	1.29E-09	2.2	0.549	1.073

Table 6: ^{155}In(n,n') Reaction Rate

^{56}Fe(n,p) Reaction Rate							
Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
3.43	8.47E-05	3.0	7.85E-05	8.14E-05	0.12	0.926	0.963
10.32	1.41E-05	3.0	1.28E-05	1.32E-05	0.3	0.910	0.974
17.15	3.51E-06	3.5	3.07E-06	3.14E-06	0.51	0.875	0.978
23.95	1.03E-06	3.5	8.77E-07	9.00E-07	0.74	0.851	0.975
30.8	3.31E-07	4.0	2.84E-07	2.94E-07	0.96	0.857	0.967
41.85	6.61E-08	4.5	5.72E-08	5.84E-08	1.4	0.865	0.980
46.85	2.80E-08	5.5	2.39E-08	2.51E-08	1.7	0.854	0.951
53.8	1.00E-08	7.0	8.21E-09	8.45E-09	2.1	0.821	0.971
60.55	3.67E-09	8.0	2.95E-09	3.04E-09	2.6	0.804	0.970
67.4	1.30E-09	10.5	1.07E-09	1.15E-09	3.2	0.826	0.936
74.4	4.50E-10	12.0	3.85E-10	4.14E-10	3.7	0.857	0.931
81.1	1.21E-10	15.0	1.47E-10	N/A	N/A	1.211	N/A

Table 7: ^{56}Fe(n,p) Reaction Rate

^{55}Mn(n,?) Reaction Rate							
Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
3.53	2.49E-04	4.5	2.32E-04	2.64E-04	1.0	0.933	0.880
10.42	4.86E-04	4.0	3.73E-04	4.39E-04	1.0	0.767	0.849
17.25	2.97E-04	4.5	2.23E-04	2.61E-04	1.0	0.752	0.855
24.05	1.36E-04	4.5	1.12E-04	1.22E-04	1.0	0.821	0.915
30.9	5.19E-05	5.0	4.40E-05	4.96E-05	1.0	0.847	0.887
42.15	1.00E-05	6.0	1.00E-05	1.05E-05	1.0	0.999	0.955
47.15	3.12E-06	6.0	2.45E-06	2.34E-06	1.0	0.787	1.049
54.1	2.00E-06	7.0	1.63E-06	1.75E-06	2.0	0.816	0.930
60.85	8.40E-07	7.0	7.63E-07	7.73E-07	2.0	0.909	0.987
67.7	3.47E-07	8.0	2.73E-07	3.23E-07	2.0	0.788	0.845
74.7	1.27E-07	10.0	1.14E-07	1.18E-07	2.0	0.897	0.964
81.4	5.55E-08	12.0	5.07E-08	4.63E-08	2.0	0.913	1.094

Table 8: ^{55}Mn(n,?) Reaction Rate

In the above tables “N/A” indicates that the experimental measured data was not available at the location for the reaction rate of interest.

Files

The files necessary to run this calculation can be made available upon request.

References

[1] **abs.txt**, P. Batistoni, M. Angelone, M. Pillon, L. Petrizzi, ENEA: Centro Ricerche Energie, Frascati, Italy
[2] **exp.txt**, P. Batistoni, M. Angelone, M. Pillon, L. Petrizzi, ENEA: Centro Ricerche Energie, Frascati, Italy

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