



## Introduction

The calculations for the ITER Benchmark Experiment on Tungsten of the Shielding Integral Benchmark Archive and Database (SINBAD 2000) kept by the Radiation Safety Information Computational Center (RSICC) were performed with Attila. This calculation is a reproduction of the neutronics mock-up of the International Thermonuclear Experimental Reactor (ITER) shielding system irradiated with an anisotropic neutron source. Foils embedded in the shield were used to measure various reaction rates.

## Problem Summary

Figure 1 gives the quarter symmetric geometry of the ITER mock-up assembly. The anisotropic point source is located at (-5.31 cm, 0 cm, 0 cm) represented by the red dot (see Ref. [2] for complete source specification).

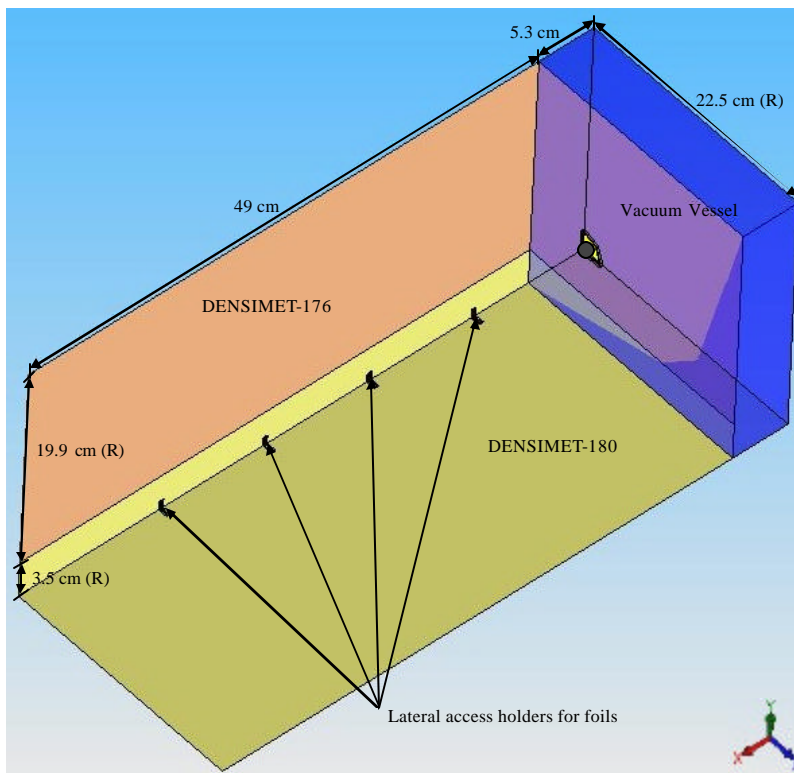


Figure 1: ITER mock-up geometry

The base of the model containing the point source is representative of the ITER vacuum vessel. The shield is made of two similar types of a tungsten based alloy called DENSIMET. Ref. [2] gives the compositions of both DENSIMET-179 and DENSIMET-180.

Figure 1 shows that the reflected size of the mock-up geometry is 54.3 cm x 46.8 cm x 45 cm. The foil assembly modeled in each of the lateral access holders shown in Figure 1 is shown in Figure 2.

## Neutron Source

The source of neutrons were those 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 anisotropic point source in both angle and energy. The energy and angle distribution can be found in Ref [2] or in the Attila anisotropic point source input (eighteen\_srcs.ptsrc.inp).



## Measurement Locations

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Reaction rate measurements were taken by activation of foils embedded in the Tungsten alloy shield. These foils were simulated in the Attila calculation. Figure 2 shows the foil assemblies used in each of the four lateral access holders.

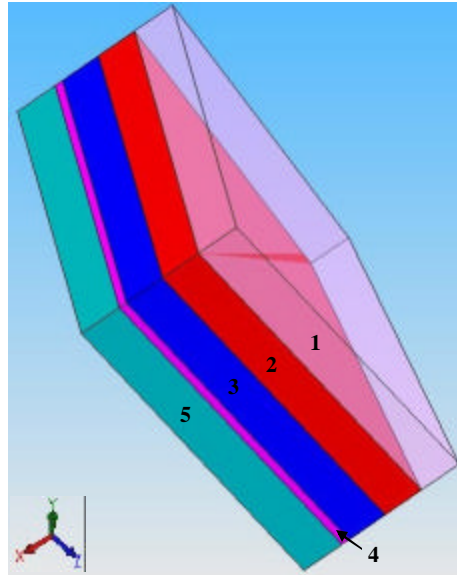


Figure 2: Foil assembly in lateral access holders in ITER mock-up assembly

Figure 2 shows each of the foil regions 1-5 composing the foil assembly. Table 1 shows the material used and thickness of each foil and the corresponding Attila calculation.

Foil	Calculation: NbNiAu		Calculation: ZrAlMn		Calculation: FeIn	
	Material	Foil Thickness (cm)	Material	Foil Thickness (cm)	Material	Foil Thickness (cm)
1	Void	0.11	Void	0.11	Void	0.11
2	<sup>93</sup> Nb	0.10	<sup>90</sup> Zr	0.10	Fe	0.10
3	<sup>58</sup> Ni	0.10	Al	0.10	Fe	0.10
4	<sup>107</sup> Au	0.01	<sup>55</sup> Mn	0.02	<sup>107</sup> Au	0.01
5	Al	0.12	Al	0.11	Al	0.12

Table 1: Foil materials and thickness and corresponding Attila calculation

## Attila Calculation

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The following specifies some parameters of the Attila calculation:

- ☉ Source: Anisotropic Point
- ☉ Geometry: ¼ Symmetry: 14,600 tetrahedral cells
- ☉ Cross Section Library:
  - ☉ FENDL2.1: 171 neutron groups (15.683 MeV – 1E-11 MeV)
- ☉ Quadrature: Triangular Chebychev Legendre, S<sub>12</sub>
- ☉ Scattering Expansion: Galerkin, P<sub>3</sub>
- ☉ Response Functions : IRDF-90



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### Results

Nine reaction rates were calculated with Attila using the IRDF-90 response function:  $^{93}\text{Nb}(n,2n)$ ,  $^{58}\text{Ni}(n,2n)$ ,  $^{90}\text{Zr}(n,2n)$ ,  $^{27}\text{Al}(n,a)$ ,  $^{56}\text{Fe}(n,p)$ ,  $^{58}\text{Ni}(n,p)$ ,  $^{115}\text{In}(n,n')$ ,  $^{197}\text{Au}(n,?)$ , and  $^{55}\text{Mn}(n,?)$ . Tables 2a and 2b 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. The reported MCNP results are those calculated with FENDL-2 cross sections, except those indicated by a (\*) where the only available results were those using FENDL-1 cross section data.

Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
$^{93}\text{Nb}(n,2n)$ Reaction Rate							
4.94	1.88E-04	4	1.64E-04	1.82E-04	0.44	0.87	0.90
14.94	1.04E-05	5	9.89E-06	9.99E-06	0.84	0.95	0.99
24.94	9.95E-07	5	9.19E-07	8.45E-07	1.5	0.92	1.09
34.94	1.08E-07	6	9.95E-08	8.14E-08	2.85	0.92	1.22
$^{58}\text{Ni}(n,2n)$ Reaction Rate							
5.04	1.49E-05	4	1.37E-05	1.40E-05	0.5	0.92	0.98
15.04	8.15E-07	4.5	7.84E-07	7.29E-07	0.95	0.96	1.08
25.04	7.19E-08	5.5	6.90E-08	5.90E-08	1.75	0.96	1.17
35.04	N/A	N/A	7.14E-09	5.64E-09	2.85	N/A	1.27
$^{90}\text{Zr}(n,2n)$ Reaction Rate							
4.94	3.06E-04	4.4	2.83E-04	3.06E-04	0.54	0.92	0.92
14.94	1.76E-05	5	1.64E-05	1.57E-05	1.06	0.93	1.05
24.94	1.57E-06	5.5	1.48E-06	1.32E-06	1.91	0.94	1.12
34.94	1.76E-07	6	1.56E-07	1.23E-07	3	0.89	1.27
$^{27}\text{Al}(n,a)$ Reaction Rate							
5.04	4.45E-05	4	4.02E-05	4.51E-05	0.6	0.90	0.89
15.04	2.72E-06	5	2.52E-06	2.54E-06	1	0.92	0.99
25.04	2.53E-07	6	2.39E-07	2.30E-07	1.8	0.95	1.04
35.04	2.78E-08	6.5	2.65E-08	2.25E-08	3.3	0.95	1.18
$^{56}\text{Fe}(n,p)$ Reaction Rate							
4.94	4.56E-05	5	3.89E-05	4.38E-05	0.38	0.85	0.89
14.94	2.79E-06	5	2.41E-06	2.48E-06	0.7	0.86	0.97
24.94	2.62E-07	5.5	2.29E-07	2.17E-07	1.29	0.87	1.05
34.94	2.91E-08	6.4	2.52E-08	2.18E-08	2.35	0.87	1.16

Table 2a: Reaction rate results



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Foil Position	Experiment	E.U. (%)	Attila	MCNP	MCNP % Uncertainty	Attila C/E	Attila / MCNP
$^{58}\text{Ni}(n,p)$ Reaction Rate							
5.04	1.58E-04	4.5	1.47E-04	1.71E-04	0.49	0.93	0.86
15.04	1.16E-05	5.5	1.11E-05	1.22E-05	0.82	0.95	0.91
25.04	1.14E-06	5.5	1.14E-06	1.21E-06	1.45	1.00	0.94
35.04	1.35E-07	5.5	1.32E-07	1.33E-07	2.6	0.98	0.99
$^{115}\text{In}(n,n')$ Reaction Rate							
5.04	1.38E-04	4.6	1.15E-04	1.29E-04	0.51	0.83	0.89
15.04	1.50E-05	5.5	1.21E-05	1.43E-05	0.61	0.80	0.84
25.04	1.67E-06	5.7	1.39E-06	1.74E-06	0.94	0.83	0.80
35.04	N/A	N/A	N/A	N/A	N/A	N/A	N/A
$^{197}\text{Au}(n,?)$ Reaction Rate							
5.09	6.23E-04	4	5.26E-04	6.45E-04	0.4	0.84	0.82
15.09	2.98E-04	4	2.46E-04	3.05E-04	0.18	0.83	0.81
25.09	1.03E-04	4	9.08E-05	1.06E-04	0.17	0.88	0.86
35.09	2.84E-05	5.5	3.00E-05	3.10E-05	0.3	1.06	0.97
$^{55}\text{Mn}(n,?)$ Reaction Rate							
5.1	1.67E-05	5	2.37E-05	2.72E-05	0.7	1.42	0.87
15.1	8.74E-06	5	1.17E-05	1.40E-05	0.24	1.34	0.84
25.1	3.30E-06	5.5	4.64E-06	5.24E-06	0.2	1.41	0.89
35.1	1.04E-06	6.4	1.64E-06	1.63E-06	0.4	1.58	1.01

Table 2b: Reaction rate results

## Files

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The files necessary to run this calculation are available to current Attila users from [www.attilasupport.com](http://www.attilasupport.com) as [iter\\_tungsten.tar.gz](http://iter_tungsten.tar.gz). All the files are listed in Table 3 below.



## Attila Benchmark Calculations ITER Benchmark Experiment on Tungsten (SINBAD 2000)

Attila Files for ITER Benchmark Experiment on Tungsten	
Main Directory Files	File Description
eighteen_srcs.ptsrc.inp	Anisotropic point source file
fendl_xs_aux.inp	Auxiliary cross section input file for FENDL 2.1
fendl_xs.inp	Cross section input file for FENDL 2.1
w-exp_nbniau.mesh.inp	Mesh file for FSDSFeIn and FSDSNbNiAu directory (see below)
w-exp_zrarmn.mesh.inp	Mesh file for FSDSZrAIMn directory (see below)
FSDSFeIn Directory Files	File Description
FeIn-coll.attila.inp	Attila input file for the collided component of the solution
FeIn-coll.edit.inp	Edit input file for the collided component of the solution
FeIn-uncol.attila.inp	Attila input file for the uncollided component of the solution
FeIn-uncol.edit.inp	Edit input file for the uncollided component of the solution
FSDSFeIn.attila.inp	Attila input file for the merged solution (uncollided + collided)
FSDSFeIn.edit.inp	Edit input file for the merged solution (uncollided + collided)
run.sh	run script
FSDSNbNiAu Directory Files	File Description
NbNiAu-coll.attila.inp	Attila input file for the collided component of the solution
NbNiAu-coll.edit.inp	Edit input file for the collided component of the solution
NbNiAu-uncol.attila.inp	Attila input file for the uncollided component of the solution
NbNiAu-uncol.edit.inp	Edit input file for the uncollided component of the solution
FSDSNbNiAu.attila.inp	Attila input file for the merged solution (uncollided + collided)
FSDSNbNiAu.edit.inp	Edit input file for the merged solution (uncollided + collided)
run.sh	run script
FSDSZrAIMn Directory Files	File Description
ZrAIMn-coll.attila.inp	Attila input file for the collided component of the solution
ZrAIMn-coll.edit.inp	Edit input file for the collided component of the solution
ZrAIMn-uncol.attila.inp	Attila input file for the uncollided component of the solution
ZrAIMn-uncol.edit.inp	Edit input file for the uncollided component of the solution
FSDSZrAIMn.attila.inp	Attila input file for the merged solution (uncollided + collided)
FSDSZrAIMn.edit.inp	Edit input file for the merged solution (uncollided + collided)
run.sh	run script

## References

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- [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

## Acknowledgements

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Transpire, Inc. would like to thank Paola Batistoni at ENEA in Frascati, Italy for providing the details of this benchmark.