



Attila Code-to-Code Comparison Subcritical Spent Nuclear Fuel Canister with Primary Neutron and Gamma Sources

Introduction

An example spent nuclear fuel canister calculation was performed with Attila, with results compared to the MCNPX Monte Carlo code. The canister contained representative subcritical neutron and gamma sources simulating spent nuclear fuel. Fission was accounted for in the subcritical assembly, and secondary gamma sources were also calculated from neutron capture and transported. Dose was compared at various point locations inside and outside of the canister.

Problem Summary

Figure 1 illustrates a 90 degree cutout of the canister geometry. The neutron source is applied to the 360.17 cm high cylindrical homogenized spent fuel region (1). Above the spent fuel region is a 29.77 cm thick plenum (2), followed by a 19.98 cm thick homogenized top end fitting (TEF) (3). Below the fuel is a 10.07 cm thick homogenized bottom end fitting (BEF) (4). Regions (1) through (4) are all cylinders with a radius of 83.82 cm. A 0.635 cm thick stainless steel liner (5) fully encompasses the canister.

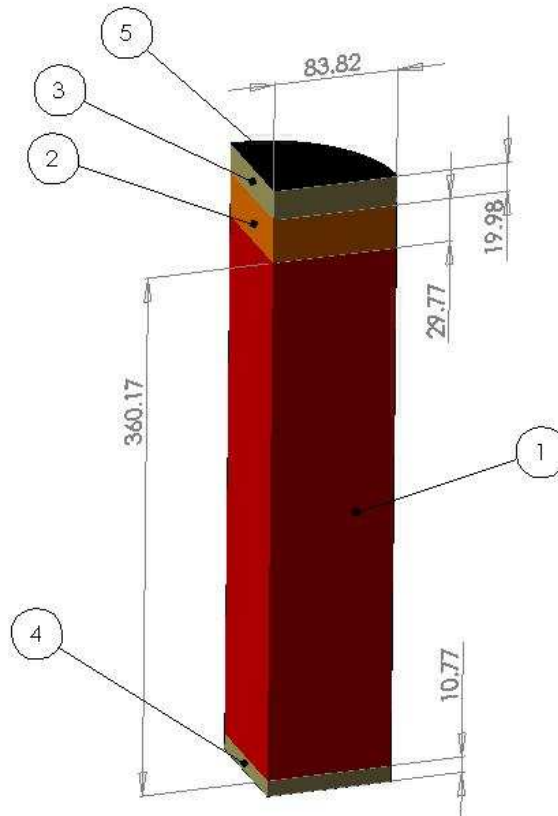


Figure 1: 90 degree cutout of the canister geometry, including: (1) spent fuel region, (2) plenum, (3) TEF, (4) BEF, and (5) 0.635 cm thick stainless steel liner. All dimensions are in cm.

The canister was centered in a 900 cm high by 600 cm diameter air cylinder. Figure 2 provides the relative locations of the measurement (edit) points where results were compared. Coordinates of these points are provided in Table 1.



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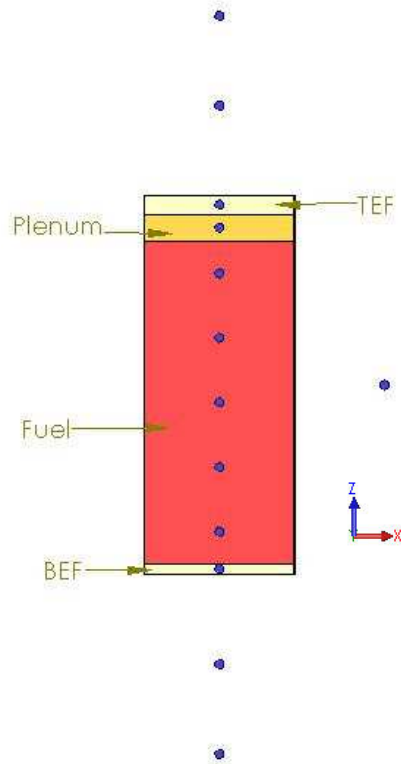


Figure 2: Canister geometry, coordinate system triad, and relative location of solution edit points (blue)

Point Edit Coordinates				
Edit #	x (cm)	y (cm)	z (cm)	Region
1	0	0	6.02	BEF
2	0	0	47.42	Fuel
3	0	0	119.46	Fuel
4	0	0	191.49	Fuel
5	0	0	263.53	Fuel
6	0	0	335.56	Fuel
7	0	0	386.46	Plenum
8	0	0	411.65	TEF
9	0	0	-200	Air
10	0	0	-100	Air
11	185	0	211	Air
12	285	0	211	Air
13	0	0	522	Air
14	0	0	622	Air

Table 1: Solution edit point locations

The primary source, consisting of both neutrons and gammas, represents a homogenized PWR assembly with 5% initial enrichment after an 80 GWd/MTU burn-up cycle and 5 years of cooling. The primary neutron source, described in Table 2, is distributed uniformly throughout the homogenized spent fuel region.



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Primary Neutron Source		
Energy Group		Source Strength (n/s)
Emin	Emax	Fuel
0.1	0.4	8.05E+07
0.4	0.9	4.11E+08
0.9	1.4	3.76E+08
1.4	1.85	2.76E+08
1.85	3	4.85E+08
3	6.43	4.43E+08
6.43	20	3.93E+07
Total (n/s)		2.11E+09

Table 2: Primary neutron source

The primary gamma source, described in Table 3, is located in the bottom end fitting (BEF), fuel, plenum, and top end fitting (TEF) regions.

Primary Gamma Source					
Energy Group		Source Strength (g/s)			
Emin	Emax	BEF	Fuel	Plenum	TEF
0.01	0.05	5.94E+11	2.33E+15	5.28E+11	3.79E+11
0.05	0.1	1.16E+11	6.44E+14	6.09E+10	7.43E+10
0.1	0.2	2.83E+10	5.22E+14	3.52E+10	1.79E+10
0.2	0.3	1.41E+09	1.48E+14	1.96E+09	8.91E+08
0.3	0.4	1.90E+09	9.85E+13	5.86E+09	1.17E+09
0.4	0.6	1.91E+09	1.53E+15	1.10E+11	7.41E+07
0.6	0.8	4.35E+09	4.70E+15	5.95E+10	2.37E+09
0.8	1	1.37E+11	7.08E+14	8.03E+09	7.66E+10
1	1.33	3.38E+13	4.55E+14	1.74E+13	2.17E+13
1.33	1.66	9.53E+12	1.30E+14	4.91E+12	6.12E+12
1.66	2	1.87E+03	1.44E+12	9.19E+02	1.13E+03
2	2.5	2.26E+08	2.49E+12	1.16E+08	1.45E+08
2.5	3	3.51E+05	1.10E+11	1.81E+05	2.25E+05
3	4	7.66E-08	1.39E+10	1.00E-08	4.16E-08
4	5	0.00E+00	7.09E+07	0.00E+00	0.00E+00
5	6.5	0.00E+00	2.86E+07	0.00E+00	0.00E+00
6.5	8	0.00E+00	5.58E+06	0.00E+00	0.00E+00
8	10	0.00E+00	1.19E+06	0.00E+00	0.00E+00
Total (g/s)		4.42E+13	1.13E+16	2.31E+13	2.84E+13

Table 3: Primary gamma source



Attila Calculation Summary

For both Attila and MCNP, two separate calculations were performed: (1) a coupled neutron gamma calculation from the primary neutron source, allowing for fission and neutron capture creating secondary gamma sources, and transport of the secondary gammas; and (2) a gamma calculation from the primary gamma source. Although these calculations could have been performed through a single calculation in either Attila or MCNP, but were kept separate so as to isolate the contribution to the total gamma dose from the secondary gammas created from neutron capture.

The Attila computational mesh contained approximately 34,000 elements. Since four spatial unknowns are solved in each tetrahedral element, this equates to approximately 136,000 spatial degrees of freedom. All 47 energy groups of the Radion15 cross section set (22 neutron, 25 gamma) were used in the coupled neutron-gamma calculation, and all 25 gamma groups were used in the primary gamma calculation. In both calculations, the Triangular Chebychev Legendre quadrature set was used with an S_{16} quadrature order. The scattering order for the coupled neutron-gamma calculation was P_2 , with P_5 used in the primary gamma calculation.

Attila results were calculated at points with and without the use of the last collided method, which semi-analytically transports the last scattered flux to the associated edit points.

Results

Section plots of the neutron, secondary gamma flux, and primary gamma flux are provided in Figures 3 and 4.

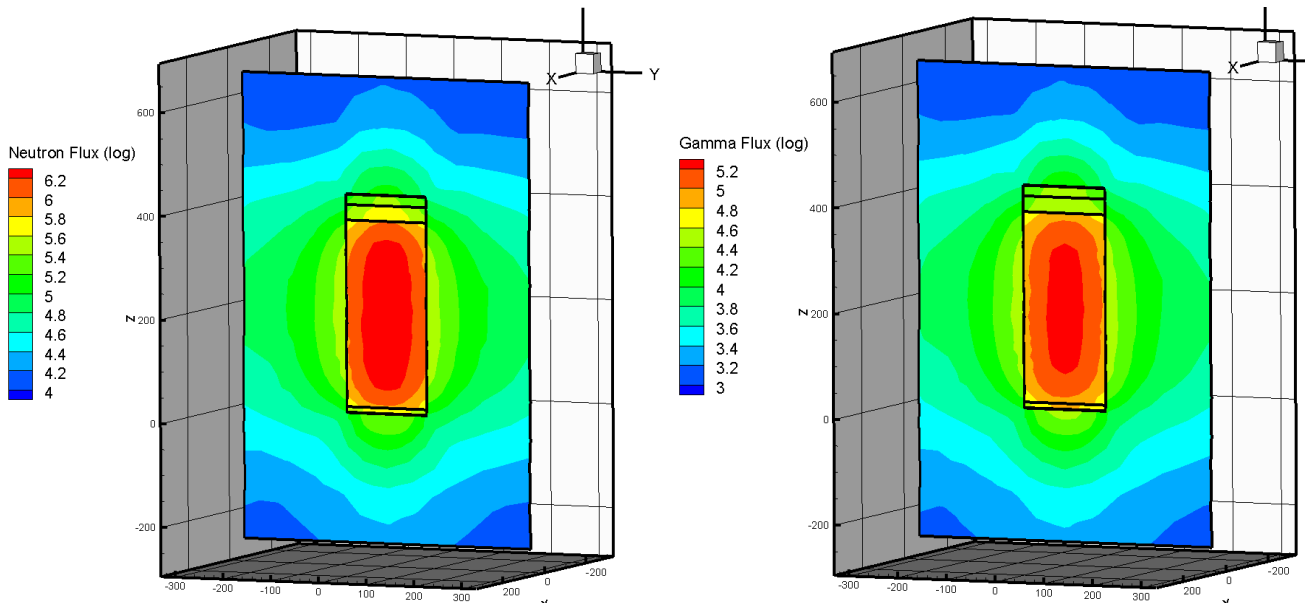


Figure 3: Total neutron flux (left) and secondary gamma flux (right)



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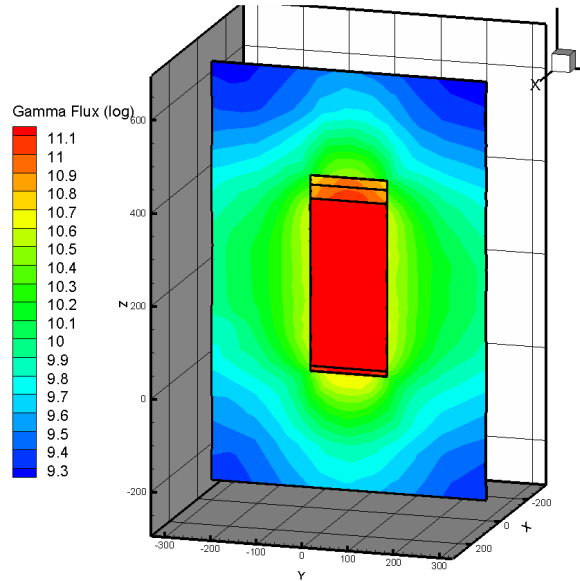


Figure 4: Primary gamma flux

Results are provided in Tables 4-9, for both Attila and MCNPX.

The primary neutron dose is presented in Tables 4 and 5.

Detector location (cm)			Neutron Dose (REM/HR)					
			MCNPX (1.25E9 Histories)				Attila	Attila/MCNPX % Difference
			Dose	R.E.	VOV	10 Tests Passed?	Dose	
0	0	6.02	4.488E+01	0.0003	0.0000	Y	4.580E+01	2.05%
0	0	47.42	1.265E+02	0.0003	0.0000	Y	1.265E+02	0.01%
0	0	119.46	1.607E+02	0.0003	0.0000	Y	1.625E+02	1.17%
0	0	191.49	1.651E+02	0.0003	0.0000	Y	1.680E+02	1.77%
0	0	263.53	1.603E+02	0.0003	0.0000	Y	1.620E+02	1.04%
0	0	335.56	1.248E+02	0.0003	0.0000	Y	1.261E+02	1.04%
0	0	386.46	3.685E+01	0.0002	0.0000	Y	3.837E+01	4.14%
0	0	411.65	2.266E+01	0.0003	0.0000	Y	2.178E+01	-3.91%
0	0	-200	2.101E+00	0.0001	0.0000	N	2.034E+00	-3.19%
0	0	-100	5.750E+00	0.0001	0.0000	N	5.569E+00	-3.15%
185	0	211	1.023E+01	0.0000	0.0000	Y	9.775E+00	-4.43%
285	0	211	4.898E+00	0.0000	0.0000	Y	4.670E+00	-4.66%
0	0	522	3.098E+00	0.0001	0.0000	Y	3.067E+00	-0.99%
0	0	622	1.270E+00	0.0001	0.0000	Y	1.248E+00	-1.67%

Table 4: Primary neutron results



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Detector location (cm)			Neutron Dose (REM/HR)				
			MCNPX	Attila	Attila-LC	Attila/MCNPX % Difference	Attila-LC/MCNPX % Difference
0	0	-200	2.101E+00	2.154E+00	2.03E+00	2.54%	-3.19%
0	0	-100	5.750E+00	5.491E+00	5.57E+00	-4.51%	-3.15%
185	0	211	1.023E+01	9.799E+00	9.77E+00	-4.19%	-4.43%
285	0	211	4.898E+00	4.769E+00	4.67E+00	-2.64%	-4.66%
0	0	522	3.098E+00	3.133E+00	3.07E+00	1.13%	-0.99%
0	0	622	1.270E+00	1.322E+00	1.25E+00	4.13%	-1.67%

Table 5: Primary neutron results, comparing use of the last collided (LC) method

Dose results for the secondary gammas are shown in Tables 6 and 7.

Detector location (cm)			Capture Gamma Dose (REM/HR)					
			MCNPX (1.25E9 Histories)				Attila	
			Dose	R.E.	VOV	10 Tests Passed?	Dose	% Difference
0	0	6.02	1.293E-01	0.0035	0.2033	N	1.328E-01	2.74%
0	0	47.42	3.010E-01	0.0178	0.9288	N	3.181E-01	5.67%
0	0	119.46	3.948E-01	0.0048	0.2595	N	4.260E-01	7.91%
0	0	191.49	4.127E-01	0.0099	0.8924	N	4.454E-01	7.92%
0	0	263.53	3.929E-01	0.0032	0.0580	N	4.242E-01	7.94%
0	0	335.56	2.899E-01	0.0045	0.2821	N	3.158E-01	8.94%
0	0	386.46	6.951E-02	0.0015	0.0381	N	7.140E-02	2.73%
0	0	411.65	5.652E-02	0.0018	0.0822	N	5.716E-02	1.13%
0	0	-200	4.869E-03	0.0009	0.2152	N	4.832E-03	-0.77%
0	0	-100	1.413E-02	0.0006	0.0184	N	1.400E-02	-0.92%
185	0	211	2.212E-02	0.0005	0.0471	N	2.264E-02	2.35%
285	0	211	1.052E-02	0.0008	0.2937	N	1.076E-02	2.23%
0	0	522	6.744E-03	0.0008	0.0386	N	6.802E-03	0.86%
0	0	622	2.554E-03	0.0009	0.3375	N	2.565E-03	0.45%

Table 6: Secondary gamma results

Detector location (cm)			Capture Gamma Dose (REM/HR)				
			MCNPX	Attila	Attila-LC	Attila/MCNPX % Difference	Attila-LC/MCNPX % Difference
0	0	-200	4.869E-03	5.139E-03	4.832E-03	5.55%	-0.77%
0	0	-100	1.413E-02	1.379E-02	1.400E-02	-2.43%	-0.92%
185	0	211	2.212E-02	2.268E-02	2.264E-02	2.53%	2.35%
285	0	211	1.052E-02	1.098E-02	1.076E-02	4.36%	2.23%
0	0	522	6.744E-03	6.984E-03	6.802E-03	3.55%	0.86%
0	0	622	2.554E-03	2.732E-03	2.565E-03	6.99%	0.45%

Table 7: Secondary gamma results, comparing use of the last collided (LC) method

Dose results for the primary gamma calculation are provided in Tables 8 and 9.



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Detector location (cm)			Primary Gamma Dose (REM/HR)						
			MCNPX (1.2E9 Histories)				Attila	Attila-MCNPX % Difference	
			Dose	R.E.	VOV	10 Tests Passed?	Dose		
0	0	6.02	2.017E+05	0.0034	0.2617	N	2.118E+05	4.99%	
0	0	47.42	2.520E+05	0.0076	0.0555	N	2.566E+05	1.85%	
0	0	119.46	2.574E+05	0.0178	0.4497	N	2.565E+05	-0.35%	
0	0	191.49	2.550E+05	0.0119	0.5179	N	2.565E+05	0.58%	
0	0	263.53	2.578E+05	0.0231	0.4561	N	2.565E+05	-0.53%	
0	0	335.56	2.521E+05	0.0097	0.1427	N	2.566E+05	1.78%	
0	0	386.46	1.546E+05	0.0024	0.4277	N	1.605E+05	3.84%	
0	0	411.65	1.260E+05	0.0025	0.1288	N	1.301E+05	3.21%	
0	0	-200	7.942E+03	0.0009	0.1741	N	7.902E+03	-0.51%	
0	0	-100	2.282E+04	0.0010	0.0529	N	2.268E+04	-0.62%	
185	0	211	2.291E+04	0.0010	0.0660	Y	2.139E+04	-6.62%	
285	0	211	1.166E+04	0.0008	0.0371	Y	1.085E+04	-6.93%	
0	0	522	1.304E+04	0.0007	0.0074	Y	1.315E+04	0.78%	
0	0	622	4.852E+03	0.0011	0.0928	Y	4.860E+03	0.17%	

Table 8: Primary gamma results

Detector location (cm)			Primary Gamma Dose (REM/HR)				
			MCNPX	Attila	Attila-LC	Attila/MCNPX % Difference	Attila-LC/MCNPX % Difference
0	0	-200	7.942E+03	8.204E+03	7.902E+03	3.30%	-0.51%
0	0	-100	2.282E+04	2.218E+04	2.268E+04	-2.78%	-0.62%
185	0	211	2.291E+04	2.133E+04	2.139E+04	-6.90%	-6.62%
285	0	211	1.166E+04	1.123E+04	1.085E+04	-3.69%	-6.93%
0	0	522	1.304E+04	1.351E+04	1.315E+04	3.58%	0.78%
0	0	622	4.852E+03	5.117E+03	4.860E+03	5.46%	0.17%

Table 9: Primary gamma results, comparing use of the last collided (LC) method