Setting Up Validation Benchmarks for Deterministic Neutron Transport Methodologies on Fast Reactors

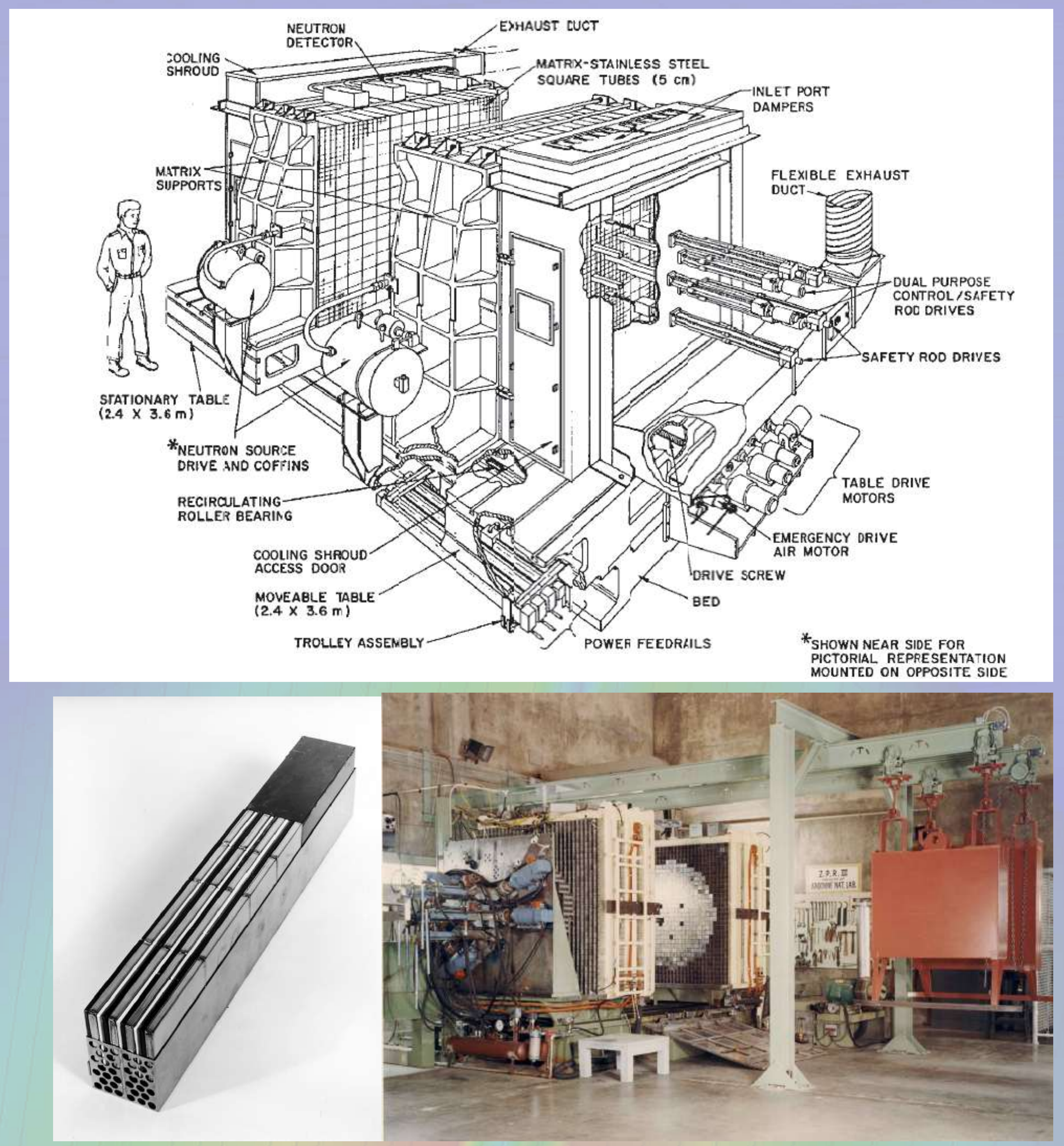
Alex Hagen, Micheal Smith | Argonne National Laboratory | Thursday, July 28, 2011

Zero Power Reactor at Argonne National Laboratory

The Zero Power Reactor (ZPR) is a critical fast type facility that was maintained and run by Argonne National Laboratory in both their Chicago and West sites from the 1950s through the 1980s. The experiments run at these facilities were based around investigating fast reactor concepts [2] – [5].

The facility itself is made of a split table type machine. On each half of the machine are steel tubes stacked lengthwise, creating two matrices of empty tubes sized 45 by 45 tubes. These tubes are loaded with drawers that are loaded with different compositions of plates. The desired average composition for each region was achieved using these plate loadings. Criticality was achieved when the movable half of the split table was moved into position so it was contacting the other half [2]-[5] [11] [12].

For the purpose of this analysis, the ZPR-6/7 experiments were used (the ZPR6 facility, experiment grouping 7). Loadings 104, 41, and 34 were used. The wealth of experimental information from the ZPR experiments make it ideal for the benchmarking of simulation tools. The simulation tool discussed is the neutronics side of the NEAMS project, PROTEUS [1].



Figures 1-3 (Clockwise from Top) A diagram of the ZPR Facility [4], A photograph of the split bed ZPR facility [12], and a photograph of a Loaded Drawer [11].

Drawer Homogenization

The facility model was simplified in the axial direction by identifying average composition regions in each drawer. A maximum of 5 were used in any given drawer. A sample of this homogenization is shown at right.

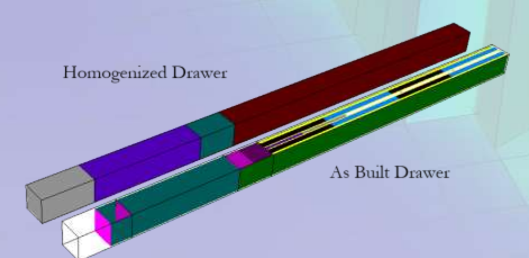


Figure 4 Diagram of homogenization of ZPR throughout axial direction

Core Homogenization

Homogenization was also done in radial directions by specifying average drawer types and mapping similar drawers to one large region. Common regions used were core, blanket, reflector and matrix.

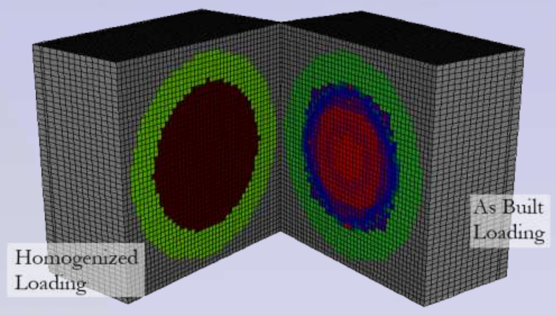


Figure 5 Diagram of homogenization of ZPR throughout radial directions

Solver Parameters

The PROTEUS methodology involves the generation of mixed material cross-section data using the MC^2 code and neutron transport calculation using the SN2ND solver. The Requirements for PROTEUS are that a mesh file, MC^2 input, and a materials assignment file be created to be used in the methodology [10]. The MC^2 input must be defined to fit the desired homogenization, as must the mesh file. The material assignment file bridges the geometric mesh to the MC^2 material definitions. With correct input, the SN2ND code then uses these input files as well as a specified cubature and resolution to obtain a solution. The visualization above shows the Carlson Equal Weight and the Legendre Chebyshev cubatures. Selection of the cubature has only a minor impact on homogenized problems like these, thus the Carlson Equal weight was chosen for its optimal asymptotic convergence properties.

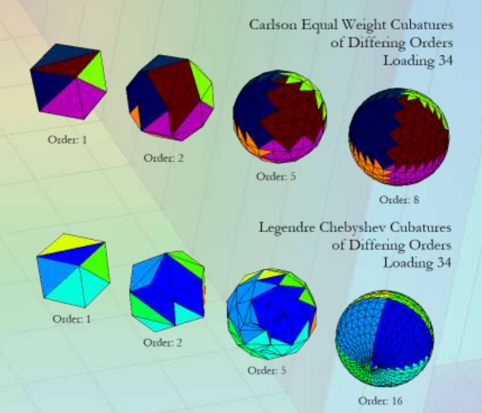


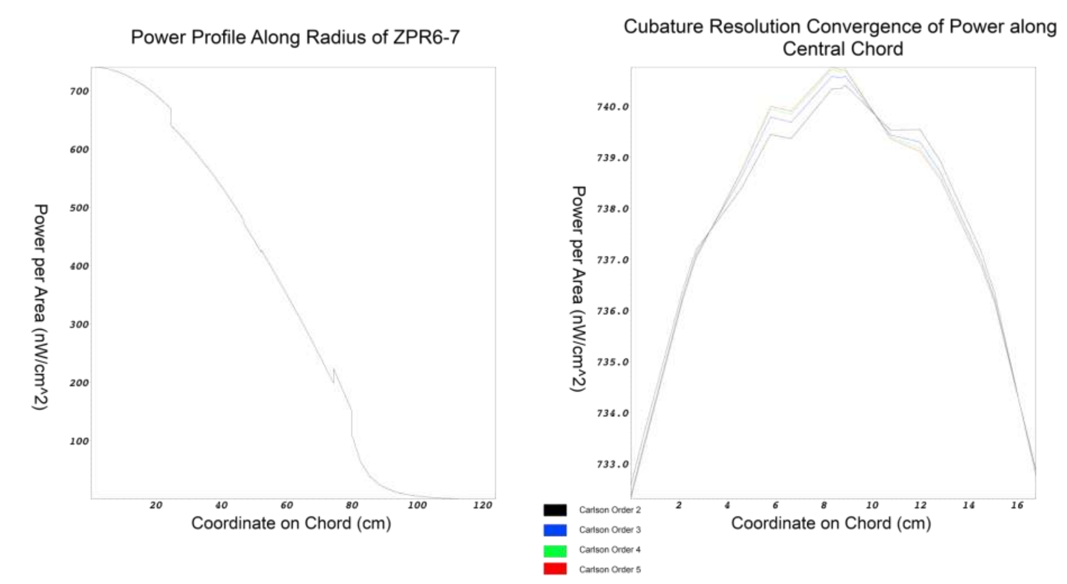
Figure 6 Comparison of different Cubature methods throughout different orders.

ZPR-6/7 Loading 104 Results

The results for ZPR-6/7 Loading 104 are shown below. The results are reasonable and comparable to the experimental result of 1.00072 [2]. These results include various levels of resolution for the neutron transport equation: cubature, spatial, and energy resolution. Although the model has been homogenized, the resolution in these three variables is very important. As shown in the table, the increasing resolution in any of the three variables provides a more accurate result. Also, the trend approaching the experimental result shows convergence of the result as resolution increases.

	9 Group		33 Group		70 Group	
Mesh Carlson Order	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
2	0.99933	1.00085	0.99941	1.00095	0.99991	1.00147
3	0.99933	1.00085	0.99940	1.00094	0.99991	1.00147
4	0.99933	1.00084	0.99940	1.00095	0.99991	1.00146
5	0.99933	1.00084	0.99940	1.00094	0.99991	1.00146

Table 1 Table of Results From SN2ND model of ZPR-6/7 Loading 104



Figures 7-8 Power Profile Along Radius of ZPR-6/7 and Cubature Resolution Convergence of Power along Central Chord

The SN2ND result was also benchmarked in more detailed analyses using the power profiles. The left hand figure shows the power profile along a radius, and includes the physical phenomena that occur at the edge of the inner core (the "cliff" seen) as well as the increase that occurs at the core/blanket interface (a small "jump"). Convergence was also proven through the cubature, spatial, and energy resolution using these power profiles. Using a chord through the high power region of the reactor, the right hand figure shown convergence of the angular cubature for the power profile.

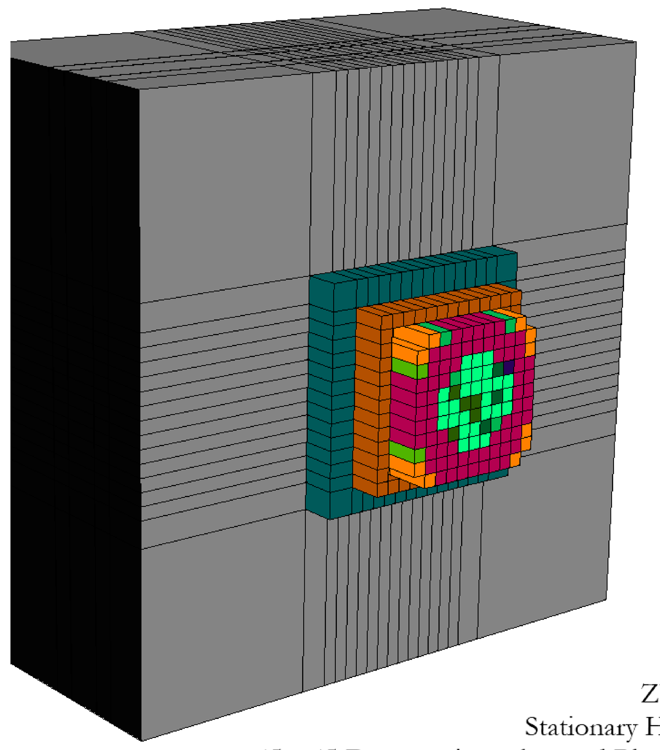
Implications and Future Work

Quality assurance work done for PROTEUS has several steps. The first is to verify the PROTEUS result against other codes (Monte Carlo VIM in this analysis) and followed by validation against experimental results. In this analysis this was done using only the criticality eigenvalue, but it is routine to do more detailed reaction rate comparisons based upon foil measurements taken druing the experiment. This PROTEUS result of 1.00146 was only 74 pcm from the experimental value of 1.00072 [2] and also comparable to the VIM result.

Convergence is also part of the quality assurance work. This analysis showed that PROTEUS provided a result that converged in eigenvalue with increasing resolution as well as converged in power distribution with increasing resolution. This was proven in the central core region as well as in the reflector region for spatial resolution, energy resolution, and cubature resolution.

In follow on work, the loadings B through F of ZPPR-21 will be analyzed. These loadings provided varying ratios of Uranium and Plutonium within their cores, and provide an interesting test case for quality assurance [3]. ZPPR also allows an analysis on the effects of including surrounding environment versus creating an artificial boundary. An example of the geometry of ZPPR-21 is shown at right.

It is important to note that through the benchmarking of ZPR-6/7, it was shown that homogenization did not cause a departure from the experimental result and that resolution was important (spatial, energy, and cubature). This quality assurance work will help support users for routine fast reactor design as well as achieve the NEAMS multi-physics simulation reactor goal.



ZPPR-21 Loading B
Stationary Half, Modeled with
45 x 45 Drawers, inner borated Blanket, Reflector, and
Core Protruding.

Figure 9 ZPPR-21 Loading B Rendering, with inner core, blanket, and reflector protruding.

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