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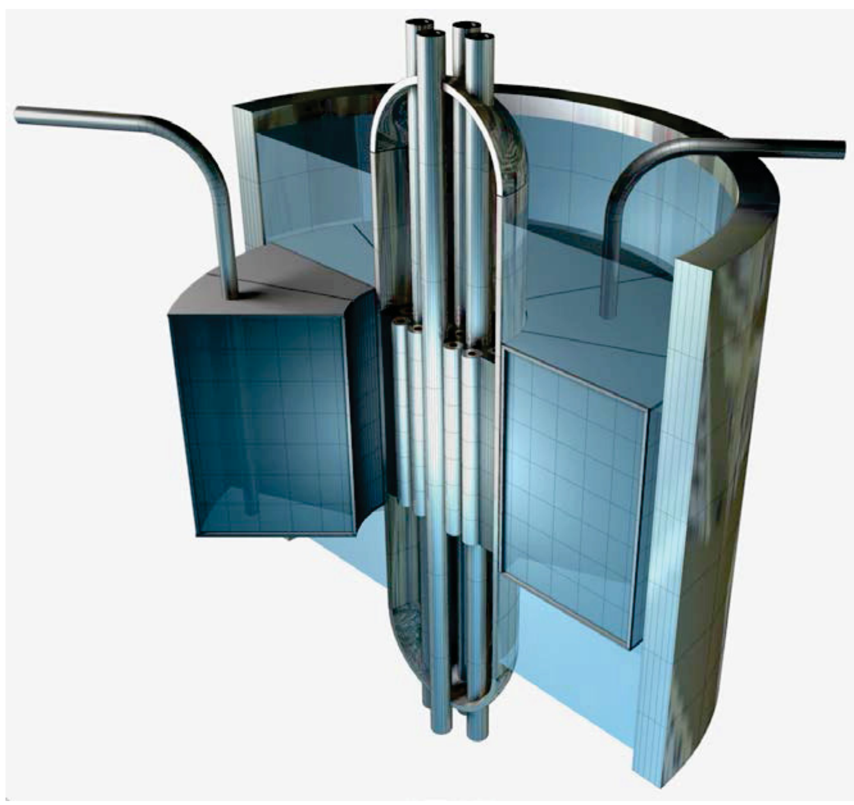

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Approved by:

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ABSTRACT

The Advanced Test Reactor (ATR) is a high power density test reactor designed primarily for accelerated irradiation of nuclear fuels and materials irradiation under controlled environmental conditions. For more than 45 years, the ATR has operated primarily in support of the Office of Naval Reactors (NR) but the mission has gradually expanded to cater to other customers, such as the DOE Office of Nuclear Energy (NE), private industry, and universities. . Featuring nine large flux traps that can accommodate independently-cooled high-pressure In-Pile Tubes (IPTs), ATR is still reliable and effective but increasingly expensive to maintain and operate every year. The sophisticated test hardware and experiments required of recent fuel and materials irradiation campaigns are limited by the safety limits and operating envelope of this aging facility, which are becoming harder to meet as equipment reliability is diminished. Furthermore, the fabrication and transport of its highly enriched uranium (HEU) fuel is deemed a proliferation concern. Under the Global Threat Reduction Initiative (GTRI), ATR and the other high flux test reactors in the US fleet must eventually be converted to low enriched uranium (LEU) in order to continue operating. Studies are underway to assess the costs and technical viability of this fuel conversion. One foreseeable outcome is that the cost of upgrades, fuel conversion, and more frequent LEU fuel loadings needed to keep ATR viable will exceed those of building and operating a replacement reactor. In anticipation of this scenario, work was commenced under the Laboratory Directed Research and Development (LDRD) program to investigate test reactor concepts that could satisfy the current missions of the ATR. Naturally, the needs of other value-adding missions were considered as part of the initial design study.

This work build upon a project from the 1990's called the Broad Application Test Reactor (BATR). In FY 2012, a survey of anticipated customer needs was performed, followed by analysis of the original BATR concepts with fuel changed to low-enriched uranium. Departing from these original BATR designs, four concepts were identified for further analysis in FY2013. The project informally adopted the acronym MATRIX (Multiple-Application Thermal Reactor for Irradiation eXperiments). This report discusses analysis of the four MATRIX concepts along with a number of variations on these main concepts. Designs were evaluated based on their satisfaction of anticipated customer requirements and the "Cylindrical" variant was selected for further analysis of options. This downselection should be considered preliminary and the backup alternatives should include the other three main designs.

The analysis described within indicates that the baseline Cylindrical MATRIX design can achieve a higher burnup than the ATR (or longer cycle length given a particular batch scheme). The volume of test space in IPTs is larger in MATRIX than in ATR with comparable magnitude of neutron flux. In addition to the IPTs, the this concept features test spaces at the centers of fuel assemblies where very high fast flux can be achieved. This magnitude of fast flux is similar to that achieved in the ATR A-positions, however, the available volume having these conditions is greater in the MATRIX design than in the ATR.

The Cylindrical MATRIX design can meet the anticipated needs of current and anticipated ATR customers This statement must be qualified by acknowledging that this design is quite immature, however, and any requirements currently met must be re-evaluated as the design matures. Also, some of the requirements were not strictly met, but are believed to be achievable once features to be added later are designed.

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ACRONYMS

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing of Materials
ATR	Advanced Test Reactor
BATR	Broad Application Test Reactor
BL	Baseline
CEA	Commissariat à l'Energie Atomique
DOE	Department of Energy
FTC	Fuel Temperature Coefficient
HEU	Highly-Enriched Uranium (> 20 % by weight)
INEL	Idaho National Engineering Laboratory
INL	Idaho National Laboratory
LDRD	Laboratory-Directed Research and Development
LEU	Low-Enriched Uranium (< 20 % by weight)
MCNP	Monte Carlo N-Particle code
M-A	Multiple-Annular
M-H	Modular-Hexagonal
MTC	Moderator Temperature Coefficient
NE	Nuclear Energy office within the DOE
NR	Naval Reactors office within the DOE
PBT	Pressure Boundary Tube
pcm	Percent mille (reactivity unit of 10^{-5})
RJH	Réacteur Jules Horowitz (Jules Horowitz Reactor)
SS304	Stainless Steel 304

Evaluation of Concepts for Multiple Application Thermal Reactor for Irradiation eXperiments (MATRIX)

1. Background

1.1 Introduction

The Advanced Test Reactor (ATR) is a high power density test reactor designed primarily for accelerated irradiation of nuclear fuels and materials irradiation under controlled environmental conditions. For more than 45 years, the ATR has operated primarily in support of the Office of Naval Reactors (NR) but the mission has gradually expanded to cater to other customers, such as the DOE Office of Nuclear Energy (NE), private industry, and universities. . Featuring nine large flux traps that can accommodate independently-cooled high-pressure In-Pile Tubes (IPTs), ATR is still reliable and effective but increasingly expensive to maintain and operate every year. The sophisticated test hardware and experiments required of recent fuel and materials irradiation campaigns are limited by the safety limits and operating envelope of this aging facility, which are becoming harder to meet as equipment reliability is diminished. Furthermore, the fabrication and transport of its highly enriched uranium (HEU) fuel is deemed a proliferation concern. Under the Global Threat Reduction Initiative (GTRI), ATR and the other high flux test reactors in the US fleet must eventually be converted to low enriched uranium (LEU) in order to continue operating. Studies are underway to assess the costs and technical viability of this fuel conversion. One foreseeable outcome is that the cost of upgrades, fuel conversion, and more frequent LEU fuel loadings needed to keep ATR viable will exceed those of building and operating a replacement reactor. In anticipation of this scenario, work was commenced under the Laboratory Directed Research and Development (LDRD) program to investigate test reactor concepts that could satisfy the current missions of the ATR. Naturally, the needs of other value-adding missions were considered as part of the initial design study.

In the early 1990's, the Idaho National Laboratory (then called Idaho National Engineering Laboratory, or INEL) undertook a similar study aimed at developing and evaluating concepts for a new test reactor. This reactor was envisioned to fulfill a range of customer needs in anticipation of the possible decommissioning of several aging test reactors in the U.S., including the ATR. A cataloguing and ranking of anticipated user needs was performed and a wide variety of reactor concepts were evaluated. The name given to the family of reactors conceptualized was the Broad Application Test Reactor (BATR). [1,2,3,4]

By the end of the BATR study in 1993, two reactor concepts had emerged as leading candidates. Both called for plate fuel and were moderated by beryllium and/or D_2O and cooled by light water with a rated power of 250 MW_{th}. Several independently cooled IPTs were also called for in both designs. The "Multiple-Annular" (M-A) core featured arcuate fuel assemblies similar to those of the ATR, each surrounding large cylindrical flux traps supporting different loop configurations. The unperturbed spectrum in each large irradiation position could be tailored to user needs through the addition of dedicated reflectors and filters. The "Modular-

Hexagonal" (M-H) core featured multiple cylindrical fuel assemblies arranged in a hexagonal matrix among an array of uniquely configured flux traps. The entire array of fuel and flux traps was surrounded by a common beryllium primary reflector, a pressure boundary, and a D_2O secondary reflector. Though each of the two concepts was judged to have advantages and disadvantages, the M-A concept was judged to be slightly superior in part because it had significantly higher fast neutron flux in test locations. The M-H core, however, also ranked highly because of its interchangeable grid, which would facilitate core reconfiguration. A third concept, which was also proposed but not analyzed in detail during the BATR project, was an upgraded ATR. This was an evolutionary ATR design calling for several key design changes including a power uprate, a change in coolant direction from downflow to upflow, and an increase in the beryllium reflector size. [1]

In the 1990's, it was assumed that proposed research and test reactors operated by the Department of Energy (DOE) could use highly enriched uranium (HEU) fuel. Because this is no longer considered an option, any new research reactors proposed will likely be required to use low-enriched uranium (LEU) fuel, which contains less than 20% ^{235}U by mass. This presents a major departure between the current work and the BATR project.

Authorized during fiscal years (FY) 2012 and 2013, this project had the following objectives;

- Update the anticipated customer needs of a new test reactor from the BATR project
- Re-evaluate the BATR concepts of the 1990's and investigate LEU options for them
- Propose modifications to the BATR concepts to better meet the anticipated customer needs
- Analyze and compare the performance of the proposed designs against metrics to be determined in the course of the project

During FY2012, updated user requirements were developed and reported. [5] Also in FY2012, reactor physics analyses were performed verifying the performance of the original BATR concepts with comparisons to LEU versions of these designs. Then, variations on the BATR concepts were introduced and analyzed. [6] From this work, four concepts were identified for further refinement and analysis. This was documented in a separate report, also released at the end of FY2012. [7]

In FY 2013, work continued refining and analyzing the concepts presented in Ref. 7. One change between the FY2012 and FY2013 concepts is a change in core height from 100 cm to 120 cm. This came as a result of feedback from potential customers regarding the undesirability of having a significantly shorter active core height than that which is currently available in ATR. In addition, a concept having square fuel assembly geometry was introduced as another baseline version of the design. The project also informally adopted the acronym MATRIX (Multiple-Application Thermal Reactor for Irradiation eXperiments).

Section 2 of this report contains descriptions of the four main baseline concepts and their basic performance parameters. Section 3 shows results from comparison of aluminum pressure boundaries to stainless steel. Section 4 gives results from analysis of various reflector contents. Section 5 gives results of analysis of the content of the core rack. Section 6 shows results of comparisons of a fallback fuel meat option. Section 7 discusses comparisons made to an analogous Serpent 2 model of ATR with HEU fuel. Section 8 makes comparisons between the reactor concepts and provides some basis for a tentative down-selection to a lead candidate. Section 9 presents further analysis of the down-selected Cylindrical MATRIX design. Finally Conclusions and proposed additional work are given in Section 10.

1.2 Summary of Customer Requirements

The needs of the primary ATR customers (NE and NR), gathered through a survey and a meeting held at INL in March of 2012, are [5]:

- High availability/capacity factor (>70%)
- Must be licensable by the Nuclear Regulatory Commission (NRC)
- High neutron flux (total flux $>10^{15}$ $n \cdot cm^{-2} \cdot s^{-1}$) in a large sample volume
- Multiple independently cooled and instrumented IPTs required (variable dimensions)
- Modular type core (re-conformable, flexible) to accommodate changing missions
- Hydraulic shuttle irradiation system (Rabbit)
- Easy access to loops, rabbit tubes, neutron beams, etc.
- Primarily thermal neutron flux spectrum, but some positions capable of fast and epithermal spectra
- Minimum waste stream effluents/environmental impact
- Primary coolant flow in upward direction through the core

The ATR is currently in the conceptual design phase of converting from highly-enriched uranium (HEU) low-enriched uranium (LEU) fuel. The requirements for the converted core are given below [8]:

- An operational cycle length of 56 days at 120 MW
- Fast-to-thermal neutron flux ratio within 5% of current values in a pressurized-water loop test
- Greater than 4.8×10^{14} fissions per second per gram ^{235}U in a specimen with l gram ^{235}U per linear inch in a standard in-pile tube (SE or SW) operating at 60 MW
- 3/1 lobe power split with south corner lobes operating at three times the lobe power of the northern lobes
- Gamma-to-neutron flux ratio within +10%/-0% of current values

These are written specifically for the converted ATR core and therefore some of them cannot be applied directly to the MATRIX, though the intents of these requirements are considered to be the most important design requirements.

Assuming that the primary mission can be so served, a number of secondary missions were identified for possible, albeit not essential, implementation into the MATRIX design. These include;

- Neutron imaging (e.g. radiography)

- Neutron scattering and activation experiments
- Radioisotope production (e.g. ^{99}Mo, ^{60}Co, ^{238}Pu, ^{252}Cf, etc.)

The spectral and operational needs of these missions vary, placing significant demands on the design of the facility in addition to those listed above. Whether or not a single reactor can serve some or all of these secondary missions will depend on the modularity and configurability of the reactor (the reflector in particular) as well as the functionality of the experimental support systems.

1.3 Reactor Physics Calculation Methodology

Reactor physics analyses were performed using the Monte Carlo depletion code Serpent 2 [9]. At a very early conceptual design stage, Monte Carlo simulation tools have clear advantages over most deterministic codes because creating and meshing deterministic models for a wide variety of core geometries is a very labor-intensive process. With modern Monte Carlo tools, geometry definition is efficient and the need to converge the spatial mesh is reduced. Furthermore, cross-section processing is not needed for Monte Carlo analysis since continuous energy cross-sections are used directly. Developed at the VTT Technical Research Center in Finland, Serpent 2 was selected based on the following factors:

- Modern programming – faster than MCNP [10]
- Easy to use, built-in visualization of core model and neutron reactions and flux
- Built-in depletion capable of handling many burnable regions with configurable memory management options
- Automatic fission source development
- Responsive developers

Each case was depleted assuming all fresh fuel at beginning of life (BOL) until k_{eff} fell below 1.0. Since this is the point at which the reactor is critical, neutron flux tallies were taken from the time step closest to this condition. The number of days of burnup required to reach this point is called B_1. This value can be used to compare the achievable burnup between reactors and to estimate what the cycle length and discharge burnup would be if other refueling schemes were applied.

2. Baseline Reactor Concepts

This section presents descriptions of the four main reactor concepts along with some preliminary analysis. The descriptions in this section are considered baseline cases from which parametric studies are performed in later sections. Those reactor parameters common among all the baseline concepts are:

- Rated power of 250 MW_{th}
- Active core height of 120 cm
- Primary coolant in upflow through the core

- Primary coolant inlet and outlet temperatures of 52°C and 89°C, respectively
- Nominal primary coolant mass flow rate of 1600 kg/s
- Plate fuel having coolant channel, fuel meat, and overall plate thicknesses of 2.0 mm, 0.5 mm, and 1.25 mm, respectively
- Primary coolant pressure of 2.3 MPa
- Surrounding reflector tank at atmospheric pressure and 27°C
- Fuel meat temperature of 170°C

Many of the above parameters are based on the ATR except the last item. Although the ATR is normally operated at less than half its rated thermal power, these studies were performed generally assuming full 250 MW_{th} power. The addition of a secondary reflector tank (nominally containing D_2O) was an idea borrowed from the original BATR work and carried forward to the MATRIX studies. The primary purpose of this feature is ease of integration of secondary missions into the capabilities of the MATRIX reactor. The large atmospheric pressure reflector tank offers space for irradiations, beam tubes, etc. without a high-pressure boundary between the test location and operator access points. Alternatives to this approach are also explored in this work. Descriptions of the four baseline reactor concepts are given in the following subsections.

2.1 Cylindrical Fuel Concept

Table 2-1 gives parameters for the "Cylindrical" reactor core, shown in a diagram in Figure 2-1. The Cylindrical concept is so named because the fuel assemblies are constructed as concentric cylinders of plate-type fuel. The core is currently modeled such that each cylindrical element is a single assembly, as is shown schematically in Figure 2-2. However, criticality or other fuel management constraints may dictate that each cylinder be made up of multiple assemblies. For example, three assemblies, each spanning 120º angle rather than a single element. The 30 fuel assemblies are arranged in a hexagonal array placed in an aluminum core rack having 5% water by volume for cooling. This rack is surrounded by a pressure vessel, nominally constructed of Al-6064 with stainless steel 304 (SS304) as a fallback alternative. The inner radius of the pressure vessel is 44 cm and it is 4 cm thick. Outside the pressure vessel is a tank of D_2O at atmospheric pressure having outer dimensions the same as other variants.

The fuel plates nominally have the same thicknesses as the other concepts and the HEU fuel of the ATR (1.25 mm thick plates with 0.5 mm thick meat). The baseline fuel form for MATRIX is U-10Mo having uranium density of 15.2 g/cm^3 and Zircaloy cladding. The innermost coolant channel has an inner diameter of 3.95 cm and the outermost coolant channel has an outer diameter of 10.85 cm. Inside the fuel assembly is a location that can either contain an irradiation test, a control rod or rod follower, or a simple filler to displace coolant water. Unless otherwise specified, this space is modeled as Al-6061. The baseline Cylindrical core is designed to have approximately the same fuel content as the other baseline concepts with approximately 100 kg of ^{235}U in each. As mentioned previously, all of the baseline cores have an active fueled height of 120 cm, close to the 4 ft (121.92 cm) height found in ATR. The total mass of uranium in the baseline Cylindrical core is 508 kg, 100 kg of which is ^{235}U.

Dispersed among the fuel assemblies are seven IPTs, each corresponding to a flux trap. Figure 2-3 shows a diagram of a flux trap and its associated IPT. Note that Figure 2-2 and Figure 2-3 are not scaled to one another. These are modeled to have similar features as those of the ATR with the sizes of the piping adjusted to fit the size of the flux traps in the Cylindrical design. The outermost layer is an Aluminum baffle. In the ATR, this baffle serves as the structural feature from which fuel elements hang. The same type of fuel assembly support will not be possible in any of the MATRIX designs as currently envisioned. This is because 1) the coolant will be in upflow and simply hanging the elements from a baffle will not be sufficient to keep them in place and 2) the Cylindrical core concept has fuel elements that are not formed around the flux traps as they are in ATR. Nevertheless, some material is included in each of the IPTs here as a placeholder for any structure that would need to be present. These may be removed or modified as design details are added. Inside the baffle are (from outermost to innermost) a water gap, a SS304 insulation tube, a helium gap, the SS304 pressure tube, another water gap, and a SS304 flow tube. Inside this innermost tube is the test space. Assumed for baseline calculations to contain pure Al-6061, this test space has a diameter of 9.3 cm. This is a similar diameter to that of the large NW flux trap in ATR (See Appendix B).

Above and below the fueled portion of the fuel elements are assumed to be regions of plates having no fuel meat and end boxes. Figure 2-4 shows a schematic representation of this. Just above and below the fueled portion of the assembly are homogenized regions of 39% Zircaloy and 61% H_2O coolant with height of 2.0 cm. These percentages come from the assumption that sections of plate not having fuel meat will have the same overall thickness as the fueled portion of the core. Above and below these sections are the top and bottom end boxes. These are assumed to be 20 cm tall homogenized regions of 80% H_2O and 20% Zircaloy, similar to the representation of end boxes used in ATR modeling. [10]

Figure 2-5 shows an above view of the core, pressure vessel, and the D_2O reflector tank. Surrounding the pressure vessel, the reflector tank contains D_2O at atmospheric pressure and near room temperature (assumed to be at P=1 atm and T=300 K). This feature was envisioned to provide a versatile space of very high thermal flux for irradiation experiments, beam tubes, etc. This feature is compared to other options for reflector tank contents in Section 4 of this report. The numbered reflector tally locations in Figure 2-5 give the distances from core center where flux values are given. These are arranged at an angle of 30º from the x-axis with distances given in cm. These tally locations will be kept constant among the various reactor concepts discussed in this report in order to provide a consistent comparison among their performances. Figure 2-6 shows a vertical cross section of the Cylindrical core design. From this, one can see how the IPTs extend from the bottom to the top of the reflector tank while the active core and fuel assemblies are centered axially in the tank. For neutronic modeling purposes, beyond the outer boundary of the D_2O tank was considered void.

Table 2-2 shows neutron flux calculated by Serpent 2 for various locations in the core broken down into energy groups. The energy groups are fast (>1 MeV), thermal (<0.625 eV), and total. The tallies were taken in 10 axial segments extending from bottom to top of the 120 cm tall active core. The center two segments together span 24 cm of axial height and form the "peak" flux values and the "axially averaged" values are taken as the average over the height of the active core. For the Cylindrical core model, the center and one peripheral flux trap are tallied along with the center of an inner-ring fuel assembly. These calculations were performed assuming 100% aluminum fill. This gives an estimate of the upper bound of fast neutron flux that is achievable and provides a fair comparison between concepts. If higher thermal neutron flux is desired, this can be moderated accordingly to produce it, though the amount of cooling water in the test location may be constrained by loop void reactivity limits. Therefore, the magnitude of the fast neutron flux in the test locations is used as a measure of the achievable thermal neutron flux in these positions. The four reflector tallies shown in Figure 2-5 are also given in Table 2-2 with the same axial segmentation.

Results from Serpent 2 depletion calculations indicate that the baseline Cylindrical reactor has an initial k_{eff} of 1.18427 and a B_1 value of 101 days. The center flux trap has a peak fast and total flux of 3.2×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ and 2.1×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$, respectively and the axial flux peaking factor in the center flux trap is 1.3. The peak thermal flux in the center flux trap is 2.8×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$, but as mentioned before, this does not represent the actual peak thermal flux possible in the flux trap. Later studies should provide more insight into the achievable thermal flux. The peripheral flux traps have a peak fast and total flux of 2.8×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ and 1.8×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$, respectively. The test spaces inside the inner fuel assemblies have a peak fast and total flux of 5.1×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ and 2.1×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$, respectively. Reflector tally position #1 has a peak thermal neutron flux of 9.8×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$.

Figure 2-7 shows a neutron flux map of the Cylindrical core model having all fresh fuel at beginning of depletion. The white areas represent regions of high thermal flux, while blue areas represent low thermal flux. The yellow and red regions represent higher and lower fission power, respectively. Figure 2-7 illustrates how the configuration of this reactor and reflector preserve high fast flux inside the vessel in the IPTs while generating a very large thermal flux outside the pressure vessel in the reflector tank. The flux inside the IPTs can be thermalized up to limits dictated by loop void reactivity. This configuration also permits relatively easy access to a large volume of high thermal neutron flux in the reflector tank without having to penetrate a pressure boundary. This has significant implications with regard to options for using this neutron flux for a variety of missions.

Table 2-1. Parameters of baseline Cylindrical core concept.

Parameter	
Active Fuel Height (cm)	120
Fuel Meat Material	U-10Mo
^{235}U density (g/cm^3)	3.00
Total U density (g/cm^3)	15.2
Enrichment (wt. %)	19.7
Number of Assemblies	24
Fuel Plates Per Assembly	10
Inner diameter of innermost coolant channel (cm)	3.95
Outer diameter of outermost coolant channel (cm)	10.85
Width of coolant channels between fuel plates (cm)	0.2
Fuel plate thickness (cm)	0.125
Fuel meat thickness (cm)	0.05
Cladding Composition	Zircaloy-4
Central Cylinder Composition	Zircaloy-4
Total ^{235}U per assembly (kg)	4.2
Total ^{238}U per assembly (kg)	17.0
Total ^{235}U in core (kg)	100
Total ^{238}U in core (kg)	408

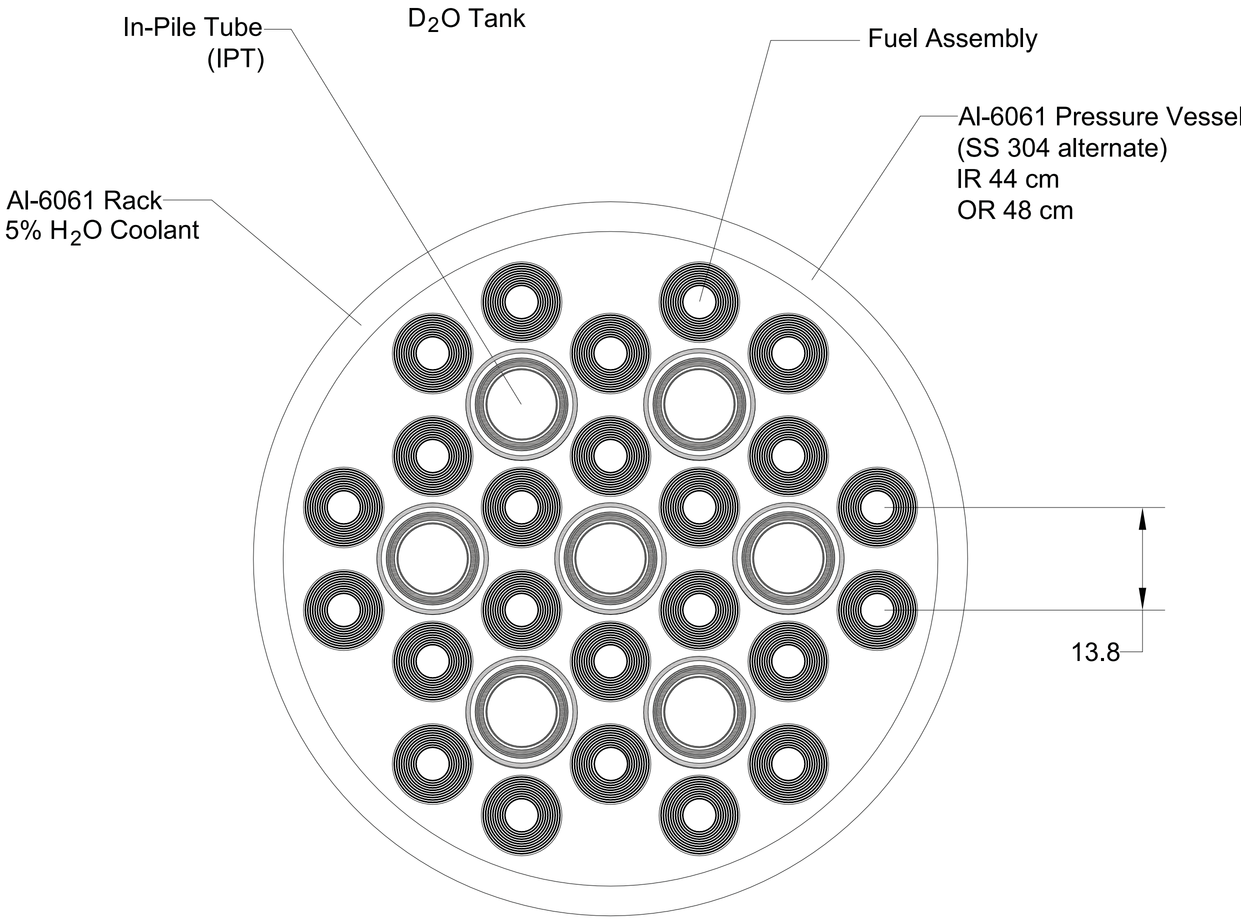

Figure 2-1. Detailed view of baseline cylindrical core concept (dimensions in cm).

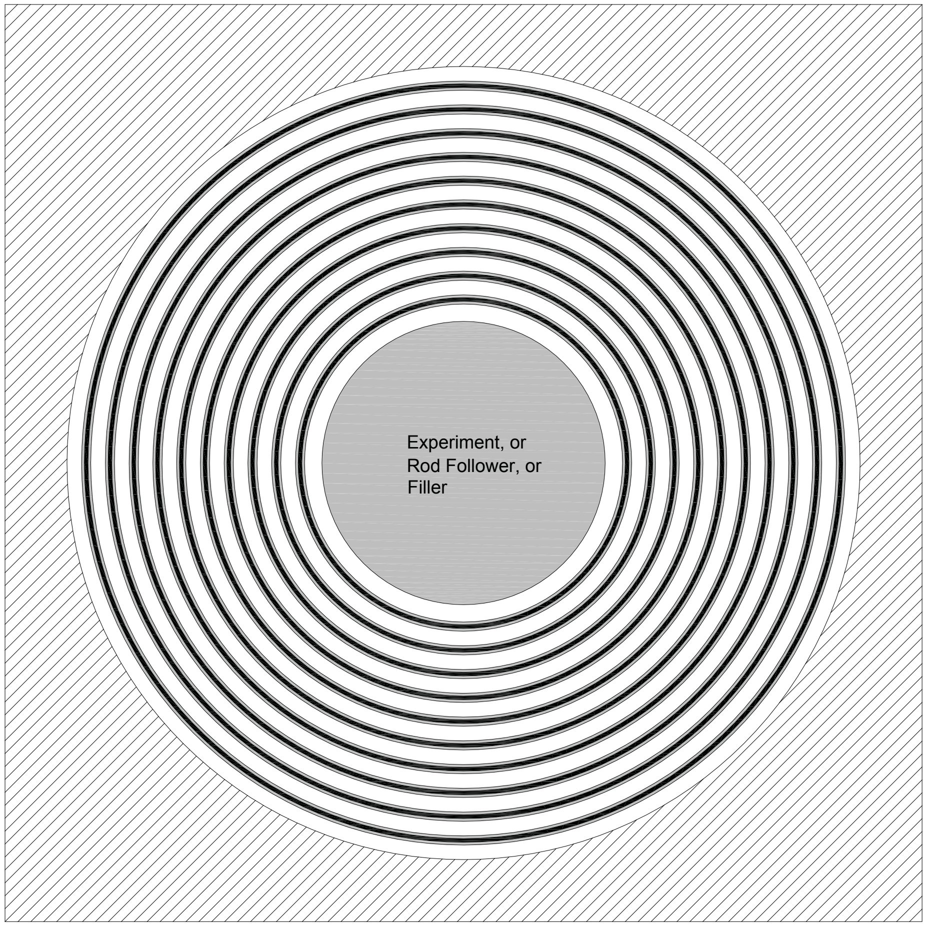

Figure 2-2. Schematic showing arrangement of fuel plates in cylindrical fuel type.

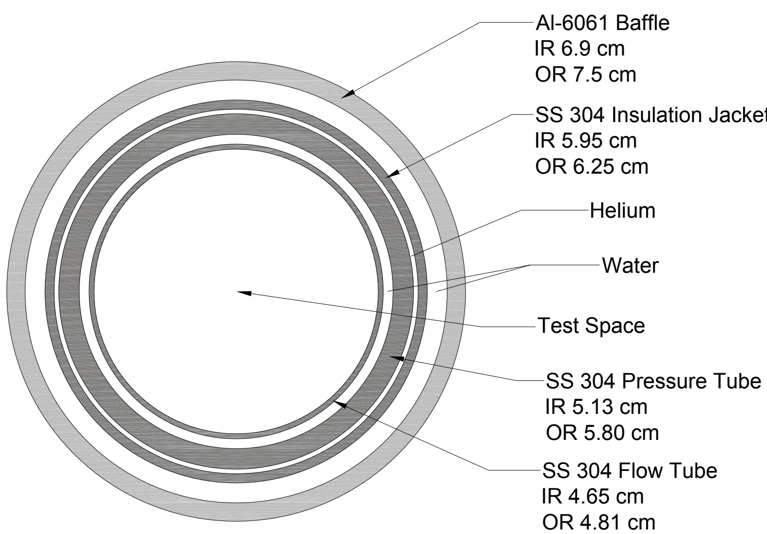

Figure 2-3. Diagram of in-pile tubes (IPTs) specified for cylindrical-type core.

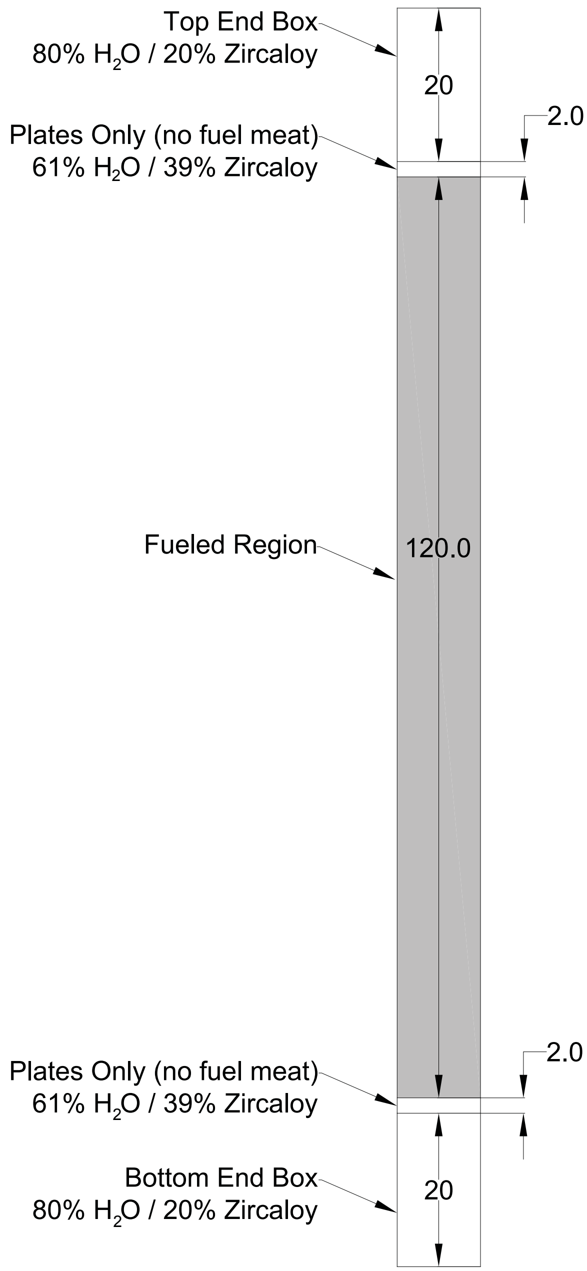

Figure 2-4. Diagram of axial sections of fuel assemblies.

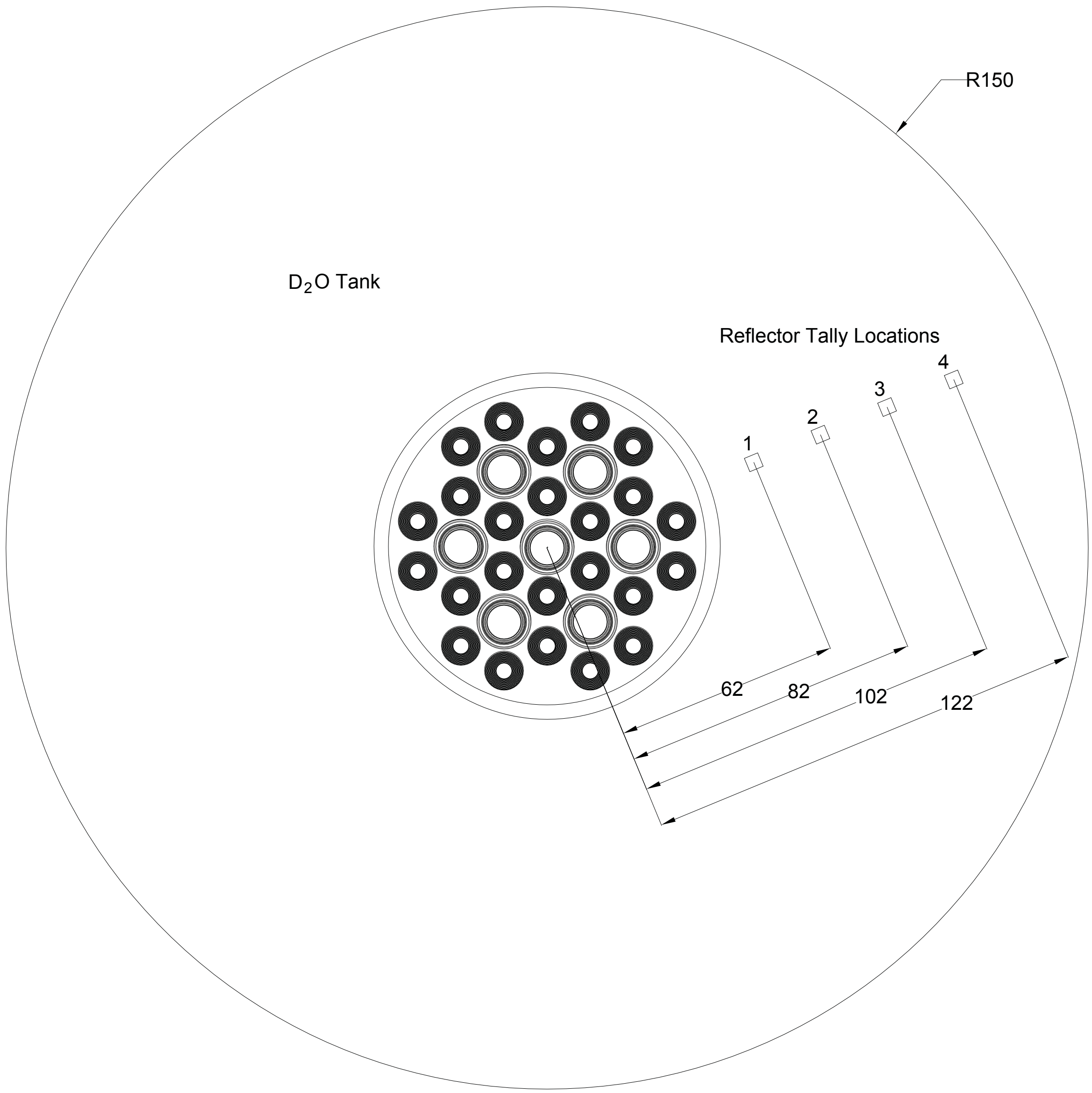

Figure 2-5. Above view of cylindrical concept with reflector tally locations (dimensions in cm).

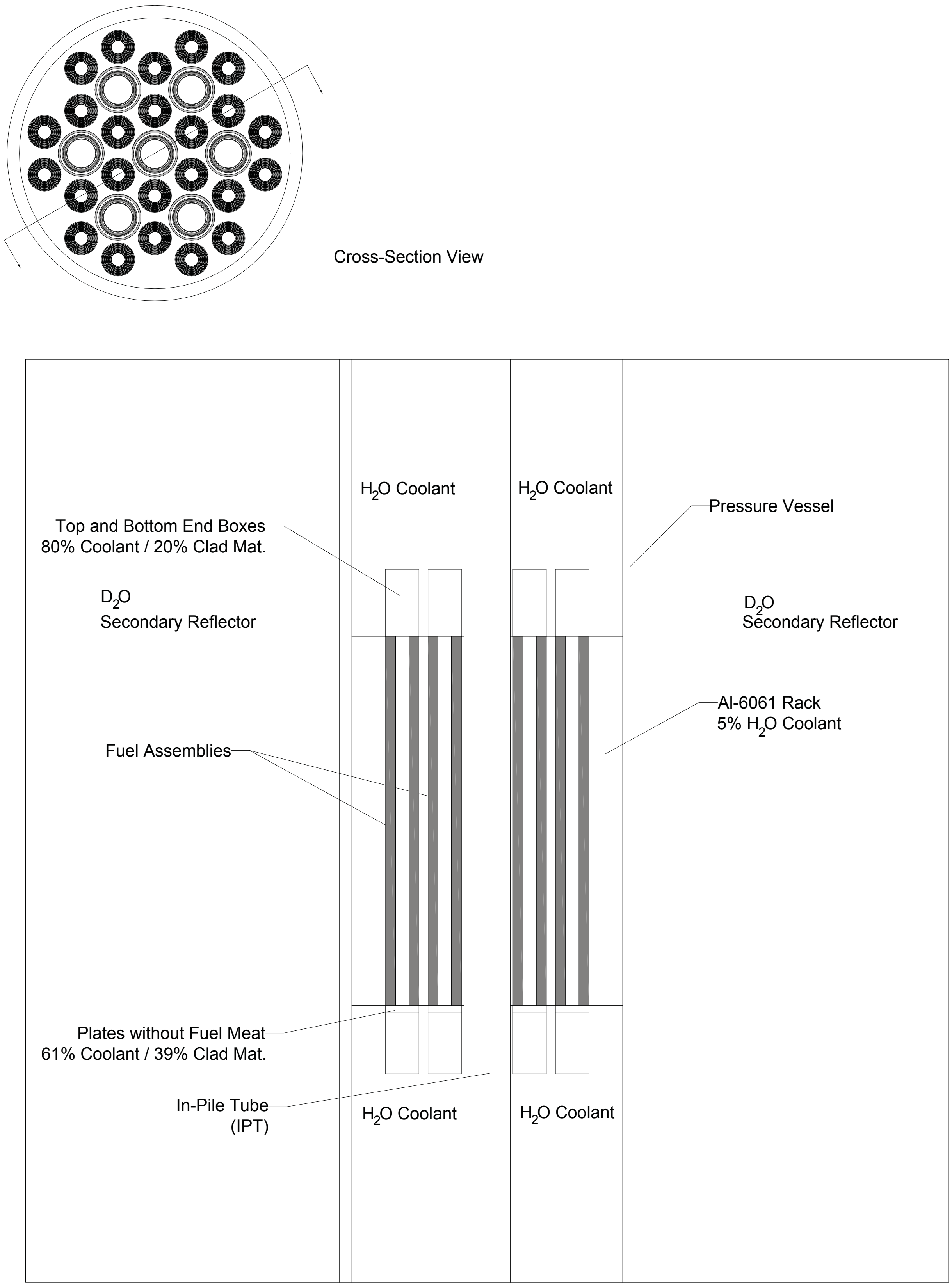

Figure 2-6. Vertical cross section view of cylindrical core concept.

Table 2-2. Neutron flux in various locations of baseline Cylindrical core.[a]

Tally Location	Neutron Flux in Reflector (n·cm^{-2}s^{-1}) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux		
	Peak	Axially Averaged	Peak/ Average
Center Flux Trap	3.22E+14	2.42E+14	1.33
	2.77E+14	2.12E+14	1.31
	2.07E+15	1.55E+15	1.33
Peripheral Flux Trap	2.79E+14	2.11E+14	1.32
	2.42E+14	1.87E+14	1.29
	1.80E+15	1.36E+15	1.32
Inner Fuel Assembly	5.07E+14	3.86E+14	1.31
	1.42E+14	1.12E+14	1.28
	2.14E+15	1.62E+15	1.32
Reflector Tally 1	5.52E+12	4.27E+12	1.29
	9.82E+14	7.96E+14	1.23
	1.14E+15	9.20E+14	1.24
Reflector Tally 2	—	—	—
	7.13E+14	5.96E+14	1.20
	7.22E+14	6.03E+14	1.20
Reflector Tally 3	—	—	—
	4.18E+14	3.58E+14	1.17
	4.19E+14	3.59E+14	1.17
Reflector Tally 4	—	—	—
	2.12E+14	1.85E+14	1.15
	2.12E+14	1.85E+14	1.15

[a] Initial k_{eff} =1.18427, B_1=100 days

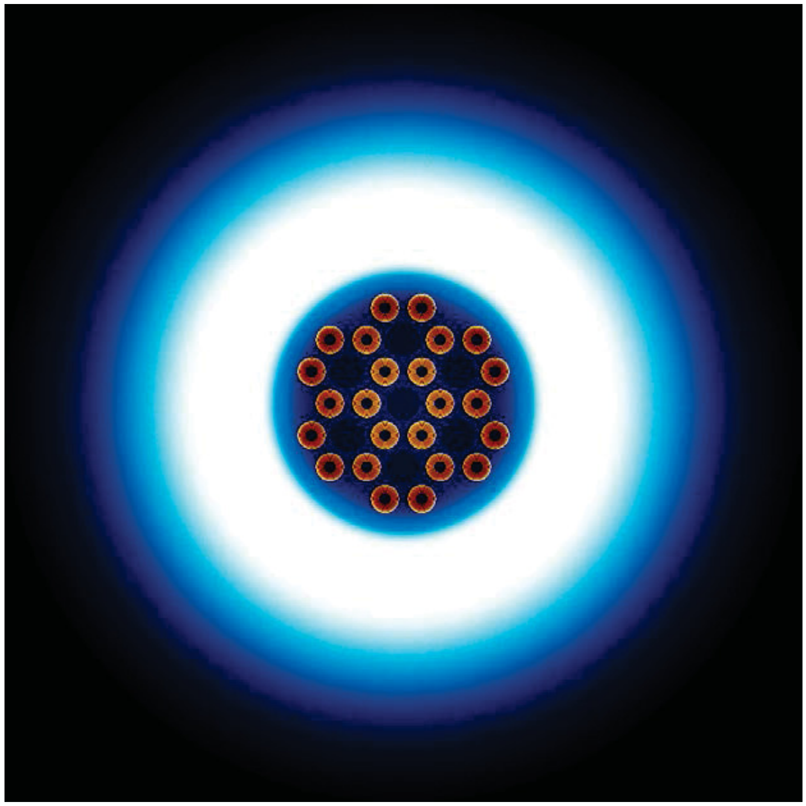

Figure 2-7. Neutron flux and power map of Cylindrical core model having all fresh fuel.

2.2 Square Concept

The fuel assemblies of the Cylindrical core model have a minimum plate diameter of approximately 4 cm. There is some uncertainty as to whether or not plates with this curvature can be fabricated from cladded U10Mo . Therefore, an alternative fuel assembly concept was proposed having similar features as the Cylindrical core (e.g. single aluminum vessel surrounding aluminum core rack) but with square fuel assemblies. Henceforth referred to as the "Square" core, this concept uses 36 square assemblies with 7.5 cm sides.

Table 2-3 shows the main parameters of the Square core concept. A cross-section view of one of the assemblies is shown in Figure 2-8. The wall thicknesses of the outer can of the assemblies are 0.2375 cm thick and the axial top and bottom of the assemblies have the same homogenized regions described for the Cylindrical core and depicted in Figure 2-4. There are 21 plates per fuel assembly and fuel cladding and the outer can of the assemblies are Zircaloy.

The core height and the design of the IPTs and flux traps are the same as the Cylindrical core. Figure 2-9 shows an above view of the general core layout. As with all of the baseline cores, the fuel is U-10Mo having uranium density of 15.2 g/cm^3. Fuel plate thickness and fuel meat thickness is the same between all baseline core models. The Square core was designed to have roughly the same amount of fuel as the Cylindrical core with 485 kg of uranium. For initial analysis, the outer boundaries of the assembly cans are assumed to just touch. In a final design, allowance would have to be made for cooling between cans and room for expansion. However, this is neglected for simplification of scoping calculations.

The assemblies are arranged in a square array with 7 IPTs displacing four lattice positions each. Additional test positions and locations for shim and or shutdown rods are also included as placeholders. The pressure vessel was expanded slightly from the Cylindrical core to accommodate the arrangement of fuel assemblies, test spaces, and control spaces. The inner diameter of the vessel is 47 cm and the thickness remains 4 cm. Figure 2-10 shows an above view of the core, pressure vessel, and the D_2O reflector tank. Just as in the Cylindrical core, the reflector tank contains D_2O at atmospheric pressure and near room temperature (again assumed to be at P=1 atm and T=300 K). The numbered reflector tallies are located at the same distances from core center as in the Cyindrical core. Figure 2-11 shows a diagram of the IPTs surrounding a flux trap in the Square core. Again, the available test space has a diameter of approximately 9 cm.

Figure 2-12 shows a vertical cross section view of square core concept. Because a center cut-away as shown in the upper left corner of the figure is between assemblies, detail is not shown in the core sections. Note that the assemblies have homogenized regions extending above and below the 120 cm active core region as was the case in the Cylindrical core. Again, the IPTs extend the entire height of the 3 m tall D_2O tank.

Results from Serpent depletion calculations indicate that the baseline Square reactor has an initial k_{eff} of 1.14066 and a B_1 of 70 days. Table 2-4 shows neutron flux in various locations of baseline Square core. The center flux trap has a peak fast and total flux of 2.7x10^{14} n·cm^{-2}·s^{-1} and 2.0x10^{15} n·cm^{-2}·s^{-1}, respectively and the axial flux peaking factor in the center flux trap is 1.3. The peripheral flux traps are not identical in this core. The peak fast flux values in the peripheral flux traps range from 2.4x10^{14} n·cm^{-2}·s^{-1} to 2.7x10^{14} n·cm^{-2}·s^{-1}. The peak total flux values in the peripheral flux traps range from 1.6x10^{15} n·cm^{-2}·s^{-1} to 1.8x10^{15} n·cm^{-2}·s^{-1}. Reflector tally position #1 has a peak thermal neutron flux of 1.1x10^{15} n·cm^{-2}·s^{-1}. Figure 2-13 shows a neutron flux map of the all-fresh core at beginning of irradiation.

Table 2-3. Parameters of baseline Square core assemblies and core

Parameter	
Active Fuel Height (cm)	120
Fuel Meat Material	U-10Mo
^{235}U density (g/cm^3)	3.00
Total U density (g/cm^3)	15.2
Enrichment (wt. %)	19.7
Number of Assemblies	36
Square Assembly Width (cm)	7.5
Fuel Plates Per Assembly	21
Width of coolant channels between fuel plates (cm)	0.2
Fuel plate thickness (cm)	0.125
Fuel meat thickness (cm)	0.05
Cladding Composition	Zircaloy-4
Assembly Wall Composition	Zircaloy-4
Assembly Wall Plate Thickness (cm)	0.2375
Total ^{235}U per assembly (kg)	2.66
Total ^{238}U per assembly (kg)	10.8
Total ^{235}U in core (kg)	95.6
Total ^{238}U in core (kg)	389

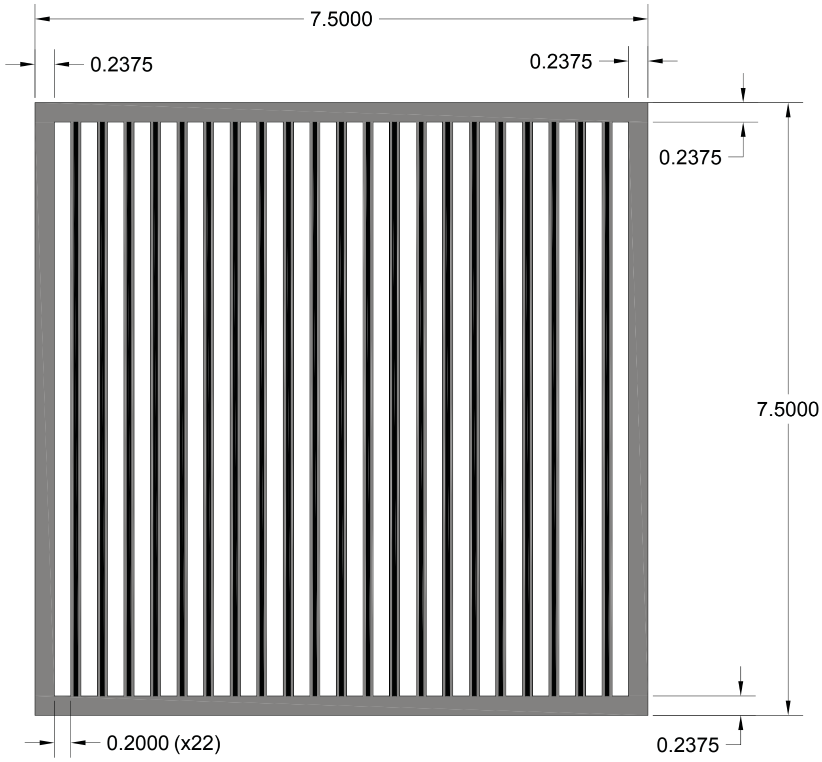

Figure 2-8. Cutaway of square fuel assembly with 21 fuel plates (dimensions in cm).

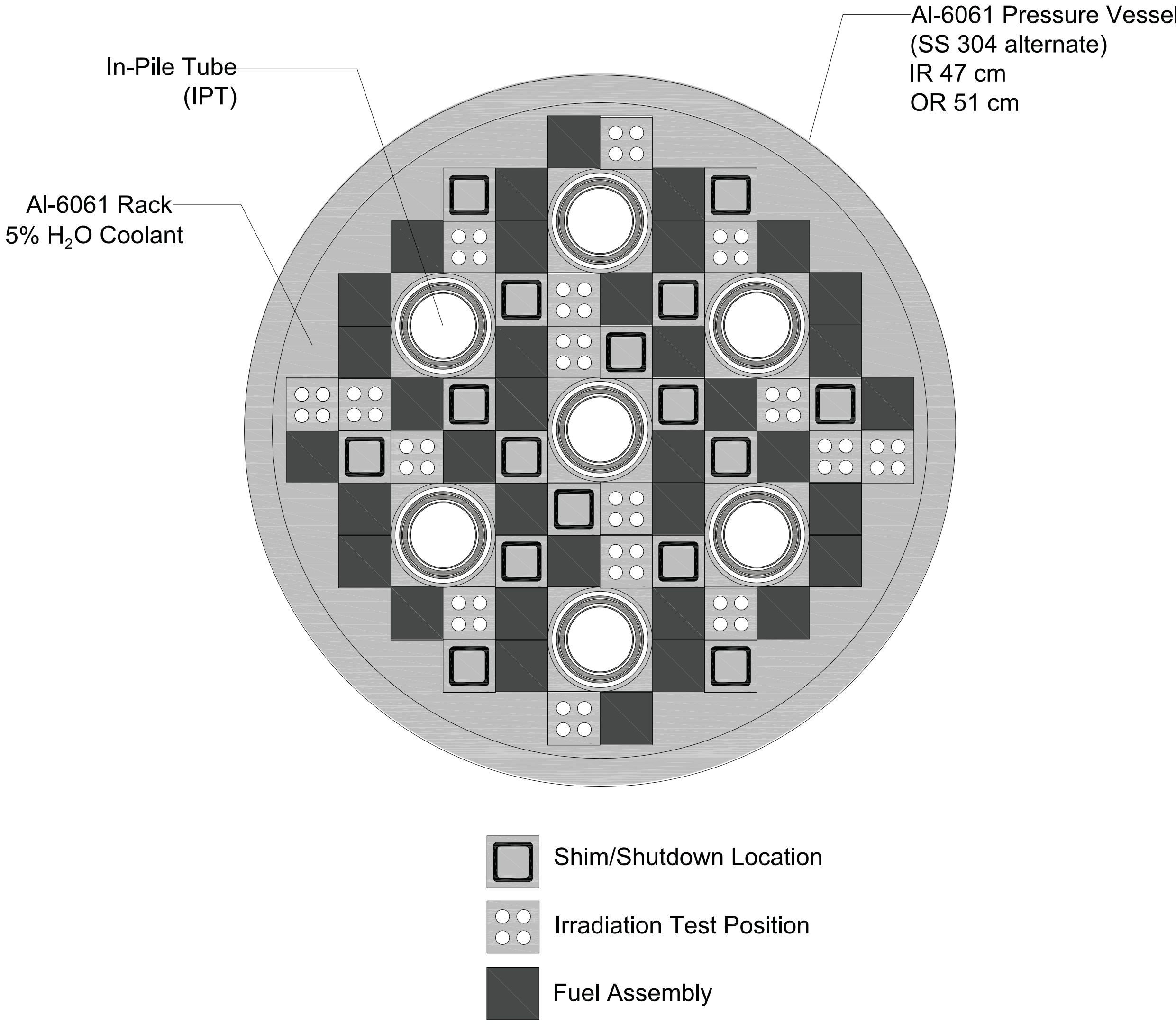

Figure 2-9. Detailed view of square core concept (dimensions in cm).

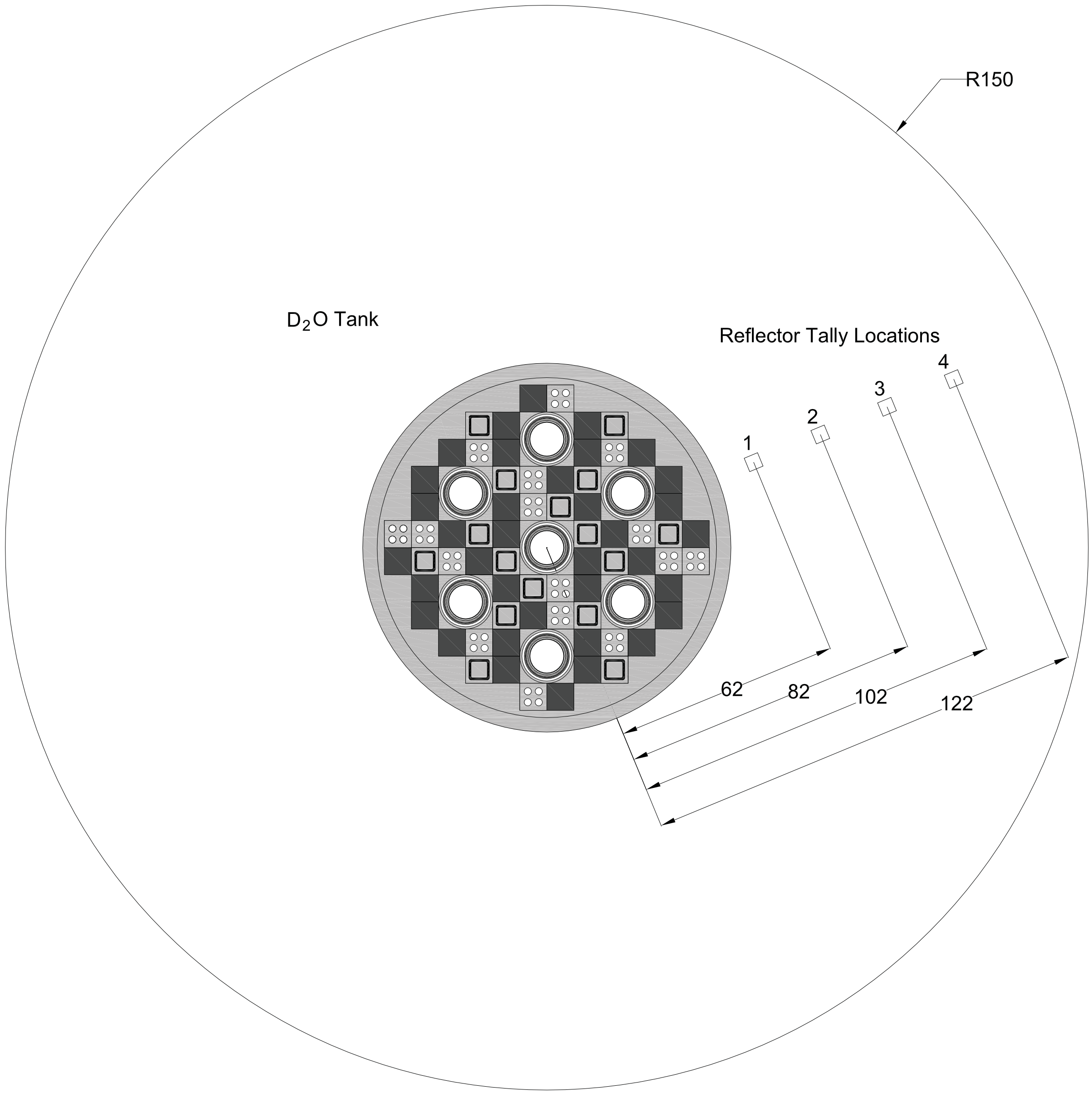

Figure 2-10. Above view of square concept with reflector tally locations (dimensions in cm).

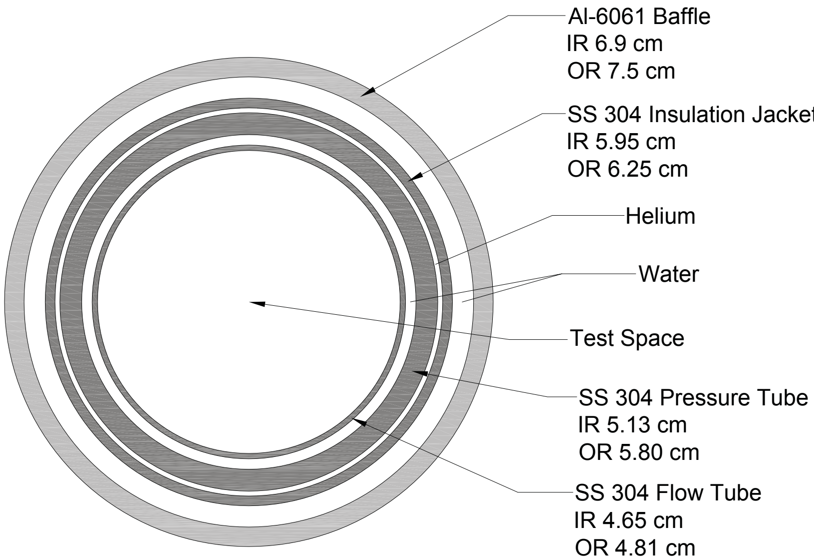

Figure 2-11. Schematic of flux trap in square assembly core.

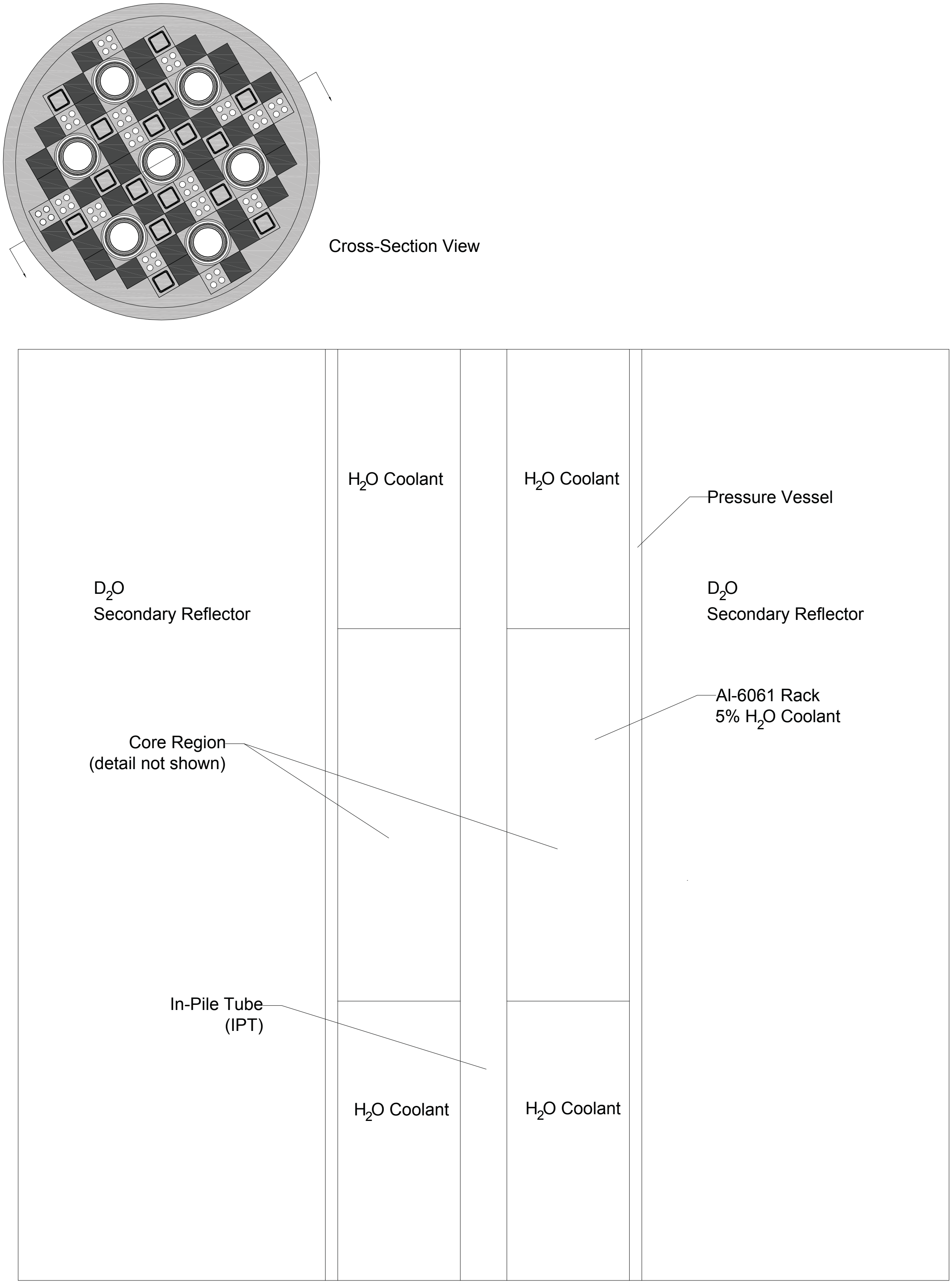

Figure 2-12. Vertical cross section view of square core concept.

Table 2-4. Neutron flux in various locations of baseline Square core.[a]

Tally Location	Neutron Flux in Reflector ($n \cdot cm^{-2} s^{-1}$) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux		
	Peak	Axially Averaged	Peak/ Average
Center Flux Trap	2.71E+14	2.06E+14	1.32
	2.84E+14	2.19E+14	1.30
	2.00E+15	1.52E+15	1.32
NE Flux Trap	2.68E+14	2.04E+14	1.32
	2.34E+14	1.82E+14	1.29
	1.79E+15	1.36E+15	1.32
N Flux Trap	2.43E+14	1.85E+14	1.31
	2.18E+14	1.69E+14	1.29
	1.62E+15	1.23E+15	1.32
NW Flux Trap	2.70E+14	2.05E+14	1.32
	2.37E+14	1.83E+14	1.30
	1.80E+15	1.37E+15	1.32
Reflector Tally 1	6.83E+12	5.64E+12	1.21
	9.09E+14	7.36E+14	1.24
	1.12E+15	8.99E+14	1.25
Reflector Tally 2	—	—	—
	7.17E+14	5.95E+14	1.21
	7.30E+14	6.05E+14	1.21
Reflector Tally 3	—	—	—
	4.23E+14	3.58E+14	1.18
	4.23E+14	3.58E+14	1.18
Reflector Tally 4	—	—	—
	2.10E+14	1.83E+14	1.14
	2.10E+14	1.83E+14	1.14

[a] Initial k_{eff} =1.14066, B_1=70 days

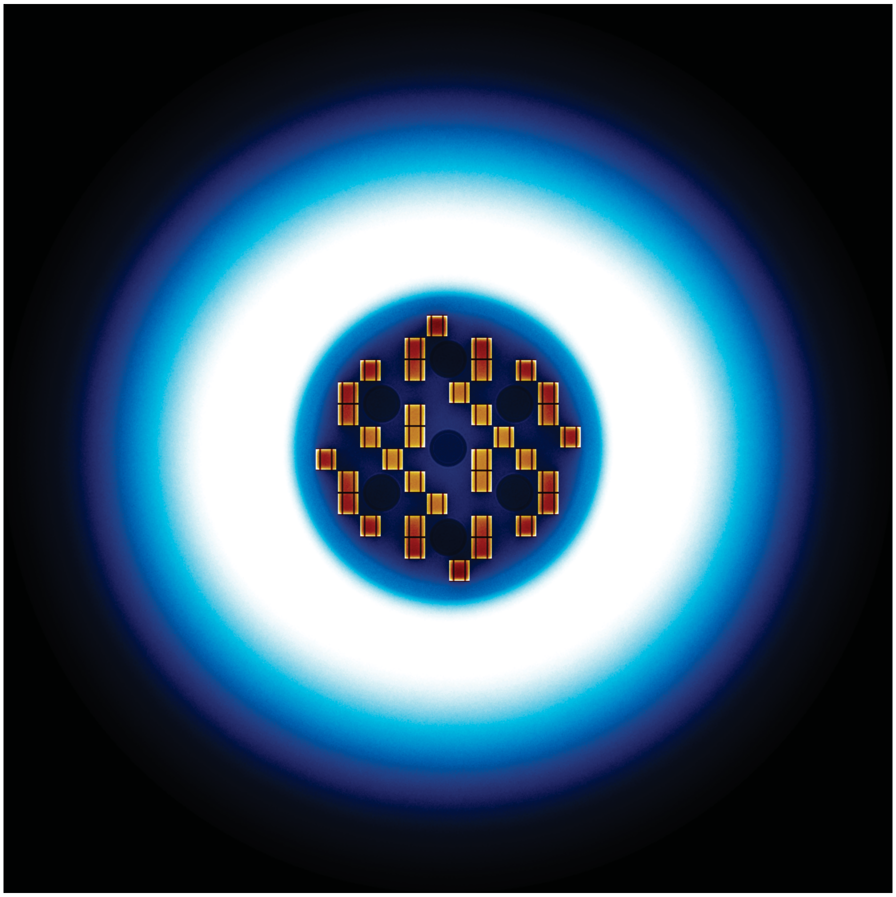

Figure 2-13. Neutron flux and power map of Square core model having all fresh fuel.

2.3 Annular Fuel Concept

The “Annular” fuel core concept is described in this section.

Table 2-5 presents the basic parameters of this reactor. The water-cooled fuel assemblies are arcuate (similar in basic shape to ATR assemblies) and are comprised of 12 plates of U-10Mo fuel meat clad in Zircaloy-4. Fuel plates again have an outer thickness of 0.125 cm and a meat thickness of 0.05 cm. Each arcuate fuel assembly subtends an angle of 45º, as is shown in Figure 2-14. The total mass of uranium in the baseline Annular core is 493 kg, 97 kg of which is ^{235}U. Side plates of the fuel assemblies are 0.475 cm wide and coolant channels are again 2 mm wide. Though it may be required in a final design, no offset of fuel from the side plates is assumed at this time. The fuel plate cladding and the outer can of the assemblies are Zircaloy.

Figure 2-15 shows a schematic view of the Annular core concept. The 56 arcuate fuel assemblies are arranged in groups of eight surrounding seven flux traps, each having an associated IPT. The fuel assemblies sit in an aluminum core rack in the same way as described in the Cylindrical and the Square baseline designs. The aluminum rack is again assumed to contain 5% H_2O coolant by volume for cooling. An aluminum pressure vessel having inner and outer radii of 51 and 55 cm, respectively surrounds the core rack. Outside the pressure vessel is the atmospheric pressure D_2O tank.

Figure 2-16 shows the layout of fuel assemblies surrounding one of the peripheral flux traps. The IPT is located at the center with the same piping as was described for the Cylindrical and the Square designs, only now they are reduced in diameter with the central test space having a diameter of 7 cm. This was done in order to accommodate the anticipated need for safety (ultimate shutdown) rods between the IPT and the fuel assemblies. This arrangement is the same as that found in six of the nine main flux traps in ATR. The worth and design of the safety rods have not been evaluated, but aluminum followers and a guide tube are included in the model at this stage.

Figure 2-17 shows the fuel and IPT surrounding the central flux trap. In this case, no safety rod is included and the flux trap and IPT hardware are expanded to fill the available space. In this case, the diameter of the available test space is approximately 13 cm. Figure 2-18 shows another above view of the Annular core concept with the D_2O tank and the reflector tank flux tally positions shown. Figure 2-19 shows an axial view of a center cross-section of the core. As can be seen in the figure the assemblies again have homogenized regions extending above and below the 120 cm active core region. The IPTs extend the entire height of the 3 m tall D_2O tank and a void boundary is assumed beyond this for neutronic calculations.

Results from Serpent depletion calculations indicate that the baseline Annular reactor has an initial k_{eff} of 1.13172 and a B_1 value of 63 days. Table 2-6 shows neutron flux in various positions in the Annular core. The center flux trap has a peak fast and total flux of $3.0\text{x}10^{14}$ $n \cdot cm^{-2} \cdot s^{-1}$ and $2.0\text{x}10^{15}$ $n \cdot cm^{-2} \cdot s^{-1}$, respectively, and the axial flux peaking factor in the center flux trap is 1.3. The peripheral flux traps have a peak fast and total flux of $1.9\text{x}10^{14}$ $n \cdot cm^{-2} \cdot s^{-1}$ and $1.3\text{x}10^{15}$ $n \cdot cm^{-2} \cdot s^{-1}$, respectively. Reflector tally position #1 has a peak total neutron flux of $9.0\text{x}10^{14}$ $n \cdot cm^{-2} \cdot s^{-1}$. This reactor exhibits generally lower flux values in the flux traps than those of the Cylindrical and Square cores. This is likely due to the amount of IPT and control rod hardware and its associated cooling between the fuel assemblies and the test spaces. It should be noted, however, that the control elements have not been designed in detail for any of the concepts. Therefore, differences in performance stemming from effects of control elements should be considered accordingly. Figure 2-20 shows a neutron flux map of the all-fresh Annular core at beginning of irradiation.

Table 2-5. Parameters of baseline annular fuel assemblies and core.

Parameter	
Active Fuel Height (cm)	120
Fuel Meat Material	U-10Mo
^{235}U density (g/cm^3)	3.00
Total U density (g/cm^3)	15.2
Enrichment (wt. %)	19.7
Number of Assemblies	56
Fuel Plates Per Assembly	12
Inner diameter of innermost coolant channel (cm)	23.0
Outer diameter of outermost coolant channel (cm)	31.2
Width of coolant channels between fuel plates (cm)	0.2
Fuel plate thickness (cm)	0.125
Fuel meat thickness (cm)	0.05
Cladding Composition	Zircaloy-4
Side Plate Composition	Zircaloy-4
Side Plate Width (cm)	0.475
Total ^{235}U per assembly (kg)	1.74
Total ^{238}U per assembly (kg)	7.06
Total ^{235}U in core (kg)	97.3
Total ^{238}U in core (kg)	395.6

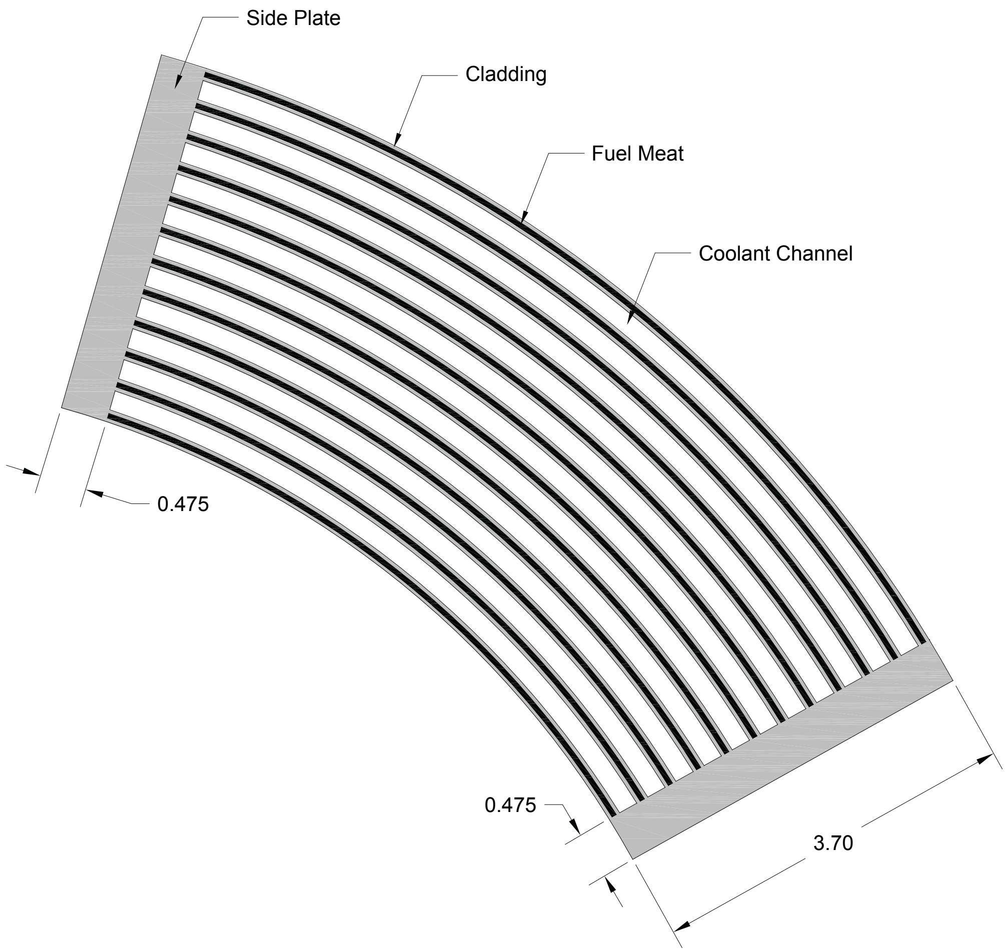

Figure 2-14. Cutaway of arcuate fuel assembly of the annular concept.

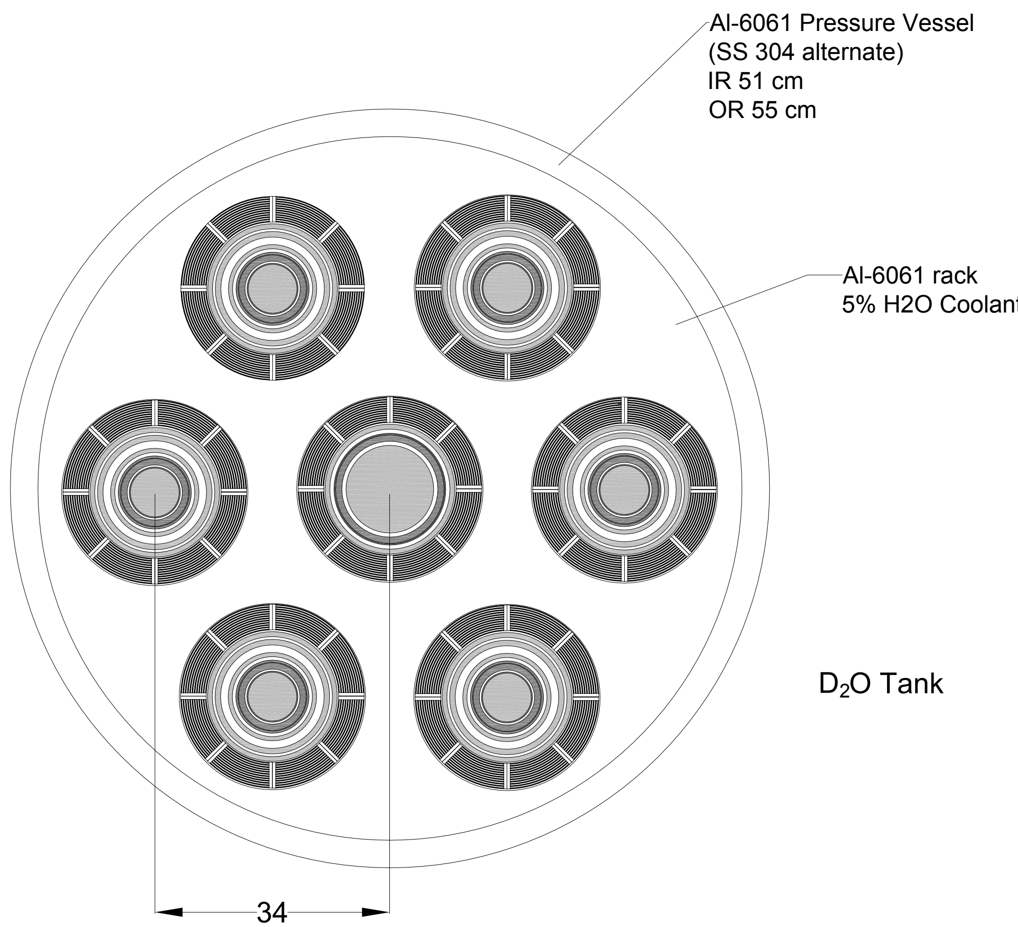

Figure 2-15. Detailed view of annular core concept (dimensions in cm).

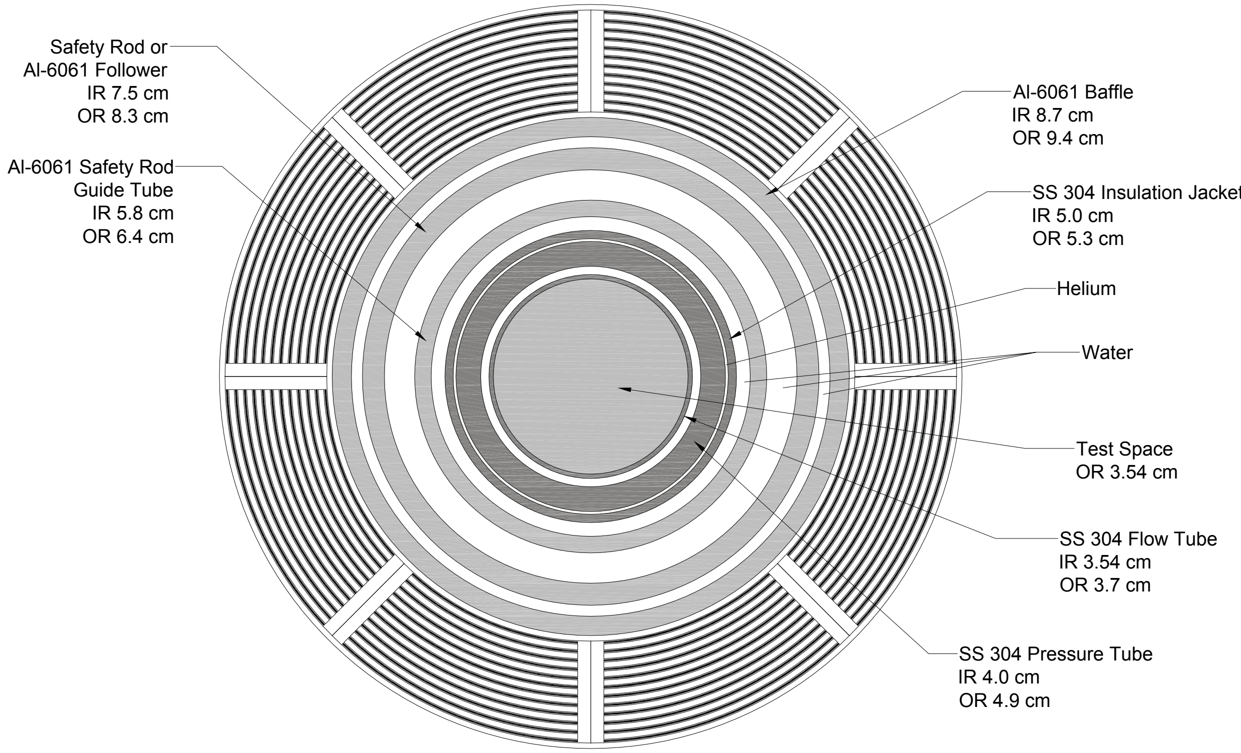

Figure 2-16. Schematic of peripheral module of annular design with safety rod.

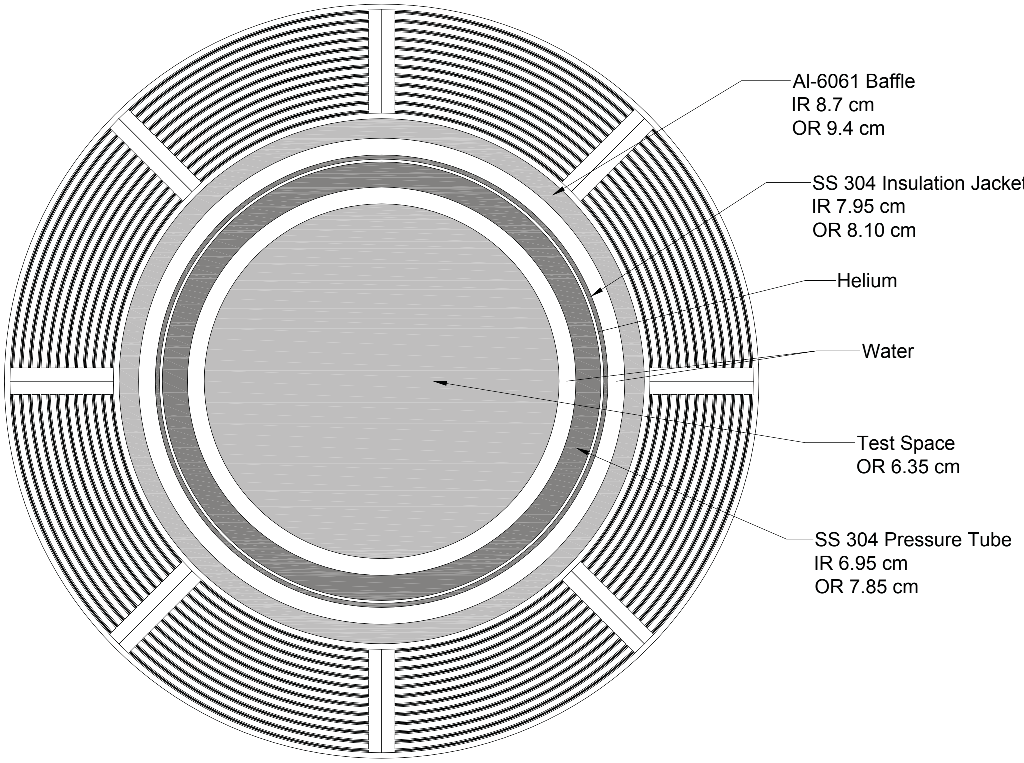

Figure 2-17. Schematic of center module of annular design with no safety rod.

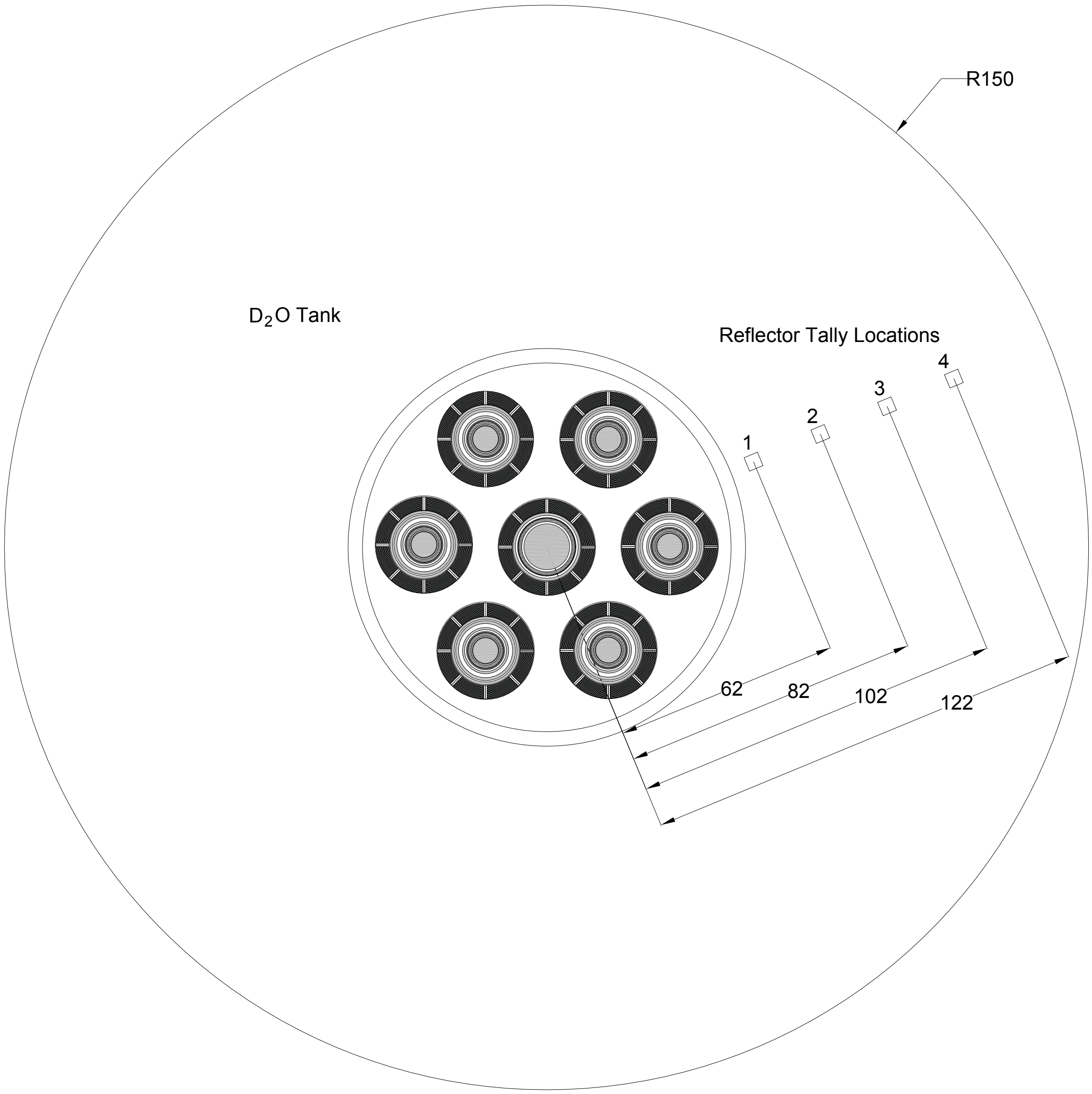

Figure 2-18. Above view of annular concept with reflector tally locations (dimensions in cm).

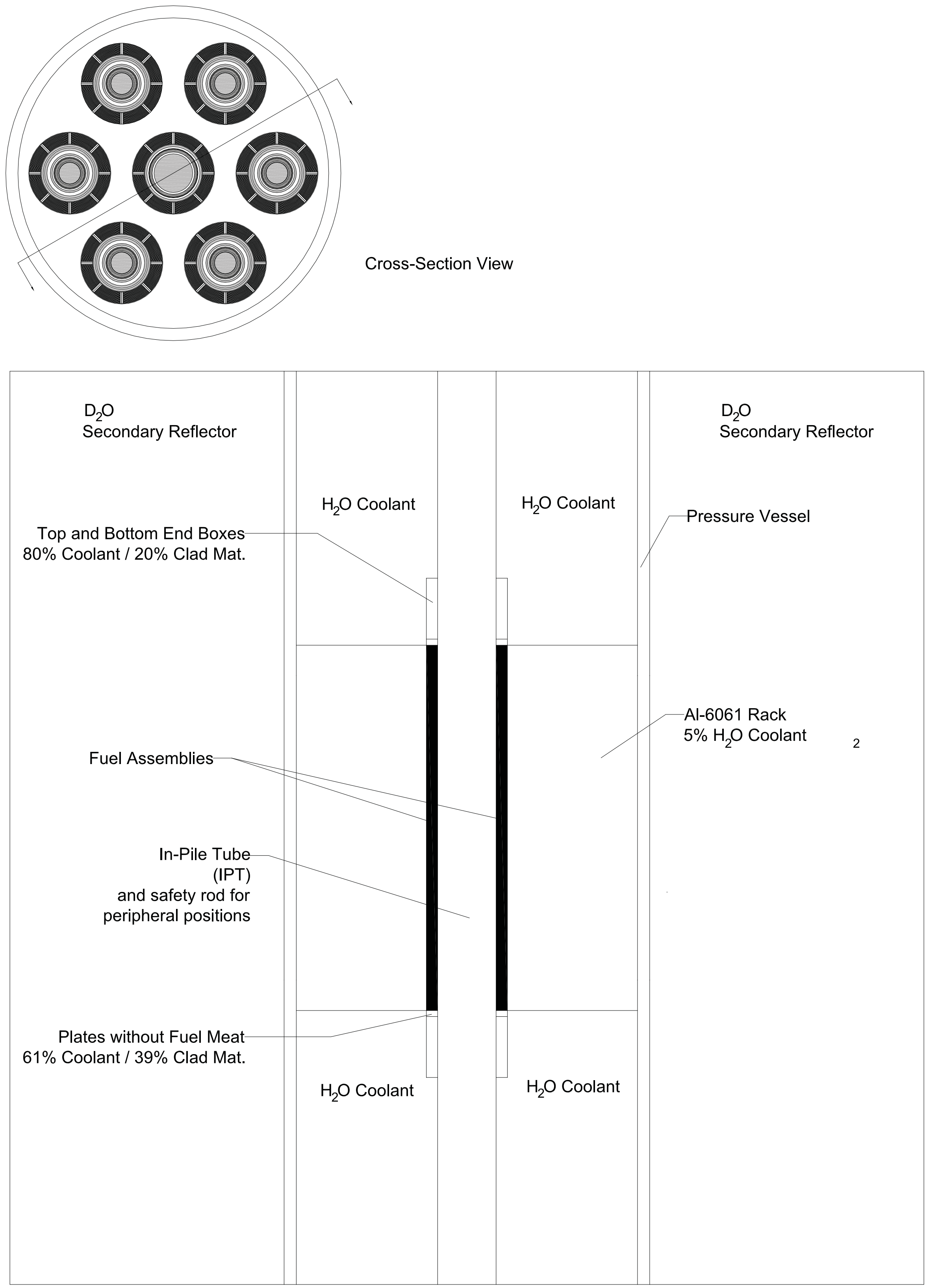

Figure 2-19. Vertical cross section view of annular core concept.

Table 2-6. Neutron flux in various locations in the Annular core. [a]

Tally Location	Neutron Flux in Reflector ($n \cdot cm^{-2} \cdot s^{-1}$) **Fast Flux (>1 MeV)** **Thermal Flux (<0.625 eV)** **Total Flux**		
	Peak	Axially Averaged	Peak/ Average
Center Flux Trap	2.99E+14	2.28E+14	1.31
	3.57E+14	2.75E+14	1.30
	2.05E+15	1.56E+15	1.31
Peripheral Flux Trap	1.87E+14	1.43E+14	1.31
	2.52E+14	1.93E+14	1.31
	1.26E+15	9.57E+14	1.32
Reflector Tally 1	9.92E+12	7.47E+12	1.33
	6.45E+14	5.22E+14	1.24
	8.96E+14	7.12E+14	1.26
Reflector Tally 2	—	—	—
	6.00E+14	4.90E+14	1.22
	6.17E+14	5.03E+14	1.23
Reflector Tally 3	—	—	—
	3.57E+14	3.01E+14	1.19
	3.58E+14	3.02E+14	1.19
Reflector Tally 4	—	—	—
	1.79E+14	1.55E+14	1.16
	1.80E+14	1.55E+14	1.16

[a] Initial k_{eff} =1.13172, B_1=63 days

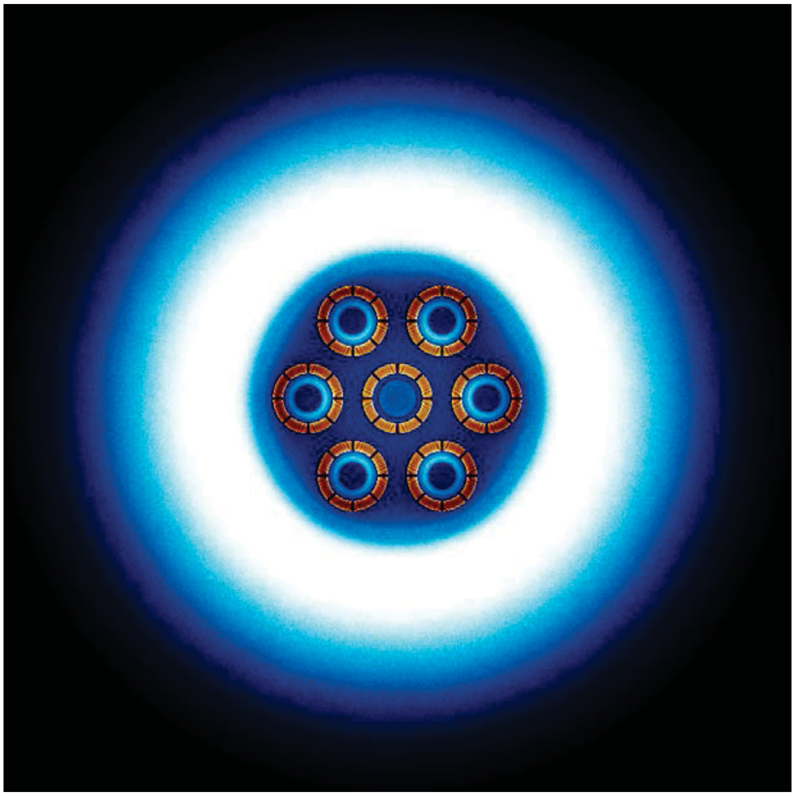

Figure 2-20. Neutron flux and power map of Annular core model having all fresh fuel.

2.4 Pressure Boundary Tube (PBT) Concept

The Pressure Boundary Tube (PBT) concept is very closely related to the Multiple-Annular (M-A) design from the original BATR work. Table 2-7 gives the main parameters of the baseline PBT concept. The baseline configuration of the PBT concept uses the same fuel assemblies as the Annular concept (Figure 2-14), again surrounding the safety rods and IPTs. The departure from the Annular concept comes just outside the fuel elements' outer radius. Rather than the assemblies sitting in a core rack, they are positioned inside seven individual 1.1 cm-thick aluminum pressure boundary tubes (PBTs). These tubes extend the entire axial height of the D_2O tank and collectively serve as the pressure boundary containing the primary H_2O coolant. This is illustrated in Figure 2-21 for the center fuel grouping and in Figure 2-22 for the peripheral modules.

Figure 2-23 shows an above view of the PBT concept with the tally locations shown in the D_2O reflector tank. Figure 2-24 shows an axial view of the PBT concept. As can be seen in the figure the assemblies again have homogenized regions extending above and below the 120 cm active core region. The IPTs extend the entire height of the 3 m tall D_2O tank and a void boundary is assumed beyond this for neutronic calculations.

Results from Serpent 2 depletion calculations indicate that the baseline PBT reactor has an initial k_{eff} of 1.32352 and a B_1 value of 184 days. Table 2-8 shows neutron flux in various positions in the PBT core. The center flux trap has a peak fast and total flux of 2.2×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ and 1.5×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$, respectively and the axial flux peaking factor in the center flux trap is again 1.3. The peripheral flux traps have a peak fast and total flux of 1.7×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ and 1.1×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$, respectively. Reflector tally position #1 has a peak total neutron flux of 1.3×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$. This reactor exhibits much higher reactivity than the other cores. This is due to the presence of the very effectively moderating D_2O in close proximity to fuel. This is in contrast to the low-moderating aluminum core rack used in the other concepts. It should be again noted that the control elements assumed here have not been designed in detail. Figure 2-25 shows a neutron flux map of the all-fresh PBT core at beginning of irradiation. This figure illustrates the high thermal flux close to the outer boundary of the fuel compared to the relatively hard spectrum nominally present in the reactors having aluminum core racks.

Table 2-7. Parameters of baseline PBT concept fuel assemblies and core.

Parameter	
Active Fuel Height (cm)	100
Fuel Meat Material	U-10Mo
^{235}U density (g/cm^3)	3.00
Total U density (g/cm^3)	15.2
Enrichment (wt. %)	19.7
Number of Assemblies	56
Fuel Plates Per Assembly	12
Inner diameter of innermost coolant channel (cm)	23.0
Outer diameter of outermost coolant channel (cm)	31.2
Width of coolant channels between fuel plates (cm)	0.2
Fuel plate thickness (cm)	0.125
Fuel meat thickness (cm)	0.05
Cladding Composition	Zircaloy-4
Side Plate Composition	Zircaloy-4
Side Plate Thickness (cm)	0.475
Total ^{235}U per assembly (kg)	1.74
Total ^{238}U per assembly (kg)	7.06
Total ^{235}U in core (kg)	97.3
Total ^{238}U in core (kg)	395.6

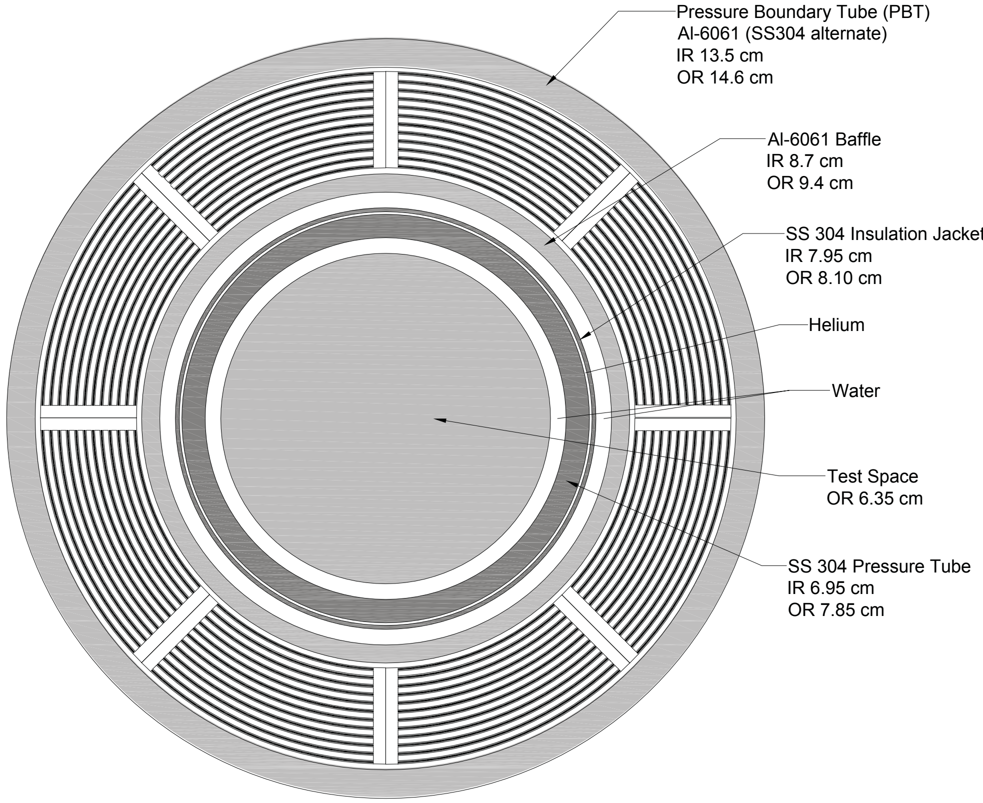

Figure 2-21. Schematic of center module of PBT design with no safety rod.

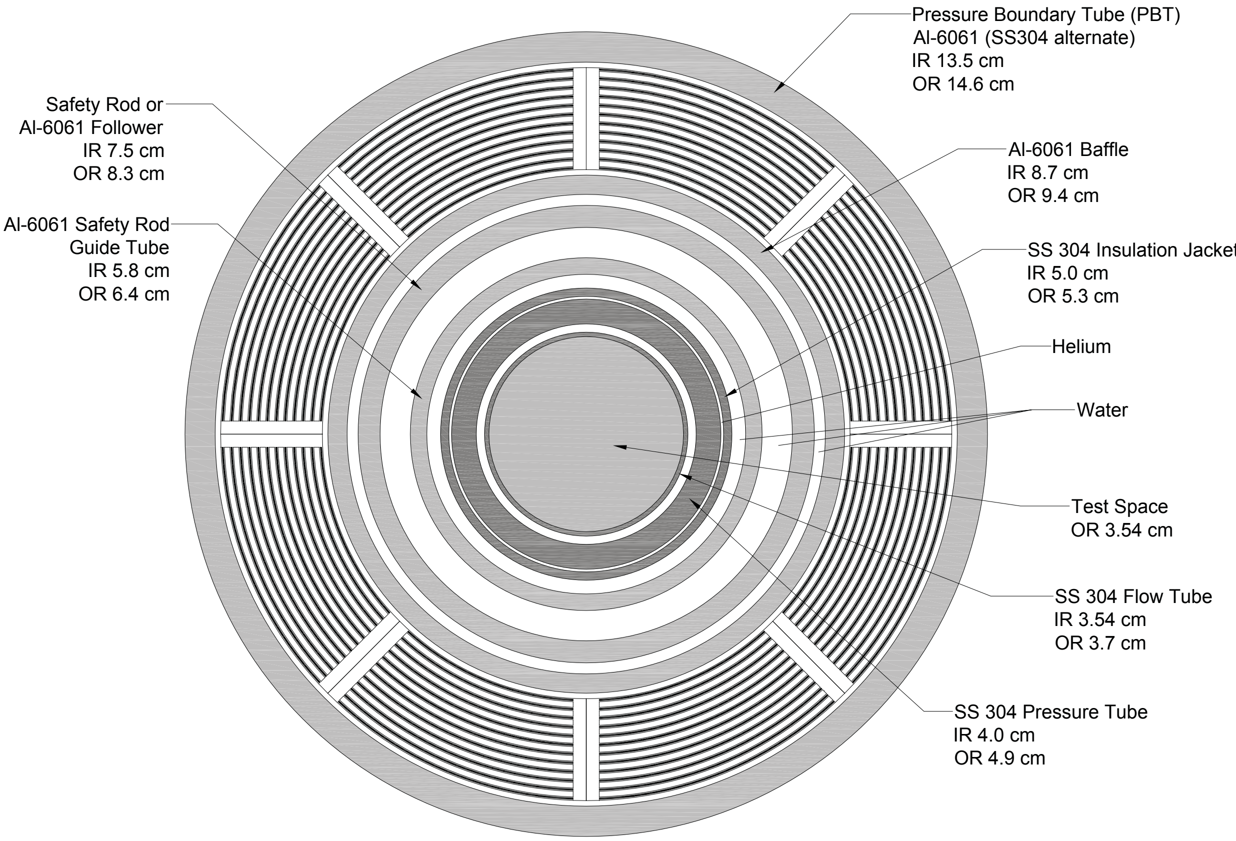

Figure 2-22. Schematic of peripheral module of PBT design with no safety rod.

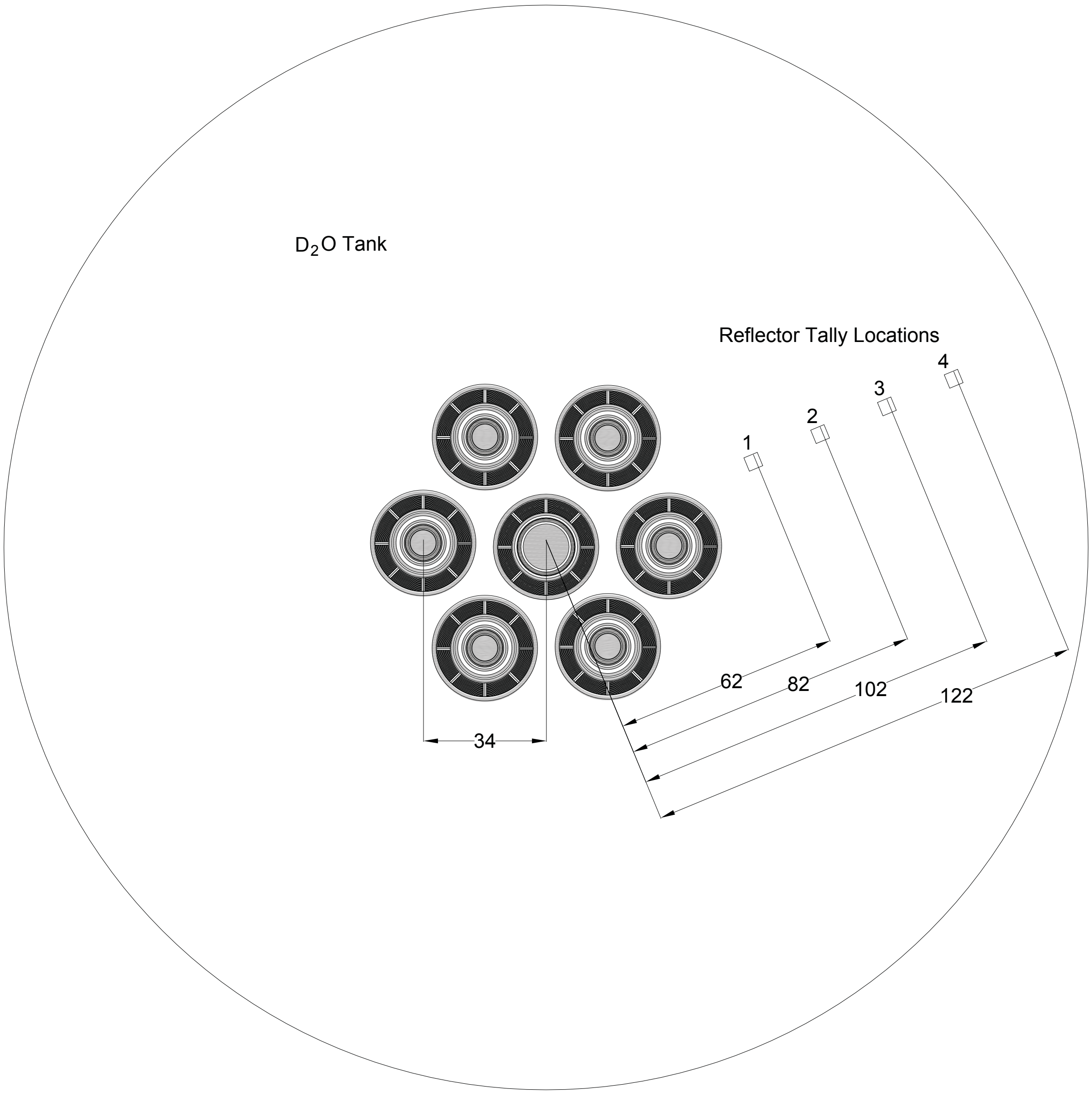

Figure 2-23. Above view of PBT concept with reflector tally locations (dimensions in cm).

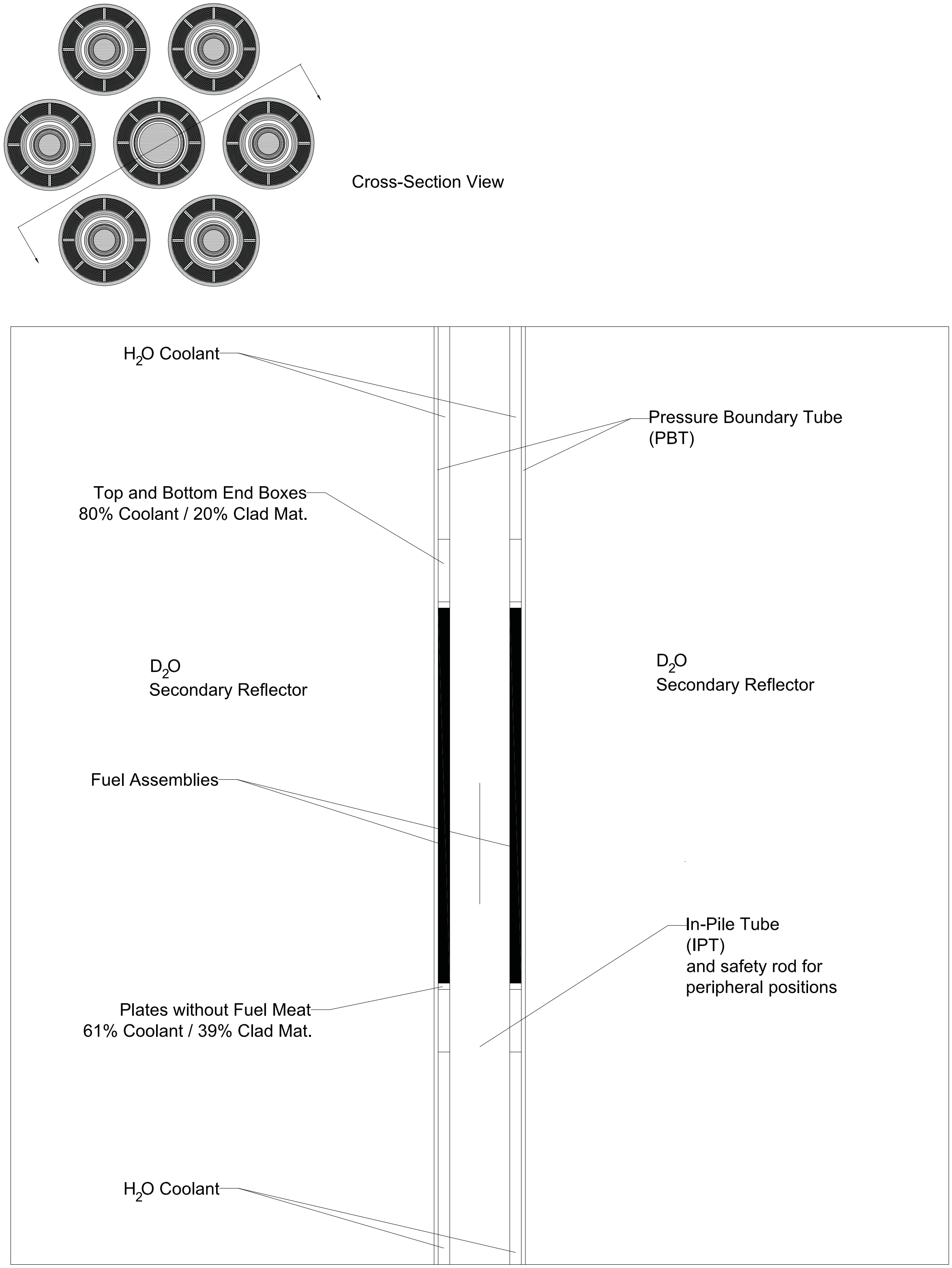

Figure 2-24. Vertical cross section view of PBT concept.

Table 2-8. Neutron flux in various locations in the PBT core. [a]

Tally Location	Neutron Flux in Reflector ($n \cdot cm^{-2} \cdot s^{-1}$) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux		
	Peak	Axially Averaged	Peak/ Average
Center Flux Trap	2.23E+14	1.70E+14	1.32
	2.98E+14	2.29E+14	1.30
	1.53E+15	1.17E+15	1.31
Peripheral Flux Trap	1.68E+14	1.28E+14	1.32
	2.34E+14	1.82E+14	1.28
	1.10E+15	8.44E+14	1.30
Reflector Tally 1	4.75E+12	3.70E+12	1.28
	1.14E+15	9.38E+14	1.22
	1.26E+15	1.03E+15	1.23
Reflector Tally 2	—	—	—
	7.84E+14	6.60E+14	1.19
	7.91E+14	6.66E+14	1.19
Reflector Tally 3	—	—	—
	4.62E+14	3.96E+14	1.17
	4.63E+14	3.96E+14	1.17
Reflector Tally 4	—	—	—
	2.33E+14	2.04E+14	1.14
	2.33E+14	2.04E+14	1.14

[a] Initial k_{eff} =1.32352, B_1 =184 days

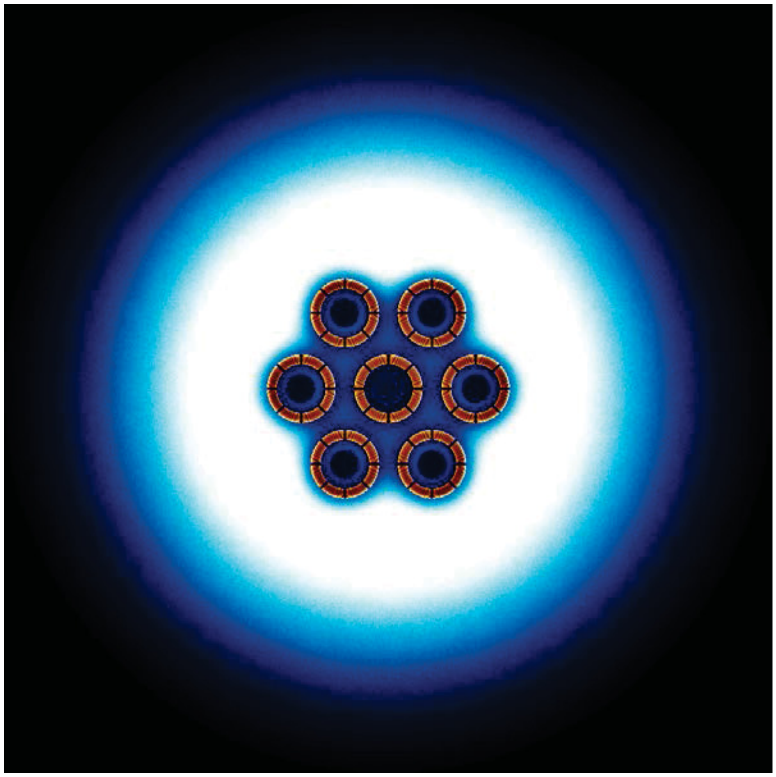

Figure 2-25. Neutron flux map of PBT core model loaded with all fresh fuel.

3. Pressure Vessel and PBT Considerations

In reactor designs featuring a reactor pressure vessel (RPV) located close to the fueled portion of the core, vessel materials with low neutron capture cross-section are favorable for two main reasons. One reason is that the vessel is close enough to fuel that neutron capture affects core reactivity substantially, particularly in the cases where a low-moderation core rack is used. The other motivation for a low-absorption RPV is the desire for high flux outside the RPV. Aluminum (specifically Al-6061) was identified as a candidate material to serve as a low-absorption pressure boundary in the BATR project [3]. It is also the material to be used in the RPV for the Jules Horowitz Reactor at CEA, Cadarache[13]. An alternative fallback material is the more conventional stainless steel 304 (SS304). In this section, the existing ASME Boiler and Pressure Vessel Code [Ref ASME code] is used to determine minimum RPV thickness required for three materials; SS304, Al-6061 T4, and Al-6061 T6. The T4 and T6 designations represent different heat treatments on the same starting material. Table 3-1 gives maximum allowable stress for the three materials for the various temperatures were the code exists. For Al-6061, this extends only to 400ºF (204ºC). A minimum wall thickness (t) for a pressure vessel can then be determined using the following equation [Ref ASME code]:

$$t = P*R/(S_m-0.5P)$$

where P is design pressure, R is inner radius of the vessel, and S_m is maximum allowable stress as given in the code. Values for a 1 m diameter vessel and 2.5 MPa design pressure are given in the rightmost column in Table 1. These are plotted in Figure 3-1 as well.

As can be seen in the Table 3-1 and Figure 3-1, the allowable stress for the Al6061 T6 is higher than that of the T4 up to 177ºC (350ºF), where the T6 assumes the T4 value. Beyond this temperature up to 204ºC (400ºF), both of these essentially lose their heat treatment and the allowable stress drops to the T0 (or untreated) value. On the other hand, the maximum allowable stress for the SS304 is higher than either type of aluminum and only changes slightly in the temperature range of interest. If we assume a design pressure of 2.5 MPa, a temperature of up to 204ºC, and a vessel diameter of 1 m, the minimum wall thickness for either aluminum type would be 3.6 cm. Under the same conditions, the minimum wall thickness for SS304 would be 1 cm. If the temperature of the vessel could be limited to less than 177ºC, the minimum wall thickness for Al-6061 would drop to 1.7 cm while that for SS304 would be essentially unchanged.

During normal operation, the RPV would not be expected to reach temperatures in excess of the 89ºC coolant outlet temperature. The peak RPV temperature would likely occur during the period of natural convection following a primary pump coastdown.

Figure 3-2 shows the same information as Figure 3-1 except directed at the PBT option. Therefore, it shows the minimum PBT pressure boundary thickness versus temperature for ~28 cm diameter vessels.

Figure 3-3 and Figure 3-4 show radiative capture and elastic scattering cross-sections, respectively, for Fe-56 and Al-27. These are the two major constituents of the aluminum and SS304 material candidates examined here in detail.

Table 3-2 shows results of neutronic calculations with the candidate pressure vessel materials for each of the baseline MATRIX concepts. From these results, one sees that in all cases, use of a SS304 pressure boundary carries a heavy reactivity penalty over aluminum. This is due primarily to the much larger absorption cross-section seen in Figure 3-3. This is particularly true in the PBT case since the pressure boundary is closest to the fuel in this concept. However, the PBT core has enough excess reactivity to absorb the loss in reactivity and remain viable. One also may note that although the SS304 material carries a significant reactivity penalty, flux in the flux traps and in the reflector are not affected adversely. As for the flux in the reflector, the thinness of the SS304 is likely responsible for the lack of a significant reduction in flux. Zircaloy was also added to the Cylindrical core with the same thickness as the SS304. One sees that this material performs best of all three, though costs may be prohibitive.

Note that this analysis has not considered the effects of neutron fluence and whether this would add additional thickness requirements to the RPV and how it would dictate its change-out interval.

Also note that while calculations are not included in this section for Zircaloy pressure boundaries for the PBT core, it would be expected to perform quite well neutronically (similar to aluminum) while requiring the same or smaller thickness as SS304. Future work on PBT designs should consider Zircaloy as a lead pressure boundary candidate.

Table 3-1. Maximum allowable stress and minimum wall thickness of candidate pressure boundary materials for various maximum temperatures.

Material and Treatment	Temperature		Maximum Allowable Stress [Ref. ASME Code]		Min. Wall Thickness (cm)	
	(ºF)	(ºC)	(ksi)	(MPa)	1 m Dia.	28 cm Dia.
Al-6061 T4 Drawn, Seamless Tube	200	93	10.4	71	1.8	0.50
	250	121	10.2	69	1.8	0.51
	300	149	10.2	69	1.8	0.51
	350	177	10.2	69	1.8	0.51
	400	204	5.2	35	3.7	1.0
Al-6061 T6 Drawn, Seamless Tube	200	93	17.5	119	1.1	0.30
	250	121	17.5	119	1.1	0.30
	300	149	16.7	114	1.1	0.31
	350	177	10.7	73	1.7	0.49
	400	204	5.2	35	3.7	1.0
18Cr-8Ni Stainless Steel 304 Seamless Tube or Pipe	200	93	20.0	136	0.9	0.26
	250	121	20.0	136	0.9	0.26
	300	149	20.0	136	0.9	0.26
	350	177	19.3	131	1.0	0.27
	400	204	18.6	127	1.0	0.28
	450	232	18.0	122	1.0	0.29
	500	260	17.5	119	1.1	0.30
	550	288	17.0	116	1.1	0.31
	600	316	16.6	113	1.1	0.31
	650	343	16.2	110	1.1	0.32
	700	371	15.8	107	1.2	0.33
	750	399	15.5	105	1.2	0.34
	800	427	15.2	103	1.2	0.34

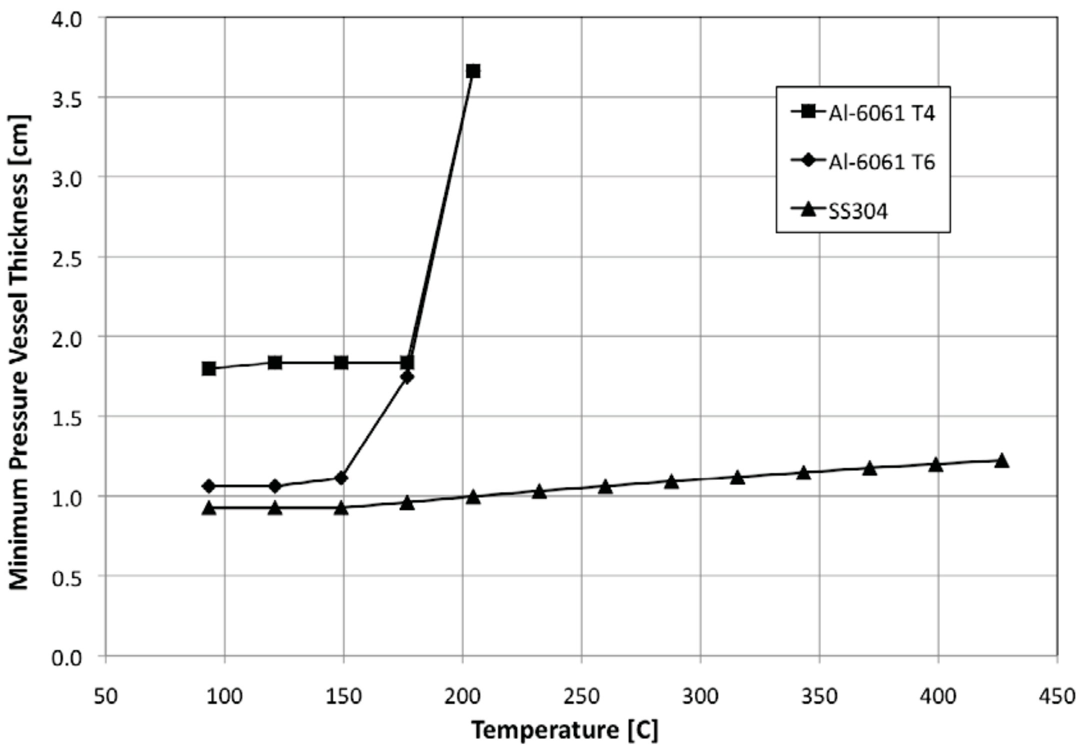

Figure 3-1. Minimum wall thickness of candidate RPV materials versus temperature for 1-meter inner diameter.

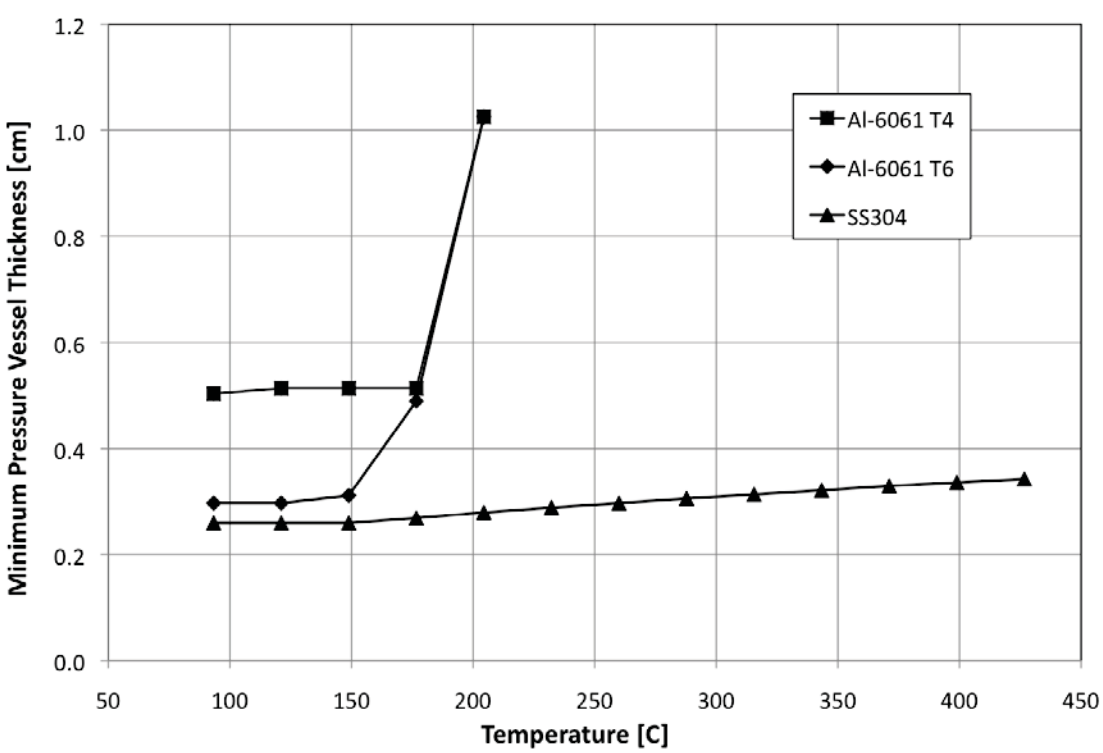

Figure 3-2. Minimum wall thickness of candidate PBT materials versus temperature for 28 cm diameter.

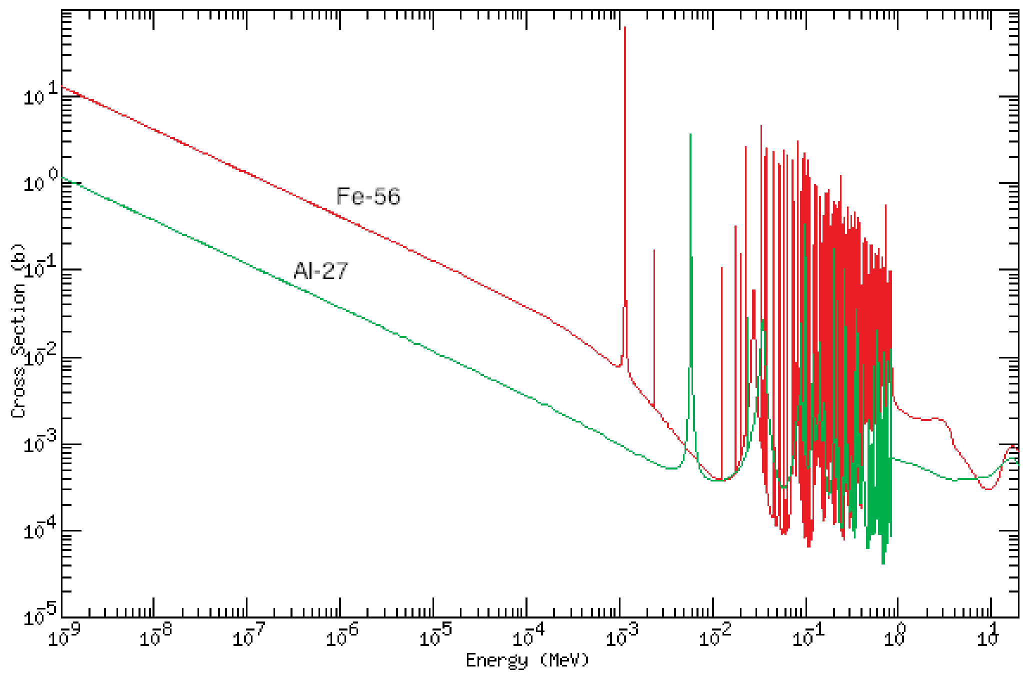

Figure 3-3. Radiative capture cross-sections of ^{27}Al and ^{56}Fe. [14]

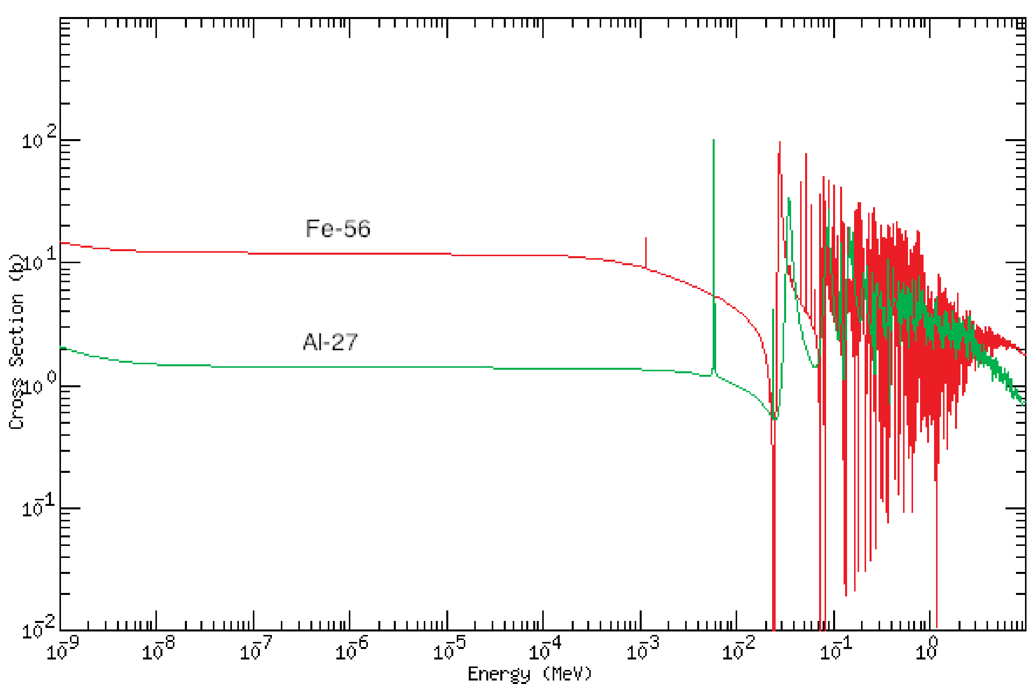

Figure 3-4. Elastic scattering cross-sections of ^{27}Al and ^{56}Fe. [14]

Table 3-2. Results of studies of SS304 pressure boundaries with comparisons to Al-6061.

Core Design	Pressure Boundary	Initial k_{eff}	B_1 (days)	Peak Neutron Flux in Reflector ($n \cdot cm^{-2} \cdot s^{-1}$) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux		
				Center Flux Trap	Peripheral Flux Trap[a]	Reflector Position 1
Cylindrical	Al-6061 P.V. 4 cm thick	1.18427	101	3.22E+14	2.79E+14	5.52E+12
				2.77E+14	2.42E+14	9.82E+14
				2.07E+15	1.80E+15	1.14E+15
	S.S. 304 P.V. 1.1 cm thick	1.13797	68	3.67E+14	2.94E+14	3.80E+12
				3.07E+14	2.45E+14	8.46E+14
				2.33E+15	1.87E+15	9.58E+14
	Zircaloy P.V. 1.1 cm thick	1.21359	119	2.93E+14	2.67E+14	5.81E+12
				2.58E+14	2.32E+14	1.11E+15
				1.89E+15	1.71E+15	1.25E+15
Square	Al-6061 P.V. 4 cm thick	1.14066	70	2.71E+14	2.43E+14	6.83E+12
				2.84E+14	2.18E+14	9.09E+14
				2.00E+15	1.62E+15	1.12E+15
	S.S. 304 P.V. 1.1 cm thick	1.10069	40	3.09E+14	2.55E+14	5.07E+12
				3.13E+14	2.24E+14	8.37E+14
				2.25E+15	1.68E+15	9.89E+14
Annular	Al-6061 P.V. 4 cm thick	1.13172	63	2.99E+14	1.87E+14	9.92E+12
				3.57E+14	2.52E+14	6.45E+14
				2.05E+15	1.26E+15	8.96E+14
	S.S. 304 P.V. 1.1 cm thick	1.10011	40	3.29E+14	1.90E+14	6.75E+12
				3.87E+14	2.55E+14	5.77E+14
				2.24E+15	1.27E+15	7.47E+14
PBT	Al-6061 PBT 1.1 cm thick	1.32352	184	2.99E+14	1.68E+14	4.75E+12
				3.57E+14	2.34E+14	1.14E+15
				2.05E+15	1.10E+15	1.26E+15
	S.S. 304 PBT 0.35 cm thick	1.22919	129	2.41E+14	1.68E+14	4.20E+12
				3.17E+14	2.37E+14	1.07E+15
				1.64E+15	1.10E+15	1.18E+15

[a] For the Square core concept, the peripheral flux traps are not identical and here the North flux trap is used.

4. Reflector Tank Content

4.1 General Considerations for Reflector Tank Content

The D_2O reflector tank described in the baseline case descriptions in Section 2 was proposed in the BATR project as a versatile and reconfigurable region of high thermal flux at atmospheric pressure. The objective of this is to allow for various types of secondary missions to be satisfied, such as beam tubes, multiple irradiation positions, etc. These would ideally be accessible during reactor operation so as not to require additional reactor shut downs on account of reflector experiment change outs. This is the motivation for placing this region outside the main pressure boundary containing the primary coolant system. With its high moderating power, extremely low capture cross section, and liquid phase, D_2O is an attractive candidate for such a reflector region. However, D_2O is extremely expensive with prices ranging from $300 to $600 per kg. Furthermore, it may need to be sealed from the environment to avoid contamination by H_2O in the air, partially compromising the easy accessibility afforded by its location outside the primary pressure boundary. For this reason, other reflector options were investigated for their neutronic performance. Though the possible need for sealing D_2O from surrounding air in part drove this analysis, it should be noted that this requirement is not certain. In this application, some contamination of the D_2O may be acceptable. Future work should evaluate this.

The alternative reflector materials evaluated here are H2O, beryllium, graphite, and a concept for removable, reconfigurable D_2O tanks in an H_2O pool. For the solid phase reflectors, some fraction of H_2O cooling is assumed. Because of its high moderating power and near-zero initial cost, H_2O is the most common reactor coolant/moderator in the world and is also considered a reflector in many reactors. Its main neutronic disadvantage is the high thermal neutron capture cross section (664 mb, mostly due to hydrogen) relative to that of D_2O (1.33 mb), beryllium (9.2 mb), and graphite (3.4 mb)[a]. This has the effect of lowering k_{eff}, but also attenuating neutron flux quite sharply in a large reflector used for irradiations such as those specified for the MATRIX concepts.

Graphite is a reflector and moderator material used in many reactors throughout history. Beryllium is a reflector and moderating material used in many research reactors. This is the material used as a reflector in ATR. Despite its very attractive neutronic properties, disposal of used beryllium has proven to be difficult. As of the time of this writing, all beryllium reflector blocks that have been used in ATR remain in the spent fuel canal. Both beryllium and graphite are analyzed as pure having 10% by volume H_2O coolant homogeneously mixed into them. This gives a rough approximation of the neutronic impact of cooling them, albeit an exaggerated one since homogeneous mixing of the water can increase its impact over discrete cooling channels.

4.2 Replaceable, Reconfigurable D_2O Tanks

Another reflector configuration to be investigated here is that of replaceable, reconfigurable D_2O tanks in a water pool. This is proposed as a compromise between the low initial cost and open access to a water pool with the low capture cross section of D_2O. Figure 4-1 shows schematics of what this concept could look like. The above view shows that the tanks surround

[a] 0.0253 eV values from Lamarsh & Baratta, *Introduction to Nuclear Engineering*, 3rd Edition, 2001.

the core and pressure boundary in eight segments, each subtending a 45º angle. The tanks are constructed from Al-6061 and are here assumed to have 2 cm thick walls. These tank walls will bear minimal load since the inside and outside pressures are nearly atmospheric. Test positions could be machined into the tanks such that the D_2O is sealed inside and experiments could be raised and lowered out of their irradiation positions from above the tank without shutting down the reactor and without penetrating the D_2O-filled chamber. Figure 4-1 shows optional piping that could be used for D_2O cleanup, such as tritium removal, online. However, since these tanks would be removable, it may be more attractive to leave the tanks sealed with space for gases to accumulate and process the tanks periodically outside the core.

Figure 4-2 shows an above cross sectional view of the baseline Cylindrical core model with the removable, reconfigurable D_2O tanks positioned outside the pressure boundary as modeled in Serpent. The clearance between the D_2O tanks is 1.0 cm and that between the pressure vessel outer surface and the D_2O tank wall is 0.5 cm. A distance of 8.0 cm is selected rather arbitrarily as the clearance between the outer D_2O tank surface and the boundary of the H_2O pool. Figure 4-3 shows a vertical cross section view of the same Serpent model. This shows that the D_2O tanks were conceptualized such that they extend 10 cm above and below the active core height of 120 cm. The baseline Cylindrical model described in Section 2.1 has a large D_2O reflector tank with a volume of approximately 9.5 m^3. This amounts to 10,500 kg of D_2O, and given the price range above, a capital cost of approximately \$3 to \$6 million. The removable reflector tanks described here and shown in Figure 4-2 and Figure 4-3 would reduce the amount of D_2O required by roughly a factor of two.

Figure 4-4 shows an above view of the neutron flux in the Cylindrical core at BOL. The white areas represent regions of high thermal flux, while blue areas represent high fast flux. The yellow and red regions represent higher and lower fission power, respectively. The thermal neutron flux is observed to be reduced somewhat in the gaps between the D_2O tanks where H_2O is present. Figure 4-5 shows a flux plot of the same case in an axial cross section view.

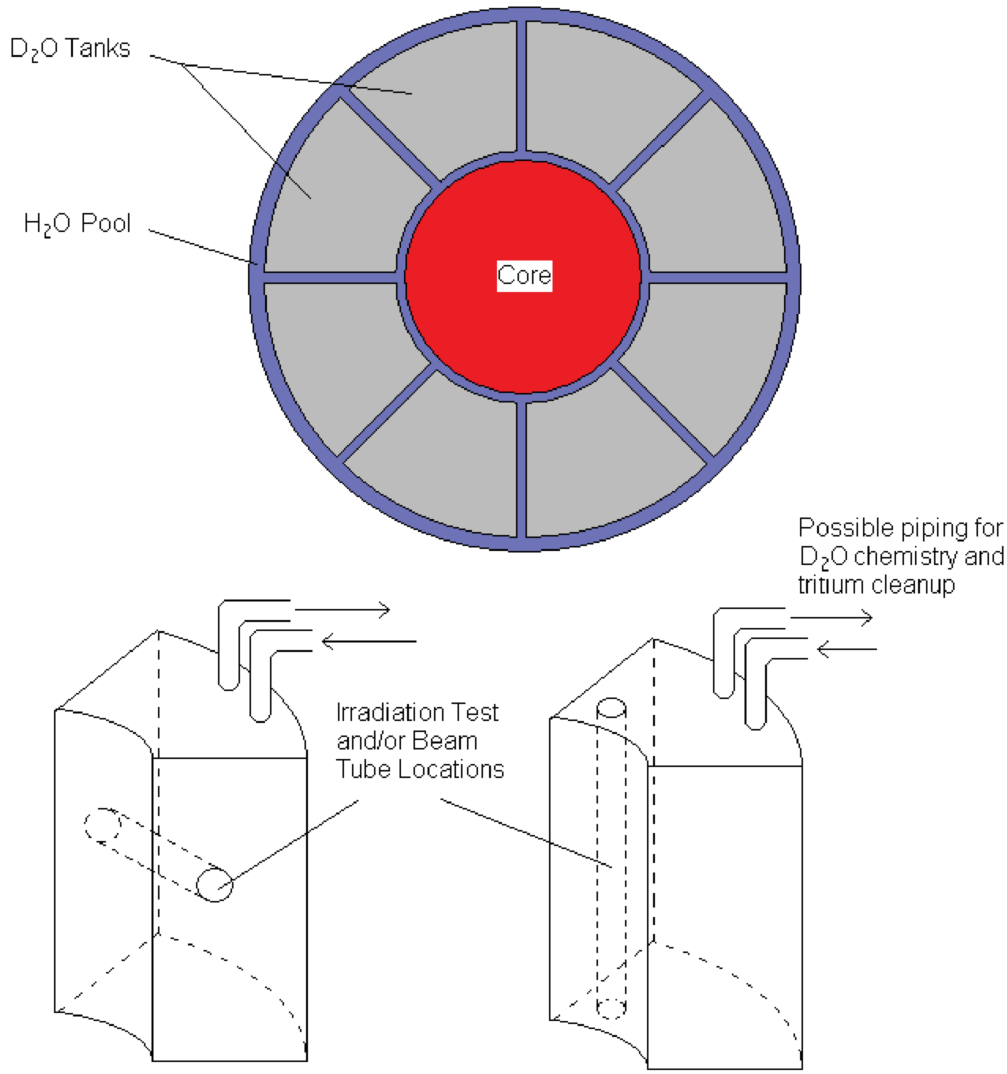

Figure 4-1. Sketches of removable, reconfigurable D_2O reflector tanks.

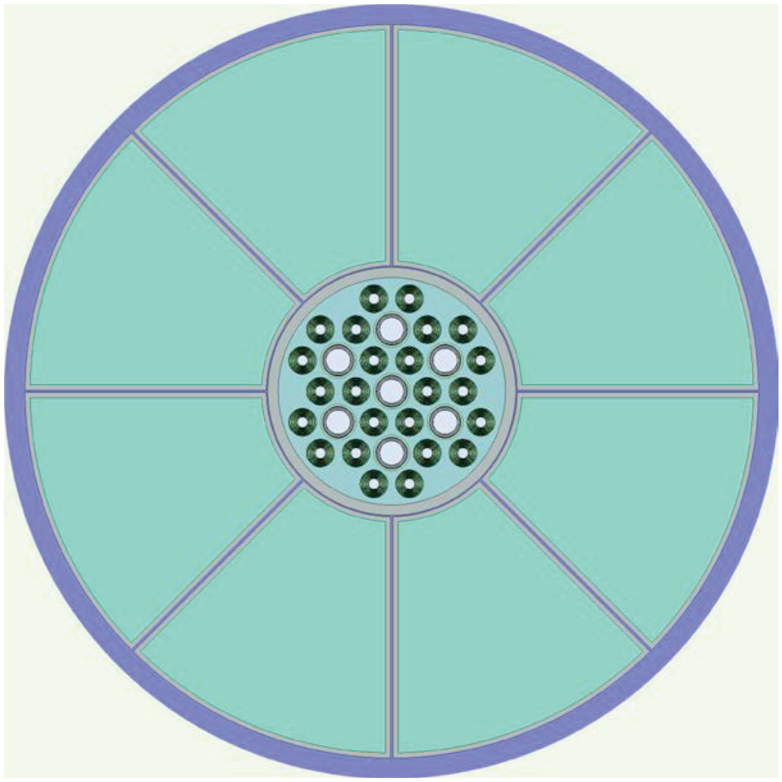

Figure 4-2. Above view of cylindrical core model with D_2O tanks at axial core center.

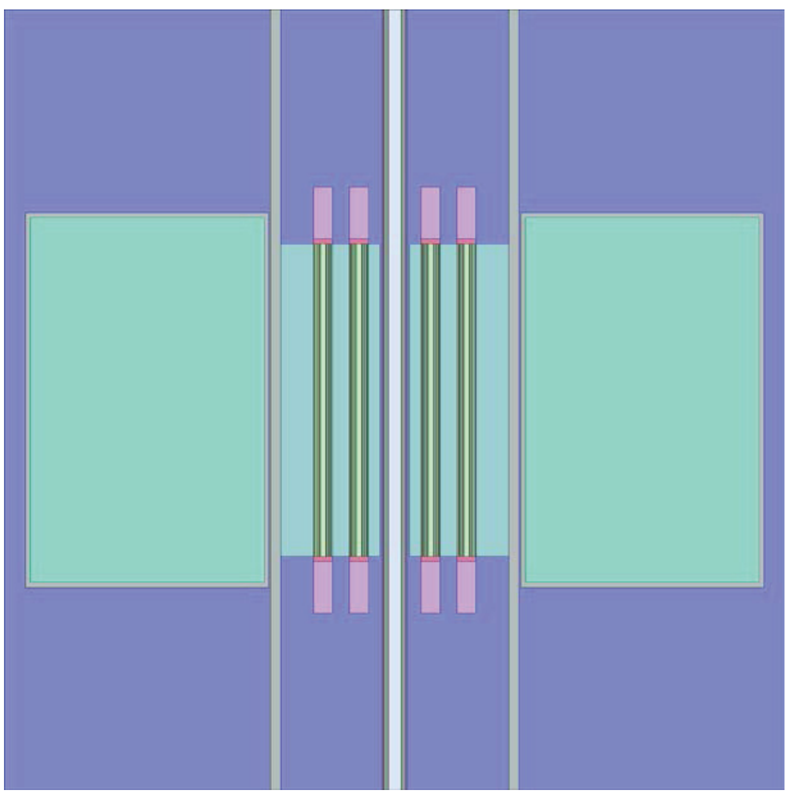

Figure 4-3. Side view of cylindrical core model with D_2O tanks at axial core center.

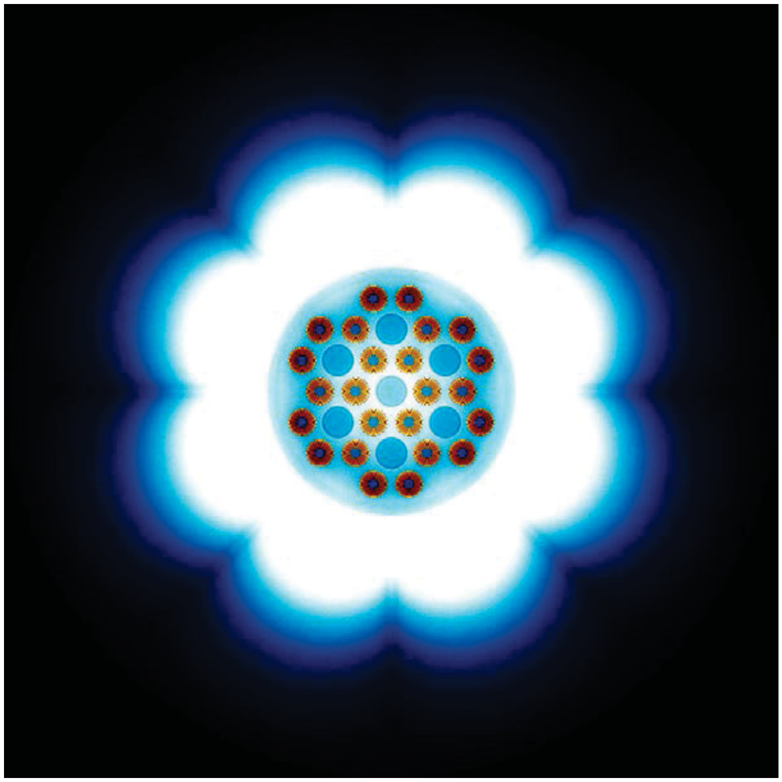

Figure 4-4. Above view flux plot of cylindrical core with D_2O reflector tanks.

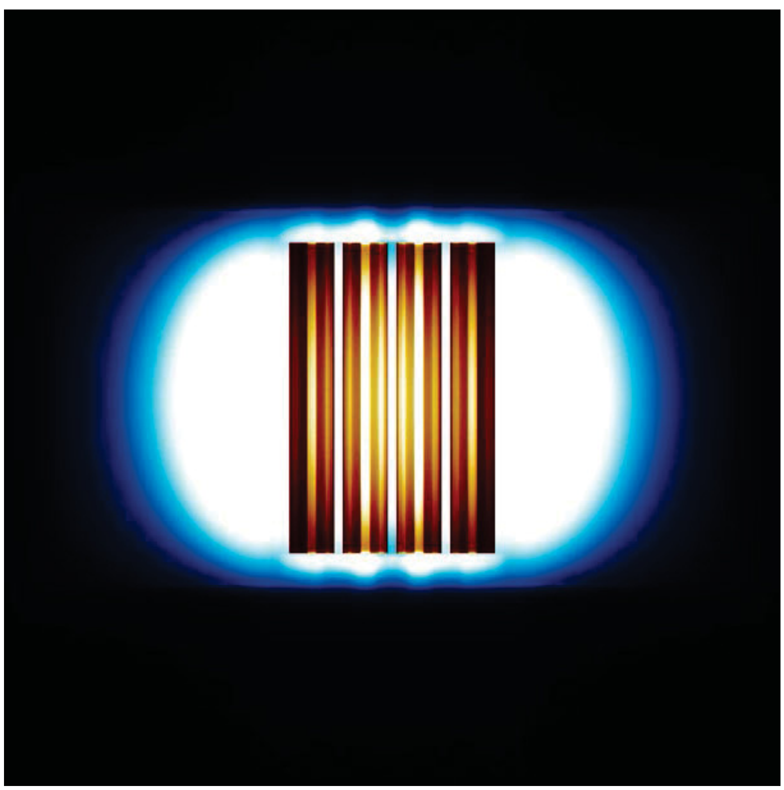

Figure 4-5. Side view flux plot of cylindrical core with D_2O reflector tanks.

4.3 Performance Comparison

Serpent cases were generated comparing seven different reflector tank contents for the otherwise baseline Cylindrical reactor. The baseline case of 100% D_2O is repeated here for comparison. The six other cases were 100% graphite, graphite with 10% H_2O, 100% beryllium, beryllium with 10% H_2O, the removable D_2O tanks described above, the same removable D_2O tanks with 10% water in the D_2O, and 100% H_2O. Figure 4-6 shows the peak (axially centered) thermal neutron flux versus distance from the outer surface of the pressure vessel. As expected, the reflector material that preserves the highest flux versus distance from the vessel is D_2O, with a thermal flux in excess of 10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ for essentially the entire distance to the outer reflector tank wall. This was followed by 100% graphite, and then by the D_2O tanks in a water pool. The case with 100% beryllium had the next highest flux far from the pressure vessel (though close to the vessel, it had higher thermal flux than the 100% graphite and D_2O tanks cases). The worst case by far with regard to flux in the reflector tank was the 100% H_2O case.

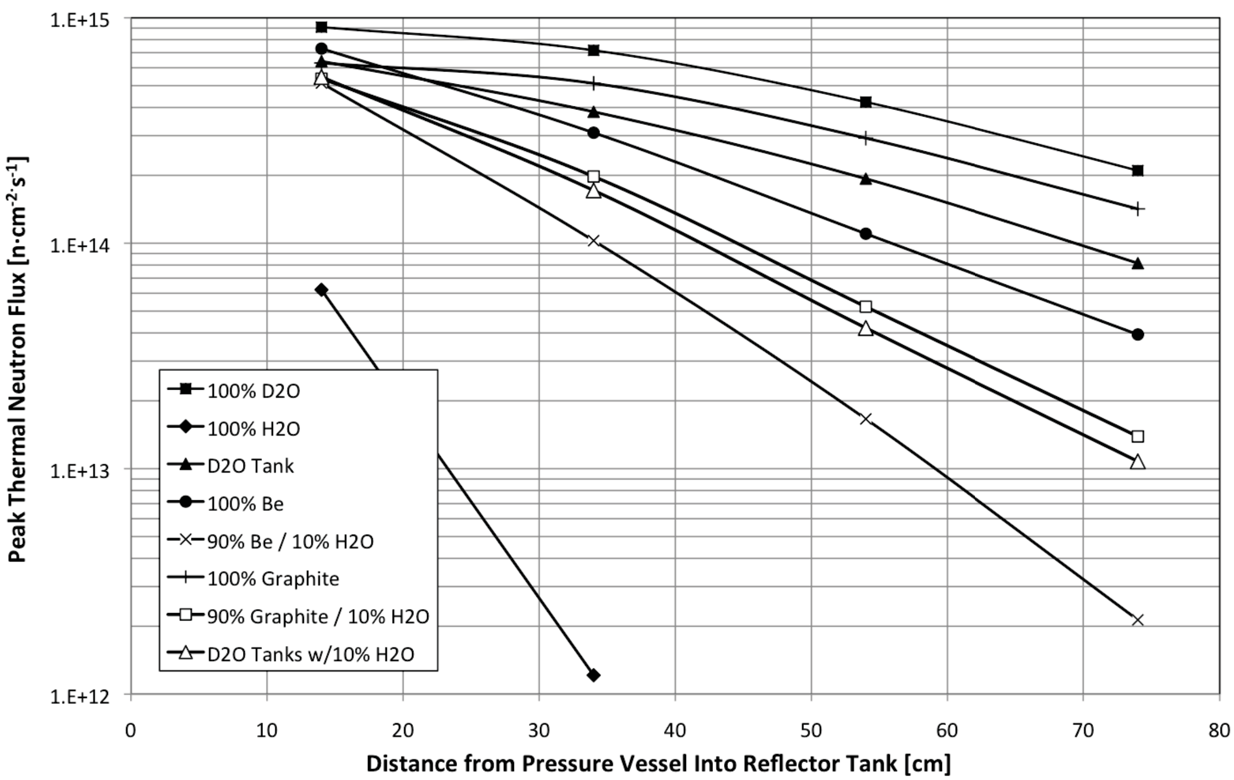

Figure 4-6. Peak thermal flux (at axial centerline) in reflector versus distance from pressure vessel with various reflector tank contents in cylindrical core.

Table 4-1 shows the initial k_{eff} and B_1 values calculated for the cylindrical core with the various contents of the reflector tank region. The general trend is that the reflectors which give greatest overall thermal flux in the reflector tank also yield the highest k_{eff}. However, this trend is not absolute, as some materials are better reflectors, but may absorb more neutrons than other materials. An example is the case of 100% beryllium, which gives the highest initial k_{eff} of any of the materials examined here. However, it does not have the highest thermal flux in the reflector region (though the slope of its curve in Figure 4-6 indicates that it may indeed have the highest thermal flux very close to the pressure vessel. Though beryllium is acting as the best reflector with regard to neutron reflection, it has greater absorption than some of the other candidate materials. Therefore, it may not be the best material for extending the thermal flux to as great a distance from the pressure vessel as possible. Also seen in Table 4-1 is H_2O performing worse than any of the other candidate reflectors with regard to both initial k_{eff} and B_1. Figure 4-7 shows the radiative capture cross sections of four of the key nuclides in these reflector materials. This shows that ^{2}H has a much lower capture cross-section than ^{1}H, and that ^{12}C has a lower capture cross-section than ^{9}Be. This gives a heuristic explanation for the performance of these materials in this application.

Table 4-1. Reactivity performance of cylindrical core with various reflector contents.

Reflector Tank Contents	**Initial k_{eff}**	**B_1 (days)**
D_2O	1.18427	100
H_2O	1.10190	42
D_2O Tanks in H_2O	1.13833	69
100% Beryllium	1.19594	108
90% Beryllium / 10% H_2O	1.17034	91
100% Graphite	1.19133	105
90% Graphite / 10% H_2O	1.15750	82
D2O Tanks with 10% H_2O in D_2O	1.12587	60

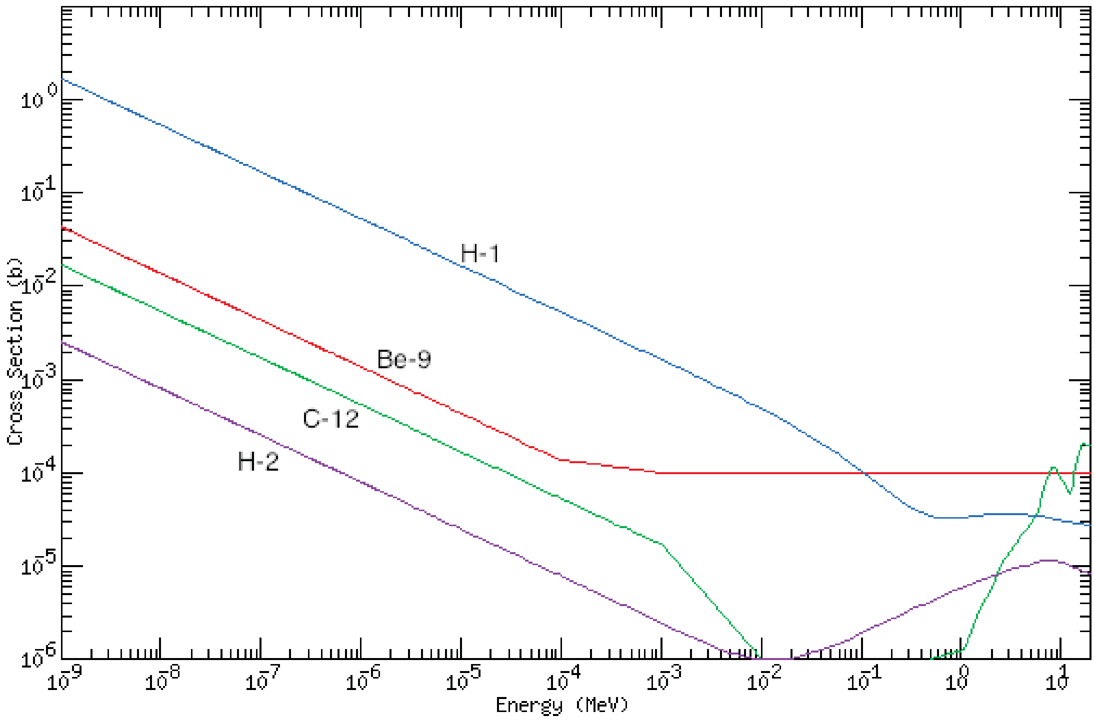

Figure 4-7. Radiative capture cross-sections of ^{1}H and ^{2}H, ^{12}C, and ^{9}Be. [14]

5. Core Rack Content Options

Three of the baseline reactor concepts introduced in Section 2 specify an aluminum core rack cooled by an assumed 6.3% by volume coolant H_2O. This configuration is meant to allow for maintaining a high fast flux, which can be thermalized if desired. It also avoids the use of beryllium, which suffers from embrittlement under irradiation that limits its lifetime and carries a toxicity which poses a challenge to disposal. [16]. Furthermore, because the aluminum rack does not moderate neutrons effectively, it contributes to a rather low reactivity core. For example, a core with a beryllium rack and the same fuel would have a much higher reactivity. This has implications toward achievable cycle length and the feasibility of using alternative fuel forms with lower heavy metal (HM) density than U-10Mo. This will be discussed further in Section 6. As an alternative to the aluminum rack, it has been proposed that aluminum/beryllium alloys be considered for this application. Adding beryllium content affects the neutronic characteristics of the core by 1) increasing reactivity, 2) reducing fast flux in test positions, and 2) reducing fast fluence on the pressure vessel.

Serpent calculations were performed on the baseline Cylindrical and Annular core designs to quantify the effects of different core rack contents. The cases examined are shown in Table 5-1 along with a Rack ID, which is used in the subsequent tables for identifying the content of the core rack in each case. Beryllium was varied from 0 to 93.7 % with H_2O assumed to occupy 6.3% by volume.

Table 5-1. Core rack contents evaluated identified by a Rack ID.

Rack ID	Vol. % Aluminum	Vol. % beryllium	Vol. % H_2O
Be-0	93.7	0	6.3
Be-20	73.7	20	
Be-50	43.7	50	
Be-100	0	93.7	

Results of calculations carried out on the Annular core are given in Table 5-1. The table shows k_{eff} and B_1 along with neutron flux in three different locations; center flux trap, peripheral flux trap, and Reflector Tally Position #1 (see Figure 2-18 on page 31). From the table, one also sees that the reduction in fast flux as a result of increased beryllium content in the rack is minimal in the center and peripheral flux traps. On the other hand, the thermal flux in the flux trap is roughly doubled in going from the Be-0 case to the Be-100 case. Going from all aluminum to all beryllium core rack material also increases the thermal flux in Reflector position #1 slightly, though it does decrease total flux somewhat. Meanwhile, the initial k_{eff} has increased from 1.13 to 1.32, offering quite a bit of flexibility in design such as the option of reducing HM loading, having longer cycle lengths, etc. The B_1 values increased from 63 days in the baseline Be-0 case to 176 days in the Be-100 case. Also of note is the somewhat lower axial peaking in fast flux in the flux traps for the aluminum rack than the beryllium rack. The aluminum rack case has lower axial peaking because it has moderation concentrated at the top and bottom from cooling water with less moderation along the length of the fuel. The beryllium rack provides moderation along its length, so a more peaked shape results.

Results of calculations carried out on the Cylindrical core are given in Table 5-3 in a similar format to Table 5-2. The basic trends are the same as with the Annular core. Here, the additional location in a fuel assembly center is available. From this point, one sees how the increased moderation in the Be-100 case reduces the thermal flux substantially from the baseline Be-0 case. This is because the more thermal spectrum results in higher effective fission cross-sections in the fuel and a lower thermal flux for a given power. The initial k_{eff} has increased from 1.18 to 1.28 in moving from the Be-0 to the Be-100 case while the B_1 values increased from 100 days to 165 days.

Table 5-4 gives neutron fluence rates at the inner surface of the pressure vessel at the axial center for the Cylindrical and Annular cases discussed above. These results show that replacing the Be-0 rack with the Be-100 rack reduces the fast fluence in the pressure vessel by approximately a factor of 2 while only slightly decreasing the total fluence. Since most of the neutron damage is caused by fast neutrons, this may have important implications on the frequency of pressure vessel replacement.

Table 5-2. Performance parameters for Annular core with varying rack contents.

Core Rack Content and Tally Location		Neutron Flux ($n \cdot cm^{-2} \cdot s^{-1}$) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux		
Core Rack ID k_{eff} and B_1	Tally Location	Peak	Axially Averaged	Peak/ Average
Be-0 Initial k_{eff}=1.13172 B_1 = 63 days	Center Flux Trap	3.05E+14	2.30E+14	1.33
		3.57E+14	2.74E+14	1.30
		2.07E+15	1.56E+15	1.32
	Peripheral Flux Trap	1.87E+14	1.43E+14	1.31
		2.45E+14	1.91E+14	1.29
		1.24E+15	9.48E+14	1.31
	Reflector Tally Position 1	1.01E+13	7.37E+12	1.37
		6.75E+14	5.39E+14	1.25
		9.19E+14	7.22E+14	1.27
Be-20 Initial k_{eff}=1.17019 B_1 = 89 days	Center Flux Trap	3.10E+14	2.28E+14	1.36
		3.71E+14	2.80E+14	1.32
		2.10E+15	1.56E+15	1.34
	Peripheral Flux Trap	1.83E+14	1.39E+14	1.32
		2.55E+14	1.91E+14	1.34
		1.25E+15	9.32E+14	1.34
	Reflector Tally Position 1	7.11E+12	6.28E+12	1.13
		6.33E+14	5.17E+14	1.22
		8.37E+14	6.69E+14	1.25
Be-50 Initial k_{eff}=1.22543 B_1 = 124 days	Center Flux Trap	2.98E+14	2.20E+14	1.36
		3.88E+14	2.87E+14	1.35
		2.08E+15	1.53E+15	1.36
	Peripheral Flux Trap	1.83E+14	1.35E+14	1.36
		2.59E+14	1.90E+14	1.37
		1.24E+15	9.11E+14	1.36
	Reflector Tally Position 1	5.95E+12	4.70E+12	1.27
		6.30E+14	4.96E+14	1.27
		7.97E+14	6.18E+14	1.29
Be-100 Initial k_{eff}=1.31918 B_1 = 176 days	Center Flux Trap	2.70E+14	1.99E+14	1.36
		3.77E+14	2.73E+14	1.38
		1.94E+15	1.40E+15	1.38
	Peripheral Flux Trap	1.76E+14	1.29E+14	1.36
		2.54E+14	1.88E+14	1.36
		1.21E+15	8.86E+14	1.36
	Reflector Tally Position 1	4.20E+12	3.42E+12	1.23
		6.53E+14	5.01E+14	1.30
		7.74E+14	5.90E+14	1.31

Table 5-3. Performance parameters for Cylindrical core with varying rack contents.

Core Rack Content and Tally Location		**Neutron Flux (n·cm^{-2}·s^{-1}) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux**		
Core Rack ID k_{eff} and B_1	Tally Location	Peak	Axially Averaged	Peak/ Average
Be-0 Initial k_{eff}=1.18313 B_1 = 100 days	Center Flux Trap	3.21E+14	2.42E+14	1.33
		2.87E+14	2.16E+14	1.32
		2.07E+15	1.55E+15	1.33
	Peripheral Flux Trap	2.78E+14	2.09E+14	1.33
		2.50E+14	1.90E+14	1.32
		1.79E+15	1.35E+15	1.32
	Inner Fuel Assembly	5.20E+14	3.91E+14	1.33
		1.42E+14	1.12E+14	1.27
		2.14E+15	1.62E+15	1.32
	Reflector Tally Position 1	5.30E+12	4.48E+12	1.18
		1.00E+15	8.12E+14	1.24
		1.17E+15	9.35E+14	1.25
Be-20 Initial k_{eff}=1.20621 B_1 = 114 days	Center Flux Trap	3.12E+14	2.31E+14	1.35
		3.07E+14	2.29E+14	1.34
		2.07E+15	1.53E+15	1.35
	Peripheral Flux Trap	2.69E+14	1.97E+14	1.36
		2.64E+14	1.97E+14	1.34
		1.79E+15	1.32E+15	1.36
	Inner Fuel Assembly	4.91E+14	3.68E+14	1.33
		1.42E+14	1.12E+14	1.27
		2.10E+15	1.58E+15	1.33
	Reflector Tally Position 1	5.45E+12	3.82E+12	1.43
		9.51E+14	7.70E+14	1.24
		1.09E+15	8.78E+14	1.24
Be-50 Initial k_{eff}=1.23587 B_1 = 135 days	Center Flux Trap	2.92E+14	2.17E+14	1.35
		3.32E+14	2.43E+14	1.37
		2.05E+15	1.51E+15	1.36
	Peripheral Flux Trap	2.59E+14	1.90E+14	1.37
		2.83E+14	2.14E+14	1.32
		1.77E+15	1.31E+15	1.35
	Inner Fuel Assembly	4.86E+14	3.62E+14	1.34
		1.50E+14	1.12E+14	1.34
		2.11E+15	1.55E+15	1.36
	Reflector Tally Position 1	4.54E+12	3.23E+12	1.40
		9.38E+14	7.48E+14	1.25
		1.07E+15	8.45E+14	1.27
Be-100 Initial k_{eff}=1.28381 B_1 = 165 days	Center Flux Trap	2.68E+14	1.94E+14	1.38
		3.61E+14	2.65E+14	1.36
		2.00E+15	1.44E+15	1.39
	Peripheral Flux Trap	2.41E+14	1.75E+14	1.38
		3.24E+14	2.39E+14	1.35
		1.77E+15	1.29E+15	1.37
	Inner Fuel Assembly	4.74E+14	3.46E+14	1.37
		1.57E+14	1.18E+14	1.33
		2.05E+15	1.51E+15	1.36
	Reflector Tally Position 1	4.24E+12	3.12E+12	1.36
		9.41E+14	7.56E+14	1.24
		1.06E+15	8.46E+14	1.25

Table 5-4. Fluence rates in pressure vessels for Annular and Cylindrical cores with various core rack contents.

Core and Rack Content		Peak Fluence Rate in Vessel ($cm^{-2} \cdot year^{-1}$) >1.0 MeV >0.1 MeV Total
Annular	Be-0	3.03E+21
		8.52E+21
		3.33E+22
	Be-20	3.00E+21
		9.09E+21
		3.28E+22
	Be-50	2.64E+21
		6.80E+21
		3.08E+22
	Be-100	1.88E+21
		4.93E+21
		2.70E+22
Cylindrical	Be-0	3.50E+21
		9.78E+21
		4.16E+22
	Be-20	3.19E+21
		8.83E+21
		4.00E+22
	Be-50	2.83E+21
		6.97E+21
		4.26E+22
	Be-100	1.69E+21
		5.87E+21
		4.24E+22

6. Alternative Fuel Options

6.1 U_3Si_2 (6.0 g U/cm^3)

Monolithic U-10Mo fuel has not been fully qualified for use in a high heat flux test reactor at the time of this writing. Therefore, the reactor variants presented in this report were evaluated for their ability to use U_3Si_2 fuel, a fuel with lower uranium density than U-10Mo, but lower anticipated technical development risk as well. U_3Si_2 fuel can be fabricated with various volume fractions of aluminum. While U_3Si_2 fuel has been qualified with a uranium density of 4.8 g/cm^3, it is believed that a uranium density of 6 g/cm^3 (53% by volume U_3Si_2) is feasible with relatively low development risk. This was therefore used for evaluating the possibility of using U_3Si_2 fuel in the reactor variants studied here.

This analysis was performed by simply replacing the U-10Mo fuel meat with U_3Si_2 fuel having the same thickness in selected cases. The uranium enrichment was left at 19.7 w/o and the fuel temperature was not changed from the U-10Mo values used previously. For the Annular and Cylindrical cores, the various beryllium contents in the core rack presented in the previous section were also included in the analysis since they have a profound effect on reactivity. Table 6-1 shows initial k_{eff}, B_1, and neutron flux in various locations of the Annular core with U_3Si_2 fuel meat. With the aluminum core rack (Be-0), the reactor is barely critical at BOL and has essentially no burnup capability based on the B_1 value of 1 day. In contrast, the Be-100 core rack gives the Annular core much greater capability to accept the U_3Si_2 fuel with initial k_{eff} of 1.27 and B_1 of 61 days. Flux values do not differ significantly between the U_3Si_2 cases and their respective U-10Mo cases.

Table 6-2 shows initial k_{eff}, B_1, and neutron flux in various locations of the Cylindrical core with U_3Si_2 fuel meat. With the aluminum core rack (Be-0), the reactor is has initial k_{eff} of 1.11 and a B_1 value of 23 days. As with the Annular core the Be-100 core rack gives the Cylindrial core much greater capability to accept the U_3Si_2 fuel with initial k_{eff} of 1.25 and B_1 of 61 days. Again, flux values do not differ significantly between the U_3Si_2 cases and their respective U-10Mo cases.

Table 6-3 and Table 6-4 show initial k_{eff}, B_1, and neutron flux in various locations using U_3Si_2 fuel meat for the Square and PBT cores, respectively. The Square core using this fuel has an initial k_{eff} value of 1.06 and a B_1 value of 5 days whereas the PBT core has initial k_{eff} value of 1.26 and a B_1 value of 61 days.

Table 6-1. Reactivity and flux performance of Annular concepts with U_3Si_2 fuel.

Core Rack Content Initial k_{eff} and B_1	**Tally Location**	**Neutron Flux ($n \cdot cm^{-2} \cdot s^{-1}$) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux**		
		Peak	Axially Averaged	Peak/ Average
(Baseline Case) 93.7% Aluminum No Beryllium 6.3% H_2O Initial k_{eff}=1.04033 B_1 = 1 day	Center Flux Trap	3.30E+14	2.48E+14	1.33
		4.64E+14	3.52E+14	1.32
		2.30E+15	1.73E+15	1.33
	Peripheral Flux Trap	1.94E+14	1.45E+14	1.34
		2.94E+14	2.21E+14	1.33
		1.32E+15	9.94E+14	1.33
	Reflector Tally Position 1	9.36E+12	7.54E+12	1.24
		6.93E+14	5.65E+14	1.23
		9.48E+14	7.56E+14	1.25
73.7% Aluminum 20% Be 6.3% H_2O Initial k_{eff}=1.09238 B_1 = 15 days	Center Flux Trap	3.38E+14	2.51E+14	1.34
		4.87E+14	3.68E+14	1.32
		2.38E+15	1.77E+15	1.35
	Peripheral Flux Trap	1.85E+14	1.39E+14	1.34
		2.91E+14	2.16E+14	1.34
		1.29E+15	9.60E+14	1.34
	Reflector Tally Position 1	7.86E+12	5.84E+12	1.35
		6.87E+14	5.43E+14	1.27
		8.88E+14	6.93E+14	1.28
43.7% Aluminum 50% Be 6.3% H_2O Initial k_{eff}=1.15601 B_1 = 34 days	Center Flux Trap	3.24E+14	2.37E+14	1.37
		5.04E+14	3.71E+14	1.36
		2.35E+15	1.71E+15	1.37
	Peripheral Flux Trap	1.83E+14	1.34E+14	1.36
		2.97E+14	2.16E+14	1.37
		1.28E+15	9.39E+14	1.37
	Reflector Tally Position 1	6.33E+12	4.72E+12	1.34
		6.61E+14	5.25E+14	1.26
		8.23E+14	6.45E+14	1.28
No Aluminum 93.7% Be 6.3% H_2O Initial k_{eff}=1.26817 B_1 = 61 days	Center Flux Trap	2.86E+14	2.08E+14	1.38
		4.99E+14	3.61E+14	1.38
		2.13E+15	1.54E+15	1.38
	Peripheral Flux Trap	1.89E+14	1.37E+14	1.38
		3.07E+14	2.23E+14	1.38
		1.31E+15	9.49E+14	1.38
	Reflector Tally Position 1	5.01E+12	3.78E+12	1.33
		7.22E+14	5.51E+14	1.31
		8.47E+14	6.43E+14	1.32

Table 6-2. Reactivity and flux performance of Cylindrical concepts with U_3Si_2 fuel.

Core Rack Content Initial k_{eff} and B_1	**Tally Location**	**Neutron Flux ($n \cdot cm^{-2} \cdot s^{-1}$) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux**		
		Peak	Axially Averaged	Peak/ Average
(Baseline Case) 93.7% Aluminum No Beryllium 6.3% H_2O Initial k_{eff}=1.11269 B_1 = 23 days	Center Flux Trap	3.39E+14	2.52E+14	1.35
		3.57E+14	2.70E+14	1.32
		2.23E+15	1.65E+15	1.35
	Peripheral Flux Trap	2.95E+14	2.19E+14	1.35
		3.09E+14	2.37E+14	1.30
		1.91E+15	1.44E+15	1.33
	Inner Fuel Assembly	5.29E+14	4.04E+14	1.31
		3.52E+14	2.64E+14	1.33
		2.45E+15	1.85E+15	1.33
	Reflector Tally Position 1	5.89E+12	4.77E+12	1.23
		1.06E+15	8.76E+14	1.21
		1.22E+15	1.00E+15	1.22
73.7% Aluminum 20% Be 6.3% H_2O Initial k_{eff}=1.14250 B_1 = 33 days	Center Flux Trap	3.28E+14	2.42E+14	1.36
		3.88E+14	2.92E+14	1.33
		2.22E+15	1.65E+15	1.35
	Peripheral Flux Trap	2.85E+14	2.10E+14	1.36
		3.41E+14	2.53E+14	1.35
		1.93E+15	1.43E+15	1.36
	Inner Fuel Assembly	5.36E+14	4.02E+14	1.33
		3.62E+14	2.72E+14	1.33
		2.51E+15	1.86E+15	1.35
	Reflector Tally Position 1	5.58E+12	4.20E+12	1.33
		1.06E+15	8.49E+14	1.25
		1.21E+15	9.62E+14	1.25
43.7% Aluminum 50% Be 6.3% H_2O Initial k_{eff}=1.18330 B_1 = 45 days	Center Flux Trap	3.09E+14	2.26E+14	1.36
		4.08E+14	3.05E+14	1.34
		2.19E+15	1.61E+15	1.35
	Peripheral Flux Trap	2.68E+14	1.95E+14	1.37
		3.60E+14	2.69E+14	1.34
		1.91E+15	1.41E+15	1.36
	Inner Fuel Assembly	5.34E+14	3.87E+14	1.38
		3.81E+14	2.79E+14	1.36
		2.49E+15	1.81E+15	1.37
	Reflector Tally Position 1	4.64E+12	3.40E+12	1.36
		1.06E+15	8.38E+14	1.26
		1.19E+15	9.38E+14	1.26
No Aluminum 93.7% Be 6.3% H_2O Initial k_{eff}=1.24779 B_1 = 61 days	Center Flux Trap	2.78E+14	2.02E+14	1.38
		4.53E+14	3.32E+14	1.36
		2.10E+15	1.54E+15	1.37
	Peripheral Flux Trap	2.52E+14	1.81E+14	1.39
		4.04E+14	2.95E+14	1.37
		1.91E+15	1.38E+15	1.38
	Inner Fuel Assembly	4.91E+14	3.61E+14	1.36
		4.08E+14	3.06E+14	1.34
		2.43E+15	1.78E+15	1.36
	Reflector Tally Position 1	4.44E+12	3.12E+12	1.42
		1.05E+15	8.36E+14	1.25
		1.17E+15	9.25E+14	1.27

Table 6-3. Reactivity and flux performance of baseline Square concept with U_3Si_2 fuel.[a]

Tally Location	Neutron Flux ($n \cdot cm^{-2} \cdot s^{-1}$) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux		
	Peak	Axially Averaged	Peak/ Average
Center Flux Trap	2.87E+14	2.19E+14	1.31
	3.62E+14	2.78E+14	1.30
	2.19E+15	1.65E+15	1.33
NW Flux Trap	2.88E+14	2.18E+14	1.32
	3.11E+14	2.37E+14	1.31
	1.95E+15	1.48E+15	1.32
Reflector Tally Position 1	8.44E+12	5.84E+12	1.45
	1.05E+15	8.30E+14	1.26
	1.27E+15	9.99E+14	1.27

Table 6-4. Reactivity and flux performance of baseline PBT concept with U_3Si_2 fuel.[b]

Tally Location	Neutron Flux ($n \cdot cm^{-2} \cdot s^{-1}$) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux		
	Peak	Axially Averaged	Peak/ Average
Center Flux Trap	2.43E+14	1.81E+14	1.34
	4.09E+14	3.13E+14	1.31
	1.73E+15	1.31E+15	1.32
Peripheral Flux Trap	1.76E+14	1.33E+14	1.32
	2.88E+14	2.18E+14	1.32
	1.20E+15	9.09E+14	1.32
Reflector Tally Position 1	4.04E+12	3.52E+12	1.15
	1.33E+15	1.09E+15	1.23
	1.45E+15	1.18E+15	1.23

[a] Initial k_{eff}=1. 06337, B_l= 5 days

[b] Initial k_{eff}=1. 25558, B_l= 61 days

7. Comparisons to Serpent Model of ATR

7.1 Description of Serpent ATR Model

To evaluate whether the proposed MATRIX designs can meet specified requirements, particularly those adopted from the NR requirements (Section 1.2), comparisons to a detailed ATR model were performed. A Serpent 2 model of ATR was adopted from M. DeHart (INL). This model was based on the 1994 Core Internals Changeout (94-CIC configuration). A core loaded in conjunction with the 94-CIC was comprised entirely of fresh HEU Mark VII fuel. This core was never operated at full power, but used as a low-power critical configuration to validate computational models. This core configuration was later described in detail and archived in the International Handbook of Evaluated Reactor Physics Benchmark Experiments [17]. A schematic of the core configuration is given in Figure 7-1.

The general layout of the ATR core is a serpentine arrangement of arcuate fuel assemblies containing plates of HEU fuel. The fuel meat consists of 93 w/o enriched uranium aluminide powder (UAl_x) dispersed in aluminum. The cladding is Al-6061 and the fuel meat, cladding, and coolant channel thicknesses are the same as those of the MATRIX baseline configurations. Reactivity is held down by 1) neck shim rods located in the neck shim rod housing 2) rotating Outer Shim Control Cylinders (OSCCs) having a surface partially covered with hafnium absorber and 3) boron carbide burnable poison mixed into the fuel meat of the inner and outer four plates of each fuel assembly.

The 94-CIC configuration specifies that the test region of the NW IPT be filled with Al-6061. The W, SW, and SE IPTs were filled with coolant H_2O. Deviations made from the exact 94-CIC specifications for the purposes of this study are described below. For a full description of the 94-CIC test configuration, see Reference [17].

Comparisons to this ATR configuration are useful in the MATRIX project for a number of reasons. First, some of the requirements enumerated in Section 1.2 are borrowed from the LEU conversion project of ATR. Among these, some require a minimum change of a parameter from ATR. In evaluating whether or not these requirements are met, one must have analogous ATR calculations for comparison. More generally, the MATRIX will be expected to perform as well or better than ATR by most metrics. Therefore, comparing to an ATR model allows one to predict whether or not an improvement over ATR can be expected without actually knowing the real performance with a high degree of certainty.

In the MATRIX studies presented thus far, the actual reactor models are very simplified. For example; omission of burnable poisons and control rods, fully fresh cores depleted in a single pass, and uniform temperatures. While these assumptions are necessary to accommodate the large option space in early studies, they do make comparisons to real data from the operating ATR less meaningful.

To accommodate this, the 94-CIC model from DeHart was modified in the following ways to be more analogous to the MATRIX calculations performed here:

- In the ATR's Mark VII HEU fuel, the inner and outer four fuel plates have boron carbide mixed into the fuel meat. The boron carbide was removed from the fuel meat of these plates leaving the uranium nuclides as they were. This gives a model with the same amount of HM as the actual ATR core but with no burnable poison.

- All neck shim rods were withdrawn.
- The hafnium absorber material on the surface of the OSCCs was replaced with beryllium.
- The SW flux trap was filled with Al-6061, leaving W and SE filled with H_2O as specified for the benchmark.
- Reactor power was set to 250 MW_{th} rather than the zero power of the 94-CIC critical or the ~120 MW_{th} at which ATR is typically operated.

This provides a "flat" core (meaning not purposefully tilted as is common in operation of ATR) with all fresh unpoisoned HEU fuel. Depletion was performed on this model without changing the control shim position or OSCC rotation and neutron flux tallies were calculated at each burnup step. This methodology provides an analogous ATR case to which one may compare the MATRIX cases. This model was depleted with flux tallies in four different positions; the NW flux trap, the SW flux trap, the SE flux trap, center capsule location #3, and the A-1 hole.

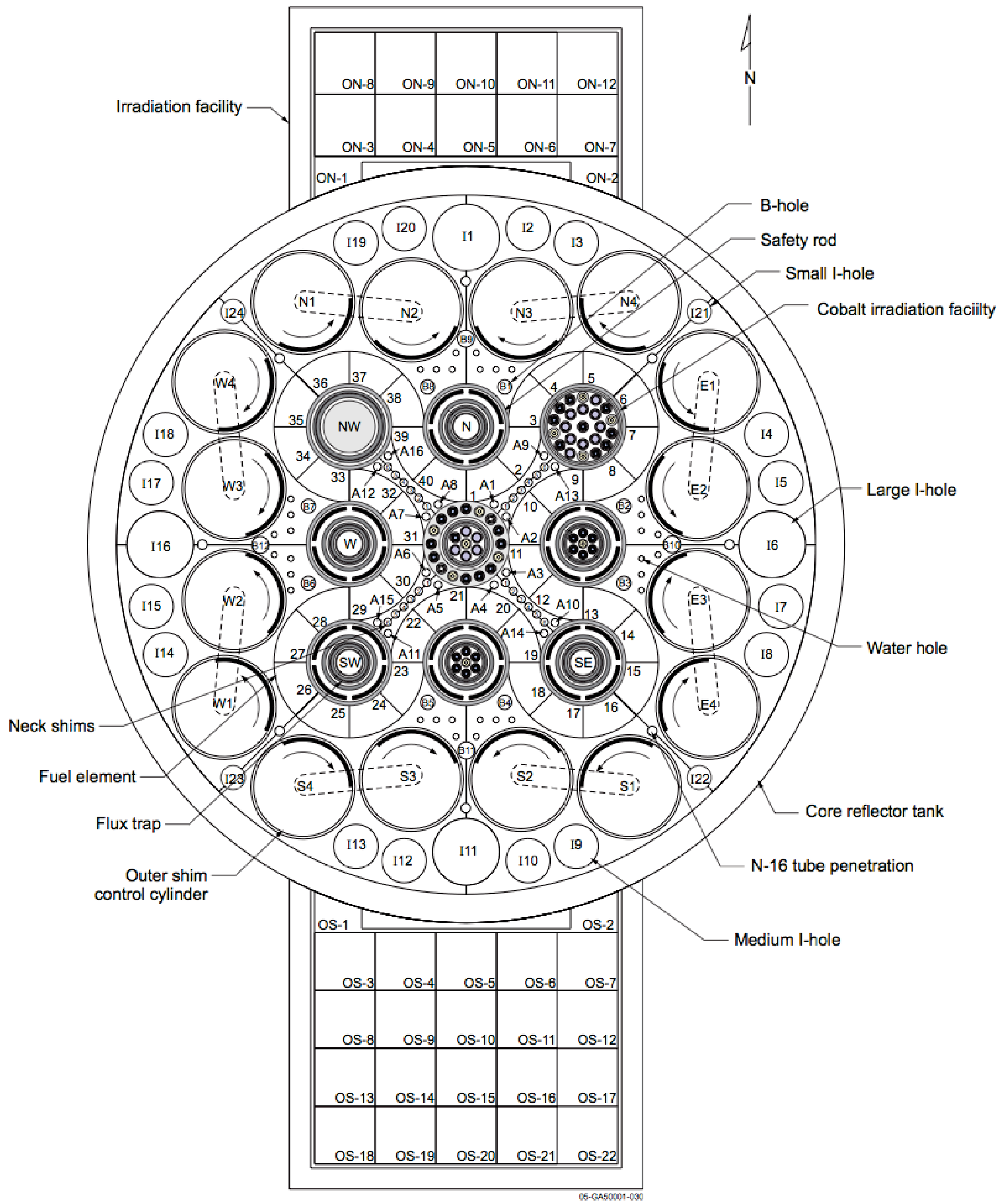

Figure 7-1. Cross-sectional view of the ATR core in the 94-CIC configuration. [17]

7.2 Initial Results of ATR Depletion Analysis

As was done for the baseline MATRIX case studies, B_1 was calculated by linear interpolation and the detector tallies were taken from the burnup step closest to $k_{eff} = 1$. The initial k_{eff} for this core was calculated to be 1.222 and the B_1 value was 56 days. Table 7-1 shows flux values in the locations described above. As with the MATRIX studies, the tallies spanned the entire axial length of the active core and were divided into 10 axial segments. Peak/average ratios are given for each tally.

As seen in the table, the aluminum-filled NW and SW flux traps have fast flux values of approximately 2.9×10^{14} and 3.5×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$, respectively, and total fluxes of 1.9×10^{15} and 2.3×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$, respectively. In the water-filled SE flux trap, the thermal and total flux are 1.2×10^{15} and 2.4×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$, respectively. The highest fast flux of the locations sampled here was located in the A-1 hole filled with an aluminum flow restrictor. This location had a fast neutron flux of 4.4×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$.

Table 7-1. Flux values from simplified ATR model depletion calculation.[a]

Tally Location and Location Content	**Neutron Flux ($n \cdot cm^{-2} \cdot s^{-1}$) Fast Flux (>1 MeV) Thermal Flux (<0.625 eV) Total Flux**		
	Peak	Axially Averaged	Peak/ Average
NW Flux Trap Al-6061 filled	2.89E+14	2.08E+14	1.39
	4.47E+14	3.20E+14	1.40
	1.87E+15	1.33E+15	1.40
SW Flux Trap Al-6061 filled[b]	3.48E+14	2.48E+14	1.40
	5.30E+14	3.68E+14	1.44
	2.28E+15	1.60E+15	1.42
SE Flux Trap H_2O filled	2.29E+14	1.60E+14	1.43
	1.22E+15	8.65E+14	1.41
	2.38E+15	1.68E+15	1.42
Center Capsule Location #3 Al-6061 filled	2.99E+14	2.10E+14	1.42
	1.26E+15	9.24E+14	1.37
	2.67E+15	1.95E+15	1.37
A-1 Hole Al-6061 flow restrictor	4.44E+14	3.20E+14	1.38
	7.24E+14	5.23E+14	1.38
	2.53E+15	1.81E+15	1.40

[a] B_1 = 56 days, Initial k_{eff} = 1.22208

[b] Denotes different filler than that specified in the 94-CIC benchmark.

7.3 Comparison of Fast-to-Thermal Flux Ratios

One of the NR requirements for a converted ATR is a fast-to-thermal neutron flux ratio within 5% of current values in a pressurized-water loop test. The same requirement could be directly applied to the MATRIX designs. In order to compare these ratios between ATR and the various MATRIX concepts, selected flux tally data already reported in this document was organized into a single table of fast-to-thermal flux ratios. The result of this is shown in Table 7-2.

In the simplified ATR case described in Section 7.1, the fast-to-thermal flux ratios range from 2.5-3.3 in the aluminum-filled locations to just below 1 in the water-filled SE flux trap. As for the MATRIX cases, a number of test locations in various baseline and variant reactor designs are evaluated, not all of which will be discussed in the text. Several of these, however, warrant comment.

In the Cylindrical baseline reactor with the aluminum core rack, the center and peripheral IPT locations have fast-to-thermal flux ratios of approximately 6 while the location at the center of a centrally located fuel assembly has a ratio of 14. These are all for aluminum-filled test locations. The very high ratio is a result of the use of the low-moderating aluminum core rack and the resulting hard spectrum this facilitates. When these same locations are filled with water, the reduction in fast-to-thermal ratio is substantial. The IPTs and the assembly location then have ratios of 0.6 and 2.3, respectively. This substantial change in the case of the IPTs is partially a result of the rather large size of all of the IPTs in the Cylindrical core model (9.3 cm dia.). These are approximately the size of the NW IPT in ATR (9.0 cm dia.), significantly larger than the SE and SW IPTs in ATR (4.4 cm dia.). The large diameter of these locations provides a large amount of thermalization when totally water-filled. If the Cylindrical core rack is changed to the 100% beryllium case, the aluminum-filled test locations see a significant reduction in fast-to-thermal flux ratios. For these test locations, when water-filled, the rack material has little impact. This is because in the IPTs, there is present enough water to provide rather complete thermalization, and in the location inside the fuel assembly, the spectrum is decoupled from the environment outside the fuel assembly.

Due to the similarity in design between the Square and Cylindrical cores, the fast-to-thermal ratios between their IPT locations are quite similar, as can be seen in Table 7-2.

With regard to the Annular and PBT designs, two main trends are notable. First, the thermalization is quite strong in the very large center IPTs (12.7 cm dia.) in both cases when water-filled. Also, the difference in rack content between aluminum and beryllium makes little difference in either core design. This is a result of the decoupling between outside and inside the fuel assembly modules, much as in the case of the inter-assembly locations of the Cylindrical core.

Table 7-2. Fast-to-thermal flux ratios in selected MATRIX cases and ATR model.

Reactor	Location	Content	Fast-to-Thermal Flux Ratio at Axial Center (Cutoff at 0.625 eV)
ATR Simplified case described in Section 7.1	NW Flux Trap	Al-6061 filled	3.18
	SW Flux Trap	Al-6061 filled	3.30
	SE Flux Trap	H_2O filled	0.95
	Center Capsule Loc. #3	Al-6061 filled	1.12
	A-1 Hole	Al-6061 filled	2.49
Cylindrical MATRIX Baseline Al Rack	Center IPT	Al-6061 filled	6.47
	Peripheral IPT	Al-6061 filled	6.44
	Inside Fuel Assy	Al-6061 filled	14.07
	Center IPT	H_2O filled	0.58
	Peripheral IPT	H_2O filled	0.56
	Inside Fuel Assy	H_2O filled	2.31
Cylindrical MATRIX 100% Be Rack	Center IPT	Al-6061 filled	4.54
	Peripheral IPT	Al-6061 filled	4.46
	Inside Fuel Assy	Al-6061 filled	12.06
	Center IPT	H_2O filled	0.52
	Peripheral IPT	H_2O filled	0.53
	Inside Fuel Assy	H_2O filled	2.09
Square MATRIX Baseline	Center IPT	Al-6061 filled	6.04
	NW IPT	Al-6061 filled	6.59
Annular MATRIX Baseline Al Rack	Center IPT	Al-6061 filled	4.80
	Peripheral IPT	Al-6061 filled	4.06
	Center IPT	H_2O filled	0.34
	Peripheral IPT	H_2O filled	0.75
Annular MATRIX 100% Be Rack	Center IPT	Al-6061 filled	4.15
	Peripheral IPT	Al-6061 filled	3.76
	Center IPT	H_2O filled	0.34
	Peripheral IPT	H_2O filled	0.73
PBT MATRIX Baseline	Center IPT	Al-6061 filled	4.13
	Peripheral IPT	Al-6061 filled	3.70

More calculations and further development of a design would certainly be required before definitive statements may be made regarding the ability to mimic the spectrum of ATR in the MATRIX reactors. A main barrier to this is the restrictions that would likely be placed on IPT void reactivity. This places limits on the amount of water that may be present in an IPT since the loop void reactivity is generally positive. Without knowing the maximum amount of water allowable, one may not characterize the flux completely in a test location. However, these preliminary results indicate that the range of fast-to-thermal ratios encountered in ATR is likely to be enveloped by many, if not all, of the MATRIX concepts. The question of whether these can be met while respecting any reactivity insertion limits upon voiding remains for further analysis as work progresses. Thermalization of the spectrum must be performed within the bounds of IPT loop void reactivity requirements. This is addressed for the Cylindrical core in Section 9.6.

7.4 Power Generated in HEU Test Specimen

One of the NR requirements listed in Section 1.2 is that the converted ATR achieve greater than 4.8×10^{14} fissions per second per gram ^{235}U in a specimen with l gram ^{235}U per linear inch in a standard in-pile tube (SE or SW) operating at 60 MW. Because there is no clear analog to "lobe power" in the Cylindrical MATRIX concept, this is evaluated by a one-to-one comparison with the ATR model. To accomplish this, a Serpent 2 model was developed where a simple cylinder of HEU fuel was placed at the center of an IPT in the Cylindrical MATRIX. A variation on the ATR model discussed in Section 7.1 was developed that assumed a 0.28615 cm radius, 60.96 cm (24")-long cylinder positioned in the center of both SE and SW IPTs. The target mixture was assumed to be the same composition as plate 5 of a fresh ATR HEU (Mark VII) fuel element; Table 6 provides the composition of this cylinder. A total density of 3.94 g/cm^3 of fuel material in the 15.68 cm^3 volume of the cylinder gives a total mass of 61.81 g. With the 0.28615 cm radius, the target contains exactly 1 g of ^{235}U per inch of height. The HEU plug is surrounded by water.

Calculations were performed to obtain the fission rate averaged over full cylinder volume. In each case, fission rates were calculated in the 24" tall experimental HEU plug in both the SW and SE positions at the point in depletion closest to k_{eff}=1. The HEU plugs were not modeled as depletable, so it was as though a fresh HEU experiment was inserted at each step, affecting flux and reactivity, but not changing in composition with depletion.

The same procedure was followed for the Cylindrical MATRIX model in a peripheral IPT. All dimensions of the HEU plug were the same as in the ATR model. The main difference was that the amount of water surrounding the HEU plug was greater in the Cylindrical model than in the ATR due to the larger flux trap size than the ATR SE and SW flux traps.

It is important to note that the requirement for power in the HEU specimen in ATR is based on a tilted core and a 60 MW lobe. Ability to tilt the power in the MATRIX core will impact the ability to meet this criterion. Therefore, these results should be considered preliminary and the issue should be revisited in future work.

Table 7-3. Composition of 24" Tall Cylinder of HEU.

Nuclide	Atomic Density (atoms/b-cm)
^{234}U	4.2343×10^{-5}
^{235}U	3.9211×10^{-3}
^{236}U	1.4694×10^{-5}
^{238}U	2.3521×10^{-4}
^{27}Al	5.1237×10^{-2}

Table 7-4. Fission rates per gram ^{235}U in prototypic HEU cylinder in ATR and MATRIX.

Reactor	Location	Fission Rate (fissions/s/g ^{235}U)
ATR Simplified case described in Section 7.1	SW Flux Trap	5.22×10^{14}
	SE Flux Trap	5.10×10^{14}
Cylindrical MATRIX Baseline Al Rack	Peripheral Flux Trap	5.88×10^{14}
	Center Flux Trap	7.05×10^{14}

8. Comparisons and Downselection

At this stage in the analysis, calculations had been performed on the main reactor types and many variations on those baseline cases. From this information, comparisons were and a down-selection performed. This narrowing of the field of candidates facilitates the further development and analysis of the selected concept. The criteria used to compare the reactor options were derived essentially from the mission requirements developed in Ref. [5] and summarized in Section 1.2 of this report. The following sections give criteria and comparisons between the MATRIX concepts used in downselection. The numerical scores are tallied in Table 8-5 on page 80.

8.1 Achievable Cycle Length

The first criterion used was the cycle length requirement. From the comparison to an analogous ATR model described in Section 7, it was determined that the B_1 for ATR with no poison, no control material, and a full core of fresh fuel is approximately 56 days. The various concepts introduced and analyzed in this report are summarized in Table 8-1. The four baseline concepts (bolded) are given along with the variations on the baseline designs with the varied parameters given in red. It is expected that a replacement reactor should have at least the capability to achieve the same cycle length as the ATR in its current configuration. This characteristic is judged using the B_1 value of 56 days on a pass/fail basis in the far-right column of Table 8-1. Burnup in excess of this minimum value of 56 days may be advantageous, but this is not given additional consideration at the present stage of the analysis.

All four of the baseline candidate reactors pass the achievable burnup criterion with their nominal Al-6061 pressure vessels. However, replacement of this pressure vessel material with SS304 causes the Annular and Square concepts to fail the burnup criterion. Only Cylindrical and PBT, as designed, had enough reactivity to allow for the reactivity and burnup penalty of the SS304 vessel and still satisfy the burnup criterion.

The various reflector tank contents studied in Section 4 were only examined for the Cylindrical core. With all other parameters being nominal, all of the reflectors tested with the exception of H_2O satisfied the burnup criterion. Any of the concepts featuring an aluminum core rack and an Al-6061 pressure vessel would be expected to exhibit a similar reactivity effect for each of the reflector material options. Therefore, other concepts than the Cylindrical were not used to repeat that analysis.

Replacement of the Al-6061 core racks in the Cylindrical and Annular baseline cores with Al/Be alloys of increasing beryllium fraction increases the achievable burnup substantially. Because there is no analogous feature in the PBT concept, this analysis is not carried out for that core. Simply replacing the U-10Mo fuel meat with U_3Si_2 carries a substantial reactivity and burnup penalty. None of the otherwise-baseline concepts satisfy the burnup criterion with the U_3Si_2 alternative fuel except for the PBT core with Al-6061 pressure boundaries. In the Cylindrical and Annular cores, however, addition of beryllium to the core rack facilitates the use of U_3Si_2 alternative fuel meat.

Concepts not satisfying the imposed burnup criterion were removed from consideration at this stage. The reduced field of candidate concepts is given in Table 8-2 along with an alphanumeric identifier. This identifier will be used in a later table for convenience as a final comparison table is constructed. In addition to removing the concepts that fail the achievable burnup criterion, the Cylindrical concepts with various reflector contents were removed. This was done to avoid confusion since these reflectors can be judged somewhat independently from the reactors. The exception to this is, of course, the PBT concept, since the shape of the reflector tank is quite different from the other three concepts.

Table 8-1. Summary table of B_1 values for MATRIX baseline and variant cases.

Reactor Type	Fuel Meat	Rack content	Pressure Vessel (or PBT)	Reflector Type	B_1 (days)	$B_1 \geq$ ATR (56) ?
Cylindrical	**U-10Mo**	**Aluminum**	**Aluminum (4 cm thick)**	**D_2O**	**100**	**Pass**
Cylindrical	U-10Mo	Aluminum	SS304 (1.1 cm thick)	D_2O	68	**Pass**
Cylindrical	U-10Mo	Aluminum	Aluminum (4 cm thick)	H_2O	42	Fail
Cylindrical	U-10Mo	Aluminum	Aluminum (4 cm thick)	D_2O Tanks in H_2O Pool	69	**Pass**
Cylindrical	U-10Mo	Aluminum	Aluminum (4 cm thick)	100% Beryllium	108	**Pass**
Cylindrical	U-10Mo	Aluminum	Aluminum (4 cm thick)	90% Beryllium / 10% H2O	91	**Pass**
Cylindrical	U-10Mo	Aluminum	Aluminum (4 cm thick)	100% Graphite	105	**Pass**
Cylindrical	U-10Mo	Aluminum	Aluminum (4 cm thick)	90% Graphite / 10% H_2O	82	**Pass**
Cylindrical	U-10Mo	20% beryllium	Aluminum (4 cm thick)	D_2O	114	**Pass**
Cylindrical	U-10Mo	50% beryllium	Aluminum (4 cm thick)	D_2O	135	**Pass**
Cylindrical	U-10Mo	100% beryllium	Aluminum (4 cm thick)	D_2O	165	**Pass**
Cylindrical	U_3Si_2	Aluminum	Aluminum (4 cm thick)	D_2O	23	Fail
Cylindrical	U_3Si_2	20% beryllium	Aluminum (4 cm thick)	D_2O	33	Fail
Cylindrical	U_3Si_2	50% beryllium	Aluminum (4 cm thick)	D_2O	45	Fail
Cylindrical	U_3Si_2	100% beryllium	Aluminum (4 cm thick)	D_2O	61	**Pass**
Annular	**U-10Mo**	**Aluminum**	**Aluminum (4 cm thick)**	**D_2O**	**63**	**Pass**
Annular	U-10Mo	Aluminum	SS304 (1.1 cm thick)	D_2O	25	Fail
Annular	U-10Mo	20% beryllium	Aluminum (4 cm thick)	D_2O	89	**Pass**
Annular	U-10Mo	50% beryllium	Aluminum (4 cm thick)	D_2O	124	**Pass**
Annular	U-10Mo	100% beryllium	Aluminum (4 cm thick)	D_2O	176	**Pass**
Annular	U_3Si_2	Aluminum	Aluminum (4 cm thick)	D_2O	1	Fail
Annular	U_3Si_2	20% beryllium	Aluminum (4 cm thick)	D_2O	15	Fail
Annular	U_3Si_2	50% beryllium	Aluminum (4 cm thick)	D_2O	34	Fail
Annular	U_3Si_2	100% beryllium	Aluminum (4 cm thick)	D_2O	61	**Pass**
Square	**U-10Mo**	**Aluminum**	**Aluminum (4 cm thick)**	**D_2O**	**70**	**Pass**
Square	U-10Mo	Aluminum	SS304 (1.1 cm thick)	D_2O	40	Fail
Square	U_3Si_2	Aluminum	Aluminum (4 cm thick)	D_2O	5	Fail
PBT	**U-10Mo**	—	**Aluminum (1.1 cm thick)**	**D_2O**	**184**	**Pass**
PBT	U-10Mo	—	SS304 (0.35 cm thick)	D_2O	129	**Pass**
PBT	U_3Si_2	—	Aluminum (1.1 cm thick)	D_2O	61	**Pass**

Table 8-2. Reduced field of candidates with alphanumeric identifiers.

Reactor Type	Fuel Meat	Rack content	Pressure Vessel (or PBT)	Reflector Type	ID
Cylindrical	**U-10Mo**	**Aluminum**	**Aluminum (4 cm thick)**	**D_2O**	C1
Cylindrical	U-10Mo	Aluminum	SS304 (1.1 cm thick)	D_2O	C2
Cylindrical	U-10Mo	20% beryllium	Aluminum (4 cm thick)	D_2O	C3
Cylindrical	U-10Mo	50% beryllium	Aluminum (4 cm thick)	D_2O	C4
Cylindrical	U-10Mo	100% beryllium	Aluminum (4 cm thick)	D_2O	C5
Cylindrical	U_3Si_2	100% beryllium	Aluminum (4 cm thick)	D_2O	C6
Annular	**U-10Mo**	**Aluminum**	**Aluminum (4 cm thick)**	**D_2O**	A1
Annular	U-10Mo	20% beryllium	Aluminum (4 cm thick)	D_2O	A2
Annular	U-10Mo	50% beryllium	Aluminum (4 cm thick)	D_2O	A3
Annular	U-10Mo	100% beryllium	Aluminum (4 cm thick)	D_2O	A4
Annular	U_3Si_2	100% beryllium	Aluminum (4 cm thick)	D_2O	A5
Square	**U-10Mo**	**Aluminum**	**Aluminum (4 cm thick)**	**D_2O**	S1
PBT	**U-10Mo**	NA	**Aluminum (1.1 cm thick)**	**D_2O**	P1
PBT	U-10Mo	NA	SS304 (0.35 cm thick)	D_2O	P2
PBT	U_3Si_2	NA	Aluminum (1.1 cm thick)	D_2O	P3

8.2 High Availability/Capacity Factor

One of the requirements imposed on the new MATRIX concept is that it has high availability and capacity factor. Though no concrete number is proposed at this point, one may assume that the same or higher availability than the current ATR value would be desirable. Key factors in availability are refueling time and frequency, along with the time and frequency of major maintenance outages. The refueling frequency is dictated by experiment schedules within limits ultimately imposed by the burnup capability of the core. Because the experiment schedules are unknown and the burnup capability was addressed in a separate section, these are not discussed further here.

With regard to refueling time, the MATRIX concepts are at too immature a design stage to make firm assertions as to their relative merits. All of these designs feature a pressure boundary located in close proximity to the fuel. Therefore, replacement of the pressure vessel is likely. No calculations have been made in regard to this. However, the French CEA has stated that for their RJH reactor, a 10-year interval is anticipated for replacement of their aluminum pressure vessel. [13] All but impossible for many existing nuclear reactors, pressure vessel replacement must be planned from the early stages of design for the MATRIX reactor. Lessons learned from the RJH experience should be of value in this process as well. As was shown in Section 5, increasing the moderation from the core rack reduces the fast fluence on the pressure vessel. This may be shown to extend the time between required replacements. However, this has not been quantified at this time.

For routine refueling, speculation on the relative times between the concepts is premature, and so this will be reserved for future work. From both the standpoints of routine refueling and major maintenance outages, no clear advantages could be gleaned from consideration of the present state of the MATRIX designs. They are therefore considered equivalent with regard to this criterion.

8.3 NRC Licensable

Ability to obtain a construction and operation license from the NRC is an anticipated requirement for MATRIX. This is a significant departure from the DOE-licensed test reactor paradigm of the past. The implications of the various designs on the licensing process have not been analyzed in detail. However, some observations can be made based on available information.

The choice of Al-6061 for the pressure vessel material is arguably the most significant departure from more conventional high-pressure test reactors in the U.S. Currently, ASME pressure vessel codes do not include aluminum alloys at high temperatures normally associated with this type of application. One possible strategy for eliminating this obstacle would be to build a qualification case at higher temperatures. It may be possible to leverage CEA experience in licensing the JHR in this. Another possible strategy would be to provide sufficient cooling such that exceeding the temperatures currently included in the code is precluded.

Because there may be additional cost and possible licensing risk associated with specifying an aluminum pressure vessel, the concepts that include this feature are somewhat disadvantaged in this category. Generally, this makes the Cylindrical and PBT concepts stronger since these are the only two that still meet the burnup criterion with the SS304 pressure vessel in place (albeit with the beryllium core rack option only). Aside from the selection of pressure vessel material, no other discriminating features are known at this time.

8.4 High Flux in Large Test Volumes

Perhaps one of the most important performance metrics for a new test reactor would be that it produces high neutron flux in large test volumes. In this section, data generated and reported in previous sections is condensed and arranged to assess the volume of test locations and the average total flux in those locations. The reduced field of candidates is shown with their usable volumes and average total flux in

Table 8-3. Center and peripheral test locations are handled separately and the usable volume was determined by taking all space within the innermost pipe of the IPTs having the full 120 cm axial height of active fuel.

The Cylindrical core and the Square core have the same IPT design with all seven (one central and six peripheral) of them being identical. Each has a usable volume of 8.2 liters, so the peripheral six have a total volume of 48.9 liters. Total flux values averaged over the axial length of the test space are given in

Table 8-3. All of the Cylindrical cases remaining (C1-C6) have comparable flux values in the IPTs. As for the locations inside the fuel assemblies, half of them were assumed to be occupied by shim rods for this calculation. The total remaining volume of these spaces is 17.6 liters. The square core is missing the locations inside assemblies, however other spaces would become available for tests, which are not analyzed in detail here. These concepts are believed therefore to have a strong advantage with regard to this criterion

The Annular and PBT cores share the same IPT design with a larger central location and smaller peripheral locations. The peripheral locations are smaller due to the assumed need for shutdown rods in these locations. The large central location has a volume of 18.2 liters and the sum of the volumes of surrounding peripheral locations is 28.3 liters. Therefore, as currently designed, the Square and Cylindrical designs have much more IPT volume than the Annular and PBT designs. Of course, other irradiation positions are anticipated to be available in all of the concepts.

In the ATR, there were originally nine in-pile tubes in the reactor. In six of these locations, annular safety rods were installed, effectively shrinking the available space for irradiation tests. For the calculation of usable volume in the flux traps in ATR, it was assumed that all of the large flux traps (without shutdown rods) are designed to approximate the NW flux trap and all of the small positions (with shutdown rods) look like the North, West, Southwest, and Southeast flux traps. With this assumption, the usable volume in the small locations totals 11.3 liters and that of the large locations is 29.7 liters. Therefore, all of the designs in

Table 8-3 have more total usable space in flux traps having IPTs than does the current ATR. From the analysis of the flat ATR core in Section 7, the average flux in the small locations is approximately 1.7×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$ while that in the large locations (based on the NW flux trap) is approximately 1.3×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$. Note again that this is for a flat core and there would be a great deal of variation based on the loading of fuel and experiments. Therefore, these numbers should be used as a rough estimate. However, from these values, it can be observed that the total flux values in the IPTs of the Cylindrical and Square MATRIX concepts are comparable (if slightly lower in the Annular and PBT designs) to those of ATR. In practice, higher fluxes are routinely achieved in ATR by tilting the power. Capability for power tilts is anticipated, but not yet analyzed thoroughly, in the MATRIX designs as well. Therefore this simplified comparison approach is used.

As is anticipated with the MATRIX designs, there are many more usable locations in the ATR for irradiation experiments. Because the number and size of these locations in MATRIX concepts have not been determined yet, they are omitted from this simplified comparison. Note that this is an important figure of merit to continually revisit as designs develop. From this comparison, the conclusion is drawn that the MATRIX designs do not have a distinct advantage in terms of magnitude of total neutron flux in test locations. However, their fluxes are comparable (particularly in the Cylindrical and Square concepts) and they all appear to have a significant volume advantage over ATR. Among the MATRIX concepts, the Cylindrical and Square concepts are thus considered to be at a strong advantage with the Annular core being neutral and the PBT core having a slight disadvantage.

Table 8-3. Summary table of average total neutron fluxes and volumes of test spaces.

ID	**Center Test Location**		**Peripheral Test Location**		**Inside Fuel Assembly**	
	Volume (liters)	**Ave. Flux ($n \cdot cm^{-2} \cdot s^{-1}$)**	**Volume (liters)**	**Ave. Flux ($n \cdot cm^{-2} \cdot s^{-1}$)**	**Volume (liters)**	**Ave. Flux ($n \cdot cm^{-2} \cdot s^{-1}$)**
C1	8.2	1.55E+15	48.9	1.36E+15	17.6[a]	1.62E+15
C2	8.2	1.73E+15	48.9	1.40E+15	17.6	1.78E+15
C3	8.2	1.53E+15	48.9	1.32E+15	17.6	1.58E+15
C4	8.2	1.51E+15	48.9	1.31E+15	17.6	1.55E+15

[a] Assumes half of the fuel assemblies are unavailable for experiment volume.

C5	8.2	1.44E+15	48.9	1.29E+15	17.6	1.51E+15
C6	8.2	1.54E+15	48.9	1.38E+15	17.6	1.78E+15
A1	18.2	1.56E+15	28.3	9.57E+14	NA	NA
A2	18.2	1.56E+15	28.3	9.32E+14	NA	NA
A3	18.2	1.53E+15	28.3	9.11E+14	NA	NA
A4	18.2	1.40E+15	28.3	8.86E+14	NA	NA
A5	18.2	1.54E+15	28.3	9.49E+14	NA	NA
S1	8.2	1.52E+15	48.9	1.36E+15[a]	NA	NA
P1	18.2	1.17E+15	28.3	8.44E+14	NA	NA
P2	18.2	1.23E+15	28.3	8.30E+14	NA	NA
P3	18.2	1.31E+15	28.3	9.09E+14	NA	NA

8.5 Fast Spectrum Capabilities

Table 8-4 summarizes the peak fast flux values in IPT locations of the MATRIX concepts (and inner-assembly locations of the Cylindrical design). The center IPT locations in the matrix designs have peak fast flux values ranging from $2.2\text{x}10^{14}$ to $3.7\text{x}10^{14}$ $n \cdot cm^{-2} \cdot s^{-1}$ with the higher values occurring in some of the Cylindrical concepts. The same relative trend between concepts can be observed in the peripheral IPTs, albeit at reduced magnitudes. In the calculations performed on the simplified ATR, the fast flux values in the small and large IPTs yielded fast flux values of $3.5\text{x}10^{14}$ and $2.9\text{x}10^{14}$ $n \cdot cm^{-2} \cdot s^{-1}$, respectively. These were taken in the SW and NW flux traps, respectively and both were assumed to be aluminum filled like in the MATRIX concepts. As with the average total flux values the IPTs of the MATRIX concept show no distinct advantage over ATR with regard to peak fast flux. This is because fast flux in a test location is largely determined by power density in fuel and proximity to said fuel. These features are essentially common among the MATRIX and ATR concepts.

As mentioned before, the ATR does have a number of other irradiation locations, some of which have higher fast flux than in the IPTs. The A-holes of ATR, for example, are drilled out of the inner beryllium reflector and are quite close in proximity to fuel elements. From Table 7-2, one sees that the peak fast flux in the A-1 hole for the simplified flat core modeled was found to be approximately $4.4\text{x}10^{14}$ $n \cdot cm^{-2} \cdot s^{-1}$. None of the IPTs of MATRIX designs show a value this high. However, the locations inside the fuel elements of the Cylindrical design have fast flux somewhat higher than this. The total volume of these locations (again assuming half are unavailable) is 17.6 liters. There are 16 A-holes in ATR. Four of them are larger having a diameter of 1.95 cm, and 12 of them smaller having a diameter of 1.59 cm. The total volume of the A-hole space combined is therefore 4.4 liters. If we assume that the eight small B-holes (diameter = 2.22 cm) can achieve a similar fast flux due to their close proximity to fuel, and we add their volume to that of the A-holes, one arrives at a volume of 8.2 liters of space having the peak fast flux of between $4\text{x}10^{14}$ and $5\text{x}10^{14}$ $n \cdot cm^{-2} \cdot s^{-1}$. This is still substantially less than that of the inter-assembly space in the Cylindrical design, even if fewer than half of these spaces are available for experiments.

Thus it is concluded that in the comparison of available fast flux, the Cylindrical core holds an advantage over ATR and the other MATRIX concepts. The Cylindrical design has

[a] NE flux trap

comparable fast flux in IPTs to those of ATR, but with a larger volume of usable space. Furthermore, the test space inside fuel assemblies provides a larger volume of very-high fast flux irradiation space than those of ATR. The Inter-assembly test spaces are absent in the other MATRIX concepts, which lack a dedicated space with higher fast flux than their IPTs.

Table 8-4. Summary table of peak fast fluxes and volumes of test spaces.

ID	Center Test Location		Peripheral Test Location		Inside Fuel Assembly	
	Volume (liters)	Peak Fast Flux ($n\cdot cm^{-2}\cdot s^{-1}$)	Volume (liters)	Peak Fast Flux ($n\cdot cm^{-2}\cdot s^{-1}$)	Volume (liters)	Peak Fast Flux ($n\cdot cm^{-2}\cdot s^{-1}$)
C1	8.2	3.22E+14	48.9	2.79E+14	17.6[a]	5.07E+14
C2	8.2	3.67E+14	48.9	2.94E+14	17.6	5.73E+14
C3	8.2	3.12E+14	48.9	2.69E+14	17.6	4.91E+14
C4	8.2	2.92E+14	48.9	2.59E+14	17.6	4.86E+14
C5	8.2	2.68E+14	48.9	2.41E+14	17.6	4.74E+14
C6	8.2	2.78E+14	48.9	2.52E+14	17.6	4.91E+14
A1	18.2	2.99E+14	28.3	1.87E+14	NA	NA
A2	18.2	3.10E+14	28.3	1.83E+14	NA	NA
A3	18.2	2.98E+14	28.3	2.20E+14	NA	NA
A4	18.2	2.70E+14	28.3	1.99E+14	NA	NA
A5	18.2	2.86E+14	28.3	1.89E+14	NA	NA
S1	8.2	2.71E+14	48.9	2.68E+14	NA	NA
P1	18.2	2.23E+14	28.3	1.68E+14	NA	NA
P2	18.2	2.99E+14	28.3	1.68E+14	NA	NA
P3	18.2	2.41E+14	28.3	1.68E+14	NA	NA

8.6 Modularity of Core

Another figure of merit in judging a replacement test reactor is the modularity and flexibility of the core. As has been the case during the 50+ year lifetime of ATR, the missions of a reactor can change substantially. Through the creativity of its reactor engineers and physicists, ATR was adapted to its changing mission with a high degree of success. Nevertheless, any new reactor should be designed with adaptability in mind.

The D_2O tank nominally designed in all of the concepts is anticipated to provide a very high degree of flexibility to both the initial designers and to the custodians of the machine for its lifetime. Being at or near atmospheric pressure should allow for rather straightforward modifications of the contents of the tank, although the presence of D_2O presents some operational complications in its need to be sealed from the surrounding environment. The alternative reflector tank concepts discussed in Section 5 could relieve some of this, however these alternatives are rather concept-neutral with the exception of the PBT design.

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[a] Assumes half of the fuel assemblies are unavailable for experiment volume.

The main differences in flexibility would likely arise from the reactor components inside the pressure boundary. Among the MATRIX candidate designs, the Square and Cylindrical possess the greatest capability for adaptation to changing missions inside the pressure vessel. The core rack should be designed such that a fuel location can accept either a fuel assembly or a test train of the same size. Reactor control hardware, such as control or shim rods, should be designed to be movable such that they can be placed in locations of appropriate worth for various configurations.

On the other hand, it cannot be ruled out that a fuel assembly could be removed and replaced with a test train in the Annular and PBT cores. These concepts have arcuate assemblies similar to those of ATR, which may be more difficult to replace with non-fuel, though this should not be considered impossible at this point. Because of this uncertainty, only a slight advantage is assigned to the Square and Cylindrical concepts based on this criterion.

8.7 Online Experiment Access and Rabbits

The capability to insert and remove experiments during operation can provide substantial advantages and expansion of the option space for simultaneous reactor missions. Pneumatically driven "rabbits" have been used for decades to provide access to test locations in reactors, including ATR, during operation. These can be designed to cross high-pressure boundaries, although it increases cost and complexity somewhat. At the current stage of design of the MATRIX concepts, no significant differences are known that would render one design or another more advantageous over others with regard to access to experiments within the pressure boundary.

The reflector tanks of all of the MATRIX designs are to be constructed such that they provide a large low-pressure environment with online access to irradiation spaces. Because all of the concepts call for this, no differences are known between the MATRIX concepts with regard to this criterion. The primary differences in online experiment access between the ideas presented in this report likely arise from the selection of the reflector tank content; the reference D_2O or one of the alternatives presented in Section 4. For example, the option of an open-top water tank with D_2O cans inside may offer an attractive combination of high flux and easy access. However, because this option is concept neutral (with the exception of the PBT core), it is not considered a determining factor here.

8.8 Minimum waste stream effluents/environmental impact

Minimization of waste streams and reducing environmental impact are important objectives of a new reactor concept. With regard to fuel, all of the MATRIX options have been designed to be very similar, differing primarily in the geometry of elements. Thus no significant differences in waste stream are anticipated in relation to fuel.

The D_2O reflector tank specified for all of the baseline reactor concepts will share the environmental issue of tritium production. The production rate has yet to be quantified, but must be accounted for since this is a high flux environment and many neutron captures are anticipated. The PBT concepts contain more D_2O in a higher-flux environment than the other designs. Therefore, these are likely to be the most prolific producers of tritium. For this reason, they are considered to be at a slight disadvantage compared to the other three concepts. Among the other candidates, the D_2O tank is roughly the same size and positioned the same with respect to the core. Therefore, no substantial difference between these is known at this time.

The baseline cases of each reactor have omitted beryllium as a major material in the core. This is considered favorable due to the beryllium disposal difficulties that have been encountered in ATR operation over the years. Variations on the Cylindrical and Annular designs that contain aluminum/beryllium alloy core racks introduce beryllium into the waste stream. Therefore, these are considered to be at a slight disadvantage compared to the concepts that do not contain beryllium.

8.9 Imaging, Neutron Scattering

The secondary mission of imaging and neutron scattering experimentation is facilitated by high thermal neutron flux outside the core. In all of the MATRIX concepts, the idea behind the large D_2O tank is to facilitate high thermal flux outside the main pressure boundary. This provides a reconfigurable space with relatively straightforward access for these types of secondary missions. Because the PBT concepts have larger D_2O tanks than the other three main types, these are considered to be at a slight advantage with regard to this criterion.

8.10 Radioisotope Production

With regard to radioisotope production, high flux and ease of access are two of the most important features one could desire in a reactor design. For this reason, a similar comparison exists to that related to imaging and neutron scattering. All of the MATRIX concepts feature the large D_2O tank outside the pressure boundary. Therefore, the Square, Cylindrical, and Annular concepts are considered equivalent in this regard. Again, because the PBT concepts have larger D_2O tanks than the other three main types, these are considered to be at a slight advantage with regard to this criterion.

8.11 Comparison Summary

Table 8-5 shows a summary of downselection criteria and the scores given to the remaining field of candidates. The Cylindrical concepts receive the highest total scores among the MATRIX concepts. This is the baseline design, therefore, that is carried forward for further design and analysis.

Table 8-5. Summary table of downselection criteria and scores.

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**A1**	**A2**	**A3**	**A4**	**A5**	**S1**	**P1**	**P2**	**P3**
Availability / Capacity Factor	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
NRC Licensable	2	3	2	2	2	2	2	2	2	2	2	2	2	3	2

High Flux in Large Volume	4	4	4	4	4	4	3	3	3	3	3	4	2	2	2
Fast Spectrum Capability	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
Modularity of Core	4	4	4	4	4	4	3	3	3	3	3	4	3	3	3
Online Experiment Access	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Minimum Waste / Environ. Impact	3	3	2	2	2	2	3	2	2	2	2	3	2	2	2
Imaging / Neutron Scattering	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4
Radioisotope Production	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4
TOTAL	30	31	29	29	29	29	26	25	25	25	25	28	26	27	26

1 = Significant Disadvantage
2 = Slight Disadvantage
3 = Neutral
4 = Slight Advantage
5 = Significant Advantage

9. Further Design Considerations for Cylindrical Concept

9.1 Potential for PWR Fuel Pin Irradiations in Reflector Tank

The potential for various types of irradiation experiments in the reflector tank is briefly addressed in this section. The design of the JHR specifies PWR-type fuel irradiation experiments in pressurized tubes in the reflector tank. This arrangement could provide flexibility as well as offer a large amount of space for multiple irradiations. The JHR design also calls for tests that can be moved radially to simulate transients. [13] In this section, calculations are described that give a preliminary evaluation of what linear power can be achieved in a test such as this in the MATRIX reactors.

The baseline Cylindrical core was used for this analysis. Conceptual test hardware was devised by changing the radii of the IPTs such that a PWR pin having radius 0.41 cm can fit inside without a great deal of additional space. The resulting dimensions are shown in Figure 9-1. Note that this is a concept borrowing from approximate dimensions from ATR and JHR and has not been analyzed for structural integrity, etc. It is only meant for preliminary reactor physics scoping calculations. The fuel pin was assumed to be composed of 4.5 w/o enriched UO_2 fuel having the nuclide densities shown in Table 9-1. The height of the pin was assumed to be 60.96 cm (24”) centered at the axial center of the axial core. This amounts to approximately half of the core height. Cladding was ignored for this calculation, a simplification that would not be expected to change the results of this calculation drastically. The cooling water surrounding the pin and just outside the flow tube is assumed to be at typical PWR conditions (ρ=741 g/cm^3, T=580 K). The pin temperature is assumed to be 1500K with a flat temperature profile. The calculation was run for distances between the outer wall of the vessel and the center of the PWR fuel test ranging from 6 to 36 cm. Figure 9-2 shows a screen capture of the Serpent model containing the PWR pin test in the reflector at 6 cm from the vessel wall, the closest position evaluated here.

The resulting linear power values for the PWR pin test are given in Table 9-2 along with the core reactivity for each case. A case with no test hardware in the reflector at all is given at the bottom of the table. Linear powers for the PWR pin test range from 104-210 kW/m for the configurations tested here. Typical average linear power in a PWR is 17.8 kW/m with a typical peak value of 42.7 kW/m. [18] Therefore, it appears that typical PWR linear power values can be achieved in this type of arrangement. Some of the alternative reflectors evaluated in Section 4 have lower flux values than the D_2O reflector used in this analysis. However, even a reduction by a factor of two in flux should still facilitate prototypic PWR power densities in this test arrangement. Other measures may be possible to increase the potential power density of a reflector PWR test, such as tilting the core power, etc.

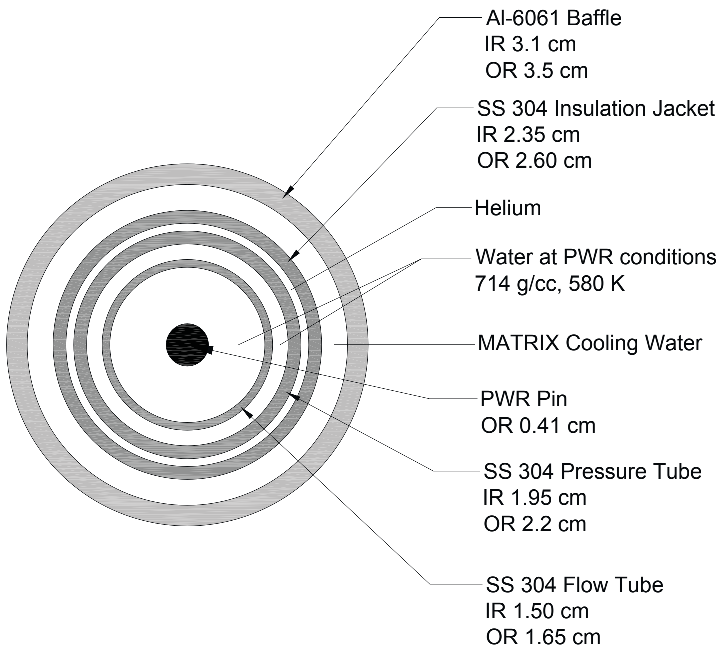


Figure 9-1. Reflector PWR pin irradiation hardware dimensions and materials.

Table 9-1. Composition of 24” Tall Cylinder of PWR fuel.

Nuclide	Atomic Density (atoms/b-cm)
^{235}U	1.056×10^{-3}
^{238}U	2.215×10^{-2}
^{16}O	4.461×10^{-2}

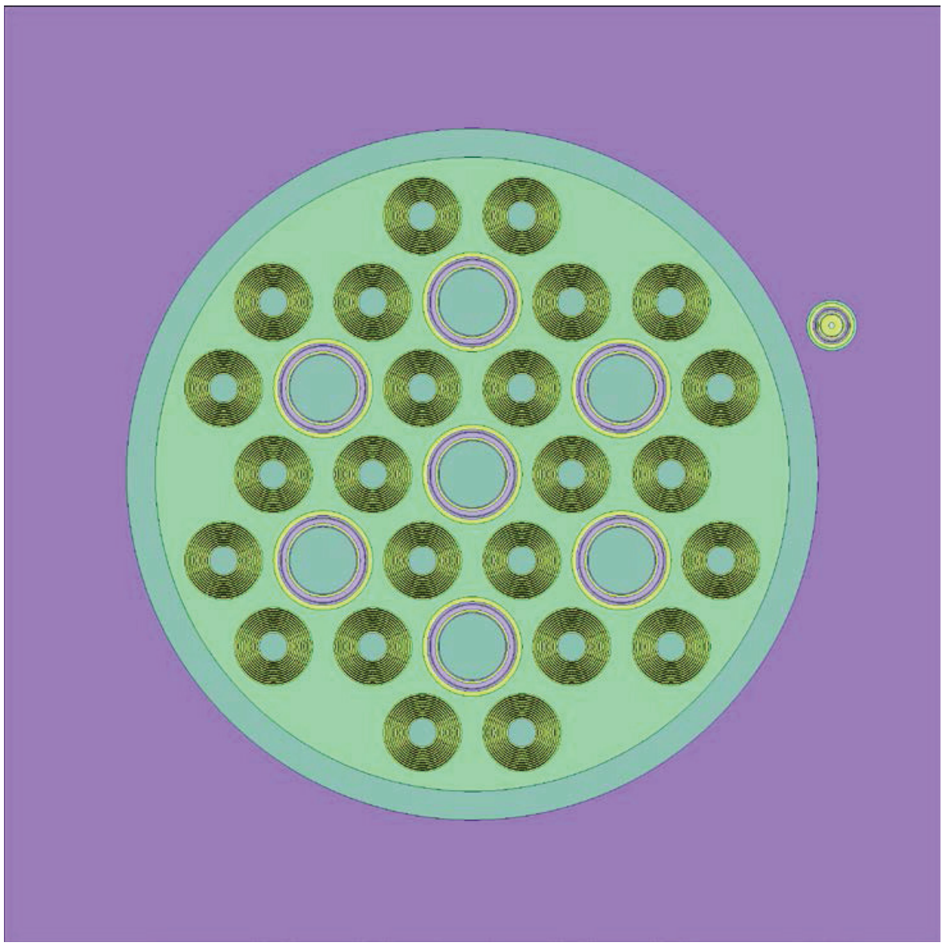


Figure 9-2. Baseline Cylindrical core model with PWR irradiation apparatus in reflector.

Table 9-2. Reactivity and linear power of PWR fuel pin test in reflector of baseline Cylindrical in core.

D1[a] (cm)	D2[b] (cm)	Initial k_{eff}	Linear Power in PWR Fuel Pin	
			kW/ft	kW/m

[a] D1 = Distance from core center to PWR pin sample center.

[b] D2 = Distance from outer pressure vessel surface to PWR pin sample center.

54	6	1.18040 ± 0.00015	64.1	210
64	16	1.18179 ± 0.00015	54.8	180
74	26	1.18239 ± 0.00015	42.6	140
84	36	1.18294 ± 0.00015	31.7	104
No PWR Pin Test		1.18448 ± 0.00015		

Table 9-3 shows analogous results, except with the SS304 pressure vessel described in Section 3. From these results, one sees that with the power in the PWR fuel pin in the reflector tank is reduced, although not to an extreme degree. This is expected since the results of tallies reported previously show that the flux values are not diminished greatly by using the thinner SS304 vessel.

Table 9-3. Reactivity and linear power of PWR fuel pin test in reflector of Cylindrical core with SS304 pressure vessel.

D1[a] (cm)	D2[b] (cm)	Initial k_{eff}	Linear Power in PWR Fuel Pin	
			kW/ft	kW/m
54	9	1.13678 ± 0.00015	56.0	184
64	19	1.13669 ± 0.00015	45.3	150
74	29	1.13669 ± 0.00015	34.6	114
84	39	1.13730 ± 0.00015	25.7	85
No PWR Pin Test		1.13797 ± 0.00015		

9.2 Representative Loadings and Power Tilts

In this section, preliminary consideration is given to prototypic core loadings in the Cylindrical core. First, an initial 3-batch loading was devised giving an approximately even distribution of power across the core. Note that this pattern was not optimized, but merely represents a starting point toward a flat core loading. The loading pattern is shown in Figure 9-3 with fresh, once-burned, and twice burned fuel represented by F, 1B, and 2B, respectively. Once and twice-burned fuel compositions were determined using a Serpent depletion calculation where an entire core of fresh fuel was loaded. This was depleted for 50 days at 250 MW, followed by 46 days zero-power decay, then burned for another 50 days at 250 MW, then shut down again and decayed 46 days more. Once-burned fuel compositions were taken from the end of the first 46-day decay and Twice-burned compositions taken from the end of the second 46-

[a] D1 = Distance from core center to PWR pin sample center.

[b] D2 = Distance from outer pressure vessel surface to PWR pin sample center.

day decay. These shutdown times are not based on exact expectations of operational needs, but assumed based on the need for some decay between cycles. The initial k_{eff} of this core is 1.07689 and the cycle length was determined to be 50 days. This is expected from a 3-batch core with B_1~100 days if linear reactivity assumptions are made.

The ATR is routinely expected to achieve significant power tilting across its lobes in order to support irradiations of different intensities at the same time. ATR is capable of achieving a power tilt of greater than a 3:1 ratio from its SE to NW lobes, albeit at lower than its rated thermal power. [19] It is anticipated that in a MATRIX design, similar power-tilt capabilities will be required, though the "lobe" concept may not apply. Therefore, some simple studies of achieving power tilt through 3-batch core loading were performed. In addition to the prototypic 3-batch loading discussed previously and shown in Figure 9-3, four other loadings were modeled. These are shown in Figure 9-4. Starting from the prototypic flat core, the core labeled "Tilt 1" swaps two assemblies in such a way that concentrates power near the NW flux trap at the expense of power near the SE flux trap. Each subsequent tilted core thereafter results from swapping two more assemblies.

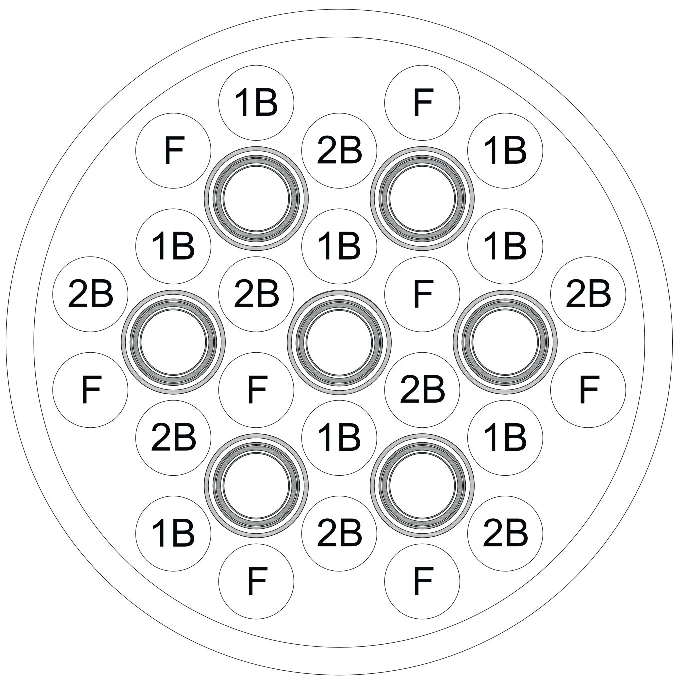
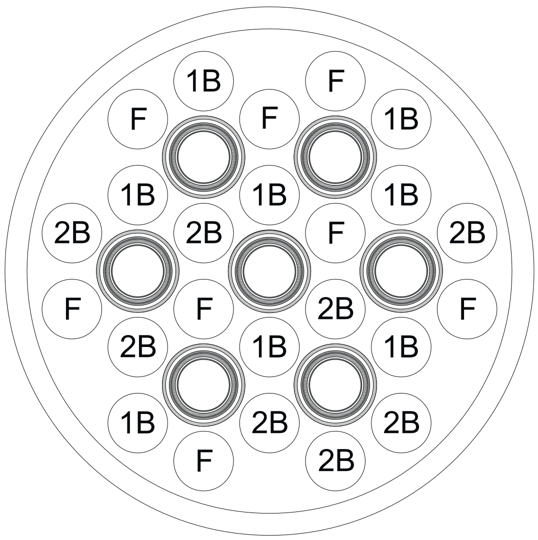
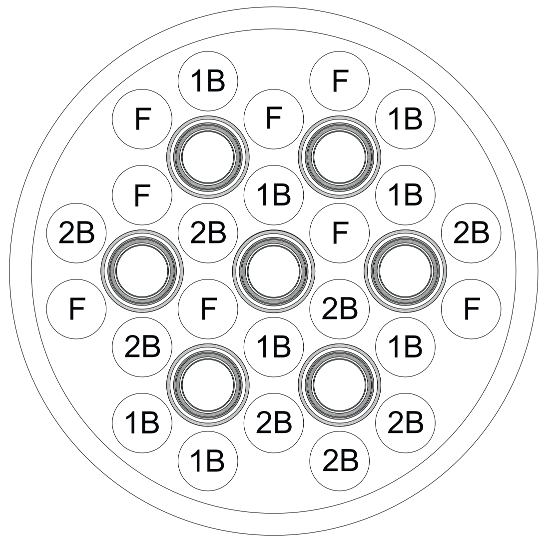


Figure 9-3. Assembly layout of prototypic flat 3-batch Cylindrical core.

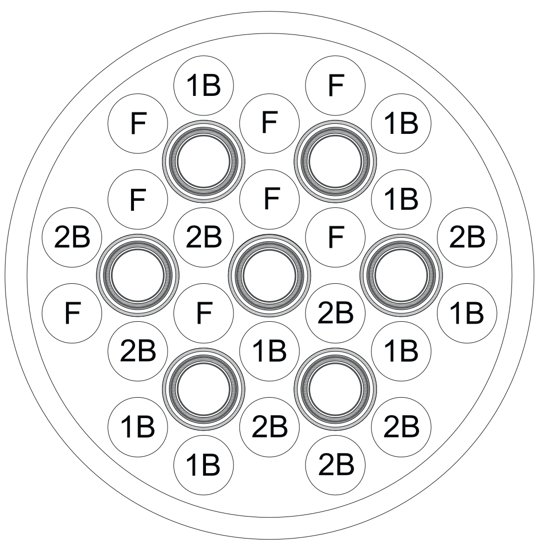
Table 9-4 gives the k_{eff}, total neutron flux in the NW and SE flux traps, and the ratio of these fluxes for the prototypic flat case along with the four tilted core loadings. This shows that concentrating fresh assemblies together in the way shown has increased reactivity somewhat. This is, in part, due to the original location of fresh assemblies being more on the periphery of the reactor. Because the reactor is not kept critical for this analysis, the magnitude of the flux is not to be considered exact, however this gives the designer information as to how much tilt can be achieved with core loading alone. With each successive swap of assemblies, the ratio of total neutron flux from SE to NW increases less, until in the case labeled Tilt 4 it has reached a ratio of 2.0. Although it is not presently known how much tilt can be achieved in ATR with fuel assembly loading alone, control drums are also used in order to achieve this tilt. For this particular MATRIX concept, it appears that some type of shim would need to be used in order to augment the loading-driven tilt in order to achieve the 3:1 ratio that would be anticipated as a requirement.



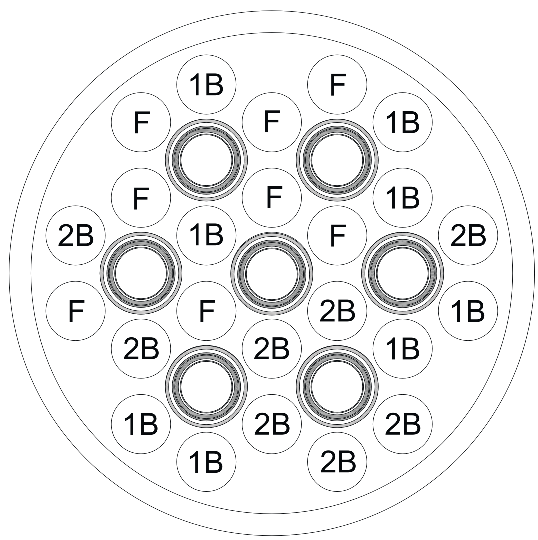
Tilt 1



Tilt 2



Tilt 3



Tilt 4

Figure 9-4. Core loading maps for 3-batch tilted Cylindrical cores.

Table 9-4. Flux in IPTs and power tilt for prototypic flat loading and tilted cores.

Core Loading	**Total Neutron Flux in IPTs [n·cm^{-2}·s^{-1}]**		**Ratio NW/SE**	k_{eff}
	NW	**SE**		
Prototypic Flat	1.7×10^{15}	1.5×10^{15}	1.1	1.07689
Tilt 1	1.9×10^{15}	1.3×10^{15}	1.5	1.07445
Tilt 2	2.0×10^{15}	1.2×10^{15}	1.7	1.08443
Tilt 3	2.1×10^{15}	1.2×10^{15}	1.8	1.08781
Tilt 4	2.2×10^{15}	1.1×10^{15}	2.0	1.09556

9.3 Control Rods

Exploration of control options was also initiated using the Cylindrical MATRIX core model. In this design, a natural location for shim and/or shutdown rods would be inside the center of some of the fuel assemblies. This is favorable because these would be locations of high rod worth. However, these are also locations of high fast flux that would not be available for irradiation experiments. Using the prototypic core loading discussed above and shown in Figure 9-3, a hollow absorber rod (98% hafnium and 2% zirconium, ρ=13.1739 g/cm^3) was conceptualized to fit just inside the inner fuel plate of the assemblies. The composition of this absorber material is that of the ATR neck shim rods. [12] This is shown in Figure 9-5. The rod has Al-6061 cladding and fits inside an Al-6061 guide tube. Unlabeled white portions in the drawing are coolant water.

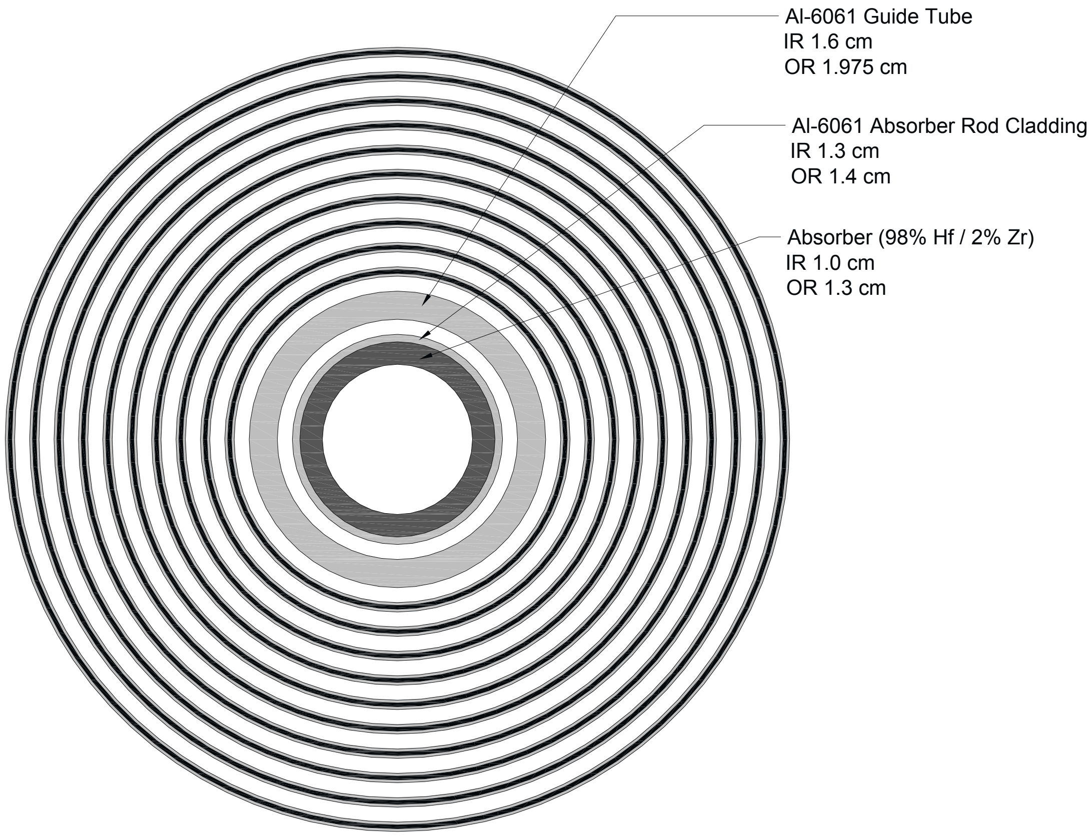


Figure 9-5. Diagram of possible shim rod design inside Cylindrical fuel assembly.

It is desirable to have the worth of a single rod worth be substantial, but less than $1 in order to avoid prompt criticality in the event of ejection (if physically possible) or rapid withdrawal. The outer diameter of the hafnium portion of the rods were selected based on this and an approximately $0.75 value was targeted.

Table 9-5 shows the worth of absorber rods for various configurations. First, the rods were placed only inside fresh assemblies (8 rods), then inside once-burned assemblies (8 rods). Finally, rods were placed inside both fresh and once-burned assemblies. In all cases, the worth per rod was close to $0.75.

Note that the discussion has avoided terming these rods as “shim” or “shut-down”. This is because rods such as these, or rods having less absorbing media or dimensions, could be selected for either shutdown or shim.

Rods could be bi-modal wherein they have a gray section to be used as shim followed by a black section for shut-down. As more information is known for the operating parameters of the reactor, these types of concepts may be investigated.

Table 9-5. Absorber rod worth for various configurations.

Shim locations	Number of Rods Inserted	k_{eff}	Total Rod Worth ($)[a]	Worth per Rod ($)
None	0	1.07689	NA	NA
Fresh Fuel only	8	1.03490	5.80	0.72
1B Fuel only	8	1.03346	6.00	0.75
Fresh and 1B Fuel	16	0.99365	12.0	0.75

9.4 Potential for Shutdown Rods in Reflector Tank

In Section 4, the results of the reflector studies indicated that the content of the D_2O reflector tank has a large reactivity effect. This was demonstrated in the Cylindrical design, but is expected to be true generally due to the similarities of the different MATRIX designs.[b] For example, as seen in Table 4-1, replacing D_2O with H_2O in the reflector tank has a reactivity effect of approximately -$10. This signals an opportunity to place shutdown control mechanisms in the reflector tank rather than inside the pressure vessel. The main advantage of this would be to simplify the core internals design and reduce the number of penetrations in the pressure vessel. Shutdown mechanisms in the reflector tank would not have to cross a high-pressure boundary and thus would be simpler and could possibly be less prone to failure. Because so much of the moderation occurs outside the pressure boundary, absorber at the interface between pressure vessel and reflector tank can take advantage of this large re-entering flux.

Shutdown blades in the reflector tank were conceptualized and modeled in the prototypic Cylindrical core described above. Figure 9-6 shows a Serpent rendering of the arrangement of blades surrounding the pressure vessel. The thickness of the blades was 1.5 cm with 0.7 cm thick hafnium inside. The clearance between the outer pressure vessel surface and the inner surface of the blades was 0.5 cm. Table 9-6 contains other relevant parameters of the shutdown blades used for this calculation.

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[a] $\beta_{eff} = 0.00650$, approximately the average value during depletion of prototypic cycle.

[b] The exception to this is likely to be any of the variations calling for a SS304 pressure vessel. The absorption of the stainless steel pressure vessel serves to decouple the core from the reflector tank content.

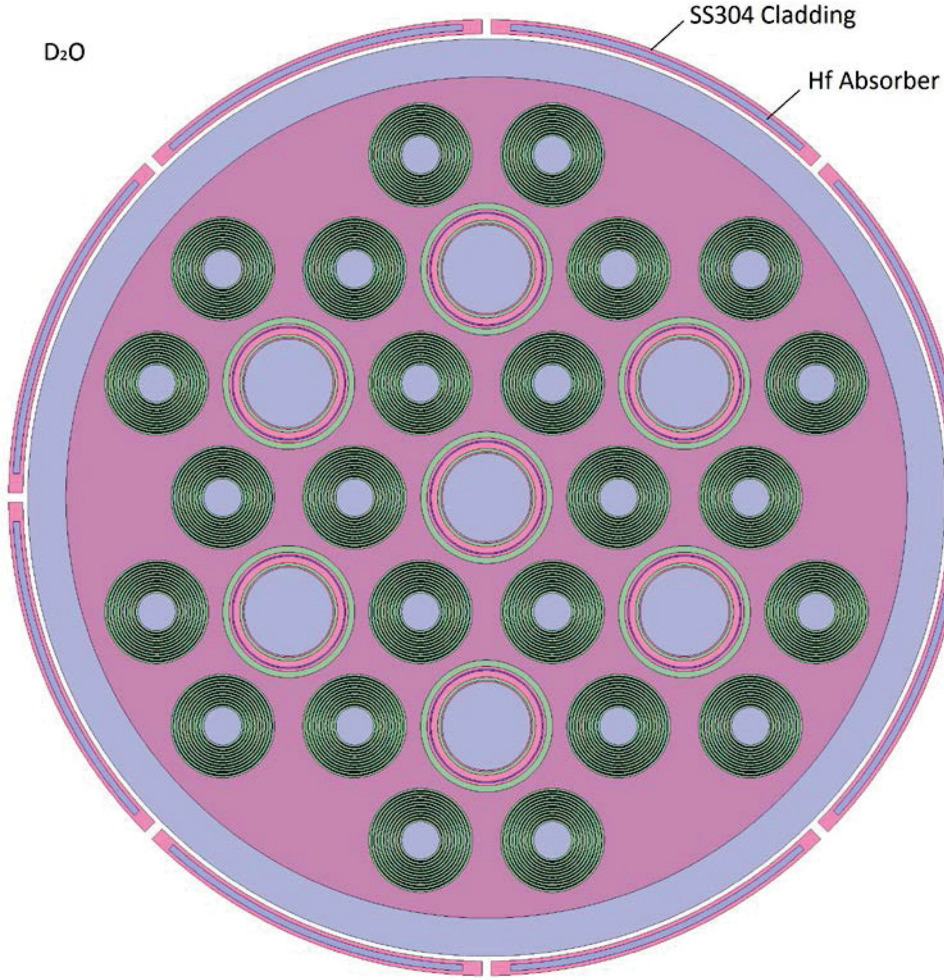

Figure 9-6. View of Cylindrical core with shutdown blades in D_2O reflector tank.

Table 9-6. Parameters of shutdown blades in reflector tank

Parameter	**Value**
Blade Thickness (cm)	1.5
Hafnium Thickness (cm)	0.7
Exclusion length at end of hafnium inside clad (cm)	2.0
Clearance between vessel and blade (cm)	0.5
Distance between ends of blades (cm)	1.0
Axial height of hafnium (cm)	140
Axial height of blades (cm)	144

The value of the inserted control blades described here was approximately -$15, resulting in a core multiplication factor of 0.97. This means that there may be potential for inserting enough reactivity outside the pressure vessel to provide adequate shutdown margin for the core. Recall that this is at BOC with no burnable poisons or shims inserted. With these measures in place, more than adequate shutdown margin may be achievable with a scheme such as this. Various modifications to this concept should be investigated for effectiveness and simplicity.

9.5 Consideration of Structural Support

Until this point, cylindrical fuel assemblies have been modeled as only 10 concentric fuel plates surrounding a central filler or test zone. This does not account for 1) the need for structural support in the form of vertical ribs, nor 2) the possibility that it would be more desirable for these fuel assemblies to be three separate arcuate assemblies spanning 120° each. Reasons for the latter could be fuel management or criticality safety (desire for an inability for a single element to go critical). Though three separate assemblies in each location were not analyzed in this work, Zircaloy ribs were placed into each assembly such that the fuel was divided into three separate arcs, as shown in Figure 9-7. This not only provides some accounting for the loss of fuel meat which would result from these structural components, but gives some estimate of the performance of the alternate three-assembly arrangement.

The resulting reactivity penalty of the addition of the Zircaloy ribs was a reduction in B_1 from 100 days to 80 days. In a 3-batch scheme, this amounts to a cycle length reduction from around 50 days to approximately 40 days. This does not compromise the advantage over ATR with regard to cycle length.

Inside the Zircaloy ribs, cadmium wires could be included to serve as burnable absorbers. This arrangement is similar to what is proposed for the LEU fuel in BR-2 [20,21] and is also shown in Figure 9-7.

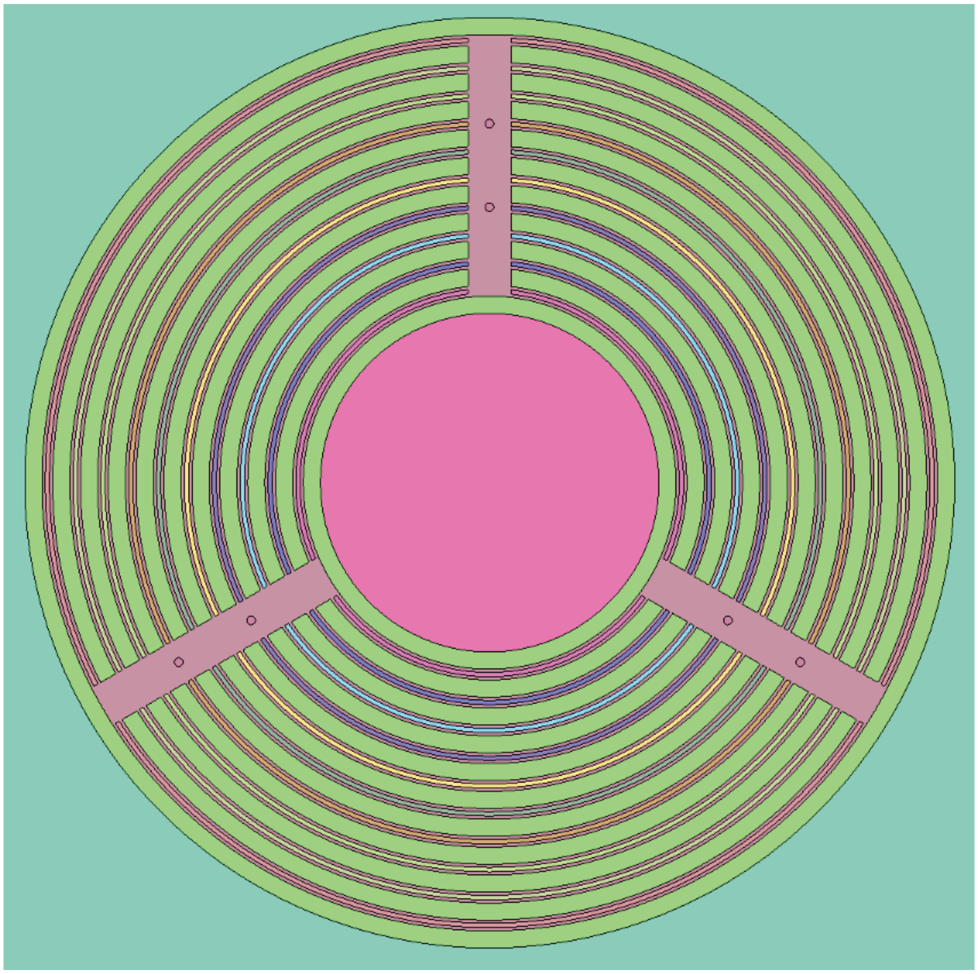

Figure 9-7. Cylindrical fuel element with 0.5 cm thick side plates and cadmium wires.

9.6 Test Loop Void Reactivity

Additional calculations were performed using the sample 3-batch loading from Section **Error! Reference source not found.** in order to provide a preliminary quantification of the test loop void reactivity. The center IPT was selected for this calculation as it is anticipated to have the most positive void reactivity. In the test space, a range of aluminum/water mixtures was evaluated from 10% to 40% water in 10% increments. For each water content value, a nominal case was modeled in Serpent followed by a voided case, which was modeled by simply removing the water from the IPT test space. The fast/thermal flux ratio for each nominal case was also tallied. Table 9-7 shows the results of the void reactivity and flux ratio calculations. These calculations indicated that in order to keep the void reactivity below $1, one would have to limit the water content in the IPT to between 30 and 40% by volume. This provides a range of fast-to-thermal flux ratios from approximately 4 to 2 in this test space. Note that this analysis was performed using coolant water having the same temperature and pressure (and thus density) as the MATRIX cooling water. If the test space contains a specimen being irradiated at PWR conditions, it would then have lower water density. This would allow for more coolant by volume to respect the same void reactivity limit as the higher density case evaluated here. One should also note that this calculation was performed using the aluminum rack with no beryllium content. Changes to the rack content should have significant effects on the loop void reactivity and this should be evaluated as the design progresses.

Table 9-7. Void reactivity results for Cylindrical core with prototypic 3-batch loading.

Nominal H_2O Content (% by vol.)	Void Reactivity ($)	Fast/Thermal Flux Ratio (energy cutoff at 0.625 eV)
10	0.32	4.3
20	0.54	3.0
30	0.86	2.2
40	1.08	1.6

10. Conclusions and Path Forward

This report provides analysis of potential MATRIX reactor concepts that could be deployed in the event the ATR were to shut down permanently. A continuation of FY 2012 work, this report details four main designs, which served as a starting point for work performed in FY 2013, along with a number of variations on these main concepts. Designs were evaluated based on their satisfaction of anticipated customer requirements and the Cylindrical variant was selected for further analysis of options. Because design is at a very early stage, not enough information is known about the concepts for some of the performance metrics to be considered discriminators. Therefore, this downselection should be considered preliminary and the backup alternatives should the other three main designs. Some three-dimensional renderings of the cylindrical MATRIX concept are included in Appendix C of this report.

The baseline Cylindrical MATRIX design is expected to be capable of higher burnup than the ATR (or longer cycle length given a particular batch scheme). The volume of test space in IPTs is larger in MATRIX with comparable magnitude of neutron flux. In addition to the IPTs, the Cylindrical MATRIX concept features test spaces at the centers of fuel assemblies where very high fast flux can be achieved. This magnitude of fast flux is similar to that achieved in the ATR A-positions, however, the available volume having these conditions is greater in the MATRIX design than in the ATR.

Perhaps the most significant advantage of the Cylindrical MATRIX design over the ATR is the large reflector tank located outside the pressure vessel. Constructed from aluminum and located close to the fuel elements, the low parasitic capture pressure vessel facilitates a very high thermal neutron flux in the reflector tank. This concept is borrowed both from some of the original BATR designs and from the Jules Horowitz reactor under construction in France. Nominally, the reflector tank would be an atmospheric pressure (or near-atmospheric) D_2O volume to serve as a high thermal flux test space. In this work, an alternative concept was introduced wherein aluminum cans containing D_2O are placed in an open H_2O pool. From preliminary neutronic studies, this concept appears to perform well.

From the analyses performed in this work, it appears that the Cylindrical MATRIX design can be designed to meet the anticipated needs of the ATR replacement reactor. However, this statement must be qualified by acknowledging that this design is quite immature, and therefore any requirements currently met must be re-evaluated as the design matures. Also, some of the requirements were not strictly met, but are believed to be achievable once features to be added later are designed. An example of this is the 3/1 power tilt. This has not been demonstrated in the simulations, but it is expected that a control scheme can be developed that meets this requirement.

As is always the case after a conceptual design study such as this, there is a multitude of follow-on work that needs to be performed in order to verify the feasibility and understand the performance of the MATRIX reactor. This includes, but is not limited to:

- ***Power Tilt and Shim*** – The NR requirement of being able to tilt the power at a 3/1 ratio is based on lobe power. Though the concept of lobes may not have explicit meaning in the MATRIX reactor, the ability of achieving a 3/1 ratio of neutron flux in two separate IPTs would adhere to the spirit of this requirement. IN this work, tilt was quantified using the ratio of thermal flux between IPT test spaces. A ratio of 2/1 was achieved with fuel loading alone. The design of shims must be such that not excess reactivity can be held down globally, but in a way that facilitates a sufficient power tilt during depletion.
- ***Shutdown*** – Some calculations of rod worth were performed in this work but greater attention should be paid to this feature of the design. The location, geometry, and materials of the shutdown mechanisms should be evaluated in greater detail in future work.
- ***Secondary Missions*** – Detailed analysis of performance in specific secondary missions has not been performed. For example, rate of production of various radioisotopes, and the performances of a beam tube or a neutron radiograph should be analyzed. Figures of merit should be not only the performance of each secondary mission individually, but their effects on the core, if any, along with their interference with one another should be considered as well.
- ***Aluminum Pressure Vessel*** – The neutronic benefits of an aluminum pressure vessel in the MATRIX are substantial. However, the cost and licensing burdens of using an aluminum pressure vessel over a more conventional material should be analyzed. Frequency of replacement compared to other materials should also be evaluated.
- ***Fuel Element Hold-Down in Upflow*** – Hydraulic forces on a fuel element at the flow speeds typical in a high-power reactor such as MATRIX can be greater than the weight of the fuel element. The mechanisms for holding fuel elements in place in upflow should be considered at an early stage. Other items, such as tests and flow restrictors, also must be held in place as their ejection can introduce a positive reactivity effect. This must also be investigated at an early state of analysis.
- ***Transient Testing*** – The MATRIX reactor must be capable of producing transient power excursions analogous to those of PALM cycles in the current ATR. A scheme to achieve this should be devised.
- ***Thermal Hydraulic Analysis*** **–** In the early stages of this work, the decision was made to adopt the power density and plate thickness of the ATR for the MATRIX concepts. This

was done in order to simplify the design space initially, providing some assurance that the steady state thermal hydraulic conditions would be satisfactory. In FY 2012, some thermal hydraulic calculations were performed using RELAP5. This was done, however, with the 100 cm cores initially conceptualized. These need to be repeated with the 120 cm tall cores. The potential for passive decay heat removal should be evaluated as well.

11. Acknowledgements

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12. References

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Appendix A

Sample Serpent Inputs

Cylindrical - Baseline model, single batch depletion

```
% title Cylindrical MATRIX core
% Michael Pope
%
% *****************************************
% ************  Cell Cards  **************
% *****************************************
% *** Fuel Plates *** Universe 1 ****
cell  1  1  al6061  -1       -60  61   %
cell  2  1  h2o     1  -2   -60  61   % Water internal to plate 1
cell  3  1  zirc4   2  -3   -60  61   % Fuel Clad inner Plate  1
cell  4  1  fuel1   3  -4   -60  61   % Fuel Meat Plate  1
cell  5  1  zirc4   4  -5   -60  61   % Fuel Clad outer Plate  1
cell  6  1  h2o     5  -6   -60  61   % Water between Plates 1 and 2
cell  7  1  zirc4   6  -7   -60  61   % Fuel Clad inner Plate  2
cell  8  1  fuel2   7  -8   -60  61   % Fuel Meat Plate  2
cell  9  1  zirc4   8  -9   -60  61   % Fuel Clad outer Plate  2
cell 10  1  h2o     9 -10   -60  61   % Water between Plates 2 and 3
cell 11  1  zirc4   10 -11  -60  61   % Fuel Clad inner Plate  3
cell 12  1  fuel3   11 -12  -60  61   % Fuel Meat Plate  3
cell 13  1  zirc4   12 -13  -60  61   % Fuel Clad outer Plate  3
cell 14  1  h2o     13 -14  -60  61   % Water between Plates 3 and 4
cell 15  1  zirc4   14 -15  -60  61   % Fuel Clad inner Plate  4
cell 16  1  fuel4   15 -16  -60  61   % Fuel Meat Plate  4
cell 17  1  zirc4   16 -17  -60  61   % Fuel Clad outer Plate  4
cell 18  1  h2o     17 -18  -60  61   % Water between Plates 4 and 5
cell 19  1  zirc4   18 -19  -60  61   % Fuel Clad inner Plate  5
cell 20  1  fuel5   19 -20  -60  61   % Fuel Meat Plate  5
cell 21  1  zirc4   20 -21  -60  61   % Fuel Clad outer Plate  5
cell 22  1  h2o     21 -22  -60  61   % Water between Plates 5 and 6
cell 23  1  zirc4   22 -23  -60  61   % Fuel Clad inner Plate  6
cell 24  1  fuel6   23 -24  -60  61   % Fuel Meat Plate  6
cell 25  1  zirc4   24 -25  -60  61   % Fuel Clad outer Plate  6
cell 26  1  h2o     25 -26  -60  61   % Water between Plates 6 and 7
cell 27  1  zirc4   26 -27  -60  61   % Fuel Clad inner Plate  7
cell 28  1  fuel7   27 -28  -60  61   % Fuel Meat Plate  7
cell 29  1  zirc4   28 -29  -60  61   % Fuel Clad outer Plate  7
cell 30  1  h2o     29 -30  -60  61   % Water between Plates 7 and 8
cell 31  1  zirc4   30 -31  -60  61   % Fuel Clad inner Plate  8
cell 32  1  fuel8   31 -32  -60  61   % Fuel Meat Plate  8
cell 33  1  zirc4   32 -33  -60  61   % Fuel Clad outer Plate  8
cell 34  1  h2o     33 -34  -60  61   % Water between Plates 8 and 9
cell 35  1  zirc4   34 -35  -60  61   % Fuel Clad inner Plate  9
cell 36  1  fuel9   35 -36  -60  61   % Fuel Meat Plate  9
cell 37  1  zirc4   36 -37  -60  61   % Fuel Clad outer Plate  9
cell 38  1  h2o     37 -38  -60  61   % Water between Plates 9 and 10
cell 39  1  zirc4   38 -39  -60  61   % Fuel Clad inner Plate  10
cell 40  1  fuel10  39 -40  -60  61   % Fuel Meat Plate  10
cell 41  1  zirc4   40 -41  -60  61   % Fuel Clad outer Plate  10
cell 42  1  h2o     41 -42  -60  61   % Water between Plate 10 rack
cell 43  1  AlRack  42      -60  61   % al6061 rack

%  Upper and lower plates without fuel homogenized
cell  55  1  TopPlat  -42      60 -62  % upper end plates
cell  56  1  BotPlat  -42     -61  63  % lower end plates
%  Upper and lower end boxes homogenized
cell  57  1  TopBox  -42      62 -64   % upper end plate
cell  58  1  BotBox  -42     -63  65   % lower end plate

%  h2o above and below fuel assembly
cell  59  1  h2o     -42     64       % water above fuel assembly above fuel
cell  60  1  h2o     -42     -65      % water below fuel assembly above fuel
cell  61  1  h2o      42     60       % water above fuel assembly outside fuel
cell  62  1  h2o      42     -61      % water below fuel assembly outside fuel

% *** Small Test Location *** Universe 2 ****
cell 120 2  al6061   -110 61 -60       % test space
cell 121 2  al6061   -110 60       % above test space
cell 122 2  al6061   -110 -61      % below test space
cell 123 2  ss304    110  -111     % flow tube
cell 124 2  h2o      111  -112     % return flow
cell 125 2  ss304    112  -113     % pressure tube
cell 126 2  helium   113  -114     % helium annulus
cell 127 2  ss304    114  -115     % insulation jacket
cell 128 2  h2o      115  -116     % water gap
cell 129 2  AlRack   116  -117  -60  61  % baffle
cell 230 2  AlRack   117    -60  61    %  al6061 rack adjacent to test location
cell 228 2  h2o      116    60         %  water above core next to test loc.
```

```
cell 328 2  h2o      116    -61         %  water below core next to test loc.

cell 200 4 AlRack  -201   -60  61       %  large area of al6061.  used for filling lat.
cell 201 4 h2o  -201    60              %  large area of coolant above core
cell 202 4 h2o  -201   -61              %  large area of coolant above core

% ---------------------------------
%  ----------- core map -----------
% ---------------------------------
lat 150  2 0.0 0.0 9 9 13.80
   4 4 4 4 4 4 4 4 4
   4 4 4 4 4 1 1 4 4
   4 4 4 1 1 2 1 1 4
   4 4 1 2 1 1 2 1 4
   4 4 1 1 2 1 1 4 4
   4 1 2 1 1 2 1 4 4
   4 1 1 2 1 1 4 4 4
   4 4 1 1 4 4 4 4 4
   4 4 4 4 4 4 4 4 4
cell 151 0 fill 150 -170  202 -203         % inside pressure vessel
cell 152 0 al6061       170 -171  202 -203  % inside pressure vessel
cell 153 0 d2o  171 -201  202 -203          % d2o tank
%
% ------ Void Outside Core ------
cell 1001 0 outside 201 203         % rest of universe
cell 1002 0 outside 201 -202        % rest of universe
cell 1003 0 outside -201 203        % rest of universe
cell 1004 0 outside -201 -202       % rest of universe
cell 1005 0 outside 201 -203 202    % rest of universe

% ******************************************
% ******** End Of Cell Cards **************
% ******************************************

% ******************************************
% ************ Surface Cards **************
% ******************************************

% *** Fuel Plate Surfaces ****
surf  1 cyl  0.0  0.0   1.97500          % Outside of filler
surf  2 cyl  0.0  0.0   2.17500          % Fuel Cld inner Plate  1
surf  3 cyl  0.0  0.0   2.21250          % Fuel Mt inner Plate  1
surf  4 cyl  0.0  0.0   2.26250          % Fuel Mt outer  Plate  1
surf  5 cyl  0.0  0.0   2.30000          % Fuel Cld outer  Plate  1
surf  6 cyl  0.0  0.0   2.50000          % Fuel Cld inner Plate  2
surf  7 cyl  0.0  0.0   2.53750          % Fuel Mt inner Plate  2
surf  8 cyl  0.0  0.0   2.58750          % Fuel Mt outer  Plate  2
surf  9 cyl  0.0  0.0   2.62500          % Fuel Cld outer  Plate  2
surf 10 cyl  0.0  0.0   2.82500          % Fuel Cld inner Plate  3
surf 11 cyl  0.0  0.0   2.86250          % Fuel Mt inner Plate  3
surf 12 cyl  0.0  0.0   2.91250          % Fuel Mt outer  Plate  3
surf 13 cyl  0.0  0.0   2.95000          % Fuel Cld outer  Plate  3
surf 14 cyl  0.0  0.0   3.15000          % Fuel Cld inner Plate  4
surf 15 cyl  0.0  0.0   3.18750          % Fuel Mt inner Plate  4
surf 16 cyl  0.0  0.0   3.23750          % Fuel Mt outer  Plate  4
surf 17 cyl  0.0  0.0   3.27500          % Fuel Cld outer  Plate  4
surf 18 cyl  0.0  0.0   3.47500          % Fuel Cld inner Plate  5
surf 19 cyl  0.0  0.0   3.51250          % Fuel Mt inner Plate  5
surf 20 cyl  0.0  0.0   3.56250          % Fuel Mt outer  Plate  5
surf 21 cyl  0.0  0.0   3.60000          % Fuel Cld outer  Plate  5
surf 22 cyl  0.0  0.0   3.80000          % Fuel Cld inner Plate  6
surf 23 cyl  0.0  0.0   3.83750          % Fuel Mt inner Plate  6
surf 24 cyl  0.0  0.0   3.88750          % Fuel Mt outer  Plate 6
surf 25 cyl  0.0  0.0   3.92500          % Fuel Cld outer  Plate  6
surf 26 cyl  0.0  0.0   4.12500          % Fuel Cld inner Plate  7
surf 27 cyl  0.0  0.0   4.16250          % Fuel Mt inner Plate  7
surf 28 cyl  0.0  0.0   4.21250          % Fuel Mt outer  Plate  7
surf 29 cyl  0.0  0.0   4.25000          % Fuel Cld outer  Plate  7
surf 30 cyl  0.0  0.0   4.45000          % Fuel Cld inner Plate  8
surf 31 cyl  0.0  0.0   4.48750          % Fuel Mt inner Plate  8
surf 32 cyl  0.0  0.0   4.53750          % Fuel Mt outer  Plate  8
surf 33 cyl  0.0  0.0   4.57500          % Fuel Cld outer  Plate  8
surf 34 cyl  0.0  0.0   4.77500          % Fuel Cld inner Plate  9
surf 35 cyl  0.0  0.0   4.81250          % Fuel Mt inner Plate  9
surf 36 cyl  0.0  0.0   4.86250          % Fuel Mt outer  Plate  9
surf 37 cyl  0.0  0.0   4.90000          % Fuel Cld outer  Plate  9
surf 38 cyl  0.0  0.0   5.10000          % Fuel Cld inner Plate 10
surf 39 cyl  0.0  0.0   5.13750          % Fuel Mt inner Plate 10
surf 40 cyl  0.0  0.0   5.18750          % Fuel Mt outer  Plate 10
surf 41 cyl  0.0  0.0   5.22500          % Fuel Cld outer  Plate 10
```

```
surf 42 cyl  0.0  0.0  5.4250  % outer boundary of outermost channel
%
% *** Top and Bottom End Plates ***
surf 60  pz  60.     % Top of fuel meat
surf 61  pz -60.     % Bottom of fuel meat
surf 62  pz  62.     % Top of plates
surf 63  pz -62.     % Bottom of plates
surf 64  pz  82.     % Top of Top End Box
surf 65  pz -82.     % Bottom of Bottom End Box

% *** hexagonal surface defining lattice ***
% surf 65 hexxc 0.0 0.0 12.355

%  *** Small Test Space Surfaces ***
surf 110 cyl  0.0  0.0  4.645  % Outer boundary of test space
surf 111 cyl  0.0  0.0  4.810  % Outer surface of flow tube
surf 112 cyl  0.0  0.0  5.130  % Inner surface of pressure tube
surf 113 cyl  0.0  0.0  5.800  % Outer surface of pressure tube
surf 114 cyl  0.0  0.0  5.950  % Inner surface of insulation jacket
surf 115 cyl  0.0  0.0  6.250  % Outer surface of insulation jacket
surf 116 cyl  0.0  0.0  6.900  % Inner surface of Al baffle
surf 117 cyl  0.0  0.0  7.500  % Outer surface of Al baffle

% *** Al rack boundary reflector boundary ***
surf 170  cyl 0.0 0.0 44.    %
surf 171  cyl 0.0 0.0 48.    %

% *** D2O tank outer boundary ***
surf 201  cyl 0.0 0.0 150.0   %

surf 202 pz -150.
surf 203 pz  150.

% ******************************************
% ********  End Of Surface Cards **********
% ******************************************

% vacuum boundary
set bc 1

% source entropy mesh
set entr [4 4 4 -150. 150. -150. 150. -50. 50. ]

% cross section library path
set acelib "/home/popema/SERPENT/SERPENT/data/xsdata_combined"
set declib "/home/popema/SERPENT/SERPENT/data/sss_endfb7.dec"
set nfylib "/home/popema/SERPENT/SERPENT/data/sss_endfb7.nfy"

mesh 3 1000 1000 0 -150 150 -150 150

set power 250.E06

set opti 1
set pop 100000 1000 5 1.2
% ------- Material Cards --------------------------------------------
mat fuel1 4.9186E-02 tmp 433. vol  2024. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel2 4.9186E-02 tmp 433. vol  2318. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel3 4.9186E-02 tmp 433. vol  2613. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel4 4.9186E-02 tmp 433. vol  2907. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel5 4.9186E-02 tmp 433. vol  3201. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel6 4.9186E-02 tmp 433. vol  3495. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel7  4.9186E-02 tmp 433. vol  3789. burn 1
```

```
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel8  4.9186E-02 tmp 433. vol  4083. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel9  4.9186E-02 tmp 433. vol  4377. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel10 4.9186E-02 tmp 433. vol  4671. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
% ------ H2O Coolant ------
% T=70C, P=2.3 MPa, rho=0.979 g/cc
mat h2o  9.818E-02       moder h2o 1001
     1001.03c  6.545E-02
     8016.03c  3.273E-02
% ------ D2O ------
mat d2o 9.986E-02     moder d2o 1002
     1002.03c  6.657E-02
     8016.03c  3.329E-02
% ------ Al-6061 ------
mat al6061 -2.715       % Al-6061 density 2.715 g/cc
   14000.03c  -0.7   %      0.7   % Si
   26000.03c  -0.6   %      0.60  % Fe
   29000.03c  -0.22  %      0.22  % Cu
   25055.03c  -0.08  %      0.08  % Mn
   12000.03c  -1.0   %      1.0   % Mg
   24000.03c  -0.2   %      0.1   % Cr
   30000.03c  -0.08  %      0.08  % Zn
   22000.03c  -0.03  %      0.03  % Ti
   13027.03c  -97.09 %      97.09 % Al
% ------ Al-6061 Rack / part water ------
mat AlRack    6.22E-02       % 5% water
   14000.03c  3.87E-04 %
   26000.03c  1.67E-04 %
   29000.03c  5.38E-05 %
   25055.03c  2.26E-05 %
   12000.03c  6.39E-04 %
   24000.03c  5.97E-05 %
   30000.03c  1.90E-05 %
   22000.03c  9.73E-06 %
   13027.03c  5.59E-02 %
    1001.03c  3.27E-03
    8016.03c  1.64E-03
% ------ Beryllium ------
% assumed 6.3% by volume H2O
mat be9  1.2188E-01  moder be 4009 moder h2o 1001  % moder be
   4009.03c  1.157E-01
   1001.03c  4.120E-03
   8016.03c  2.060E-03
mat AlBe10  7.09E-02  moder be 4009 moder h2o 1001  % moder be
       4009.03c  1.616E-02
  13027.03c  4.859E-02
   1001.03c  4.120E-03
   8016.03c  2.060E-03
mat AlBe20  7.85E-02  moder be 4009 moder h2o 1001  % moder be
       4009.03c  3.097E-02
  13027.03c  4.137E-02
   1001.03c  4.120E-03
   8016.03c  2.060E-03
mat AlBe30  8.55E-02  moder be 4009 moder h2o 1001  % moder be
       4009.03c  4.457E-02
  13027.03c  3.474E-02
   1001.03c  4.120E-03
   8016.03c  2.060E-03
mat AlBe40  9.19E-02  moder be 4009 moder h2o 1001  % moder be
       4009.03c  5.712E-02
  13027.03c  2.862E-02
   1001.03c  4.120E-03
   8016.03c  2.060E-03
mat AlBe60  1.03E-01  moder be 4009 moder h2o 1001  % moder be
       4009.03c  7.951E-02
  13027.03c  1.771E-02
   1001.03c  4.120E-03
   8016.03c  2.060E-03
mat AlBe80  1.13E-01  moder be 4009 moder h2o 1001  % moder be
```

```
      4009.03c  9.889E-02
   13027.03c  8.258E-03
    1001.03c  4.120E-03
    8016.03c  2.060E-03
% ------  SS 304   ------
% Fe-0.08C-2.0Mn-0.045P-0.03S-1.0Si-19Cr-9Ni
mat ss304   -8.0       % ss 304 8g/cc
     6000.03c  -0.08   %     0.08   % C
    25055.03c  -2.0    %     2.0    % Mn
    15031.03c  -0.045  %     0.045  % P
    16000.03c  -0.03   %     0.03   % S
    14000.03c  -0.75   %     0.75   % Si
    24000.03c  -19.    %     19.    % Cr
    28000.03c  -9.25   %     9.25   % Ni
     7014.03c  -0.05   %     0.05   % N
    26000.03c  -68.795 %    68.795  % Fe
% ------ Helium Coolant ------
mat helium 0.0007
      2004.03c  7.0000E-04
% ---- Al/H2O 50/50 mix in test spaces -----
mat AlH2Omix  7.929E-02  moder h2o 1001
      1001.03c  3.270E-02
      8016.03c  1.635E-02
     13027.03c  3.024E-02
% ----- Zircalloy4 -------
mat zirc4  -6.56     tmp 398.
     40000.03c  -98.23   %     98.23 % Zr
     50000.03c  -1.45    %     1.45  % Sn
     26000.03c  -0.21    %     0.21  % Fe
     24000.03c  -0.10    %     0.10  % Cr
     72000.03c  -0.01    %     0.01  % Hf
% ----- Top End Box -------
mix TopBox
  zirc4 0.20
  h2o   0.80
% ----- Bottom End Box -------
mix BotBox
  zirc4 0.20
  h2o   0.80
% ----- Top plate no fuel -------
mix TopPlat
  zirc4 0.39
  h2o   0.61
% ----- Bottom plate no fuel -------
mix BotPlat
  zirc4 0.39
  h2o   0.61

therm h2o lwtr.01t
therm d2o hwtr.01t
therm be  be.01t

% Depletion Steps
dep daytot
0.1 0.5 1.0 2.0 3.5 5.0 10.0 15. 20. 30. 40. 50. 60. 80. 100. 120. 140. 160.

% TALLIES
% Flux 1MeV cutoff in  test zones
det CTrap dc 120 du 2 dv 432. de 1MeV dx -3.   3.   1  dy  -3.   3.   1  dz -60. 60. 10
det PTrap dc 120 du 2 dv 432. de 1MeV dx -3.   3.   1  dy 20.9  26.9  1  dz -60. 60. 10
det Fassy dc 1   du 1  dv 48. de 1MeV dx 5.9   7.9  1  dy 10.95 12.95 1  dz -60. 60. 10
% Flux broken down into 3.
det FTref1 dc 153  du 0  dv 192. de 1MeV dx  55.4  59.4 1 dy 21.7 25.7 1  dz -60. 60. 10
det FTref2 dc 153  du 0  dv 192. de 1MeV dx  73.8  77.8 1 dy 29.4 33.4 1  dz -60. 60. 10
det FTref3 dc 153  du 0  dv 192. de 1MeV dx  92.3  96.3 1 dy 37.0 41.0 1  dz -60. 60. 10
det FTref4 dc 153  du 0  dv 192. de 1MeV dx 110.8 114.8 1 dy 44.7 48.7 1  dz -60. 60. 10

ene 1MeV   1 1.0E-15 0.625E-06 1.0  20.
```

Square – Baseline model, single-batch depletion

```
% title Initial Square Core
% Michael Pope
%
% ******************************************
% ************   Cell Cards  **************
% ******************************************

cell 99 1 zirc4 190 -191  -60  61             % Fuel Assembly Can

cell 100  1  h2o   -190  -100  -60  61
cell 101  1  zirc4  100    -101  -190 -60  61
cell 102  1  fuel   101    -102  -190 -60  61  % fuel plate 1
cell 103  1  zirc4  102    -103  -190 -60  61
cell 104  1  h2o    103    -104  -190 -60  61
cell 105  1  zirc4  104    -105  -190 -60  61
cell 106  1  fuel   105    -106  -190 -60  61  % fuel plate 2
cell 107  1  zirc4  106    -107  -190 -60  61
cell 108  1  h2o    107    -108  -190 -60  61
cell 109  1  zirc4  108    -109  -190 -60  61
cell 110  1  fuel   109    -110  -190 -60  61  % fuel plate 3
cell 111  1  zirc4  110    -111  -190 -60  61
cell 112  1  h2o    111    -112  -190 -60  61
cell 113  1  zirc4  112    -113  -190 -60  61
cell 114  1  fuel   113    -114  -190 -60  61  % fuel plate 4
cell 115  1  zirc4  114    -115  -190 -60  61
cell 116  1  h2o    115    -116  -190 -60  61
cell 117  1  zirc4  116    -117  -190 -60  61
cell 118  1  fuel   117    -118  -190 -60  61  % fuel plate 5
cell 119  1  zirc4  118    -119  -190 -60  61
cell 120  1  h2o    119    -120  -190 -60  61
cell 121  1  zirc4  120    -121  -190 -60  61
cell 122  1  fuel   121    -122  -190 -60  61  % fuel plate 6
cell 123  1  zirc4  122    -123  -190 -60  61
cell 124  1  h2o    123    -124  -190 -60  61
cell 125  1  zirc4  124    -125  -190 -60  61
cell 126  1  fuel   125    -126  -190 -60  61  % fuel plate 7
cell 127  1  zirc4  126    -127  -190 -60  61
cell 128  1  h2o    127    -128  -190 -60  61
cell 129  1  zirc4  128    -129  -190 -60  61
cell 130  1  fuel   129    -130  -190 -60  61  % fuel plate 8
cell 131  1  zirc4  130    -131  -190 -60  61
cell 132  1  h2o    131    -132  -190 -60  61
cell 133  1  zirc4  132    -133  -190 -60  61
cell 134  1  fuel   133    -134  -190 -60  61  % fuel plate 9
cell 135  1  zirc4  134    -135  -190 -60  61
cell 136  1  h2o    135    -136  -190 -60  61
cell 137  1  zirc4  136    -137  -190 -60  61
cell 138  1  fuel   137    -138  -190 -60  61  % fuel plate 10
cell 139  1  zirc4  138    -139  -190 -60  61
cell 140  1  h2o    139    -140  -190 -60  61
cell 141  1  zirc4  140    -141  -190 -60  61
cell 142  1  fuel   141    -142  -190 -60  61  % fuel plate 11
cell 143  1  zirc4  142    -143  -190 -60  61
cell 144  1  h2o    143    -144  -190 -60  61
cell 145  1  zirc4  144    -145  -190 -60  61
cell 146  1  fuel   145    -146  -190 -60  61  % fuel plate 12
cell 147  1  zirc4  146    -147  -190 -60  61
cell 148  1  h2o    147    -148  -190 -60  61
cell 149  1  zirc4  148    -149  -190 -60  61
cell 150  1  fuel   149    -150  -190 -60  61  % fuel plate 13
cell 151  1  zirc4  150    -151  -190 -60  61
cell 152  1  h2o    151    -152  -190 -60  61
cell 153  1  zirc4  152    -153  -190 -60  61
cell 154  1  fuel   153    -154  -190 -60  61  % fuel plate 14
cell 155  1  zirc4  154    -155  -190 -60  61
cell 156  1  h2o    155    -156  -190 -60  61
cell 157  1  zirc4  156    -157  -190 -60  61
cell 158  1  fuel   157    -158  -190 -60  61  % fuel plate 15
cell 159  1  zirc4  158    -159  -190 -60  61
cell 160  1  h2o    159    -160  -190 -60  61
cell 161  1  zirc4  160    -161  -190 -60  61
cell 162  1  fuel   161    -162  -190 -60  61  % fuel plate 16
cell 163  1  zirc4  162    -163  -190 -60  61
cell 164  1  h2o    163    -164  -190 -60  61
cell 165  1  zirc4  164    -165  -190 -60  61
cell 166  1  fuel   165    -166  -190 -60  61  % fuel plate 17
cell 167  1  zirc4  166    -167  -190 -60  61
```

```
cell 168  1  h2o    167    -168  -190 -60  61
cell 169  1  zirc4  168    -169  -190 -60  61
cell 170  1  fuel   169    -170  -190 -60  61  % fuel plate 18
cell 171  1  zirc4  170    -171  -190 -60  61
cell 172  1  h2o    171    -172  -190 -60  61
cell 173  1  zirc4  172    -173  -190 -60  61
cell 174  1  fuel   173    -174  -190 -60  61  % fuel plate 19
cell 175  1  zirc4  174    -175  -190 -60  61
cell 176  1  h2o    175    -176  -190 -60  61
cell 177  1  zirc4  176    -177  -190 -60  61
cell 178  1  fuel   177    -178  -190 -60  61  % fuel plate 20
cell 179  1  zirc4  178    -179  -190 -60  61
cell 180  1  h2o    179    -180  -190 -60  61
cell 181  1  zirc4  180    -181  -190 -60  61
cell 182  1  fuel   181    -182  -190 -60  61   % fuel plate 21
cell 183  1  zirc4  182    -183  -190 -60  61
cell 184  1  h2o    183    -190 -60  61

%  Upper and lower plates without fuel homogenized
cell 185  1  TopPlat   -191       60 -62    % upper end plates
cell 186  1  BotPlat   -191      -61  63    % lower end plates
%  Upper and lower end boxes homogenized
cell 187  1  TopBox   -191       62 -64    % upper end plate
cell 188  1  BotBox   -191      -63  65    % lower end plate

cell 189  1  h2o    -191   64  % water above assy
cell 190  1  h2o    -191  -65  % water below assy

% ***  Test location *** Universe 3 ****
cell 300 3 AlRack  -191 61 -60
cell 301 3 h2o  -191 60
cell 302 3 h2o  -191 -61

% ***  Control Rod location *** Universe 4 ****
cell 400 4 AlRack  -191 61 -60
cell 401 4 h2o  -191 60
cell 402 4 h2o  -191 -61

% ***  Rack Fill *** Universe 5 ****
cell 500 5 AlRack  -191 61 -60
cell 501 5 h2o  -191 60
cell 502 5 h2o  -191 -61

% ---------------------------------
%  ----------- core map -----------
% ---------------------------------
lat 10 1 0 0 14 14 7.5
5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 1 5 5 5 5 5 5 5
5 5 5 5 5 1 5 5 1 5 5 5 5 5
5 5 5 1 5 1 5 5 1 5 1 5 5 5
5 5 1 5 5 5 5 1 5 5 5 1 5 5
5 5 1 5 5 1 5 5 1 5 5 1 5 5
5 5 5 1 5 1 5 5 5 1 5 5 1 5
5 1 5 5 1 5 5 5 1 5 1 5 5 5
5 5 1 5 5 1 5 5 1 5 5 1 5 5
5 5 1 5 5 5 1 5 5 5 5 1 5 5
5 5 5 1 5 1 5 5 1 5 1 5 5 5
5 5 5 5 5 1 5 5 1 5 5 5 5 5
5 5 5 5 5 5 5 1 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5

cell 851 0 fill 10 217 227 237 247 257 267 277 -1000  802 -803  % inside pressure vessel
cell 852 0 al6061   1000 -1001  802 -803  %  pressure vessel
cell 853 0 d2o  1001 -801  802 -803  % d2o tank

% ***  Center In-Pile Tube  ****
cell 1220 0  al6061  -210    61 -60           % test space
cell 1221 0  al6061  -210    60 -803          % above test space
cell 1222 0  al6061  -210   -61  802          % below test space
cell 1223 0  ss304    210  -211  802 -803     % flow tube
cell 1224 0  h2o      211  -212  802 -803     % return flow
cell 1225 0  ss304    212  -213  802 -803     % pressure tube
cell 1226 0  helium   213  -214  802 -803     % helium annulus
cell 1227 0  ss304    214  -215  802 -803     % insulation jacket
cell 1228 0  h2o      215  -216  802 -803     % water gap
cell 1229 0  AlRack   216  -217  -60   61     % baffle - extends to 15cm x 15cm square
cell 1231 0  h2o      216  -217   60 -803     %  water above core next to test loc.
cell 1232 0  h2o      216  -217  -61  802     %  water below core next to test loc.
% ***  NE In-Pile Tube  ****
```

```
cell 2220 0  al6061  -220    61 -60           % test space
cell 2221 0  al6061  -220    60 -803          % above test space
cell 2222 0  al6061  -220   -61  802          % below test space
cell 2223 0  ss304    220  -221  802 -803     % flow tube
cell 2224 0  h2o      221  -222  802 -803     % return flow
cell 2225 0  ss304    222  -223  802 -803     % pressure tube
cell 2226 0  helium   223  -224  802 -803     % helium annulus
cell 2227 0  ss304    224  -225  802 -803     % insulation jacket
cell 2228 0  h2o      225  -226  802 -803     % water gap
cell 2229 0  AlRack   226  -227  -60   61     % baffle - extends to 15cm x 15cm square
cell 2231 0  h2o      226  -227   60 -803     %  water above core next to test loc.
cell 2232 0  h2o      226  -227  -61  802     %  water below core next to test loc.
% ***  N In-Pile Tube  ****
cell 3220 0  al6061  -230    61  -60          % test space
cell 3221 0  al6061  -230    60 -803          % above test space
cell 3222 0  al6061  -230   -61  802          % below test space
cell 3223 0  ss304    230  -231  802 -803     % flow tube
cell 3224 0  h2o      231  -232  802 -803     % return flow
cell 3225 0  ss304    232  -233  802 -803     % pressure tube
cell 3226 0  helium   233  -234  802 -803     % helium annulus
cell 3227 0  ss304    234  -235  802 -803     % insulation jacket
cell 3228 0  h2o      235  -236  802 -803     % water gap
cell 3229 0  AlRack   236  -237  -60  61      % baffle - extends to 15cm x 15cm square
cell 3231 0  h2o      236  -237   60 -803     %  water above core next to test loc.
cell 3232 0  h2o      236  -237  -61  802     %  water below core next to test loc.
% ***  NW In-Pile Tube  ****
cell 4220 0  al6061  -240    61  -60          % test space
cell 4221 0  al6061  -240    60 -803          % above test space
cell 4222 0  al6061  -240   -61  802          % below test space
cell 4223 0  ss304    240  -241  802 -803     % flow tube
cell 4224 0  h2o      241  -242  802 -803     % return flow
cell 4225 0  ss304    242  -243  802 -803     % pressure tube
cell 4226 0  helium   243  -244  802 -803     % helium annulus
cell 4227 0  ss304    244  -245  802 -803     % insulation jacket
cell 4228 0  h2o      245  -246  802 -803     % water gap
cell 4229 0  AlRack   246  -247  -60   61     % baffle - extends to 15cm x 15cm square
cell 4231 0  h2o      246  -247   60 -803     %  water above core next to test loc.
cell 4232 0  h2o      246  -247  -61  802     %  water below core next to test loc.
% ***  SW In-Pile Tube  ****
cell 5220 0  al6061  -250    61  -60          % test space
cell 5221 0  al6061  -250    60 -803          % above test space
cell 5222 0  al6061  -250   -61  802          % below test space
cell 5223 0  ss304    250  -251  802 -803     % flow tube
cell 5224 0  h2o      251  -252  802 -803     % return flow
cell 5225 0  ss304    252  -253  802 -803     % pressure tube
cell 5226 0  helium   253  -254  802 -803     % helium annulus
cell 5227 0  ss304    254  -255  802 -803     % insulation jacket
cell 5228 0  h2o      255  -256  802 -803     % water gap
cell 5229 0  AlRack   256  -257  -60   61     % baffle - extends to 15cm x 15cm square
cell 5231 0  h2o      256  -257   60 -803     %  water above core next to test loc.
cell 5232 0  h2o      256  -257  -61  802     %  water below core next to test loc.
% ***  S In-Pile Tube  ****
cell 6220 0  al6061  -260    61  -60          % test space
cell 6221 0  al6061  -260    60  -803         % above test space
cell 6222 0  al6061  -260   -61  802          % below test space
cell 6223 0  ss304    260  -261  802 -803     % flow tube
cell 6224 0  h2o      261  -262  802 -803     % return flow
cell 6225 0  ss304    262  -263  802 -803     % pressure tube
cell 6226 0  helium   263  -264  802 -803     % helium annulus
cell 6227 0  ss304    264  -265  802 -803     % insulation jacket
cell 6228 0  h2o      265  -266  802 -803     % water gap
cell 6229 0  AlRack   266  -267  -60   61     % baffle - extends to 15cm x 15cm square
cell 6231 0  h2o      266  -267   60 -803     %  water above core next to test loc.
cell 6232 0  h2o      266  -267  -61  802     %  water below core next to test loc.
% ***  SE In-Pile Tube  ****
cell 7220 0  al6061  -270    61   -60         % test space
cell 7221 0  al6061  -270    60  -803         % above test space
cell 7222 0  al6061  -270   -61   802         % below test space
cell 7223 0  ss304    270  -271   802 -803    % flow tube
cell 7224 0  h2o      271  -272   802 -803    % return flow
cell 7225 0  ss304    272  -273   802 -803    % pressure tube
cell 7226 0  helium   273  -274   802 -803    % helium annulus
cell 7227 0  ss304    274  -275   802 -803    % insulation jacket
cell 7228 0  h2o      275  -276   802 -803    % water gap
cell 7229 0  AlRack   276  -277   -60   61    % baffle - extends to 15cm x 15cm square
cell 7231 0  h2o      276  -277    60 -803    %  water above core next to test loc.
cell 7232 0  h2o      276  -277   -61  802    %  water below core next to test loc.

% ------ Void Outside Core ------
cell 1001 0 outside 801 803 % rest of universe
```

```
cell 1002 0 outside 801 -802 % rest of universe
cell 1003 0 outside -801 803 % rest of universe
cell 1004 0 outside -801 -802 % rest of universe
cell 1005 0 outside 801 -803 802 % rest of universe

%%%%%%%%%%%
% SURFACES
%%%%%%%%%%%

% FUEL PLATE SURFACES
surf  100 px -3.3125
surf  101 px -3.2750
surf  102 px -3.2250
surf  103 px -3.1875
surf  104 px -2.9875
surf  105 px -2.9500
surf  106 px -2.9000
surf  107 px -2.8625
surf  108 px -2.6625
surf  109 px -2.6250
surf  110 px -2.5750
surf  111 px -2.5375
surf  112 px -2.3375
surf  113 px -2.3000
surf  114 px -2.2500
surf  115 px -2.2125
surf  116 px -2.0125
surf  117 px -1.9750
surf  118 px -1.9250
surf  119 px -1.8875
surf  120 px -1.6875
surf  121 px -1.6500
surf  122 px -1.6000
surf  123 px -1.5625
surf  124 px -1.3625
surf  125 px -1.3250
surf  126 px -1.2750
surf  127 px -1.2375
surf  128 px -1.0375
surf  129 px -1.000
surf  130 px -0.9500
surf  131 px -0.9125
surf  132 px -0.7125
surf  133 px -0.6750
surf  134 px -0.6250
surf  135 px -0.5875
surf  136 px -0.3875
surf  137 px -0.3500
surf  138 px -0.3000
surf  139 px -0.2625
surf  140 px -0.0625
surf  141 px -0.0250
surf  142 px 0.0250
surf  143 px 0.0625
surf  144 px 0.2625
surf  145 px 0.3000
surf  146 px 0.3500
surf  147 px 0.3875
surf  148 px 0.5875
surf  149 px 0.6250
surf  150 px 0.6750
surf  151 px 0.7125
surf  152 px 0.9125
surf  153 px 0.9500
surf  154 px 1.000
surf  155 px 1.0375
surf  156 px 1.2375
surf  157 px 1.2750
surf  158 px 1.3250
surf  159 px 1.3625
surf  160 px 1.5625
surf  161 px 1.6000
surf  162 px 1.6500
surf  163 px 1.6875
surf  164 px 1.8875
surf  165 px 1.9250
surf  166 px 1.9750
surf  167 px 2.0125
surf  168 px 2.2125
surf  169 px 2.2500
```

```
surf  170 px 2.3000
surf  171 px 2.3375
surf  172 px 2.5375
surf  173 px 2.5750
surf  174 px 2.6250
surf  175 px 2.6625
surf  176 px 2.8625
surf  177 px 2.9000
surf  178 px 2.9500
surf  179 px 2.9875
surf  180 px 3.1875
surf  181 px 3.2250
surf  182 px 3.2750
surf  183 px 3.3125

surf  190 sqc  0  0  3.5125
surf  191 sqc  0  0  3.75

%  ***  Center Space Surfaces ***
surf 210 cyl  0.0  0.0. 4.645     % Outer boundary of test space
surf 211 cyl  0.0  0.0  4.810     % Outer surface of flow tube
surf 212 cyl  0.0  0.0  5.130     % Inner surface of pressure tube
surf 213 cyl  0.0  0.0  5.800     % Outer surface of pressure tube
surf 214 cyl  0.0  0.0  5.950     % Inner surface of insulation jacket
surf 215 cyl  0.0  0.0  6.250     % Outer surface of insulation jacket
surf 216 cyl  0.0  0.0  6.900     % Inner surface of Al baffle
surf 217 sqc  0.0  0.0  7.500     % Square Outer surface of Al baffle
%  ***  NE Space Surfaces ***
surf 220 cyl  22.5   15.  4.645   % Outer boundary of test space
surf 221 cyl  22.5   15.  4.810   % Outer surface of flow tube
surf 222 cyl  22.5   15.  5.130   % Inner surface of pressure tube
surf 223 cyl  22.5   15.  5.800   % Outer surface of pressure tube
surf 224 cyl  22.5   15.  5.950   % Inner surface of insulation jacket
surf 225 cyl  22.5   15.  6.250   % Outer surface of insulation jacket
surf 226 cyl  22.5   15.  6.900   % Inner surface of Al baffle
surf 227 sqc  22.5   15.  7.500   % Square Outer surface of Al baffle
%  ***  N  Space Surfaces ***
surf 230 cyl  0.0  30.0  4.645    % Outer boundary of test space
surf 231 cyl  0.0  30.0  4.810    % Outer surface of flow tube
surf 232 cyl  0.0  30.0  5.130    % Inner surface of pressure tube
surf 233 cyl  0.0  30.0  5.800    % Outer surface of pressure tube
surf 234 cyl  0.0  30.0  5.950    % Inner surface of insulation jacket
surf 235 cyl  0.0  30.0  6.250    % Outer surface of insulation jacket
surf 236 cyl  0.0  30.0  6.900    % Inner surface of Al baffle
surf 237 sqc  0.0  30.0  7.500    % Square Outer surface of Al baffle
%  ***  NW Space Surfaces ***
surf 240 cyl  -22.5   15.  4.645  % Outer boundary of test space
surf 241 cyl  -22.5   15.  4.810  % Outer surface of flow tube
surf 242 cyl  -22.5   15.  5.130  % Inner surface of pressure tube
surf 243 cyl  -22.5   15.  5.800  % Outer surface of pressure tube
surf 244 cyl  -22.5   15.  5.950  % Inner surface of insulation jacket
surf 245 cyl  -22.5   15.  6.250  % Outer surface of insulation jacket
surf 246 cyl  -22.5   15.  6.900  % Inner surface of Al baffle
surf 247 sqc  -22.5   15.  7.500  % Square Outer surface of Al baffle
%  ***  SW Space Surfaces ***
surf 250 cyl  -22.5  -15.  4.645  % Outer boundary of test space
surf 251 cyl  -22.5  -15.  4.810  % Outer surface of flow tube
surf 252 cyl  -22.5  -15.  5.130  % Inner surface of pressure tube
surf 253 cyl  -22.5  -15.  5.800  % Outer surface of pressure tube
surf 254 cyl  -22.5  -15.  5.950  % Inner surface of insulation jacket
surf 255 cyl  -22.5  -15.  6.250  % Outer surface of insulation jacket
surf 256 cyl  -22.5  -15.  6.900  % Inner surface of Al baffle
surf 257 sqc  -22.5  -15.  7.500  % Square Outer surface of Al baffle
%  ***  S Space Surfaces ***
surf 260 cyl  0.0  -30.0  4.645   % Outer boundary of test space
surf 261 cyl  0.0  -30.0  4.810   % Outer surface of flow tube
surf 262 cyl  0.0  -30.0  5.130   % Inner surface of pressure tube
surf 263 cyl  0.0  -30.0  5.800   % Outer surface of pressure tube
surf 264 cyl  0.0  -30.0  5.950   % Inner surface of insulation jacket
surf 265 cyl  0.0  -30.0  6.250   % Outer surface of insulation jacket
surf 266 cyl  0.0  -30.0  6.900   % Inner surface of Al baffle
surf 267 sqc  0.0  -30.0  7.500   % Square Outer surface of Al baffle
%  ***  SE Space Surfaces ***
surf 270 cyl  22.5   -15.  4.645  % Outer boundary of test space
surf 271 cyl  22.5   -15.  4.810  % Outer surface of flow tube
surf 272 cyl  22.5   -15.  5.130  % Inner surface of pressure tube
surf 273 cyl  22.5   -15.  5.800  % Outer surface of pressure tube
surf 274 cyl  22.5   -15.  5.950  % Inner surface of insulation jacket
surf 275 cyl  22.5   -15.  6.250  % Outer surface of insulation jacket
surf 276 cyl  22.5   -15.  6.900  % Inner surface of Al baffle
```

```
surf 277 sqc  22.5   -15.  7.500  % Square Outer surface of Al baffle

% *** Top and Bottom End Plates ***
surf 60  pz  60.      % Top of fuel meat
surf 61  pz -60.      % Bottom of fuel meat
surf 62  pz  62.      % Top of plates
surf 63  pz -62.      % Bottom of plates
surf 64  pz  82.      % Top of Top End Box
surf 65  pz -82.      % Bottom of Bottom End Box

% *** Pressure Vessel ***
surf 1000 cyl  0.0  0.0 47.
surf 1001 cyl  0.0  0.0 51.

% infinite surfaces as placeholders for control rod and test locations
surf 300 inf
surf 400 inf
surf 500 inf

% *** D2O tank outer boundary ***
surf 801  cyl 0.0 0.0 150.0   %
surf 802 pz -150.
surf 803 pz  150.

%%%%%%%%%%%%%%%%%%%%%%%%
% END OF SURFACES
%%%%%%%%%%%%%%%%%%%%%%%%

% vacuum boundary
set bc 1

% cross section library path !!!! for Fission machine !!!!
set acelib "/home/popema/SERPENT/SERPENT/data/xsdata_combined"
set declib "/home/popema/SERPENT/SERPENT/data/sss_endfb7.dec"
set nfylib "/home/popema/SERPENT/SERPENT/data/sss_endfb7.nfy"

mesh 3 1000 1000 0 -150 150 -150 150

set power 250.E06
set opti 3
set pop 100000 1000 5 1.2

% ------- Material Cards --------------------------------------------
% ------ H2O Coolant ------
% T=70C, P=2.3 MPa, rho=0.979 g/cc
mat h2o  9.818E-02       moder h2o 1001
     1001.03c  6.545E-02
     8016.03c  3.273E-02
% ------ D2O ------
mat d2o 9.986E-02       moder d2o 1002
     1002.03c  6.657E-02
     8016.03c  3.329E-02
% -------Fuel--------
mat fuel 4.9186E-02  tmp 433.  vol 31865. burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
% ------ Al-6061 ------
mat al6061 -2.715       % Al-6061 density 2.715 g/cc
   14000.03c  -0.7   %      0.7   % Si
   26000.03c  -0.6   %      0.60  % Fe
   29000.03c  -0.22  %      0.22  % Cu
   25055.03c  -0.08  %      0.08  % Mn
   12000.03c  -1.0   %      1.0   % Mg
   24000.03c  -0.2   %      0.1   % Cr
   30000.03c  -0.08  %      0.08  % Zn
   22000.03c  -0.03  %      0.03  % Ti
   13027.03c  -97.09 %      97.09 % Al
% ------ Al-6061 Rack / part water ------
mat AlRack    6.22E-02       % 5% water
   14000.03c  3.87E-04 %
   26000.03c  1.67E-04 %
   29000.03c  5.38E-05 %
   25055.03c  2.26E-05 %
   12000.03c  6.39E-04 %
   24000.03c  5.97E-05 %
   30000.03c  1.90E-05 %
   22000.03c  9.73E-06 %
   13027.03c  5.59E-02 %
    1001.03c  3.27E-03
```

```
     8016.03c  1.64E-03
% ------  SS 304   ------
% Fe-0.08C-2.0Mn-0.045P-0.03S-1.0Si-19Cr-9Ni
mat ss304   -8.0       % ss 304 8g/cc
     6000.03c  -0.08   %     0.08   % C
    25055.03c  -2.0    %     2.0    % Mn
    15031.03c  -0.045  %     0.045  % P
    16000.03c  -0.03   %     0.03   % S
    14000.03c  -0.75   %     0.75   % Si
    24000.03c  -19.    %     19.    % Cr
    28000.03c  -9.25   %     9.25   % Ni
     7014.03c  -0.05   %     0.05   % N
    26000.03c  -68.795 %    68.795  % Fe
% ----- Zircalloy4 -------
mat zirc4  -6.56    tmp 398.
     40000.03c  -98.23   %     98.23 % Zr
     50000.03c  -1.45    %     1.45  % Sn
     26000.03c  -0.21    %     0.21  % Fe
     24000.03c  -0.10    %     0.10  % Cr
     72000.03c  -0.01    %     0.01  % Hf
% ------ Helium Coolant ------
mat helium 0.0007
      2004.03c  7.0000E-04
% ----- Top End Box -------
mix TopBox
  zirc4 0.20
  h2o   0.80
% ----- Bottom End Box -------
mix BotBox
  zirc4 0.20
  h2o   0.80
% ----- Top plate no fuel -------
mix TopPlat
  zirc4 0.39
  h2o   0.61
% ----- Bottom plate no fuel -------
mix BotPlat
  zirc4 0.39
  h2o   0.61

% for installation on Fission
therm h2o lwtr.01t
therm d2o hwtr.01t
therm be  be.01t

dep daytot
 0.1 0.5 1.0 2.0 3.5 5.0 10.0 15. 20. 30. 40. 50. 60. 80. 100. 120. 140. 160.

% TALLIES
% Flux 1MeV cutoff in  test zones
det CTrap  dc 1220 du 0 dv 432. de 1MeV dx  -3.   3.  1  dy -3.  3. 1  dz -60. 60. 10
det NTrap  dc 3220 du 0 dv 432. de 1MeV dx  -3.   3.  1  dy 27. 33. 1  dz -60. 60. 10
det NETrap dc 2220 du 0 dv 432. de 1MeV dx  19.5 25.5 1  dy 12. 18. 1  dz -60. 60. 10
det NWTrap dc 4220 du 0 dv 432. de 1MeV dx -25.5 -19.5 1  dy 12. 18. 1  dz -60. 60. 10
% Flux broken down into 3.
det FTref1 dc 853  du 0  dv 192. de 1MeV dx  55.4  59.4 1 dy 21.7 25.7 1  dz -60. 60. 10
det FTref2 dc 853  du 0  dv 192. de 1MeV dx  73.8  77.8 1 dy 29.4 33.4 1  dz -60. 60. 10
det FTref3 dc 853  du 0  dv 192. de 1MeV dx  92.3  96.3 1 dy 37.0 41.0 1  dz -60. 60. 10
det FTref4 dc 853  du 0  dv 192. de 1MeV dx 110.8 114.8 1 dy 44.7 48.7 1  dz -60. 60. 10

ene 1MeV   1 1.0E-15 0.625E-06 1.0  20.
```

Annular – Baseline case, single batch depletion

```
% title Baseline Annular Core
% Michael Pope
%
% *****************************************
% ************   Cell Cards  **************
% *****************************************

% *** Universe 1 *** Large central Location ****
% *** Test Space ****
cell 140 1  al6061  -121        % test space
cell 142 1  h2o     121  -122    % return flow
cell 143 1  ss304    122  -123    % pressure tube
cell 144 1  helium   123  -124    % helium annulus
cell 145 1  ss304    124  -125    % insulation jacket
cell 146 1  h2o     125  -126    % water gap
cell 147 1  al6061   126  -127    % baffle
cell 148 1  h2o     127    -1        % water outside baffle inside fuel plate 1
cell 149 1  h2o      48  -128 -80  81  % water outside fuel inside Rack
cell 150 1  AlRack   128   -80  81      % al next to fuel
cell 151 1  h2o     128    80 -203     % water above rack, outside fuel
cell 152 1  h2o     128   -81  202     % water below rack, outside fuel

% *** NNE Octant ***
cell 1002  1  zirc4    1  -2   -80  81 308 302 % Fuel Clad inner Plate  1
cell 1003  1  fuel1    2  -3   -80  81 308 302 % Fuel Meat Plate  1
cell 1004  1  zirc4    3  -4   -80  81 308 302 % Fuel Clad outer Plate  1
cell 1005  1  h2o      4  -5   -80  81 308 302 % Water between Plates 1 and 2
cell 1006  1  zirc4    5  -6   -80  81 308 302 % Fuel Clad inner Plate  2
cell 1007  1  fuel2    6  -7   -80  81 308 302 % Fuel Meat Plate  2
cell 1008  1  zirc4    7  -8   -80  81 308 302 % Fuel Clad outer Plate  2
cell 1009  1  h2o      8  -9   -80  81 308 302 % Water between Plates 2 and 3
cell 1010  1  zirc4    9  -10   -80  81 308 302 % Fuel Clad inner Plate  3
cell 1011  1  fuel3   10  -11   -80  81 308 302 % Fuel Meat Plate  3
cell 1012  1  zirc4   11  -12   -80  81 308 302 % Fuel Clad outer Plate  3
cell 1013  1  h2o     12  -13   -80  81 308 302 % Water between Plates 3 and 4
cell 1014  1  zirc4   13  -14   -80  81 308 302 % Fuel Clad inner Plate  4
cell 1015  1  fuel4   14  -15   -80  81 308 302 % Fuel Meat Plate  4
cell 1016  1  zirc4   15  -16   -80  81 308 302 % Fuel Clad outer Plate  4
cell 1017  1  h2o     16  -17   -80  81 308 302 % Water between Plates 4 and 5
cell 1018  1  zirc4   17  -18   -80  81 308 302 % Fuel Clad inner Plate  5
cell 1019  1  fuel5   18  -19   -80  81 308 302 % Fuel Meat Plate  5
cell 1020  1  zirc4   19  -20   -80  81 308 302 % Fuel Clad outer Plate  5
cell 1021  1  h2o     20  -21   -80  81 308 302 % Water between Plates 5 and 6
cell 1022  1  zirc4   21  -22   -80  81 308 302 % Fuel Clad inner Plate  6
cell 1023  1  fuel5   22  -23   -80  81 308 302 % Fuel Meat Plate  6
cell 1024  1  zirc4   23  -24   -80  81 308 302 % Fuel Clad outer Plate  6
cell 1025  1  h2o     24  -25   -80  81 308 302 % Water between Plates 6 and 7
cell 1026  1  zirc4   25  -26   -80  81 308 302 % Fuel Clad inner Plate  7
cell 1027  1  fuel7   26  -27   -80  81 308 302 % Fuel Meat Plate  7
cell 1028  1  zirc4   27  -28   -80  81 308 302 % Fuel Clad outer Plate  7
cell 1029  1  h2o     28  -29   -80  81 308 302 % Water between Plates 7 and 8
cell 1030  1  zirc4   29  -30   -80  81 308 302 % Fuel Clad inner Plate  8
cell 1031  1  fuel8   30  -31   -80  81 308 302 % Fuel Meat Plate  8
cell 1032  1  zirc4   31  -32   -80  81 308 302 % Fuel Clad outer Plate  8
cell 1033  1  h2o     32  -33   -80  81 308 302 % Water between Plates 8 and 9
cell 1034  1  zirc4   33  -34   -80  81 308 302 % Fuel Clad inner Plate  9
cell 1035  1  fuel9   34  -35   -80  81 308 302 % Fuel Meat Plate  9
cell 1036  1  zirc4   35  -36   -80  81 308 302 % Fuel Clad outer Plate  9
cell 1037  1  h2o     36  -37   -80  81 308 302 % Water between Plates 9 and 10
cell 1038  1  zirc4   37  -38   -80  81 308 302 % Fuel Clad inner Plate  10
cell 1039  1  fuel10   38  -39   -80  81 308 302 % Fuel Meat Plate  10
cell 1040  1  zirc4   39  -40   -80  81 308 302 % Fuel Clad outer Plate  10
cell 1041  1  h2o     40  -41   -80  81 308 302 % Water between Plates 10 and 11
cell 1042  1  zirc4   41  -42   -80  81 308 302 % Fuel Clad inner Plate  11
cell 1043  1  fuel11   42  -43   -80  81 308 302 % Fuel Meat Plate  11
cell 1044  1  zirc4   43  -44   -80  81 308 302 % Fuel Clad outer Plate  11
cell 1045  1  h2o     44  -45   -80  81 308 302 % Water between Plates 11 and 12
cell 1046  1  zirc4   45  -46   -80  81 308 302 % Fuel Clad inner Plate  12
cell 1047  1  fuel12   46  -47   -80  81 308 302 % Fuel Meat Plate  12
cell 1048  1  zirc4   47  -48   -80  81 308 302 % Fuel Clad outer Plate  12

% *** ENE Octant ***
cell 1102  1  zirc4    1  -2   -80  81 -307 305 % Fuel Clad inner Plate  1
cell 1103  1  fuel1    2  -3   -80  81 -307 305 % Fuel Meat Plate  1
cell 1104  1  zirc4    3  -4   -80  81 -307 305 % Fuel Clad outer Plate  1
cell 1105  1  h2o      4  -5   -80  81 -307 305 % Water between Plates 1 and 2
cell 1106  1  zirc4    5  -6   -80  81 -307 305 % Fuel Clad inner Plate  2
```

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cell 1107  1  fuel2     6   -7   -80  81 -307 305 % Fuel Meat Plate  2
cell 1108  1  zirc4     7   -8   -80  81 -307 305 % Fuel Clad outer Plate  2
cell 1109  1  h2o       8   -9   -80  81 -307 305 % Water between Plates 2 and 3
cell 1110  1  zirc4     9  -10   -80  81 -307 305 % Fuel Clad inner Plate  3
cell 1111  1  fuel3    10  -11   -80  81 -307 305 % Fuel Meat Plate  3
cell 1112  1  zirc4    11  -12   -80  81 -307 305 % Fuel Clad outer Plate  3
cell 1113  1  h2o      12  -13   -80  81 -307 305 % Water between Plates 3 and 4
cell 1114  1  zirc4    13  -14   -80  81 -307 305 % Fuel Clad inner Plate  4
cell 1115  1  fuel4    14  -15   -80  81 -307 305 % Fuel Meat Plate  4
cell 1116  1  zirc4    15  -16   -80  81 -307 305 % Fuel Clad outer Plate  4
cell 1117  1  h2o      16  -17   -80  81 -307 305 % Water between Plates 4 and 5
cell 1118  1  zirc4    17  -18   -80  81 -307 305 % Fuel Clad inner Plate  5
cell 1119  1  fuel5    18  -19   -80  81 -307 305 % Fuel Meat Plate  5
cell 1120  1  zirc4    19  -20   -80  81 -307 305 % Fuel Clad outer Plate  5
cell 1121  1  h2o      20  -21   -80  81 -307 305 % Water between Plates 5 and 6
cell 1122  1  zirc4    21  -22   -80  81 -307 305 % Fuel Clad inner Plate  6
cell 1123  1  fuel5    22  -23   -80  81 -307 305 % Fuel Meat Plate  6
cell 1124  1  zirc4    23  -24   -80  81 -307 305 % Fuel Clad outer Plate  6
cell 1125  1  h2o      24  -25   -80  81 -307 305 % Water between Plates 6 and 7
cell 1126  1  zirc4    25  -26   -80  81 -307 305 % Fuel Clad inner Plate  7
cell 1127  1  fuel7    26  -27   -80  81 -307 305 % Fuel Meat Plate  7
cell 1128  1  zirc4    27  -28   -80  81 -307 305 % Fuel Clad outer Plate  7
cell 1129  1  h2o      28  -29   -80  81 -307 305 % Water between Plates 7 and 8
cell 1130  1  zirc4    29  -30   -80  81 -307 305 % Fuel Clad inner Plate  8
cell 1131  1  fuel8    30  -31   -80  81 -307 305 % Fuel Meat Plate  8
cell 1132  1  zirc4    31  -32   -80  81 -307 305 % Fuel Clad outer Plate  8
cell 1133  1  h2o      32  -33   -80  81 -307 305 % Water between Plates 8 and 9
cell 1134  1  zirc4    33  -34   -80  81 -307 305 % Fuel Clad inner Plate  9
cell 1135  1  fuel9    34  -35   -80  81 -307 305 % Fuel Meat Plate  9
cell 1136  1  zirc4    35  -36   -80  81 -307 305 % Fuel Clad outer Plate  9
cell 1137  1  h2o      36  -37   -80  81 -307 305 % Water between Plates 9 and 10
cell 1138  1  zirc4    37  -38   -80  81 -307 305 % Fuel Clad inner Plate  10
cell 1139  1  fuel10   38  -39   -80  81 -307 305 % Fuel Meat Plate  10
cell 1140  1  zirc4    39  -40   -80  81 -307 305 % Fuel Clad outer Plate  10
cell 1141  1  h2o      40  -41   -80  81 -307 305 % Water between Plates 10 and 11
cell 1142  1  zirc4    41  -42   -80  81 -307 305 % Fuel Clad inner Plate  11
cell 1143  1  fuel11   42  -43   -80  81 -307 305 % Fuel Meat Plate  11
cell 1144  1  zirc4    43  -44   -80  81 -307 305 % Fuel Clad outer Plate  11
cell 1145  1  h2o      44  -45   -80  81 -307 305 % Water between Plates 11 and 12
cell 1146  1  zirc4    45  -46   -80  81 -307 305 % Fuel Clad inner Plate  12
cell 1147  1  fuel12   46  -47   -80  81 -307 305 % Fuel Meat Plate  12
cell 1148  1  zirc4    47  -48   -80  81 -307 305 % Fuel Clad outer Plate  12

% *** ESE Octant ***
cell 1202  1  zirc4     1   -2   -80  81 -304 311 % Fuel Clad inner Plate  1
cell 1203  1  fuel1     2   -3   -80  81 -304 311 % Fuel Meat Plate  1
cell 1204  1  zirc4     3   -4   -80  81 -304 311 % Fuel Clad outer Plate  1
cell 1205  1  h2o       4   -5   -80  81 -304 311 % Water between Plates 1 and 2
cell 1206  1  zirc4     5   -6   -80  81 -304 311 % Fuel Clad inner Plate  2
cell 1207  1  fuel2     6   -7   -80  81 -304 311 % Fuel Meat Plate  2
cell 1208  1  zirc4     7   -8   -80  81 -304 311 % Fuel Clad outer Plate  2
cell 1209  1  h2o       8   -9   -80  81 -304 311 % Water between Plates 2 and 3
cell 1210  1  zirc4     9  -10   -80  81 -304 311 % Fuel Clad inner Plate  3
cell 1211  1  fuel3    10  -11   -80  81 -304 311 % Fuel Meat Plate  3
cell 1212  1  zirc4    11  -12   -80  81 -304 311 % Fuel Clad outer Plate  3
cell 1213  1  h2o      12  -13   -80  81 -304 311 % Water between Plates 3 and 4
cell 1214  1  zirc4    13  -14   -80  81 -304 311 % Fuel Clad inner Plate  4
cell 1215  1  fuel4    14  -15   -80  81 -304 311 % Fuel Meat Plate  4
cell 1216  1  zirc4    15  -16   -80  81 -304 311 % Fuel Clad outer Plate  4
cell 1217  1  h2o      16  -17   -80  81 -304 311 % Water between Plates 4 and 5
cell 1218  1  zirc4    17  -18   -80  81 -304 311 % Fuel Clad inner Plate  5
cell 1219  1  fuel5    18  -19   -80  81 -304 311 % Fuel Meat Plate  5
cell 1220  1  zirc4    19  -20   -80  81 -304 311 % Fuel Clad outer Plate  5
cell 1221  1  h2o      20  -21   -80  81 -304 311 % Water between Plates 5 and 6
cell 1222  1  zirc4    21  -22   -80  81 -304 311 % Fuel Clad inner Plate  6
cell 1223  1  fuel5    22  -23   -80  81 -304 311 % Fuel Meat Plate  6
cell 1224  1  zirc4    23  -24   -80  81 -304 311 % Fuel Clad outer Plate  6
cell 1225  1  h2o      24  -25   -80  81 -304 311 % Water between Plates 6 and 7
cell 1226  1  zirc4    25  -26   -80  81 -304 311 % Fuel Clad inner Plate  7
cell 1227  1  fuel7    26  -27   -80  81 -304 311 % Fuel Meat Plate  7
cell 1228  1  zirc4    27  -28   -80  81 -304 311 % Fuel Clad outer Plate  7
cell 1229  1  h2o      28  -29   -80  81 -304 311 % Water between Plates 7 and 8
cell 1230  1  zirc4    29  -30   -80  81 -304 311 % Fuel Clad inner Plate  8
cell 1231  1  fuel8    30  -31   -80  81 -304 311 % Fuel Meat Plate  8
cell 1232  1  zirc4    31  -32   -80  81 -304 311 % Fuel Clad outer Plate  8
cell 1233  1  h2o      32  -33   -80  81 -304 311 % Water between Plates 8 and 9
cell 1234  1  zirc4    33  -34   -80  81 -304 311 % Fuel Clad inner Plate  9
cell 1235  1  fuel9    34  -35   -80  81 -304 311 % Fuel Meat Plate  9
cell 1236  1  zirc4    35  -36   -80  81 -304 311 % Fuel Clad outer Plate  9
cell 1237  1  h2o      36  -37   -80  81 -304 311 % Water between Plates 9 and 10
```

```
cell 1238  1  zirc4    37  -38   -80  81 -304 311 % Fuel Clad inner Plate  10
cell 1239  1  fuel10   38  -39   -80  81 -304 311 % Fuel Meat Plate  10
cell 1240  1  zirc4    39  -40   -80  81 -304 311 % Fuel Clad outer Plate  10
cell 1241  1  h2o      40  -41   -80  81 -304 311 % Water between Plates 10 and 11
cell 1242  1  zirc4    41  -42   -80  81 -304 311 % Fuel Clad inner Plate  11
cell 1243  1  fuel11   42  -43   -80  81 -304 311 % Fuel Meat Plate  11
cell 1244  1  zirc4    43  -44   -80  81 -304 311 % Fuel Clad outer Plate  11
cell 1245  1  h2o      44  -45   -80  81 -304 311 % Water between Plates 11 and 12
cell 1246  1  zirc4    45  -46   -80  81 -304 311 % Fuel Clad inner Plate  12
cell 1247  1  fuel12   46  -47   -80  81 -304 311 % Fuel Meat Plate  12
cell 1248  1  zirc4    47  -48   -80  81 -304 311 % Fuel Clad outer Plate  12

% *** SSE Octant ***
cell 1302  1  zirc4     1   -2   -80  81 -310 302 % Fuel Clad inner Plate  1
cell 1303  1  fuel1     2   -3   -80  81 -310 302 % Fuel Meat Plate  1
cell 1304  1  zirc4     3   -4   -80  81 -310 302 % Fuel Clad outer Plate  1
cell 1305  1  h2o       4   -5   -80  81 -310 302 % Water between Plates 1 and 2
cell 1306  1  zirc4     5   -6   -80  81 -310 302 % Fuel Clad inner Plate  2
cell 1307  1  fuel2     6   -7   -80  81 -310 302 % Fuel Meat Plate  2
cell 1308  1  zirc4     7   -8   -80  81 -310 302 % Fuel Clad outer Plate  2
cell 1309  1  h2o       8   -9   -80  81 -310 302 % Water between Plates 2 and 3
cell 1310  1  zirc4     9  -10   -80  81 -310 302 % Fuel Clad inner Plate  3
cell 1311  1  fuel3    10  -11   -80  81 -310 302 % Fuel Meat Plate  3
cell 1312  1  zirc4    11  -12   -80  81 -310 302 % Fuel Clad outer Plate  3
cell 1313  1  h2o      12  -13   -80  81 -310 302 % Water between Plates 3 and 4
cell 1314  1  zirc4    13  -14   -80  81 -310 302 % Fuel Clad inner Plate  4
cell 1315  1  fuel4    14  -15   -80  81 -310 302 % Fuel Meat Plate  4
cell 1316  1  zirc4    15  -16   -80  81 -310 302 % Fuel Clad outer Plate  4
cell 1317  1  h2o      16  -17   -80  81 -310 302 % Water between Plates 4 and 5
cell 1318  1  zirc4    17  -18   -80  81 -310 302 % Fuel Clad inner Plate  5
cell 1319  1  fuel5    18  -19   -80  81 -310 302 % Fuel Meat Plate  5
cell 1320  1  zirc4    19  -20   -80  81 -310 302 % Fuel Clad outer Plate  5
cell 1321  1  h2o      20  -21   -80  81 -310 302 % Water between Plates 5 and 6
cell 1322  1  zirc4    21  -22   -80  81 -310 302 % Fuel Clad inner Plate  6
cell 1323  1  fuel5    22  -23   -80  81 -310 302 % Fuel Meat Plate  6
cell 1324  1  zirc4    23  -24   -80  81 -310 302 % Fuel Clad outer Plate  6
cell 1325  1  h2o      24  -25   -80  81 -310 302 % Water between Plates 6 and 7
cell 1326  1  zirc4    25  -26   -80  81 -310 302 % Fuel Clad inner Plate  7
cell 1327  1  fuel7    26  -27   -80  81 -310 302 % Fuel Meat Plate  7
cell 1328  1  zirc4    27  -28   -80  81 -310 302 % Fuel Clad outer Plate  7
cell 1329  1  h2o      28  -29   -80  81 -310 302 % Water between Plates 7 and 8
cell 1330  1  zirc4    29  -30   -80  81 -310 302 % Fuel Clad inner Plate  8
cell 1331  1  fuel8    30  -31   -80  81 -310 302 % Fuel Meat Plate  8
cell 1332  1  zirc4    31  -32   -80  81 -310 302 % Fuel Clad outer Plate  8
cell 1333  1  h2o      32  -33   -80  81 -310 302 % Water between Plates 8 and 9
cell 1334  1  zirc4    33  -34   -80  81 -310 302 % Fuel Clad inner Plate  9
cell 1335  1  fuel9    34  -35   -80  81 -310 302 % Fuel Meat Plate  9
cell 1336  1  zirc4    35  -36   -80  81 -310 302 % Fuel Clad outer Plate  9
cell 1337  1  h2o      36  -37   -80  81 -310 302 % Water between Plates 9 and 10
cell 1338  1  zirc4    37  -38   -80  81 -310 302 % Fuel Clad inner Plate  10
cell 1339  1  fuel10   38  -39   -80  81 -310 302 % Fuel Meat Plate  10
cell 1340  1  zirc4    39  -40   -80  81 -310 302 % Fuel Clad outer Plate  10
cell 1341  1  h2o      40  -41   -80  81 -310 302 % Water between Plates 10 and 11
cell 1342  1  zirc4    41  -42   -80  81 -310 302 % Fuel Clad inner Plate  11
cell 1343  1  fuel11   42  -43   -80  81 -310 302 % Fuel Meat Plate  11
cell 1344  1  zirc4    43  -44   -80  81 -310 302 % Fuel Clad outer Plate  11
cell 1345  1  h2o      44  -45   -80  81 -310 302 % Water between Plates 11 and 12
cell 1346  1  zirc4    45  -46   -80  81 -310 302 % Fuel Clad inner Plate  12
cell 1347  1  fuel12   46  -47   -80  81 -310 302 % Fuel Meat Plate  12
cell 1348  1  zirc4    47  -48   -80  81 -310 302 % Fuel Clad outer Plate  12

% *** SSW Octant ***
cell 1402  1  zirc4     1   -2   -80  81 -301 -307 % Fuel Clad inner Plate  1
cell 1403  1  fuel1     2   -3   -80  81 -301 -307 % Fuel Meat Plate  1
cell 1404  1  zirc4     3   -4   -80  81 -301 -307 % Fuel Clad outer Plate  1
cell 1405  1  h2o       4   -5   -80  81 -301 -307 % Water between Plates 1 and 2
cell 1406  1  zirc4     5   -6   -80  81 -301 -307 % Fuel Clad inner Plate  2
cell 1407  1  fuel2     6   -7   -80  81 -301 -307 % Fuel Meat Plate  2
cell 1408  1  zirc4     7   -8   -80  81 -301 -307 % Fuel Clad outer Plate  2
cell 1409  1  h2o       8   -9   -80  81 -301 -307 % Water between Plates 2 and 3
cell 1410  1  zirc4     9  -10   -80  81 -301 -307 % Fuel Clad inner Plate  3
cell 1411  1  fuel3    10  -11   -80  81 -301 -307 % Fuel Meat Plate  3
cell 1412  1  zirc4    11  -12   -80  81 -301 -307 % Fuel Clad outer Plate  3
cell 1413  1  h2o      12  -13   -80  81 -301 -307 % Water between Plates 3 and 4
cell 1414  1  zirc4    13  -14   -80  81 -301 -307 % Fuel Clad inner Plate  4
cell 1415  1  fuel4    14  -15   -80  81 -301 -307 % Fuel Meat Plate  4
cell 1416  1  zirc4    15  -16   -80  81 -301 -307 % Fuel Clad outer Plate  4
cell 1417  1  h2o      16  -17   -80  81 -301 -307 % Water between Plates 4 and 5
cell 1418  1  zirc4    17  -18   -80  81 -301 -307 % Fuel Clad inner Plate  5
cell 1419  1  fuel5    18  -19   -80  81 -301 -307 % Fuel Meat Plate  5
```

```
cell 1420  1  zirc4    19  -20   -80  81 -301 -307 % Fuel Clad outer Plate  5
cell 1421  1  h2o      20  -21   -80  81 -301 -307 % Water between Plates 5 and 6
cell 1422  1  zirc4    21  -22   -80  81 -301 -307 % Fuel Clad inner Plate  6
cell 1423  1  fuel5    22  -23   -80  81 -301 -307 % Fuel Meat Plate  6
cell 1424  1  zirc4    23  -24   -80  81 -301 -307 % Fuel Clad outer Plate  6
cell 1425  1  h2o      24  -25   -80  81 -301 -307 % Water between Plates 6 and 7
cell 1426  1  zirc4    25  -26   -80  81 -301 -307 % Fuel Clad inner Plate  7
cell 1427  1  fuel7    26  -27   -80  81 -301 -307 % Fuel Meat Plate  7
cell 1428  1  zirc4    27  -28   -80  81 -301 -307 % Fuel Clad outer Plate  7
cell 1429  1  h2o      28  -29   -80  81 -301 -307 % Water between Plates 7 and 8
cell 1430  1  zirc4    29  -30   -80  81 -301 -307 % Fuel Clad inner Plate  8
cell 1431  1  fuel8    30  -31   -80  81 -301 -307 % Fuel Meat Plate  8
cell 1432  1  zirc4    31  -32   -80  81 -301 -307 % Fuel Clad outer Plate  8
cell 1433  1  h2o      32  -33   -80  81 -301 -307 % Water between Plates 8 and 9
cell 1434  1  zirc4    33  -34   -80  81 -301 -307 % Fuel Clad inner Plate  9
cell 1435  1  fuel9    34  -35   -80  81 -301 -307 % Fuel Meat Plate  9
cell 1436  1  zirc4    35  -36   -80  81 -301 -307 % Fuel Clad outer Plate  9
cell 1437  1  h2o      36  -37   -80  81 -301 -307 % Water between Plates 9 and 10
cell 1438  1  zirc4    37  -38   -80  81 -301 -307 % Fuel Clad inner Plate  10
cell 1439  1  fuel10   38  -39   -80  81 -301 -307 % Fuel Meat Plate  10
cell 1440  1  zirc4    39  -40   -80  81 -301 -307 % Fuel Clad outer Plate  10
cell 1441  1  h2o      40  -41   -80  81 -301 -307 % Water between Plates 10 and 11
cell 1442  1  zirc4    41  -42   -80  81 -301 -307 % Fuel Clad inner Plate  11
cell 1443  1  fuel11   42  -43   -80  81 -301 -307 % Fuel Meat Plate  11
cell 1444  1  zirc4    43  -44   -80  81 -301 -307 % Fuel Clad outer Plate  11
cell 1445  1  h2o      44  -45   -80  81 -301 -307 % Water between Plates 11 and 12
cell 1446  1  zirc4    45  -46   -80  81 -301 -307 % Fuel Clad inner Plate  12
cell 1447  1  fuel12   46  -47   -80  81 -301 -307 % Fuel Meat Plate  12
cell 1448  1  zirc4    47  -48   -80  81 -301 -307 % Fuel Clad outer Plate  12

% *** WSW Octant ***
cell 1502  1  zirc4     1   -2   -80  81 -304 308 % Fuel Clad inner Plate  1
cell 1503  1  fuel1     2   -3   -80  81 -304 308 % Fuel Meat Plate  1
cell 1504  1  zirc4     3   -4   -80  81 -304 308 % Fuel Clad outer Plate  1
cell 1505  1  h2o       4   -5   -80  81 -304 308 % Water between Plates 1 and 2
cell 1506  1  zirc4     5   -6   -80  81 -304 308 % Fuel Clad inner Plate  2
cell 1507  1  fuel2     6   -7   -80  81 -304 308 % Fuel Meat Plate  2
cell 1508  1  zirc4     7   -8   -80  81 -304 308 % Fuel Clad outer Plate  2
cell 1509  1  h2o       8   -9   -80  81 -304 308 % Water between Plates 2 and 3
cell 1510  1  zirc4     9  -10   -80  81 -304 308 % Fuel Clad inner Plate  3
cell 1511  1  fuel3    10  -11   -80  81 -304 308 % Fuel Meat Plate  3
cell 1512  1  zirc4    11  -12   -80  81 -304 308 % Fuel Clad outer Plate  3
cell 1513  1  h2o      12  -13   -80  81 -304 308 % Water between Plates 3 and 4
cell 1514  1  zirc4    13  -14   -80  81 -304 308 % Fuel Clad inner Plate  4
cell 1515  1  fuel4    14  -15   -80  81 -304 308 % Fuel Meat Plate  4
cell 1516  1  zirc4    15  -16   -80  81 -304 308 % Fuel Clad outer Plate  4
cell 1517  1  h2o      16  -17   -80  81 -304 308 % Water between Plates 4 and 5
cell 1518  1  zirc4    17  -18   -80  81 -304 308 % Fuel Clad inner Plate  5
cell 1519  1  fuel5    18  -19   -80  81 -304 308 % Fuel Meat Plate  5
cell 1520  1  zirc4    19  -20   -80  81 -304 308 % Fuel Clad outer Plate  5
cell 1521  1  h2o      20  -21   -80  81 -304 308 % Water between Plates 5 and 6
cell 1522  1  zirc4    21  -22   -80  81 -304 308 % Fuel Clad inner Plate  6
cell 1523  1  fuel5    22  -23   -80  81 -304 308 % Fuel Meat Plate  6
cell 1524  1  zirc4    23  -24   -80  81 -304 308 % Fuel Clad outer Plate  6
cell 1525  1  h2o      24  -25   -80  81 -304 308 % Water between Plates 6 and 7
cell 1526  1  zirc4    25  -26   -80  81 -304 308 % Fuel Clad inner Plate  7
cell 1527  1  fuel7    26  -27   -80  81 -304 308 % Fuel Meat Plate  7
cell 1528  1  zirc4    27  -28   -80  81 -304 308 % Fuel Clad outer Plate  7
cell 1529  1  h2o      28  -29   -80  81 -304 308 % Water between Plates 7 and 8
cell 1530  1  zirc4    29  -30   -80  81 -304 308 % Fuel Clad inner Plate  8
cell 1531  1  fuel8    30  -31   -80  81 -304 308 % Fuel Meat Plate  8
cell 1532  1  zirc4    31  -32   -80  81 -304 308 % Fuel Clad outer Plate  8
cell 1533  1  h2o      32  -33   -80  81 -304 308 % Water between Plates 8 and 9
cell 1534  1  zirc4    33  -34   -80  81 -304 308 % Fuel Clad inner Plate  9
cell 1535  1  fuel9    34  -35   -80  81 -304 308 % Fuel Meat Plate  9
cell 1536  1  zirc4    35  -36   -80  81 -304 308 % Fuel Clad outer Plate  9
cell 1537  1  h2o      36  -37   -80  81 -304 308 % Water between Plates 9 and 10
cell 1538  1  zirc4    37  -38   -80  81 -304 308 % Fuel Clad inner Plate  10
cell 1539  1  fuel10   38  -39   -80  81 -304 308 % Fuel Meat Plate  10
cell 1540  1  zirc4    39  -40   -80  81 -304 308 % Fuel Clad outer Plate  10
cell 1541  1  h2o      40  -41   -80  81 -304 308 % Water between Plates 10 and 11
cell 1542  1  zirc4    41  -42   -80  81 -304 308 % Fuel Clad inner Plate  11
cell 1543  1  fuel11   42  -43   -80  81 -304 308 % Fuel Meat Plate  11
cell 1544  1  zirc4    43  -44   -80  81 -304 308 % Fuel Clad outer Plate  11
cell 1545  1  h2o      44  -45   -80  81 -304 308 % Water between Plates 11 and 12
cell 1546  1  zirc4    45  -46   -80  81 -304 308 % Fuel Clad inner Plate  12
cell 1547  1  fuel12   46  -47   -80  81 -304 308 % Fuel Meat Plate  12
cell 1548  1  zirc4    47  -48   -80  81 -304 308 % Fuel Clad outer Plate  12

% *** WNW Octant ***
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cell 1602  1  zirc4     1   -2   -80  81 -310 305 % Fuel Clad inner Plate  1
cell 1603  1  fuel1     2   -3   -80  81 -310 305 % Fuel Meat Plate  1
cell 1604  1  zirc4     3   -4   -80  81 -310 305 % Fuel Clad outer Plate  1
cell 1605  1  h2o       4   -5   -80  81 -310 305 % Water between Plates 1 and 2
cell 1606  1  zirc4     5   -6   -80  81 -310 305 % Fuel Clad inner Plate  2
cell 1607  1  fuel2     6   -7   -80  81 -310 305 % Fuel Meat Plate  2
cell 1608  1  zirc4     7   -8   -80  81 -310 305 % Fuel Clad outer Plate  2
cell 1609  1  h2o       8   -9   -80  81 -310 305 % Water between Plates 2 and 3
cell 1610  1  zirc4     9  -10   -80  81 -310 305 % Fuel Clad inner Plate  3
cell 1611  1  fuel3    10  -11   -80  81 -310 305 % Fuel Meat Plate  3
cell 1612  1  zirc4    11  -12   -80  81 -310 305 % Fuel Clad outer Plate  3
cell 1613  1  h2o      12  -13   -80  81 -310 305 % Water between Plates 3 and 4
cell 1614  1  zirc4    13  -14   -80  81 -310 305 % Fuel Clad inner Plate  4
cell 1615  1  fuel4    14  -15   -80  81 -310 305 % Fuel Meat Plate  4
cell 1616  1  zirc4    15  -16   -80  81 -310 305 % Fuel Clad outer Plate  4
cell 1617  1  h2o      16  -17   -80  81 -310 305 % Water between Plates 4 and 5
cell 1618  1  zirc4    17  -18   -80  81 -310 305 % Fuel Clad inner Plate  5
cell 1619  1  fuel5    18  -19   -80  81 -310 305 % Fuel Meat Plate  5
cell 1620  1  zirc4    19  -20   -80  81 -310 305 % Fuel Clad outer Plate  5
cell 1621  1  h2o      20  -21   -80  81 -310 305 % Water between Plates 5 and 6
cell 1622  1  zirc4    21  -22   -80  81 -310 305 % Fuel Clad inner Plate  6
cell 1623  1  fuel5    22  -23   -80  81 -310 305 % Fuel Meat Plate  6
cell 1624  1  zirc4    23  -24   -80  81 -310 305 % Fuel Clad outer Plate  6
cell 1625  1  h2o      24  -25   -80  81 -310 305 % Water between Plates 6 and 7
cell 1626  1  zirc4    25  -26   -80  81 -310 305 % Fuel Clad inner Plate  7
cell 1627  1  fuel7    26  -27   -80  81 -310 305 % Fuel Meat Plate  7
cell 1628  1  zirc4    27  -28   -80  81 -310 305 % Fuel Clad outer Plate  7
cell 1629  1  h2o      28  -29   -80  81 -310 305 % Water between Plates 7 and 8
cell 1630  1  zirc4    29  -30   -80  81 -310 305 % Fuel Clad inner Plate  8
cell 1631  1  fuel8    30  -31   -80  81 -310 305 % Fuel Meat Plate  8
cell 1632  1  zirc4    31  -32   -80  81 -310 305 % Fuel Clad outer Plate  8
cell 1633  1  h2o      32  -33   -80  81 -310 305 % Water between Plates 8 and 9
cell 1634  1  zirc4    33  -34   -80  81 -310 305 % Fuel Clad inner Plate  9
cell 1635  1  fuel9    34  -35   -80  81 -310 305 % Fuel Meat Plate  9
cell 1636  1  zirc4    35  -36   -80  81 -310 305 % Fuel Clad outer Plate  9
cell 1637  1  h2o      36  -37   -80  81 -310 305 % Water between Plates 9 and 10
cell 1638  1  zirc4    37  -38   -80  81 -310 305 % Fuel Clad inner Plate  10
cell 1639  1  fuel10   38  -39   -80  81 -310 305 % Fuel Meat Plate  10
cell 1640  1  zirc4    39  -40   -80  81 -310 305 % Fuel Clad outer Plate  10
cell 1641  1  h2o      40  -41   -80  81 -310 305 % Water between Plates 10 and 11
cell 1642  1  zirc4    41  -42   -80  81 -310 305 % Fuel Clad inner Plate  11
cell 1643  1  fuel11   42  -43   -80  81 -310 305 % Fuel Meat Plate  11
cell 1644  1  zirc4    43  -44   -80  81 -310 305 % Fuel Clad outer Plate  11
cell 1645  1  h2o      44  -45   -80  81 -310 305 % Water between Plates 11 and 12
cell 1646  1  zirc4    45  -46   -80  81 -310 305 % Fuel Clad inner Plate  12
cell 1647  1  fuel12   46  -47   -80  81 -310 305 % Fuel Meat Plate  12
cell 1648  1  zirc4    47  -48   -80  81 -310 305 % Fuel Clad outer Plate  12

% *** NNW Octant ***
cell 1702  1  zirc4    1   -2  -80  81 311 -301 % Fuel Clad inner Plate  1
cell 1703  1  fuel1    2   -3  -80  81 311 -301 % Fuel Meat Plate  1
cell 1704  1  zirc4    3   -4  -80  81 311 -301 % Fuel Clad outer Plate  1
cell 1705  1  h2o      4   -5  -80  81 311 -301 % Water between Plates 1 and 2
cell 1706  1  zirc4    5   -6  -80  81 311 -301 % Fuel Clad inner Plate  2
cell 1707  1  fuel2    6   -7  -80  81 311 -301 % Fuel Meat Plate  2
cell 1708  1  zirc4    7   -8  -80  81 311 -301 % Fuel Clad outer Plate  2
cell 1709  1  h2o      8   -9  -80  81 311 -301 % Water between Plates 2 and 3
cell 1710  1  zirc4    9  -10  -80  81 311 -301 % Fuel Clad inner Plate  3
cell 1711  1  fuel3   10  -11  -80  81 311 -301 % Fuel Meat Plate  3
cell 1712  1  zirc4   11  -12  -80  81 311 -301 % Fuel Clad outer Plate  3
cell 1713  1  h2o     12  -13  -80  81 311 -301 % Water between Plates 3 and 4
cell 1714  1  zirc4   13  -14  -80  81 311 -301 % Fuel Clad inner Plate  4
cell 1715  1  fuel4   14  -15  -80  81 311 -301 % Fuel Meat Plate  4
cell 1716  1  zirc4   15  -16  -80  81 311 -301 % Fuel Clad outer Plate  4
cell 1717  1  h2o     16  -17  -80  81 311 -301 % Water between Plates 4 and 5
cell 1718  1  zirc4   17  -18  -80  81 311 -301 % Fuel Clad inner Plate  5
cell 1719  1  fuel5   18  -19  -80  81 311 -301 % Fuel Meat Plate  5
cell 1720  1  zirc4   19  -20  -80  81 311 -301 % Fuel Clad outer Plate  5
cell 1721  1  h2o     20  -21  -80  81 311 -301 % Water between Plates 5 and 6
cell 1722  1  zirc4   21  -22  -80  81 311 -301 % Fuel Clad inner Plate  6
cell 1723  1  fuel5   22  -23  -80  81 311 -301 % Fuel Meat Plate  6
cell 1724  1  zirc4   23  -24  -80  81 311 -301 % Fuel Clad outer Plate  6
cell 1725  1  h2o     24  -25  -80  81 311 -301 % Water between Plates 6 and 7
cell 1726  1  zirc4   25  -26  -80  81 311 -301 % Fuel Clad inner Plate  7
cell 1727  1  fuel7   26  -27  -80  81 311 -301 % Fuel Meat Plate  7
cell 1728  1  zirc4   27  -28  -80  81 311 -301 % Fuel Clad outer Plate  7
cell 1729  1  h2o     28  -29  -80  81 311 -301 % Water between Plates 7 and 8
cell 1730  1  zirc4   29  -30  -80  81 311 -301 % Fuel Clad inner Plate  8
cell 1731  1  fuel8   30  -31  -80  81 311 -301 % Fuel Meat Plate  8
cell 1732  1  zirc4   31  -32  -80  81 311 -301 % Fuel Clad outer Plate  8
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cell 1733  1  h2o     32  -33  -80  81 311 -301 % Water between Plates 8 and 9
cell 1734  1  zirc4   33  -34  -80  81 311 -301 % Fuel Clad inner Plate  9
cell 1735  1  fuel9   34  -35  -80  81 311 -301 % Fuel Meat Plate  9
cell 1736  1  zirc4   35  -36  -80  81 311 -301 % Fuel Clad outer Plate  9
cell 1737  1  h2o     36  -37  -80  81 311 -301 % Water between Plates 9 and 10
cell 1738  1  zirc4   37  -38  -80  81 311 -301 % Fuel Clad inner Plate  10
cell 1739  1  fuel10  38  -39  -80  81 311 -301 % Fuel Meat Plate  10
cell 1740  1  zirc4   39  -40  -80  81 311 -301 % Fuel Clad outer Plate  10
cell 1741  1  h2o     40  -41  -80  81 311 -301 % Water between Plates 10 and 11
cell 1742  1  zirc4   41  -42  -80  81 311 -301 % Fuel Clad inner Plate  11
cell 1743  1  fuel11  42  -43  -80  81 311 -301 % Fuel Meat Plate  11
cell 1744  1  zirc4   43  -44  -80  81 311 -301 % Fuel Clad outer Plate  11
cell 1745  1  h2o     44  -45  -80  81 311 -301 % Water between Plates 11 and 12
cell 1746  1  zirc4   45  -46  -80  81 311 -301 % Fuel Clad inner Plate  12
cell 1747  1  fuel12  46  -47  -80  81 311 -301 % Fuel Meat Plate  12
cell 1748  1  zirc4   47  -48  -80  81 311 -301 % Fuel Clad outer Plate  12

%  Other materials above and below fuel assembly
cell  77  1  h2o      1   -128      64 -203   % water above fuel assembly
cell  78  1  h2o      1   -128     -65  202  % water below fuel assembly
%  Upper and lower plates without fuel homogenized
cell 185  1  TopPlat  1  -128   80 -62    % upper end plates
cell 186  1  BotPlat  1  -128  -81  63    % lower end plates
%  Upper and lower end boxes homogenized
cell 187  1  TopBox   1  -128       62 -64    % upper end box
cell 188  1  BotBox   1  -128      -63  65    % lower end box

% Side plates (fused adjacent plates
cell 90 1 zirc4   1 -48 301 -302  303 -80  81 % N sideplates
cell 91 1 zirc4   1 -48 307 -308  303 -80  81 % NE sideplates
cell 92 1 zirc4   1 -48 304 -305  300 -80  81 % E sideplates
cell 93 1 zirc4   1 -48 310 -311 -303 -80  81 % SE sideplates
cell 94 1 zirc4   1 -48 301 -302 -303 -80  81 % S sideplates
cell 95 1 zirc4   1 -48 307 -308 -303 -80  81 % SW sideplates
cell 96 1 zirc4   1 -48 304 -305 -300 -80  81 % W sideplates
cell 97 1 zirc4   1 -48 310 -311  303 -80  81 % NW sideplates

% *** Outer Test Location *** Universe 2 ****
cell 120 2  al6061  -220         % test space
cell 121 2  ss304    220  -221     % flow tube
cell 122 2  h2o      221  -222     % return flow
cell 123 2  ss304    222  -223     % pressure tube
cell 124 2  helium   223  -224     % helium annulus
cell 125 2  ss304    224  -225     % insulation jacket
cell 126 2  h2o      225  -226     % water gap
cell 127 2  al6061   226  -227     % guide tube
cell 128 2  h2o      227  -228     % water
cell 129 2  al6061   228  -229     % safety rod follower
cell 130 2  h2o      229  -126     % water just inside baffle
cell 131 2  al6061   126  -127     % baffle
cell 132 2  h2o      127    -1     % water just inside fuel plate 1
cell 133 2  h2o       48  -128 -80 81  % water outside fuel inside rack
cell 134 2  AlRack     128    -80 81  % Al Rack  next to fuel
cell 135 2  h2o      128    80 -203  % water above rack, outside fuel
cell 136 2  h2o      128   -81  202  % water below rack, outside fuel

% *** NNE Octant ***
cell 2002  2  zirc4    1   -2   -80  81 308 302 % Fuel Clad inner Plate  1
cell 2003  2  fuel13    2   -3   -80  81 308 302 % Fuel Meat Plate  1
cell 2004  2  zirc4    3   -4   -80  81 308 302 % Fuel Clad outer Plate  1
cell 2005  2  h2o      4   -5   -80  81 308 302 % Water between Plates 1 and 2
cell 2006  2  zirc4    5   -6   -80  81 308 302 % Fuel Clad inner Plate  2
cell 2007  2  fuel14    6   -7   -80  81 308 302 % Fuel Meat Plate  2
cell 2008  2  zirc4    7   -8   -80  81 308 302 % Fuel Clad outer Plate  2
cell 2009  2  h2o      8   -9   -80  81 308 302 % Water between Plates 2 and 3
cell 2010  2  zirc4    9  -10   -80  81 308 302 % Fuel Clad inner Plate  3
cell 2011  2  fuel15   10  -11   -80  81 308 302 % Fuel Meat Plate  3
cell 2012  2  zirc4    11  -12   -80  81 308 302 % Fuel Clad outer Plate  3
cell 2013  2  h2o      12  -13   -80  81 308 302 % Water between Plates 3 and 4
cell 2014  2  zirc4    13  -14   -80  81 308 302 % Fuel Clad inner Plate  4
cell 2015  2  fuel16   14  -15   -80  81 308 302 % Fuel Meat Plate  4
cell 2016  2  zirc4    15  -16   -80  81 308 302 % Fuel Clad outer Plate  4
cell 2017  2  h2o      16  -17   -80  81 308 302 % Water between Plates 4 and 5
cell 2018  2  zirc4    17  -18   -80  81 308 302 % Fuel Clad inner Plate  5
cell 2019  2  fuel17   18  -19   -80  81 308 302 % Fuel Meat Plate  5
cell 2020  2  zirc4    19  -20   -80  81 308 302 % Fuel Clad outer Plate  5
cell 2021  2  h2o      20  -21   -80  81 308 302 % Water between Plates 5 and 6
cell 2022  2  zirc4    21  -22   -80  81 308 302 % Fuel Clad inner Plate  6
cell 2023  2  fuel18   22  -23   -80  81 308 302 % Fuel Meat Plate  6
cell 2024  2  zirc4    23  -24   -80  81 308 302 % Fuel Clad outer Plate  6
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cell 2025  2  h2o      24  -25   -80  81 308 302 % Water between Plates 6 and 7
cell 2026  2  zirc4    25  -26   -80  81 308 302 % Fuel Clad inner Plate  7
cell 2027  2  fuel19   26  -27   -80  81 308 302 % Fuel Meat Plate  7
cell 2028  2  zirc4    27  -28   -80  81 308 302 % Fuel Clad outer Plate  7
cell 2029  2  h2o      28  -29   -80  81 308 302 % Water between Plates 7 and 8
cell 2030  2  zirc4    29  -30   -80  81 308 302 % Fuel Clad inner Plate  8
cell 2031  2  fuel20   30  -31   -80  81 308 302 % Fuel Meat Plate  8
cell 2032  2  zirc4    31  -32   -80  81 308 302 % Fuel Clad outer Plate  8
cell 2033  2  h2o      32  -33   -80  81 308 302 % Water between Plates 8 and 9
cell 2034  2  zirc4    33  -34   -80  81 308 302 % Fuel Clad inner Plate  9
cell 2035  2  fuel21   34  -35   -80  81 308 302 % Fuel Meat Plate  9
cell 2036  2  zirc4    35  -36   -80  81 308 302 % Fuel Clad outer Plate  9
cell 2037  2  h2o      36  -37   -80  81 308 302 % Water between Plates 9 and 10
cell 2038  2  zirc4    37  -38   -80  81 308 302 % Fuel Clad inner Plate  10
cell 2039  2  fuel22   38  -39   -80  81 308 302 % Fuel Meat Plate  10
cell 2040  2  zirc4    39  -40   -80  81 308 302 % Fuel Clad outer Plate  10
cell 2041  2  h2o      40  -41   -80  81 308 302 % Water between Plates 10 and 11
cell 2042  2  zirc4    41  -42   -80  81 308 302 % Fuel Clad inner Plate  11
cell 2043  2  fuel23   42  -43   -80  81 308 302 % Fuel Meat Plate  11
cell 2044  2  zirc4    43  -44   -80  81 308 302 % Fuel Clad outer Plate  11
cell 2045  2  h2o      44  -45   -80  81 308 302 % Water between Plates 11 and 12
cell 2046  2  zirc4    45  -46   -80  81 308 302 % Fuel Clad inner Plate  12
cell 2047  2  fuel24   46  -47   -80  81 308 302 % Fuel Meat Plate  12
cell 2048  2  zirc4    47  -48   -80  81 308 302 % Fuel Clad outer Plate  12

% *** ENE Octant ***
cell 2102  2  zirc4    1  -2   -80  81 -307 305 % Fuel Clad inner Plate  1
cell 2103  2  fuel13   2  -3   -80  81 -307 305 % Fuel Meat Plate  1
cell 2104  2  zirc4    3  -4   -80  81 -307 305 % Fuel Clad outer Plate  1
cell 2105  2  h2o      4  -5   -80  81 -307 305 % Water between Plates 1 and 2
cell 2106  2  zirc4    5  -6   -80  81 -307 305 % Fuel Clad inner Plate  2
cell 2107  2  fuel14   6  -7   -80  81 -307 305 % Fuel Meat Plate  2
cell 2108  2  zirc4    7  -8   -80  81 -307 305 % Fuel Clad outer Plate  2
cell 2109  2  h2o      8  -9   -80  81 -307 305 % Water between Plates 2 and 3
cell 2110  2  zirc4    9  -10  -80  81 -307 305 % Fuel Clad inner Plate  3
cell 2111  2  fuel15  10  -11  -80  81 -307 305 % Fuel Meat Plate  3
cell 2112  2  zirc4   11  -12  -80  81 -307 305 % Fuel Clad outer Plate  3
cell 2113  2  h2o     12  -13  -80  81 -307 305 % Water between Plates 3 and 4
cell 2114  2  zirc4   13  -14  -80  81 -307 305 % Fuel Clad inner Plate  4
cell 2115  2  fuel16  14  -15  -80  81 -307 305 % Fuel Meat Plate  4
cell 2116  2  zirc4   15  -16  -80  81 -307 305 % Fuel Clad outer Plate  4
cell 2117  2  h2o     16  -17  -80  81 -307 305 % Water between Plates 4 and 5
cell 2118  2  zirc4   17  -18  -80  81 -307 305 % Fuel Clad inner Plate  5
cell 2119  2  fuel17  18  -19  -80  81 -307 305 % Fuel Meat Plate  5
cell 2120  2  zirc4   19  -20  -80  81 -307 305 % Fuel Clad outer Plate  5
cell 2121  2  h2o     20  -21  -80  81 -307 305 % Water between Plates 5 and 6
cell 2122  2  zirc4   21  -22  -80  81 -307 305 % Fuel Clad inner Plate  6
cell 2123  2  fuel18  22  -23  -80  81 -307 305 % Fuel Meat Plate  6
cell 2124  2  zirc4   23  -24  -80  81 -307 305 % Fuel Clad outer Plate  6
cell 2125  2  h2o     24  -25  -80  81 -307 305 % Water between Plates 6 and 7
cell 2126  2  zirc4   25  -26  -80  81 -307 305 % Fuel Clad inner Plate  7
cell 2127  2  fuel19  26  -27  -80  81 -307 305 % Fuel Meat Plate  7
cell 2128  2  zirc4   27  -28  -80  81 -307 305 % Fuel Clad outer Plate  7
cell 2129  2  h2o     28  -29  -80  81 -307 305 % Water between Plates 7 and 8
cell 2130  2  zirc4   29  -30  -80  81 -307 305 % Fuel Clad inner Plate  8
cell 2131  2  fuel20  30  -31  -80  81 -307 305 % Fuel Meat Plate  8
cell 2132  2  zirc4   31  -32  -80  81 -307 305 % Fuel Clad outer Plate  8
cell 2133  2  h2o     32  -33  -80  81 -307 305 % Water between Plates 8 and 9
cell 2134  2  zirc4   33  -34  -80  81 -307 305 % Fuel Clad inner Plate  9
cell 2135  2  fuel21  34  -35  -80  81 -307 305 % Fuel Meat Plate  9
cell 2136  2  zirc4   35  -36  -80  81 -307 305 % Fuel Clad outer Plate  9
cell 2137  2  h2o     36  -37  -80  81 -307 305 % Water between Plates 9 and 10
cell 2138  2  zirc4   37  -38  -80  81 -307 305 % Fuel Clad inner Plate  10
cell 2139  2  fuel22  38  -39  -80  81 -307 305 % Fuel Meat Plate  10
cell 2140  2  zirc4   39  -40  -80  81 -307 305 % Fuel Clad outer Plate  10
cell 2141  2  h2o     40  -41  -80  81 -307 305 % Water between Plates 10 and 11
cell 2142  2  zirc4   41  -42  -80  81 -307 305 % Fuel Clad inner Plate  11
cell 2143  2  fuel23  42  -43  -80  81 -307 305 % Fuel Meat Plate  11
cell 2144  2  zirc4   43  -44  -80  81 -307 305 % Fuel Clad outer Plate  11
cell 2145  2  h2o     44  -45  -80  81 -307 305 % Water between Plates 11 and 12
cell 2146  2  zirc4   45  -46  -80  81 -307 305 % Fuel Clad inner Plate  12
cell 2147  2  fuel24  46  -47  -80  81 -307 305 % Fuel Meat Plate  12
cell 2148  2  zirc4   47  -48  -80  81 -307 305 % Fuel Clad outer Plate  12

% *** ESE Octant ***
cell 2202  2  zirc4    1  -2   -80  81 -304 311 % Fuel Clad inner Plate  1
cell 2203  2  fuel13   2  -3   -80  81 -304 311 % Fuel Meat Plate  1
cell 2204  2  zirc4    3  -4   -80  81 -304 311 % Fuel Clad outer Plate  1
cell 2205  2  h2o      4  -5   -80  81 -304 311 % Water between Plates 1 and 2
cell 2206  2  zirc4    5  -6   -80  81 -304 311 % Fuel Clad inner Plate  2
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cell 2207  2  fuel14    6   -7   -80  81 -304 311 % Fuel Meat Plate  2
cell 2208  2  zirc4     7   -8   -80  81 -304 311 % Fuel Clad outer Plate  2
cell 2209  2  h2o       8   -9   -80  81 -304 311 % Water between Plates 2 and 3
cell 2210  2  zirc4     9  -10   -80  81 -304 311 % Fuel Clad inner Plate  3
cell 2211  2  fuel15   10  -11   -80  81 -304 311 % Fuel Meat Plate  3
cell 2212  2  zirc4    11  -12   -80  81 -304 311 % Fuel Clad outer Plate  3
cell 2213  2  h2o      12  -13   -80  81 -304 311 % Water between Plates 3 and 4
cell 2214  2  zirc4    13  -14   -80  81 -304 311 % Fuel Clad inner Plate  4
cell 2215  2  fuel16   14  -15   -80  81 -304 311 % Fuel Meat Plate  4
cell 2216  2  zirc4    15  -16   -80  81 -304 311 % Fuel Clad outer Plate  4
cell 2217  2  h2o      16  -17   -80  81 -304 311 % Water between Plates 4 and 5
cell 2218  2  zirc4    17  -18   -80  81 -304 311 % Fuel Clad inner Plate  5
cell 2219  2  fuel17   18  -19   -80  81 -304 311 % Fuel Meat Plate  5
cell 2220  2  zirc4    19  -20   -80  81 -304 311 % Fuel Clad outer Plate  5
cell 2221  2  h2o      20  -21   -80  81 -304 311 % Water between Plates 5 and 6
cell 2222  2  zirc4    21  -22   -80  81 -304 311 % Fuel Clad inner Plate  6
cell 2223  2  fuel18   22  -23   -80  81 -304 311 % Fuel Meat Plate  6
cell 2224  2  zirc4    23  -24   -80  81 -304 311 % Fuel Clad outer Plate  6
cell 2225  2  h2o      24  -25   -80  81 -304 311 % Water between Plates 6 and 7
cell 2226  2  zirc4    25  -26   -80  81 -304 311 % Fuel Clad inner Plate  7
cell 2227  2  fuel19   26  -27   -80  81 -304 311 % Fuel Meat Plate  7
cell 2228  2  zirc4    27  -28   -80  81 -304 311 % Fuel Clad outer Plate  7
cell 2229  2  h2o      28  -29   -80  81 -304 311 % Water between Plates 7 and 8
cell 2230  2  zirc4    29  -30   -80  81 -304 311 % Fuel Clad inner Plate  8
cell 2231  2  fuel20   30  -31   -80  81 -304 311 % Fuel Meat Plate  8
cell 2232  2  zirc4    31  -32   -80  81 -304 311 % Fuel Clad outer Plate  8
cell 2233  2  h2o      32  -33   -80  81 -304 311 % Water between Plates 8 and 9
cell 2234  2  zirc4    33  -34   -80  81 -304 311 % Fuel Clad inner Plate  9
cell 2235  2  fuel21   34  -35   -80  81 -304 311 % Fuel Meat Plate  9
cell 2236  2  zirc4    35  -36   -80  81 -304 311 % Fuel Clad outer Plate  9
cell 2237  2  h2o      36  -37   -80  81 -304 311 % Water between Plates 9 and 10
cell 2238  2  zirc4    37  -38   -80  81 -304 311 % Fuel Clad inner Plate  10
cell 2239  2  fuel22   38  -39   -80  81 -304 311 % Fuel Meat Plate  10
cell 2240  2  zirc4    39  -40   -80  81 -304 311 % Fuel Clad outer Plate  10
cell 2241  2  h2o      40  -41   -80  81 -304 311 % Water between Plates 10 and 11
cell 2242  2  zirc4    41  -42   -80  81 -304 311 % Fuel Clad inner Plate  11
cell 2243  2  fuel23   42  -43   -80  81 -304 311 % Fuel Meat Plate  11
cell 2244  2  zirc4    43  -44   -80  81 -304 311 % Fuel Clad outer Plate  11
cell 2245  2  h2o      44  -45   -80  81 -304 311 % Water between Plates 11 and 12
cell 2246  2  zirc4    45  -46   -80  81 -304 311 % Fuel Clad inner Plate  12
cell 2247  2  fuel24   46  -47   -80  81 -304 311 % Fuel Meat Plate  12
cell 2248  2  zirc4    47  -48   -80  81 -304 311 % Fuel Clad outer Plate  12

% *** SSE Octant ***
cell 2302  2  zirc4     1   -2   -80  81 -310 302 % Fuel Clad inner Plate  1
cell 2303  2  fuel13    2   -3   -80  81 -310 302 % Fuel Meat Plate  1
cell 2304  2  zirc4     3   -4   -80  81 -310 302 % Fuel Clad outer Plate  1
cell 2305  2  h2o       4   -5   -80  81 -310 302 % Water between Plates 1 and 2
cell 2306  2  zirc4     5   -6   -80  81 -310 302 % Fuel Clad inner Plate  2
cell 2307  2  fuel14    6   -7   -80  81 -310 302 % Fuel Meat Plate  2
cell 2308  2  zirc4     7   -8   -80  81 -310 302 % Fuel Clad outer Plate  2
cell 2309  2  h2o       8   -9   -80  81 -310 302 % Water between Plates 2 and 3
cell 2310  2  zirc4     9  -10   -80  81 -310 302 % Fuel Clad inner Plate  3
cell 2311  2  fuel15   10  -11   -80  81 -310 302 % Fuel Meat Plate  3
cell 2312  2  zirc4    11  -12   -80  81 -310 302 % Fuel Clad outer Plate  3
cell 2313  2  h2o      12  -13   -80  81 -310 302 % Water between Plates 3 and 4
cell 2314  2  zirc4    13  -14   -80  81 -310 302 % Fuel Clad inner Plate  4
cell 2315  2  fuel16   14  -15   -80  81 -310 302 % Fuel Meat Plate  4
cell 2316  2  zirc4    15  -16   -80  81 -310 302 % Fuel Clad outer Plate  4
cell 2317  2  h2o      16  -17   -80  81 -310 302 % Water between Plates 4 and 5
cell 2318  2  zirc4    17  -18   -80  81 -310 302 % Fuel Clad inner Plate  5
cell 2319  2  fuel17   18  -19   -80  81 -310 302 % Fuel Meat Plate  5
cell 2320  2  zirc4    19  -20   -80  81 -310 302 % Fuel Clad outer Plate  5
cell 2321  2  h2o      20  -21   -80  81 -310 302 % Water between Plates 5 and 6
cell 2322  2  zirc4    21  -22   -80  81 -310 302 % Fuel Clad inner Plate  6
cell 2323  2  fuel18   22  -23   -80  81 -310 302 % Fuel Meat Plate  6
cell 2324  2  zirc4    23  -24   -80  81 -310 302 % Fuel Clad outer Plate  6
cell 2325  2  h2o      24  -25   -80  81 -310 302 % Water between Plates 6 and 7
cell 2326  2  zirc4    25  -26   -80  81 -310 302 % Fuel Clad inner Plate  7
cell 2327  2  fuel19   26  -27   -80  81 -310 302 % Fuel Meat Plate  7
cell 2328  2  zirc4    27  -28   -80  81 -310 302 % Fuel Clad outer Plate  7
cell 2329  2  h2o      28  -29   -80  81 -310 302 % Water between Plates 7 and 8
cell 2330  2  zirc4    29  -30   -80  81 -310 302 % Fuel Clad inner Plate  8
cell 2331  2  fuel20   30  -31   -80  81 -310 302 % Fuel Meat Plate  8
cell 2332  2  zirc4    31  -32   -80  81 -310 302 % Fuel Clad outer Plate  8
cell 2333  2  h2o      32  -33   -80  81 -310 302 % Water between Plates 8 and 9
cell 2334  2  zirc4    33  -34   -80  81 -310 302 % Fuel Clad inner Plate  9
cell 2335  2  fuel21   34  -35   -80  81 -310 302 % Fuel Meat Plate  9
cell 2336  2  zirc4    35  -36   -80  81 -310 302 % Fuel Clad outer Plate  9
cell 2337  2  h2o      36  -37   -80  81 -310 302 % Water between Plates 9 and 10
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cell 2338  2  zirc4    37  -38   -80  81 -310 302 % Fuel Clad inner Plate  10
cell 2339  2  fuel22   38  -39   -80  81 -310 302 % Fuel Meat Plate  10
cell 2340  2  zirc4    39  -40   -80  81 -310 302 % Fuel Clad outer Plate  10
cell 2341  2  h2o      40  -41   -80  81 -310 302 % Water between Plates 10 and 11
cell 2342  2  zirc4    41  -42   -80  81 -310 302 % Fuel Clad inner Plate  11
cell 2343  2  fuel23   42  -43   -80  81 -310 302 % Fuel Meat Plate  11
cell 2344  2  zirc4    43  -44   -80  81 -310 302 % Fuel Clad outer Plate  11
cell 2345  2  h2o      44  -45   -80  81 -310 302 % Water between Plates 11 and 12
cell 2346  2  zirc4    45  -46   -80  81 -310 302 % Fuel Clad inner Plate  12
cell 2347  2  fuel24   46  -47   -80  81 -310 302 % Fuel Meat Plate  12
cell 2348  2  zirc4    47  -48   -80  81 -310 302 % Fuel Clad outer Plate  12

% *** SSW Octant ***
cell 2402  2  zirc4    1   -2  -80  81 -301 -307 % Fuel Clad inner Plate  1
cell 2403  2  fuel13   2   -3  -80  81 -301 -307 % Fuel Meat Plate  1
cell 2404  2  zirc4    3   -4  -80  81 -301 -307 % Fuel Clad outer Plate  1
cell 2405  2  h2o      4   -5  -80  81 -301 -307 % Water between Plates 1 and 2
cell 2406  2  zirc4    5   -6  -80  81 -301 -307 % Fuel Clad inner Plate  2
cell 2407  2  fuel14   6   -7  -80  81 -301 -307 % Fuel Meat Plate  2
cell 2408  2  zirc4    7   -8  -80  81 -301 -307 % Fuel Clad outer Plate  2
cell 2409  2  h2o      8   -9  -80  81 -301 -307 % Water between Plates 2 and 3
cell 2410  2  zirc4    9  -10  -80  81 -301 -307 % Fuel Clad inner Plate  3
cell 2411  2  fuel15   10  -11  -80  81 -301 -307 % Fuel Meat Plate  3
cell 2412  2  zirc4    11  -12  -80  81 -301 -307 % Fuel Clad outer Plate  3
cell 2413  2  h2o      12  -13  -80  81 -301 -307 % Water between Plates 3 and 4
cell 2414  2  zirc4    13  -14  -80  81 -301 -307 % Fuel Clad inner Plate  4
cell 2415  2  fuel16   14  -15  -80  81 -301 -307 % Fuel Meat Plate  4
cell 2416  2  zirc4    15  -16  -80  81 -301 -307 % Fuel Clad outer Plate  4
cell 2417  2  h2o      16  -17  -80  81 -301 -307 % Water between Plates 4 and 5
cell 2418  2  zirc4    17  -18  -80  81 -301 -307 % Fuel Clad inner Plate  5
cell 2419  2  fuel17   18  -19  -80  81 -301 -307 % Fuel Meat Plate  5
cell 2420  2  zirc4    19  -20  -80  81 -301 -307 % Fuel Clad outer Plate  5
cell 2421  2  h2o      20  -21  -80  81 -301 -307 % Water between Plates 5 and 6
cell 2422  2  zirc4    21  -22  -80  81 -301 -307 % Fuel Clad inner Plate  6
cell 2423  2  fuel18   22  -23  -80  81 -301 -307 % Fuel Meat Plate  6
cell 2424  2  zirc4    23  -24  -80  81 -301 -307 % Fuel Clad outer Plate  6
cell 2425  2  h2o      24  -25  -80  81 -301 -307 % Water between Plates 6 and 7
cell 2426  2  zirc4    25  -26  -80  81 -301 -307 % Fuel Clad inner Plate  7
cell 2427  2  fuel19   26  -27  -80  81 -301 -307 % Fuel Meat Plate  7
cell 2428  2  zirc4    27  -28  -80  81 -301 -307 % Fuel Clad outer Plate  7
cell 2429  2  h2o      28  -29  -80  81 -301 -307 % Water between Plates 7 and 8
cell 2430  2  zirc4    29  -30  -80  81 -301 -307 % Fuel Clad inner Plate  8
cell 2431  2  fuel20   30  -31  -80  81 -301 -307 % Fuel Meat Plate  8
cell 2432  2  zirc4    31  -32  -80  81 -301 -307 % Fuel Clad outer Plate  8
cell 2433  2  h2o      32  -33  -80  81 -301 -307 % Water between Plates 8 and 9
cell 2434  2  zirc4    33  -34  -80  81 -301 -307 % Fuel Clad inner Plate  9
cell 2435  2  fuel21   34  -35  -80  81 -301 -307 % Fuel Meat Plate  9
cell 2436  2  zirc4    35  -36  -80  81 -301 -307 % Fuel Clad outer Plate  9
cell 2437  2  h2o      36  -37  -80  81 -301 -307 % Water between Plates 9 and 10
cell 2438  2  zirc4    37  -38  -80  81 -301 -307 % Fuel Clad inner Plate  10
cell 2439  2  fuel22   38  -39  -80  81 -301 -307 % Fuel Meat Plate  10
cell 2440  2  zirc4    39  -40  -80  81 -301 -307 % Fuel Clad outer Plate  10
cell 2441  2  h2o      40  -41  -80  81 -301 -307 % Water between Plates 10 and 11
cell 2442  2  zirc4    41  -42  -80  81 -301 -307 % Fuel Clad inner Plate  11
cell 2443  2  fuel23   42  -43  -80  81 -301 -307 % Fuel Meat Plate  11
cell 2444  2  zirc4    43  -44  -80  81 -301 -307 % Fuel Clad outer Plate  11
cell 2445  2  h2o      44  -45  -80  81 -301 -307 % Water between Plates 11 and 12
cell 2446  2  zirc4    45  -46  -80  81 -301 -307 % Fuel Clad inner Plate  12
cell 2447  2  fuel24   46  -47  -80  81 -301 -307 % Fuel Meat Plate  12
cell 2448  2  zirc4    47  -48  -80  81 -301 -307 % Fuel Clad outer Plate  12

% *** WSW Octant ***
cell 2502  2  zirc4    1   -2   -80  81 -304 308 % Fuel Clad inner Plate  1
cell 2503  2  fuel13   2   -3   -80  81 -304 308 % Fuel Meat Plate  1
cell 2504  2  zirc4    3   -4   -80  81 -304 308 % Fuel Clad outer Plate  1
cell 2505  2  h2o      4   -5   -80  81 -304 308 % Water between Plates 1 and 2
cell 2506  2  zirc4    5   -6   -80  81 -304 308 % Fuel Clad inner Plate  2
cell 2507  2  fuel14   6   -7   -80  81 -304 308 % Fuel Meat Plate  2
cell 2508  2  zirc4    7   -8   -80  81 -304 308 % Fuel Clad outer Plate  2
cell 2509  2  h2o      8   -9   -80  81 -304 308 % Water between Plates 2 and 3
cell 2510  2  zirc4    9  -10   -80  81 -304 308 % Fuel Clad inner Plate  3
cell 2511  2  fuel15   10  -11   -80  81 -304 308 % Fuel Meat Plate  3
cell 2512  2  zirc4    11  -12   -80  81 -304 308 % Fuel Clad outer Plate  3
cell 2513  2  h2o      12  -13   -80  81 -304 308 % Water between Plates 3 and 4
cell 2514  2  zirc4    13  -14   -80  81 -304 308 % Fuel Clad inner Plate  4
cell 2515  2  fuel16   14  -15   -80  81 -304 308 % Fuel Meat Plate  4
cell 2516  2  zirc4    15  -16   -80  81 -304 308 % Fuel Clad outer Plate  4
cell 2517  2  h2o      16  -17   -80  81 -304 308 % Water between Plates 4 and 5
cell 2518  2  zirc4    17  -18   -80  81 -304 308 % Fuel Clad inner Plate  5
cell 2519  2  fuel17   18  -19   -80  81 -304 308 % Fuel Meat Plate  5
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cell 2520  2  zirc4    19  -20   -80  81 -304 308 % Fuel Clad outer Plate  5
cell 2521  2  h2o      20  -21   -80  81 -304 308 % Water between Plates 5 and 6
cell 2522  2  zirc4    21  -22   -80  81 -304 308 % Fuel Clad inner Plate  6
cell 2523  2  fuel18   22  -23   -80  81 -304 308 % Fuel Meat Plate  6
cell 2524  2  zirc4    23  -24   -80  81 -304 308 % Fuel Clad outer Plate  6
cell 2525  2  h2o      24  -25   -80  81 -304 308 % Water between Plates 6 and 7
cell 2526  2  zirc4    25  -26   -80  81 -304 308 % Fuel Clad inner Plate  7
cell 2527  2  fuel19   26  -27   -80  81 -304 308 % Fuel Meat Plate  7
cell 2528  2  zirc4    27  -28   -80  81 -304 308 % Fuel Clad outer Plate  7
cell 2529  2  h2o      28  -29   -80  81 -304 308 % Water between Plates 7 and 8
cell 2530  2  zirc4    29  -30   -80  81 -304 308 % Fuel Clad inner Plate  8
cell 2531  2  fuel20   30  -31   -80  81 -304 308 % Fuel Meat Plate  8
cell 2532  2  zirc4    31  -32   -80  81 -304 308 % Fuel Clad outer Plate  8
cell 2533  2  h2o      32  -33   -80  81 -304 308 % Water between Plates 8 and 9
cell 2534  2  zirc4    33  -34   -80  81 -304 308 % Fuel Clad inner Plate  9
cell 2535  2  fuel21   34  -35   -80  81 -304 308 % Fuel Meat Plate  9
cell 2536  2  zirc4    35  -36   -80  81 -304 308 % Fuel Clad outer Plate  9
cell 2537  2  h2o      36  -37   -80  81 -304 308 % Water between Plates 9 and 10
cell 2538  2  zirc4    37  -38   -80  81 -304 308 % Fuel Clad inner Plate  10
cell 2539  2  fuel22   38  -39   -80  81 -304 308 % Fuel Meat Plate  10
cell 2540  2  zirc4    39  -40   -80  81 -304 308 % Fuel Clad outer Plate  10
cell 2541  2  h2o      40  -41   -80  81 -304 308 % Water between Plates 10 and 11
cell 2542  2  zirc4    41  -42   -80  81 -304 308 % Fuel Clad inner Plate  11
cell 2543  2  fuel23   42  -43   -80  81 -304 308 % Fuel Meat Plate  11
cell 2544  2  zirc4    43  -44   -80  81 -304 308 % Fuel Clad outer Plate  11
cell 2545  2  h2o      44  -45   -80  81 -304 308 % Water between Plates 11 and 12
cell 2546  2  zirc4    45  -46   -80  81 -304 308 % Fuel Clad inner Plate  12
cell 2547  2  fuel24   46  -47   -80  81 -304 308 % Fuel Meat Plate  12
cell 2548  2  zirc4    47  -48   -80  81 -304 308 % Fuel Clad outer Plate  12

% *** WNW Octant ***
cell 2602  2  zirc4     1   -2   -80  81 -310 305 % Fuel Clad inner Plate  1
cell 2603  2  fuel13    2   -3   -80  81 -310 305 % Fuel Meat Plate  1
cell 2604  2  zirc4     3   -4   -80  81 -310 305 % Fuel Clad outer Plate  1
cell 2605  2  h2o       4   -5   -80  81 -310 305 % Water between Plates 1 and 2
cell 2606  2  zirc4     5   -6   -80  81 -310 305 % Fuel Clad inner Plate  2
cell 2607  2  fuel14    6   -7   -80  81 -310 305 % Fuel Meat Plate  2
cell 2608  2  zirc4     7   -8   -80  81 -310 305 % Fuel Clad outer Plate  2
cell 2609  2  h2o       8   -9   -80  81 -310 305 % Water between Plates 2 and 3
cell 2610  2  zirc4     9  -10   -80  81 -310 305 % Fuel Clad inner Plate  3
cell 2611  2  fuel15   10  -11   -80  81 -310 305 % Fuel Meat Plate  3
cell 2612  2  zirc4    11  -12   -80  81 -310 305 % Fuel Clad outer Plate  3
cell 2613  2  h2o      12  -13   -80  81 -310 305 % Water between Plates 3 and 4
cell 2614  2  zirc4    13  -14   -80  81 -310 305 % Fuel Clad inner Plate  4
cell 2615  2  fuel16   14  -15   -80  81 -310 305 % Fuel Meat Plate  4
cell 2616  2  zirc4    15  -16   -80  81 -310 305 % Fuel Clad outer Plate  4
cell 2617  2  h2o      16  -17   -80  81 -310 305 % Water between Plates 4 and 5
cell 2618  2  zirc4    17  -18   -80  81 -310 305 % Fuel Clad inner Plate  5
cell 2619  2  fuel17   18  -19   -80  81 -310 305 % Fuel Meat Plate  5
cell 2620  2  zirc4    19  -20   -80  81 -310 305 % Fuel Clad outer Plate  5
cell 2621  2  h2o      20  -21   -80  81 -310 305 % Water between Plates 5 and 6
cell 2622  2  zirc4    21  -22   -80  81 -310 305 % Fuel Clad inner Plate  6
cell 2623  2  fuel18   22  -23   -80  81 -310 305 % Fuel Meat Plate  6
cell 2624  2  zirc4    23  -24   -80  81 -310 305 % Fuel Clad outer Plate  6
cell 2625  2  h2o      24  -25   -80  81 -310 305 % Water between Plates 6 and 7
cell 2626  2  zirc4    25  -26   -80  81 -310 305 % Fuel Clad inner Plate  7
cell 2627  2  fuel19   26  -27   -80  81 -310 305 % Fuel Meat Plate  7
cell 2628  2  zirc4    27  -28   -80  81 -310 305 % Fuel Clad outer Plate  7
cell 2629  2  h2o      28  -29   -80  81 -310 305 % Water between Plates 7 and 8
cell 2630  2  zirc4    29  -30   -80  81 -310 305 % Fuel Clad inner Plate  8
cell 2631  2  fuel20   30  -31   -80  81 -310 305 % Fuel Meat Plate  8
cell 2632  2  zirc4    31  -32   -80  81 -310 305 % Fuel Clad outer Plate  8
cell 2633  2  h2o      32  -33   -80  81 -310 305 % Water between Plates 8 and 9
cell 2634  2  zirc4    33  -34   -80  81 -310 305 % Fuel Clad inner Plate  9
cell 2635  2  fuel21   34  -35   -80  81 -310 305 % Fuel Meat Plate  9
cell 2636  2  zirc4    35  -36   -80  81 -310 305 % Fuel Clad outer Plate  9
cell 2637  2  h2o      36  -37   -80  81 -310 305 % Water between Plates 9 and 10
cell 2638  2  zirc4    37  -38   -80  81 -310 305 % Fuel Clad inner Plate  10
cell 2639  2  fuel22   38  -39   -80  81 -310 305 % Fuel Meat Plate  10
cell 2640  2  zirc4    39  -40   -80  81 -310 305 % Fuel Clad outer Plate  10
cell 2641  2  h2o      40  -41   -80  81 -310 305 % Water between Plates 10 and 11
cell 2642  2  zirc4    41  -42   -80  81 -310 305 % Fuel Clad inner Plate  11
cell 2643  2  fuel23   42  -43   -80  81 -310 305 % Fuel Meat Plate  11
cell 2644  2  zirc4    43  -44   -80  81 -310 305 % Fuel Clad outer Plate  11
cell 2645  2  h2o      44  -45   -80  81 -310 305 % Water between Plates 11 and 12
cell 2646  2  zirc4    45  -46   -80  81 -310 305 % Fuel Clad inner Plate  12
cell 2647  2  fuel24   46  -47   -80  81 -310 305 % Fuel Meat Plate  12
cell 2648  2  zirc4    47  -48   -80  81 -310 305 % Fuel Clad outer Plate  12

% *** NNW Octant ***
```

```
cell 2702  2  zirc4    1   -2  -80  81 311 -301 % Fuel Clad inner Plate  1
cell 2703  2  fuel13   2   -3  -80  81 311 -301 % Fuel Meat Plate  1
cell 2704  2  zirc4    3   -4  -80  81 311 -301 % Fuel Clad outer Plate  1
cell 2705  2  h2o      4   -5  -80  81 311 -301 % Water between Plates 1 and 2
cell 2706  2  zirc4    5   -6  -80  81 311 -301 % Fuel Clad inner Plate  2
cell 2707  2  fuel14   6   -7  -80  81 311 -301 % Fuel Meat Plate  2
cell 2708  2  zirc4    7   -8  -80  81 311 -301 % Fuel Clad outer Plate  2
cell 2709  2  h2o      8   -9  -80  81 311 -301 % Water between Plates 2 and 3
cell 2710  2  zirc4    9  -10  -80  81 311 -301 % Fuel Clad inner Plate  3
cell 2711  2  fuel15  10  -11  -80  81 311 -301 % Fuel Meat Plate  3
cell 2712  2  zirc4   11  -12  -80  81 311 -301 % Fuel Clad outer Plate  3
cell 2713  2  h2o     12  -13  -80  81 311 -301 % Water between Plates 3 and 4
cell 2714  2  zirc4   13  -14  -80  81 311 -301 % Fuel Clad inner Plate  4
cell 2715  2  fuel16  14  -15  -80  81 311 -301 % Fuel Meat Plate  4
cell 2716  2  zirc4   15  -16  -80  81 311 -301 % Fuel Clad outer Plate  4
cell 2717  2  h2o     16  -17  -80  81 311 -301 % Water between Plates 4 and 5
cell 2718  2  zirc4   17  -18  -80  81 311 -301 % Fuel Clad inner Plate  5
cell 2719  2  fuel17  18  -19  -80  81 311 -301 % Fuel Meat Plate  5
cell 2720  2  zirc4   19  -20  -80  81 311 -301 % Fuel Clad outer Plate  5
cell 2721  2  h2o     20  -21  -80  81 311 -301 % Water between Plates 5 and 6
cell 2722  2  zirc4   21  -22  -80  81 311 -301 % Fuel Clad inner Plate  6
cell 2723  2  fuel18  22  -23  -80  81 311 -301 % Fuel Meat Plate  6
cell 2724  2  zirc4   23  -24  -80  81 311 -301 % Fuel Clad outer Plate  6
cell 2725  2  h2o     24  -25  -80  81 311 -301 % Water between Plates 6 and 7
cell 2726  2  zirc4   25  -26  -80  81 311 -301 % Fuel Clad inner Plate  7
cell 2727  2  fuel19  26  -27  -80  81 311 -301 % Fuel Meat Plate  7
cell 2728  2  zirc4   27  -28  -80  81 311 -301 % Fuel Clad outer Plate  7
cell 2729  2  h2o     28  -29  -80  81 311 -301 % Water between Plates 7 and 8
cell 2730  2  zirc4   29  -30  -80  81 311 -301 % Fuel Clad inner Plate  8
cell 2731  2  fuel20  30  -31  -80  81 311 -301 % Fuel Meat Plate  8
cell 2732  2  zirc4   31  -32  -80  81 311 -301 % Fuel Clad outer Plate  8
cell 2733  2  h2o     32  -33  -80  81 311 -301 % Water between Plates 8 and 9
cell 2734  2  zirc4   33  -34  -80  81 311 -301 % Fuel Clad inner Plate  9
cell 2735  2  fuel21  34  -35  -80  81 311 -301 % Fuel Meat Plate  9
cell 2736  2  zirc4   35  -36  -80  81 311 -301 % Fuel Clad outer Plate  9
cell 2737  2  h2o     36  -37  -80  81 311 -301 % Water between Plates 9 and 10
cell 2738  2  zirc4   37  -38  -80  81 311 -301 % Fuel Clad inner Plate  10
cell 2739  2  fuel22  38  -39  -80  81 311 -301 % Fuel Meat Plate  10
cell 2740  2  zirc4   39  -40  -80  81 311 -301 % Fuel Clad outer Plate  10
cell 2741  2  h2o     40  -41  -80  81 311 -301 % Water between Plates 10 and 11
cell 2742  2  zirc4   41  -42  -80  81 311 -301 % Fuel Clad inner Plate  11
cell 2743  2  fuel23  42  -43  -80  81 311 -301 % Fuel Meat Plate  11
cell 2744  2  zirc4   43  -44  -80  81 311 -301 % Fuel Clad outer Plate  11
cell 2745  2  h2o     44  -45  -80  81 311 -301 % Water between Plates 11 and 12
cell 2746  2  zirc4   45  -46  -80  81 311 -301 % Fuel Clad inner Plate  12
cell 2747  2  fuel24  46  -47  -80  81 311 -301 % Fuel Meat Plate  12
cell 2748  2  zirc4   47  -48  -80  81 311 -301 % Fuel Clad outer Plate  12

%  Other materials above and below fuel assembly
cell  577  2  h2o      1   -128     64 -203   % water above fuel assembly
cell  578  2  h2o      1   -128    -65  202   % water below fuel assembly
%  Upper and lower plates without fuel homogenized
cell 585  2  TopPlat  1  -128   80 -62        % upper end plates
cell 586  2  BotPlat  1  -128  -81  63        % lower end plates
%  Upper and lower end boxes homogenized
cell 587  2  TopBox   1  -128      62 -64     % upper end box
cell 588  2  BotBox   1  -128     -63  65     % lower end box

% Side plates (fused adjacent plates)
cell 590 2 zirc4   1 -48 301 -302  303 -80  81 % N sideplates
cell 591 2 zirc4   1 -48 307 -308  303 -80  81 % NE sideplates
cell 592 2 zirc4   1 -48 304 -305  300 -80  81 % E sideplates
cell 593 2 zirc4   1 -48 310 -311 -303 -80  81 % SE sideplates
cell 594 2 zirc4   1 -48 301 -302 -303 -80  81 % S sideplates
cell 595 2 zirc4   1 -48 307 -308 -303 -80  81 % SW sideplates
cell 596 2 zirc4   1 -48 304 -305 -300 -80  81 % W sideplates
cell 597 2 zirc4   1 -48 310 -311  303 -80  81 % NW sideplates



cell 200 4 AlRack  -201  %  large area of Rack.  used for filling lat.

lat 150  4  0 0 2
1  0. 0.  1
6 34. 0.  2 2 2 2 2 2

cell 181 0 fill 150  -205  202 -203     % inside pressure vessel
cell 182 0 al6061  205  -206  202 -203  %  pressure vessel
cell 183 0 d2o  206  -201  202 -203     % d2o outside pressure vessel
%
```

```
% ------ Void Outside Core ------
cell 9001 0 outside 201 203 % rest of universe
cell 9002 0 outside 201 -202 % rest of universe
cell 9003 0 outside -201 203 % rest of universe
cell 9004 0 outside -201 -202 % rest of universe
cell 9005 0 outside 201 -203 202 % rest of universe

% ******************************************
% ******** End Of Cell Cards **************
% ******************************************

% ******************************************
% ************ Surface Cards **************
% ******************************************

% *** Fuel Plate Cylindrical surfaces Large Central Location ****
surf  1 cyl  0.0  0.0  9.6000          % Fuel Cld inner Plate  1
surf  2 cyl  0.0  0.0  9.6375          % Fuel Mt inner Plate  1
surf  3 cyl  0.0  0.0  9.6875          % Fuel Mt outer  Plate  1
surf  4 cyl  0.0  0.0  9.7250          % Fuel Cld outer  Plate  1
surf  5 cyl  0.0  0.0  9.9250          % Fuel Cld inner Plate  2
surf  6 cyl  0.0  0.0  9.9625          % Fuel Mt inner Plate  2
surf  7 cyl  0.0  0.0  10.0125         % Fuel Mt outer  Plate  2
surf  8 cyl  0.0  0.0  10.0500         % Fuel Cld outer  Plate  2
surf  9 cyl  0.0  0.0  10.2500         % Fuel Cld inner Plate  3
surf 10 cyl  0.0  0.0  10.2875         % Fuel Mt inner Plate  3
surf 11 cyl  0.0  0.0  10.3375         % Fuel Mt outer  Plate  3
surf 12 cyl  0.0  0.0  10.3750         % Fuel Cld outer  Plate  3
surf 13 cyl  0.0  0.0  10.5750         % Fuel Cld inner Plate  4
surf 14 cyl  0.0  0.0  10.6125         % Fuel Mt inner Plate  4
surf 15 cyl  0.0  0.0  10.6625         % Fuel Mt outer  Plate  4
surf 16 cyl  0.0  0.0  10.7000         % Fuel Cld outer  Plate  4
surf 17 cyl  0.0  0.0  10.9000         % Fuel Cld inner Plate  5
surf 18 cyl  0.0  0.0  10.9375         % Fuel Mt inner Plate  5
surf 19 cyl  0.0  0.0  10.9875         % Fuel Mt outer  Plate  5
surf 20 cyl  0.0  0.0  11.0250         % Fuel Cld outer  Plate  5
surf 21 cyl  0.0  0.0  11.2250         % Fuel Cld inner Plate  6
surf 22 cyl  0.0  0.0  11.2625         % Fuel Mt inner Plate  6
surf 23 cyl  0.0  0.0  11.3125         % Fuel Mt outer  Plate  6
surf 24 cyl  0.0  0.0  11.3500         % Fuel Cld outer  Plate  6
surf 25 cyl  0.0  0.0  11.5500         % Fuel Cld inner Plate  7
surf 26 cyl  0.0  0.0  11.5875         % Fuel Mt inner Plate  7
surf 27 cyl  0.0  0.0  11.6375         % Fuel Mt outer  Plate  7
surf 28 cyl  0.0  0.0  11.6750         % Fuel Cld outer  Plate  7
surf 29 cyl  0.0  0.0  11.8750         % Fuel Cld inner Plate  8
surf 30 cyl  0.0  0.0  11.9125         % Fuel Mt inner Plate  8
surf 31 cyl  0.0  0.0  11.9625         % Fuel Mt outer  Plate  8
surf 32 cyl  0.0  0.0  12.0000         % Fuel Cld outer  Plate  8
surf 33 cyl  0.0  0.0  12.2000         % Fuel Cld inner Plate  9
surf 34 cyl  0.0  0.0  12.2375         % Fuel Mt inner Plate  9
surf 35 cyl  0.0  0.0  12.2875         % Fuel Mt outer  Plate  9
surf 36 cyl  0.0  0.0  12.3250         % Fuel Cld outer  Plate  9
surf 37 cyl  0.0  0.0  12.5250         % Fuel Cld inner Plate 10
surf 38 cyl  0.0  0.0  12.5625         % Fuel Mt inner Plate 10
surf 39 cyl  0.0  0.0  12.6125         % Fuel Mt outer  Plate 10
surf 40 cyl  0.0  0.0  12.6500         % Fuel Cld outer  Plate 10
surf 41 cyl  0.0  0.0  12.8500         % Fuel Cld inner Plate 11
surf 42 cyl  0.0  0.0  12.8875         % Fuel Mt inner Plate 11
surf 43 cyl  0.0  0.0  12.9375         % Fuel Mt outer  Plate 11
surf 44 cyl  0.0  0.0  12.9750         % Fuel Cld outer  Plate 11
surf 45 cyl  0.0  0.0  13.1750         % Fuel Cld inner Plate 12
surf 46 cyl  0.0  0.0  13.2125         % Fuel Mt inner Plate 12
surf 47 cyl  0.0  0.0  13.2625         % Fuel Mt outer  Plate 12
surf 48 cyl  0.0  0.0  13.3000         % Fuel Cld outer  Plate 12

% *** vertical planes separating arcuate assemblies
surf 300 px  0.0
surf 301 px -0.475
surf 302 px  0.475

surf 303 py  0.0
surf 304 py -0.475
surf 305 py  0.475

surf 306 plane  -1.0 1.0 0.0  0.0
surf 307 plane  -1.0 1.0 0.0 -0.671751442
surf 308 plane  -1.0 1.0 0.0  0.671751442

surf 309 plane   1.0 1.0 0.0  0.0
surf 310 plane   1.0 1.0 0.0 -0.671751442
```

```
surf 311 plane   1.0 1.0 0.0  0.671751442

% *** Top and Bottom End Plates ***
surf 80  pz  60.      % Top of fuel meat
surf 81  pz -60.      % Bottom of fuel meat
surf 62  pz  62.      % Top of plates
surf 63  pz -62.      % Bottom of plates
surf 64  pz  82.      % Top of Top End Box
surf 65  pz -82.      % Bottom of Bottom End Box

%  *** Large Test Space Surfaces ***
surf 121 cyl  0.0  0.0  6.35  % Outer surface of flux monitor holder
surf 122 cyl  0.0  0.0  6.95  % Inner surface of pressure tube
surf 123 cyl  0.0  0.0  7.85  % Outer surface of pressure tube
surf 124 cyl  0.0  0.0  7.95  % Inner surface of insulation jacket
surf 125 cyl  0.0  0.0  8.10  % Outer surface of insulation jacket
surf 126 cyl  0.0  0.0  8.70  % Inner surface of Al baffle
surf 127 cyl  0.0  0.0  9.40  % Outer surface of Al baffle
surf 128 cyl  0.0  0.0  13.5  % Inner surface of rack hole

%  *** Small Test Space Surfaces peripheral location ***
surf 220 cyl  0.0  0.0  3.54  % Outer boundary of test space
surf 221 cyl  0.0  0.0  3.70  % Outer surface of flow tube
surf 222 cyl  0.0  0.0  4.00  % Inner surface of pressure tube
surf 223 cyl  0.0  0.0  4.90  % Outer surface of pressure tube
surf 224 cyl  0.0  0.0  5.00  % Inner surface of insulation jacket
surf 225 cyl  0.0  0.0  5.30  % Outer surface of insulation jacket
surf 226 cyl  0.0  0.0  5.80  % Inner surface of safety rod guide tube
surf 227 cyl  0.0  0.0  6.40  % Outer surface of safety rod guide tube
surf 228 cyl  0.0  0.0  7.50  % Inner surface of safety rod follower
surf 229 cyl  0.0  0.0  8.30 % Outer surface of safety rod follower

% *** Pressure Vessel tank inner/outer boundary ***
surf 205  cyl 0.0 0.0 51.    %
surf 206  cyl 0.0 0.0 55.    %

% *** D2O tank outer boundary ***
surf 201  cyl 0.0 0.0 150.0   %

surf 202 pz -150.
surf 203 pz  150.

% *****************************************
% ********  End Of Surface Cards **********
% *****************************************

% vacuum boundary
set bc 1

% source points
% src 1 sp 1.24 0.0 0.0

% source entropy mesh
set entr [4 4 4 -150. 150. -150. 150. -50. 50. ]

% cross section library path !!!! for Fission machine !!!!
set acelib "/home/popema/SERPENT/SERPENT/data/xsdata_combined"
set declib "/home/popema/SERPENT/SERPENT/data/sss_endfb7.dec"
set nfylib "/home/popema/SERPENT/SERPENT/data/sss_endfb7.nfy"

plot 3 1500 1500 0 -60 60 -60 60
mesh 3 1000 1000 0 -150 150 -150 150

set power 250.E06
set opti 1
set pop 10000 1000 5 1.2
% set nbuf 10000000
% ------- Material Cards -------------------------------------------
% ------ Fuel ------
mat fuel1 4.9186E-02      tmp 433.  vol 318.7  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel2 4.9186E-02      tmp 433.  vol 330.9  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel3 4.9186E-02      tmp 433.  vol 343.2  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
```

```
    42000.03c  1.0608E-02
mat fuel4 4.9186E-02      tmp 433.  vol 355.4  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel5 4.9186E-02      tmp 433.  vol 367.7  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel6 4.9186E-02      tmp 433.  vol 379.9  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel7 4.9186E-02      tmp 433.  vol 392.2  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel8 4.9186E-02      tmp 433.  vol 404.4  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel9 4.9186E-02      tmp 433.  vol 416.7  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel10 4.9186E-02     tmp 433.  vol 428.9  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel11 4.9186E-02     tmp 433.  vol 441.2  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel12 4.9186E-02     tmp 433.  vol 453.4  burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel13 4.9186E-02     tmp 433.  vol 1951.8 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel14 4.9186E-02     tmp 433.  vol 2026.9 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel15 4.9186E-02     tmp 433.  vol 2101.9 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel16 4.9186E-02     tmp 433.  vol 2177.0 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel17 4.9186E-02     tmp 433.  vol 2252.0 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel18 4.9186E-02     tmp 433.  vol 2327.1 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel19 4.9186E-02     tmp 433.  vol 2402.1 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel20 4.9186E-02     tmp 433.  vol 2477.2 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel21 4.9186E-02     tmp 433.  vol 2552.2 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel22 4.9186E-02     tmp 433.  vol 2627.2 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel23 4.9186E-02     tmp 433.  vol 2702.3 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
```

```
    42000.03c  1.0608E-02
mat fuel24 4.9186E-02     tmp 433.  vol 2777.3 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
% ------ H2O Coolant ------
% T=70C, P=2.3 MPa, rho=0.979 g/cc
mat h2o  9.818E-02       moder h2o 1001
     1001.03c  6.545E-02
     8016.03c  3.273E-02
% ------ D2O ------
mat d2o 9.986E-02     moder d2o 1002
     1002.03c  6.657E-02
     8016.03c  3.329E-02
% ------ Al-6061 ------
mat al6061 -2.715       % Al-6061 density 2.715 g/cc
   14000.03c  -0.7   %      0.7   % Si
   26000.03c  -0.6   %      0.60  % Fe
   29000.03c  -0.22  %      0.22  % Cu
   25055.03c  -0.08  %      0.08  % Mn
   12000.03c  -1.0   %      1.0   % Mg
   24000.03c  -0.2   %      0.1   % Cr
   30000.03c  -0.08  %      0.08  % Zn
   22000.03c  -0.03  %      0.03  % Ti
   13027.03c  -97.09 %      97.09 % Al
% ------ Al-6061 Rack / part water ------
mat AlRack    6.22E-02       % 5% water
   14000.03c  3.87E-04 %
   26000.03c  1.67E-04 %
   29000.03c  5.38E-05 %
   25055.03c  2.26E-05 %
   12000.03c  6.39E-04 %
   24000.03c  5.97E-05 %
   30000.03c  1.90E-05 %
   22000.03c  9.73E-06 %
   13027.03c  5.59E-02 %
    1001.03c  3.27E-03
    8016.03c  1.64E-03
% ------ Beryllium ------
% assumed 6% by volume H2O
mat be9  1.2188E-01  moder be 4009   % moder be
   4009.03c  1.157E-01
   1001.03c  4.120E-03
   8016.03c  2.060E-03
% ------  SS 304   ------
% Fe-0.08C-2.0Mn-0.045P-0.03S-1.0Si-19Cr-9Ni
mat ss304   -8.0       % ss 304 8g/cc
    6000.03c  -0.08   %     0.08   % C
   25055.03c  -2.0    %     2.0    % Mn
   15031.03c  -0.045  %     0.045  % P
   16000.03c  -0.03   %     0.03   % S
   14000.03c  -0.75   %     0.75   % Si
   24000.03c  -19.    %     19.    % Cr
   28000.03c  -9.25   %     9.25   % Ni
    7014.03c  -0.05   %     0.05   % N
   26000.03c  -68.795 %    68.795  % Fe
% ------ Helium Coolant ------
mat helium 0.0007
     2004.03c  7.0000E-04
% ---- Al/H2O 50/50 mix in test spaces -----
mat AlH2Omix  7.929E-02  moder h2o 1001
     1001.03c  3.270E-02
     8016.03c  1.635E-02
    13027.03c  3.024E-02
% ----- Zircalloy4 -------
mat zirc4  -6.56    tmp 398.
    40000.03c  -98.23   %     98.23 % Zr
    50000.03c  -1.45    %     1.45  % Sn
    26000.03c  -0.21    %     0.21  % Fe
    24000.03c  -0.10    %     0.10  % Cr
    72000.03c  -0.01    %     0.01  % Hf
% ----- Top End Box -------
mix TopBox
  zirc4 0.20
  h2o   0.80
% ----- Bottom End Box -------
mix BotBox
  zirc4 0.20
  h2o   0.80
% ----- Top plate no fuel -------
```

```
mix TopPlat
  zirc4 0.39
  h2o   0.61
% ----- Bottom plate no fuel -------
mix BotPlat
  zirc4 0.39
  h2o   0.61

% for installation on Fission
therm h2o lwtr.01t
therm d2o hwtr.01t
therm be  be.01t

dep daytot
0.1 0.5 1.0 2.0 3.5 5.0 10.0 15. 20. 30. 40. 50. 60. 80. 100. 120. 140. 160.

% TALLIES
% Flux 1MeV cutoff in  test zones
det CTrap dc 140 du 1 dv 432. de 1MeV dx -3.   3.   1  dy  -3.  3.  1  dz -60. 60. 10
det PTrap dc 120 du 2 dv 432. de 1MeV dx 31.  37.   1  dy  -3.  3.  1  dz -60. 60. 10

% Flux broken down into 3.
det FTref1 dc 183  du 0  dv 192. de 1MeV dx  55.4  59.4 1 dy 21.7 25.7 1  dz -60. 60. 10
det FTref2 dc 183  du 0  dv 192. de 1MeV dx  73.8  77.8 1 dy 29.4 33.4 1  dz -60. 60. 10
det FTref3 dc 183  du 0  dv 192. de 1MeV dx  92.3  96.3 1 dy 37.0 41.0 1  dz -60. 60. 10
det FTref4 dc 183  du 0  dv 192. de 1MeV dx 110.8 114.8 1 dy 44.7 48.7 1  dz -60. 60. 10

ene 1MeV   1 1.0E-15 0.625E-06 1.0  20.
```

PBT – Baseline model, single-batch depletion

```
% title Initial M-A Core
% Michael Pope
%
% ******************************************
% ************   Cell Cards  **************
% ******************************************

% *** Universe 1 *** Large central Location ****
% *** Test Space ****
cell 140 1  al6061  -121              % test space
cell 142 1  h2o      121  -122         % return flow
cell 143 1  ss304    122  -123         % pressure tube
cell 144 1  helium   123  -124         % helium annulus
cell 145 1  ss304    124  -125         % insulation jacket
cell 146 1  h2o      125  -126         % water gap
cell 147 1  al6061   126  -127         % baffle
cell 148 1  h2o      127    -1         % water outside baffle inside fuel plate 1
cell 149 1  h2o       48  -128 -80  81  % water outside fuel inside Pressure vessel
cell 150 1  al6061   128  -129 -80  81  % al6061 pressure vessel next to fuel
cell 151 1  d2o      129   -80  81      % d2o outside next to fuel


% *** NNE Octant ***
cell 1002  1  zirc4    1  -2   -80  81 308 302 % Fuel Clad inner Plate  1
cell 1003  1  fuel1    2  -3   -80  81 308 302 % Fuel Meat Plate  1
cell 1004  1  zirc4    3  -4   -80  81 308 302 % Fuel Clad outer Plate  1
cell 1005  1  h2o      4  -5   -80  81 308 302 % Water between Plates 1 and 2
cell 1006  1  zirc4    5  -6   -80  81 308 302 % Fuel Clad inner Plate  2
cell 1007  1  fuel2    6  -7   -80  81 308 302 % Fuel Meat Plate  2
cell 1008  1  zirc4    7  -8   -80  81 308 302 % Fuel Clad outer Plate  2
cell 1009  1  h2o      8  -9   -80  81 308 302 % Water between Plates 2 and 3
cell 1010  1  zirc4    9  -10   -80  81 308 302 % Fuel Clad inner Plate  3
cell 1011  1  fuel3    10  -11   -80  81 308 302 % Fuel Meat Plate  3
cell 1012  1  zirc4    11  -12   -80  81 308 302 % Fuel Clad outer Plate  3
cell 1013  1  h2o      12  -13   -80  81 308 302 % Water between Plates 3 and 4
cell 1014  1  zirc4    13  -14   -80  81 308 302 % Fuel Clad inner Plate  4
cell 1015  1  fuel4    14  -15   -80  81 308 302 % Fuel Meat Plate  4
cell 1016  1  zirc4    15  -16   -80  81 308 302 % Fuel Clad outer Plate  4
cell 1017  1  h2o      16  -17   -80  81 308 302 % Water between Plates 4 and 5
cell 1018  1  zirc4    17  -18   -80  81 308 302 % Fuel Clad inner Plate  5
cell 1019  1  fuel5    18  -19   -80  81 308 302 % Fuel Meat Plate  5
cell 1020  1  zirc4    19  -20   -80  81 308 302 % Fuel Clad outer Plate  5
cell 1021  1  h2o      20  -21   -80  81 308 302 % Water between Plates 5 and 6
cell 1022  1  zirc4    21  -22   -80  81 308 302 % Fuel Clad inner Plate  6
cell 1023  1  fuel5    22  -23   -80  81 308 302 % Fuel Meat Plate  6
cell 1024  1  zirc4    23  -24   -80  81 308 302 % Fuel Clad outer Plate  6
cell 1025  1  h2o      24  -25   -80  81 308 302 % Water between Plates 6 and 7
cell 1026  1  zirc4    25  -26   -80  81 308 302 % Fuel Clad inner Plate  7
cell 1027  1  fuel7    26  -27   -80  81 308 302 % Fuel Meat Plate  7
cell 1028  1  zirc4    27  -28   -80  81 308 302 % Fuel Clad outer Plate  7
cell 1029  1  h2o      28  -29   -80  81 308 302 % Water between Plates 7 and 8
cell 1030  1  zirc4    29  -30   -80  81 308 302 % Fuel Clad inner Plate  8
cell 1031  1  fuel8    30  -31   -80  81 308 302 % Fuel Meat Plate  8
cell 1032  1  zirc4    31  -32   -80  81 308 302 % Fuel Clad outer Plate  8
cell 1033  1  h2o      32  -33   -80  81 308 302 % Water between Plates 8 and 9
cell 1034  1  zirc4    33  -34   -80  81 308 302 % Fuel Clad inner Plate  9
cell 1035  1  fuel9    34  -35   -80  81 308 302 % Fuel Meat Plate  9
cell 1036  1  zirc4    35  -36   -80  81 308 302 % Fuel Clad outer Plate  9
cell 1037  1  h2o      36  -37   -80  81 308 302 % Water between Plates 9 and 10
cell 1038  1  zirc4    37  -38   -80  81 308 302 % Fuel Clad inner Plate  10
cell 1039  1  fuel10   38  -39   -80  81 308 302 % Fuel Meat Plate  10
cell 1040  1  zirc4    39  -40   -80  81 308 302 % Fuel Clad outer Plate  10
cell 1041  1  h2o      40  -41   -80  81 308 302 % Water between Plates 10 and 11
cell 1042  1  zirc4    41  -42   -80  81 308 302 % Fuel Clad inner Plate  11
cell 1043  1  fuel11   42  -43   -80  81 308 302 % Fuel Meat Plate  11
cell 1044  1  zirc4    43  -44   -80  81 308 302 % Fuel Clad outer Plate  11
cell 1045  1  h2o      44  -45   -80  81 308 302 % Water between Plates 11 and 12
cell 1046  1  zirc4    45  -46   -80  81 308 302 % Fuel Clad inner Plate  12
cell 1047  1  fuel12   46  -47   -80  81 308 302 % Fuel Meat Plate  12
cell 1048  1  zirc4    47  -48   -80  81 308 302 % Fuel Clad outer Plate  12

% *** ENE Octant ***
cell 1102  1  zirc4    1  -2   -80  81 -307 305 % Fuel Clad inner Plate  1
cell 1103  1  fuel1    2  -3   -80  81 -307 305 % Fuel Meat Plate  1
cell 1104  1  zirc4    3  -4   -80  81 -307 305 % Fuel Clad outer Plate  1
cell 1105  1  h2o      4  -5   -80  81 -307 305 % Water between Plates 1 and 2
cell 1106  1  zirc4    5  -6   -80  81 -307 305 % Fuel Clad inner Plate  2
```

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cell 1107  1  fuel2     6   -7   -80  81 -307 305 % Fuel Meat Plate  2
cell 1108  1  zirc4     7   -8   -80  81 -307 305 % Fuel Clad outer Plate  2
cell 1109  1  h2o       8   -9   -80  81 -307 305 % Water between Plates 2 and 3
cell 1110  1  zirc4     9  -10   -80  81 -307 305 % Fuel Clad inner Plate  3
cell 1111  1  fuel3    10  -11   -80  81 -307 305 % Fuel Meat Plate  3
cell 1112  1  zirc4    11  -12   -80  81 -307 305 % Fuel Clad outer Plate  3
cell 1113  1  h2o      12  -13   -80  81 -307 305 % Water between Plates 3 and 4
cell 1114  1  zirc4    13  -14   -80  81 -307 305 % Fuel Clad inner Plate  4
cell 1115  1  fuel4    14  -15   -80  81 -307 305 % Fuel Meat Plate  4
cell 1116  1  zirc4    15  -16   -80  81 -307 305 % Fuel Clad outer Plate  4
cell 1117  1  h2o      16  -17   -80  81 -307 305 % Water between Plates 4 and 5
cell 1118  1  zirc4    17  -18   -80  81 -307 305 % Fuel Clad inner Plate  5
cell 1119  1  fuel5    18  -19   -80  81 -307 305 % Fuel Meat Plate  5
cell 1120  1  zirc4    19  -20   -80  81 -307 305 % Fuel Clad outer Plate  5
cell 1121  1  h2o      20  -21   -80  81 -307 305 % Water between Plates 5 and 6
cell 1122  1  zirc4    21  -22   -80  81 -307 305 % Fuel Clad inner Plate  6
cell 1123  1  fuel5    22  -23   -80  81 -307 305 % Fuel Meat Plate  6
cell 1124  1  zirc4    23  -24   -80  81 -307 305 % Fuel Clad outer Plate  6
cell 1125  1  h2o      24  -25   -80  81 -307 305 % Water between Plates 6 and 7
cell 1126  1  zirc4    25  -26   -80  81 -307 305 % Fuel Clad inner Plate  7
cell 1127  1  fuel7    26  -27   -80  81 -307 305 % Fuel Meat Plate  7
cell 1128  1  zirc4    27  -28   -80  81 -307 305 % Fuel Clad outer Plate  7
cell 1129  1  h2o      28  -29   -80  81 -307 305 % Water between Plates 7 and 8
cell 1130  1  zirc4    29  -30   -80  81 -307 305 % Fuel Clad inner Plate  8
cell 1131  1  fuel8    30  -31   -80  81 -307 305 % Fuel Meat Plate  8
cell 1132  1  zirc4    31  -32   -80  81 -307 305 % Fuel Clad outer Plate  8
cell 1133  1  h2o      32  -33   -80  81 -307 305 % Water between Plates 8 and 9
cell 1134  1  zirc4    33  -34   -80  81 -307 305 % Fuel Clad inner Plate  9
cell 1135  1  fuel9    34  -35   -80  81 -307 305 % Fuel Meat Plate  9
cell 1136  1  zirc4    35  -36   -80  81 -307 305 % Fuel Clad outer Plate  9
cell 1137  1  h2o      36  -37   -80  81 -307 305 % Water between Plates 9 and 10
cell 1138  1  zirc4    37  -38   -80  81 -307 305 % Fuel Clad inner Plate  10
cell 1139  1  fuel10   38  -39   -80  81 -307 305 % Fuel Meat Plate  10
cell 1140  1  zirc4    39  -40   -80  81 -307 305 % Fuel Clad outer Plate  10
cell 1141  1  h2o      40  -41   -80  81 -307 305 % Water between Plates 10 and 11
cell 1142  1  zirc4    41  -42   -80  81 -307 305 % Fuel Clad inner Plate  11
cell 1143  1  fuel11   42  -43   -80  81 -307 305 % Fuel Meat Plate  11
cell 1144  1  zirc4    43  -44   -80  81 -307 305 % Fuel Clad outer Plate  11
cell 1145  1  h2o      44  -45   -80  81 -307 305 % Water between Plates 11 and 12
cell 1146  1  zirc4    45  -46   -80  81 -307 305 % Fuel Clad inner Plate  12
cell 1147  1  fuel12   46  -47   -80  81 -307 305 % Fuel Meat Plate  12
cell 1148  1  zirc4    47  -48   -80  81 -307 305 % Fuel Clad outer Plate  12

% *** ESE Octant ***
cell 1202  1  zirc4     1   -2   -80  81 -304 311 % Fuel Clad inner Plate  1
cell 1203  1  fuel1     2   -3   -80  81 -304 311 % Fuel Meat Plate  1
cell 1204  1  zirc4     3   -4   -80  81 -304 311 % Fuel Clad outer Plate  1
cell 1205  1  h2o       4   -5   -80  81 -304 311 % Water between Plates 1 and 2
cell 1206  1  zirc4     5   -6   -80  81 -304 311 % Fuel Clad inner Plate  2
cell 1207  1  fuel2     6   -7   -80  81 -304 311 % Fuel Meat Plate  2
cell 1208  1  zirc4     7   -8   -80  81 -304 311 % Fuel Clad outer Plate  2
cell 1209  1  h2o       8   -9   -80  81 -304 311 % Water between Plates 2 and 3
cell 1210  1  zirc4     9  -10   -80  81 -304 311 % Fuel Clad inner Plate  3
cell 1211  1  fuel3    10  -11   -80  81 -304 311 % Fuel Meat Plate  3
cell 1212  1  zirc4    11  -12   -80  81 -304 311 % Fuel Clad outer Plate  3
cell 1213  1  h2o      12  -13   -80  81 -304 311 % Water between Plates 3 and 4
cell 1214  1  zirc4    13  -14   -80  81 -304 311 % Fuel Clad inner Plate  4
cell 1215  1  fuel4    14  -15   -80  81 -304 311 % Fuel Meat Plate  4
cell 1216  1  zirc4    15  -16   -80  81 -304 311 % Fuel Clad outer Plate  4
cell 1217  1  h2o      16  -17   -80  81 -304 311 % Water between Plates 4 and 5
cell 1218  1  zirc4    17  -18   -80  81 -304 311 % Fuel Clad inner Plate  5
cell 1219  1  fuel5    18  -19   -80  81 -304 311 % Fuel Meat Plate  5
cell 1220  1  zirc4    19  -20   -80  81 -304 311 % Fuel Clad outer Plate  5
cell 1221  1  h2o      20  -21   -80  81 -304 311 % Water between Plates 5 and 6
cell 1222  1  zirc4    21  -22   -80  81 -304 311 % Fuel Clad inner Plate  6
cell 1223  1  fuel5    22  -23   -80  81 -304 311 % Fuel Meat Plate  6
cell 1224  1  zirc4    23  -24   -80  81 -304 311 % Fuel Clad outer Plate  6
cell 1225  1  h2o      24  -25   -80  81 -304 311 % Water between Plates 6 and 7
cell 1226  1  zirc4    25  -26   -80  81 -304 311 % Fuel Clad inner Plate  7
cell 1227  1  fuel7    26  -27   -80  81 -304 311 % Fuel Meat Plate  7
cell 1228  1  zirc4    27  -28   -80  81 -304 311 % Fuel Clad outer Plate  7
cell 1229  1  h2o      28  -29   -80  81 -304 311 % Water between Plates 7 and 8
cell 1230  1  zirc4    29  -30   -80  81 -304 311 % Fuel Clad inner Plate  8
cell 1231  1  fuel8    30  -31   -80  81 -304 311 % Fuel Meat Plate  8
cell 1232  1  zirc4    31  -32   -80  81 -304 311 % Fuel Clad outer Plate  8
cell 1233  1  h2o      32  -33   -80  81 -304 311 % Water between Plates 8 and 9
cell 1234  1  zirc4    33  -34   -80  81 -304 311 % Fuel Clad inner Plate  9
cell 1235  1  fuel9    34  -35   -80  81 -304 311 % Fuel Meat Plate  9
cell 1236  1  zirc4    35  -36   -80  81 -304 311 % Fuel Clad outer Plate  9
cell 1237  1  h2o      36  -37   -80  81 -304 311 % Water between Plates 9 and 10
```

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cell 1238  1  zirc4    37  -38   -80  81 -304 311 % Fuel Clad inner Plate  10
cell 1239  1  fuel10   38  -39   -80  81 -304 311 % Fuel Meat Plate  10
cell 1240  1  zirc4    39  -40   -80  81 -304 311 % Fuel Clad outer Plate  10
cell 1241  1  h2o      40  -41   -80  81 -304 311 % Water between Plates 10 and 11
cell 1242  1  zirc4    41  -42   -80  81 -304 311 % Fuel Clad inner Plate  11
cell 1243  1  fuel11   42  -43   -80  81 -304 311 % Fuel Meat Plate  11
cell 1244  1  zirc4    43  -44   -80  81 -304 311 % Fuel Clad outer Plate  11
cell 1245  1  h2o      44  -45   -80  81 -304 311 % Water between Plates 11 and 12
cell 1246  1  zirc4    45  -46   -80  81 -304 311 % Fuel Clad inner Plate  12
cell 1247  1  fuel12   46  -47   -80  81 -304 311 % Fuel Meat Plate  12
cell 1248  1  zirc4    47  -48   -80  81 -304 311 % Fuel Clad outer Plate  12

% *** SSE Octant ***
cell 1302  1  zirc4     1   -2   -80  81 -310 302 % Fuel Clad inner Plate  1
cell 1303  1  fuel1     2   -3   -80  81 -310 302 % Fuel Meat Plate  1
cell 1304  1  zirc4     3   -4   -80  81 -310 302 % Fuel Clad outer Plate  1
cell 1305  1  h2o       4   -5   -80  81 -310 302 % Water between Plates 1 and 2
cell 1306  1  zirc4     5   -6   -80  81 -310 302 % Fuel Clad inner Plate  2
cell 1307  1  fuel2     6   -7   -80  81 -310 302 % Fuel Meat Plate  2
cell 1308  1  zirc4     7   -8   -80  81 -310 302 % Fuel Clad outer Plate  2
cell 1309  1  h2o       8   -9   -80  81 -310 302 % Water between Plates 2 and 3
cell 1310  1  zirc4     9  -10   -80  81 -310 302 % Fuel Clad inner Plate  3
cell 1311  1  fuel3    10  -11   -80  81 -310 302 % Fuel Meat Plate  3
cell 1312  1  zirc4    11  -12   -80  81 -310 302 % Fuel Clad outer Plate  3
cell 1313  1  h2o      12  -13   -80  81 -310 302 % Water between Plates 3 and 4
cell 1314  1  zirc4    13  -14   -80  81 -310 302 % Fuel Clad inner Plate  4
cell 1315  1  fuel4    14  -15   -80  81 -310 302 % Fuel Meat Plate  4
cell 1316  1  zirc4    15  -16   -80  81 -310 302 % Fuel Clad outer Plate  4
cell 1317  1  h2o      16  -17   -80  81 -310 302 % Water between Plates 4 and 5
cell 1318  1  zirc4    17  -18   -80  81 -310 302 % Fuel Clad inner Plate  5
cell 1319  1  fuel5    18  -19   -80  81 -310 302 % Fuel Meat Plate  5
cell 1320  1  zirc4    19  -20   -80  81 -310 302 % Fuel Clad outer Plate  5
cell 1321  1  h2o      20  -21   -80  81 -310 302 % Water between Plates 5 and 6
cell 1322  1  zirc4    21  -22   -80  81 -310 302 % Fuel Clad inner Plate  6
cell 1323  1  fuel5    22  -23   -80  81 -310 302 % Fuel Meat Plate  6
cell 1324  1  zirc4    23  -24   -80  81 -310 302 % Fuel Clad outer Plate  6
cell 1325  1  h2o      24  -25   -80  81 -310 302 % Water between Plates 6 and 7
cell 1326  1  zirc4    25  -26   -80  81 -310 302 % Fuel Clad inner Plate  7
cell 1327  1  fuel7    26  -27   -80  81 -310 302 % Fuel Meat Plate  7
cell 1328  1  zirc4    27  -28   -80  81 -310 302 % Fuel Clad outer Plate  7
cell 1329  1  h2o      28  -29   -80  81 -310 302 % Water between Plates 7 and 8
cell 1330  1  zirc4    29  -30   -80  81 -310 302 % Fuel Clad inner Plate  8
cell 1331  1  fuel8    30  -31   -80  81 -310 302 % Fuel Meat Plate  8
cell 1332  1  zirc4    31  -32   -80  81 -310 302 % Fuel Clad outer Plate  8
cell 1333  1  h2o      32  -33   -80  81 -310 302 % Water between Plates 8 and 9
cell 1334  1  zirc4    33  -34   -80  81 -310 302 % Fuel Clad inner Plate  9
cell 1335  1  fuel9    34  -35   -80  81 -310 302 % Fuel Meat Plate  9
cell 1336  1  zirc4    35  -36   -80  81 -310 302 % Fuel Clad outer Plate  9
cell 1337  1  h2o      36  -37   -80  81 -310 302 % Water between Plates 9 and 10
cell 1338  1  zirc4    37  -38   -80  81 -310 302 % Fuel Clad inner Plate  10
cell 1339  1  fuel10   38  -39   -80  81 -310 302 % Fuel Meat Plate  10
cell 1340  1  zirc4    39  -40   -80  81 -310 302 % Fuel Clad outer Plate  10
cell 1341  1  h2o      40  -41   -80  81 -310 302 % Water between Plates 10 and 11
cell 1342  1  zirc4    41  -42   -80  81 -310 302 % Fuel Clad inner Plate  11
cell 1343  1  fuel11   42  -43   -80  81 -310 302 % Fuel Meat Plate  11
cell 1344  1  zirc4    43  -44   -80  81 -310 302 % Fuel Clad outer Plate  11
cell 1345  1  h2o      44  -45   -80  81 -310 302 % Water between Plates 11 and 12
cell 1346  1  zirc4    45  -46   -80  81 -310 302 % Fuel Clad inner Plate  12
cell 1347  1  fuel12   46  -47   -80  81 -310 302 % Fuel Meat Plate  12
cell 1348  1  zirc4    47  -48   -80  81 -310 302 % Fuel Clad outer Plate  12

% *** SSW Octant ***
cell 1402  1  zirc4     1   -2   -80  81 -301 -307 % Fuel Clad inner Plate  1
cell 1403  1  fuel1     2   -3   -80  81 -301 -307 % Fuel Meat Plate  1
cell 1404  1  zirc4     3   -4   -80  81 -301 -307 % Fuel Clad outer Plate  1
cell 1405  1  h2o       4   -5   -80  81 -301 -307 % Water between Plates 1 and 2
cell 1406  1  zirc4     5   -6   -80  81 -301 -307 % Fuel Clad inner Plate  2
cell 1407  1  fuel2     6   -7   -80  81 -301 -307 % Fuel Meat Plate  2
cell 1408  1  zirc4     7   -8   -80  81 -301 -307 % Fuel Clad outer Plate  2
cell 1409  1  h2o       8   -9   -80  81 -301 -307 % Water between Plates 2 and 3
cell 1410  1  zirc4     9  -10   -80  81 -301 -307 % Fuel Clad inner Plate  3
cell 1411  1  fuel3    10  -11   -80  81 -301 -307 % Fuel Meat Plate  3
cell 1412  1  zirc4    11  -12   -80  81 -301 -307 % Fuel Clad outer Plate  3
cell 1413  1  h2o      12  -13   -80  81 -301 -307 % Water between Plates 3 and 4
cell 1414  1  zirc4    13  -14   -80  81 -301 -307 % Fuel Clad inner Plate  4
cell 1415  1  fuel4    14  -15   -80  81 -301 -307 % Fuel Meat Plate  4
cell 1416  1  zirc4    15  -16   -80  81 -301 -307 % Fuel Clad outer Plate  4
cell 1417  1  h2o      16  -17   -80  81 -301 -307 % Water between Plates 4 and 5
cell 1418  1  zirc4    17  -18   -80  81 -301 -307 % Fuel Clad inner Plate  5
cell 1419  1  fuel5    18  -19   -80  81 -301 -307 % Fuel Meat Plate  5
```

```
cell 1420  1  zirc4    19  -20   -80  81 -301 -307 % Fuel Clad outer Plate  5
cell 1421  1  h2o      20  -21   -80  81 -301 -307 % Water between Plates 5 and 6
cell 1422  1  zirc4    21  -22   -80  81 -301 -307 % Fuel Clad inner Plate  6
cell 1423  1  fuel5    22  -23   -80  81 -301 -307 % Fuel Meat Plate  6
cell 1424  1  zirc4    23  -24   -80  81 -301 -307 % Fuel Clad outer Plate  6
cell 1425  1  h2o      24  -25   -80  81 -301 -307 % Water between Plates 6 and 7
cell 1426  1  zirc4    25  -26   -80  81 -301 -307 % Fuel Clad inner Plate  7
cell 1427  1  fuel7    26  -27   -80  81 -301 -307 % Fuel Meat Plate  7
cell 1428  1  zirc4    27  -28   -80  81 -301 -307 % Fuel Clad outer Plate  7
cell 1429  1  h2o      28  -29   -80  81 -301 -307 % Water between Plates 7 and 8
cell 1430  1  zirc4    29  -30   -80  81 -301 -307 % Fuel Clad inner Plate  8
cell 1431  1  fuel8    30  -31   -80  81 -301 -307 % Fuel Meat Plate  8
cell 1432  1  zirc4    31  -32   -80  81 -301 -307 % Fuel Clad outer Plate  8
cell 1433  1  h2o      32  -33   -80  81 -301 -307 % Water between Plates 8 and 9
cell 1434  1  zirc4    33  -34   -80  81 -301 -307 % Fuel Clad inner Plate  9
cell 1435  1  fuel9    34  -35   -80  81 -301 -307 % Fuel Meat Plate  9
cell 1436  1  zirc4    35  -36   -80  81 -301 -307 % Fuel Clad outer Plate  9
cell 1437  1  h2o      36  -37   -80  81 -301 -307 % Water between Plates 9 and 10
cell 1438  1  zirc4    37  -38   -80  81 -301 -307 % Fuel Clad inner Plate  10
cell 1439  1  fuel10   38  -39   -80  81 -301 -307 % Fuel Meat Plate  10
cell 1440  1  zirc4    39  -40   -80  81 -301 -307 % Fuel Clad outer Plate  10
cell 1441  1  h2o      40  -41   -80  81 -301 -307 % Water between Plates 10 and 11
cell 1442  1  zirc4    41  -42   -80  81 -301 -307 % Fuel Clad inner Plate  11
cell 1443  1  fuel11   42  -43   -80  81 -301 -307 % Fuel Meat Plate  11
cell 1444  1  zirc4    43  -44   -80  81 -301 -307 % Fuel Clad outer Plate  11
cell 1445  1  h2o      44  -45   -80  81 -301 -307 % Water between Plates 11 and 12
cell 1446  1  zirc4    45  -46   -80  81 -301 -307 % Fuel Clad inner Plate  12
cell 1447  1  fuel12   46  -47   -80  81 -301 -307 % Fuel Meat Plate  12
cell 1448  1  zirc4    47  -48   -80  81 -301 -307 % Fuel Clad outer Plate  12

% *** WSW Octant ***
cell 1502  1  zirc4     1   -2   -80  81 -304 308 % Fuel Clad inner Plate  1
cell 1503  1  fuel1     2   -3   -80  81 -304 308 % Fuel Meat Plate  1
cell 1504  1  zirc4     3   -4   -80  81 -304 308 % Fuel Clad outer Plate  1
cell 1505  1  h2o       4   -5   -80  81 -304 308 % Water between Plates 1 and 2
cell 1506  1  zirc4     5   -6   -80  81 -304 308 % Fuel Clad inner Plate  2
cell 1507  1  fuel2     6   -7   -80  81 -304 308 % Fuel Meat Plate  2
cell 1508  1  zirc4     7   -8   -80  81 -304 308 % Fuel Clad outer Plate  2
cell 1509  1  h2o       8   -9   -80  81 -304 308 % Water between Plates 2 and 3
cell 1510  1  zirc4     9  -10   -80  81 -304 308 % Fuel Clad inner Plate  3
cell 1511  1  fuel3    10  -11   -80  81 -304 308 % Fuel Meat Plate  3
cell 1512  1  zirc4    11  -12   -80  81 -304 308 % Fuel Clad outer Plate  3
cell 1513  1  h2o      12  -13   -80  81 -304 308 % Water between Plates 3 and 4
cell 1514  1  zirc4    13  -14   -80  81 -304 308 % Fuel Clad inner Plate  4
cell 1515  1  fuel4    14  -15   -80  81 -304 308 % Fuel Meat Plate  4
cell 1516  1  zirc4    15  -16   -80  81 -304 308 % Fuel Clad outer Plate  4
cell 1517  1  h2o      16  -17   -80  81 -304 308 % Water between Plates 4 and 5
cell 1518  1  zirc4    17  -18   -80  81 -304 308 % Fuel Clad inner Plate  5
cell 1519  1  fuel5    18  -19   -80  81 -304 308 % Fuel Meat Plate  5
cell 1520  1  zirc4    19  -20   -80  81 -304 308 % Fuel Clad outer Plate  5
cell 1521  1  h2o      20  -21   -80  81 -304 308 % Water between Plates 5 and 6
cell 1522  1  zirc4    21  -22   -80  81 -304 308 % Fuel Clad inner Plate  6
cell 1523  1  fuel5    22  -23   -80  81 -304 308 % Fuel Meat Plate  6
cell 1524  1  zirc4    23  -24   -80  81 -304 308 % Fuel Clad outer Plate  6
cell 1525  1  h2o      24  -25   -80  81 -304 308 % Water between Plates 6 and 7
cell 1526  1  zirc4    25  -26   -80  81 -304 308 % Fuel Clad inner Plate  7
cell 1527  1  fuel7    26  -27   -80  81 -304 308 % Fuel Meat Plate  7
cell 1528  1  zirc4    27  -28   -80  81 -304 308 % Fuel Clad outer Plate  7
cell 1529  1  h2o      28  -29   -80  81 -304 308 % Water between Plates 7 and 8
cell 1530  1  zirc4    29  -30   -80  81 -304 308 % Fuel Clad inner Plate  8
cell 1531  1  fuel8    30  -31   -80  81 -304 308 % Fuel Meat Plate  8
cell 1532  1  zirc4    31  -32   -80  81 -304 308 % Fuel Clad outer Plate  8
cell 1533  1  h2o      32  -33   -80  81 -304 308 % Water between Plates 8 and 9
cell 1534  1  zirc4    33  -34   -80  81 -304 308 % Fuel Clad inner Plate  9
cell 1535  1  fuel9    34  -35   -80  81 -304 308 % Fuel Meat Plate  9
cell 1536  1  zirc4    35  -36   -80  81 -304 308 % Fuel Clad outer Plate  9
cell 1537  1  h2o      36  -37   -80  81 -304 308 % Water between Plates 9 and 10
cell 1538  1  zirc4    37  -38   -80  81 -304 308 % Fuel Clad inner Plate  10
cell 1539  1  fuel10   38  -39   -80  81 -304 308 % Fuel Meat Plate  10
cell 1540  1  zirc4    39  -40   -80  81 -304 308 % Fuel Clad outer Plate  10
cell 1541  1  h2o      40  -41   -80  81 -304 308 % Water between Plates 10 and 11
cell 1542  1  zirc4    41  -42   -80  81 -304 308 % Fuel Clad inner Plate  11
cell 1543  1  fuel11   42  -43   -80  81 -304 308 % Fuel Meat Plate  11
cell 1544  1  zirc4    43  -44   -80  81 -304 308 % Fuel Clad outer Plate  11
cell 1545  1  h2o      44  -45   -80  81 -304 308 % Water between Plates 11 and 12
cell 1546  1  zirc4    45  -46   -80  81 -304 308 % Fuel Clad inner Plate  12
cell 1547  1  fuel12   46  -47   -80  81 -304 308 % Fuel Meat Plate  12
cell 1548  1  zirc4    47  -48   -80  81 -304 308 % Fuel Clad outer Plate  12

% *** WNW Octant ***
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cell 1602  1  zirc4     1   -2   -80  81 -310 305 % Fuel Clad inner Plate  1
cell 1603  1  fuel1     2   -3   -80  81 -310 305 % Fuel Meat Plate  1
cell 1604  1  zirc4     3   -4   -80  81 -310 305 % Fuel Clad outer Plate  1
cell 1605  1  h2o       4   -5   -80  81 -310 305 % Water between Plates 1 and 2
cell 1606  1  zirc4     5   -6   -80  81 -310 305 % Fuel Clad inner Plate  2
cell 1607  1  fuel2     6   -7   -80  81 -310 305 % Fuel Meat Plate  2
cell 1608  1  zirc4     7   -8   -80  81 -310 305 % Fuel Clad outer Plate  2
cell 1609  1  h2o       8   -9   -80  81 -310 305 % Water between Plates 2 and 3
cell 1610  1  zirc4     9  -10   -80  81 -310 305 % Fuel Clad inner Plate  3
cell 1611  1  fuel3    10  -11   -80  81 -310 305 % Fuel Meat Plate  3
cell 1612  1  zirc4    11  -12   -80  81 -310 305 % Fuel Clad outer Plate  3
cell 1613  1  h2o      12  -13   -80  81 -310 305 % Water between Plates 3 and 4
cell 1614  1  zirc4    13  -14   -80  81 -310 305 % Fuel Clad inner Plate  4
cell 1615  1  fuel4    14  -15   -80  81 -310 305 % Fuel Meat Plate  4
cell 1616  1  zirc4    15  -16   -80  81 -310 305 % Fuel Clad outer Plate  4
cell 1617  1  h2o      16  -17   -80  81 -310 305 % Water between Plates 4 and 5
cell 1618  1  zirc4    17  -18   -80  81 -310 305 % Fuel Clad inner Plate  5
cell 1619  1  fuel5    18  -19   -80  81 -310 305 % Fuel Meat Plate  5
cell 1620  1  zirc4    19  -20   -80  81 -310 305 % Fuel Clad outer Plate  5
cell 1621  1  h2o      20  -21   -80  81 -310 305 % Water between Plates 5 and 6
cell 1622  1  zirc4    21  -22   -80  81 -310 305 % Fuel Clad inner Plate  6
cell 1623  1  fuel5    22  -23   -80  81 -310 305 % Fuel Meat Plate  6
cell 1624  1  zirc4    23  -24   -80  81 -310 305 % Fuel Clad outer Plate  6
cell 1625  1  h2o      24  -25   -80  81 -310 305 % Water between Plates 6 and 7
cell 1626  1  zirc4    25  -26   -80  81 -310 305 % Fuel Clad inner Plate  7
cell 1627  1  fuel7    26  -27   -80  81 -310 305 % Fuel Meat Plate  7
cell 1628  1  zirc4    27  -28   -80  81 -310 305 % Fuel Clad outer Plate  7
cell 1629  1  h2o      28  -29   -80  81 -310 305 % Water between Plates 7 and 8
cell 1630  1  zirc4    29  -30   -80  81 -310 305 % Fuel Clad inner Plate  8
cell 1631  1  fuel8    30  -31   -80  81 -310 305 % Fuel Meat Plate  8
cell 1632  1  zirc4    31  -32   -80  81 -310 305 % Fuel Clad outer Plate  8
cell 1633  1  h2o      32  -33   -80  81 -310 305 % Water between Plates 8 and 9
cell 1634  1  zirc4    33  -34   -80  81 -310 305 % Fuel Clad inner Plate  9
cell 1635  1  fuel9    34  -35   -80  81 -310 305 % Fuel Meat Plate  9
cell 1636  1  zirc4    35  -36   -80  81 -310 305 % Fuel Clad outer Plate  9
cell 1637  1  h2o      36  -37   -80  81 -310 305 % Water between Plates 9 and 10
cell 1638  1  zirc4    37  -38   -80  81 -310 305 % Fuel Clad inner Plate  10
cell 1639  1  fuel10   38  -39   -80  81 -310 305 % Fuel Meat Plate  10
cell 1640  1  zirc4    39  -40   -80  81 -310 305 % Fuel Clad outer Plate  10
cell 1641  1  h2o      40  -41   -80  81 -310 305 % Water between Plates 10 and 11
cell 1642  1  zirc4    41  -42   -80  81 -310 305 % Fuel Clad inner Plate  11
cell 1643  1  fuel11   42  -43   -80  81 -310 305 % Fuel Meat Plate  11
cell 1644  1  zirc4    43  -44   -80  81 -310 305 % Fuel Clad outer Plate  11
cell 1645  1  h2o      44  -45   -80  81 -310 305 % Water between Plates 11 and 12
cell 1646  1  zirc4    45  -46   -80  81 -310 305 % Fuel Clad inner Plate  12
cell 1647  1  fuel12   46  -47   -80  81 -310 305 % Fuel Meat Plate  12
cell 1648  1  zirc4    47  -48   -80  81 -310 305 % Fuel Clad outer Plate  12

% *** NNW Octant ***
cell 1702  1  zirc4    1   -2  -80  81 311 -301 % Fuel Clad inner Plate  1
cell 1703  1  fuel1    2   -3  -80  81 311 -301 % Fuel Meat Plate  1
cell 1704  1  zirc4    3   -4  -80  81 311 -301 % Fuel Clad outer Plate  1
cell 1705  1  h2o      4   -5  -80  81 311 -301 % Water between Plates 1 and 2
cell 1706  1  zirc4    5   -6  -80  81 311 -301 % Fuel Clad inner Plate  2
cell 1707  1  fuel2    6   -7  -80  81 311 -301 % Fuel Meat Plate  2
cell 1708  1  zirc4    7   -8  -80  81 311 -301 % Fuel Clad outer Plate  2
cell 1709  1  h2o      8   -9  -80  81 311 -301 % Water between Plates 2 and 3
cell 1710  1  zirc4    9  -10  -80  81 311 -301 % Fuel Clad inner Plate  3
cell 1711  1  fuel3   10  -11  -80  81 311 -301 % Fuel Meat Plate  3
cell 1712  1  zirc4   11  -12  -80  81 311 -301 % Fuel Clad outer Plate  3
cell 1713  1  h2o     12  -13  -80  81 311 -301 % Water between Plates 3 and 4
cell 1714  1  zirc4   13  -14  -80  81 311 -301 % Fuel Clad inner Plate  4
cell 1715  1  fuel4   14  -15  -80  81 311 -301 % Fuel Meat Plate  4
cell 1716  1  zirc4   15  -16  -80  81 311 -301 % Fuel Clad outer Plate  4
cell 1717  1  h2o     16  -17  -80  81 311 -301 % Water between Plates 4 and 5
cell 1718  1  zirc4   17  -18  -80  81 311 -301 % Fuel Clad inner Plate  5
cell 1719  1  fuel5   18  -19  -80  81 311 -301 % Fuel Meat Plate  5
cell 1720  1  zirc4   19  -20  -80  81 311 -301 % Fuel Clad outer Plate  5
cell 1721  1  h2o     20  -21  -80  81 311 -301 % Water between Plates 5 and 6
cell 1722  1  zirc4   21  -22  -80  81 311 -301 % Fuel Clad inner Plate  6
cell 1723  1  fuel5   22  -23  -80  81 311 -301 % Fuel Meat Plate  6
cell 1724  1  zirc4   23  -24  -80  81 311 -301 % Fuel Clad outer Plate  6
cell 1725  1  h2o     24  -25  -80  81 311 -301 % Water between Plates 6 and 7
cell 1726  1  zirc4   25  -26  -80  81 311 -301 % Fuel Clad inner Plate  7
cell 1727  1  fuel7   26  -27  -80  81 311 -301 % Fuel Meat Plate  7
cell 1728  1  zirc4   27  -28  -80  81 311 -301 % Fuel Clad outer Plate  7
cell 1729  1  h2o     28  -29  -80  81 311 -301 % Water between Plates 7 and 8
cell 1730  1  zirc4   29  -30  -80  81 311 -301 % Fuel Clad inner Plate  8
cell 1731  1  fuel8   30  -31  -80  81 311 -301 % Fuel Meat Plate  8
cell 1732  1  zirc4   31  -32  -80  81 311 -301 % Fuel Clad outer Plate  8
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cell 1733  1  h2o     32  -33  -80  81 311 -301 % Water between Plates 8 and 9
cell 1734  1  zirc4   33  -34  -80  81 311 -301 % Fuel Clad inner Plate  9
cell 1735  1  fuel9   34  -35  -80  81 311 -301 % Fuel Meat Plate  9
cell 1736  1  zirc4   35  -36  -80  81 311 -301 % Fuel Clad outer Plate  9
cell 1737  1  h2o     36  -37  -80  81 311 -301 % Water between Plates 9 and 10
cell 1738  1  zirc4   37  -38  -80  81 311 -301 % Fuel Clad inner Plate  10
cell 1739  1  fuel10  38  -39  -80  81 311 -301 % Fuel Meat Plate  10
cell 1740  1  zirc4   39  -40  -80  81 311 -301 % Fuel Clad outer Plate  10
cell 1741  1  h2o     40  -41  -80  81 311 -301 % Water between Plates 10 and 11
cell 1742  1  zirc4   41  -42  -80  81 311 -301 % Fuel Clad inner Plate  11
cell 1743  1  fuel11  42  -43  -80  81 311 -301 % Fuel Meat Plate  11
cell 1744  1  zirc4   43  -44  -80  81 311 -301 % Fuel Clad outer Plate  11
cell 1745  1  h2o     44  -45  -80  81 311 -301 % Water between Plates 11 and 12
cell 1746  1  zirc4   45  -46  -80  81 311 -301 % Fuel Clad inner Plate  12
cell 1747  1  fuel12  46  -47  -80  81 311 -301 % Fuel Meat Plate  12
cell 1748  1  zirc4   47  -48  -80  81 311 -301 % Fuel Clad outer Plate  12

%  Other materials above and below fuel assembly
cell  77  1  h2o      1   -128      64        % water above fuel assembly
cell  78  1  h2o      1   -128     -65        % water below fuel assembly
%  Upper and lower plates without fuel homogenized
cell 185  1  TopPlat  1  -128   80 -62        % upper end plates
cell 186  1  BotPlat  1  -128  -81  63        % lower end plates
%  Upper and lower end boxes homogenized
cell 187  1  TopBox   1  -128       62 -64    % upper end box
cell 188  1  BotBox   1  -128      -63  65    % lower end box

cell  79  1  al6061   128 -129      80        % pressure vessel above fuel assembly
cell  80  1  al6061   128 -129     -81        % pressure vessel below fuel assembly
cell  81  1  d2o      129           80        % d2o outside PV above fuel assembly
cell  82  1  d2o      129          -81        % d2o outside PV below fuel assembly

% Side plates (fused adjacent plates
cell 90 1 zirc4   1 -48 301 -302  303 -80  81 % N sideplates
cell 91 1 zirc4   1 -48 307 -308  303 -80  81 % NE sideplates
cell 92 1 zirc4   1 -48 304 -305  300 -80  81 % E sideplates
cell 93 1 zirc4   1 -48 310 -311 -303 -80  81 % SE sideplates
cell 94 1 zirc4   1 -48 301 -302 -303 -80  81 % S sideplates
cell 95 1 zirc4   1 -48 307 -308 -303 -80  81 % SW sideplates
cell 96 1 zirc4   1 -48 304 -305 -300 -80  81 % W sideplates
cell 97 1 zirc4   1 -48 310 -311  303 -80  81 % NW sideplates

% *** Outer Test Location *** Universe 2 ****
cell 120 2  al6061  -220           % test space
cell 121 2  ss304    220  -221     % flow tube
cell 122 2  h2o      221  -222     % return flow
cell 123 2  ss304    222  -223     % pressure tube
cell 124 2  helium   223  -224     % helium annulus
cell 125 2  ss304    224  -225     % insulation jacket
cell 126 2  h2o      225  -226     % water gap
cell 127 2  al6061   226  -227     % guide tube
cell 128 2  h2o      227  -228     % water
cell 129 2  al6061   228  -229     % safety rod follower
cell 130 2  h2o      229  -126     % water just inside baffle
cell 131 2  al6061   126  -127     % baffle
cell 132 2  h2o      127    -1     % water just inside fuel plate 1
cell 133 2  h2o       48  -128 -80 81  % water outside fuel inside Pressure vessel
cell 134 2  al6061    128  -129 -80 81  % al6061 pressure vessel next to fuel
cell 135 2  d2o      129     -80   81  % d2o outside next to fuel

% *** NNE Octant ***
cell 2002  2  zirc4    1   -2   -80  81 308 302 % Fuel Clad inner Plate  1
cell 2003  2  fuel13   2   -3   -80  81 308 302 % Fuel Meat Plate  1
cell 2004  2  zirc4    3   -4   -80  81 308 302 % Fuel Clad outer Plate  1
cell 2005  2  h2o      4   -5   -80  81 308 302 % Water between Plates 1 and 2
cell 2006  2  zirc4    5   -6   -80  81 308 302 % Fuel Clad inner Plate  2
cell 2007  2  fuel14   6   -7   -80  81 308 302 % Fuel Meat Plate  2
cell 2008  2  zirc4    7   -8   -80  81 308 302 % Fuel Clad outer Plate  2
cell 2009  2  h2o      8   -9   -80  81 308 302 % Water between Plates 2 and 3
cell 2010  2  zirc4    9  -10   -80  81 308 302 % Fuel Clad inner Plate  3
cell 2011  2  fuel15   10  -11   -80  81 308 302 % Fuel Meat Plate  3
cell 2012  2  zirc4    11  -12   -80  81 308 302 % Fuel Clad outer Plate  3
cell 2013  2  h2o      12  -13   -80  81 308 302 % Water between Plates 3 and 4
cell 2014  2  zirc4    13  -14   -80  81 308 302 % Fuel Clad inner Plate  4
cell 2015  2  fuel16   14  -15   -80  81 308 302 % Fuel Meat Plate  4
cell 2016  2  zirc4    15  -16   -80  81 308 302 % Fuel Clad outer Plate  4
cell 2017  2  h2o      16  -17   -80  81 308 302 % Water between Plates 4 and 5
cell 2018  2  zirc4    17  -18   -80  81 308 302 % Fuel Clad inner Plate  5
cell 2019  2  fuel17   18  -19   -80  81 308 302 % Fuel Meat Plate  5
cell 2020  2  zirc4    19  -20   -80  81 308 302 % Fuel Clad outer Plate  5
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cell 2021  2  h2o      20  -21   -80  81 308 302 % Water between Plates 5 and 6
cell 2022  2  zirc4    21  -22   -80  81 308 302 % Fuel Clad inner Plate  6
cell 2023  2  fuel18   22  -23   -80  81 308 302 % Fuel Meat Plate  6
cell 2024  2  zirc4    23  -24   -80  81 308 302 % Fuel Clad outer Plate  6
cell 2025  2  h2o      24  -25   -80  81 308 302 % Water between Plates 6 and 7
cell 2026  2  zirc4    25  -26   -80  81 308 302 % Fuel Clad inner Plate  7
cell 2027  2  fuel19   26  -27   -80  81 308 302 % Fuel Meat Plate  7
cell 2028  2  zirc4    27  -28   -80  81 308 302 % Fuel Clad outer Plate  7
cell 2029  2  h2o      28  -29   -80  81 308 302 % Water between Plates 7 and 8
cell 2030  2  zirc4    29  -30   -80  81 308 302 % Fuel Clad inner Plate  8
cell 2031  2  fuel20   30  -31   -80  81 308 302 % Fuel Meat Plate  8
cell 2032  2  zirc4    31  -32   -80  81 308 302 % Fuel Clad outer Plate  8
cell 2033  2  h2o      32  -33   -80  81 308 302 % Water between Plates 8 and 9
cell 2034  2  zirc4    33  -34   -80  81 308 302 % Fuel Clad inner Plate  9
cell 2035  2  fuel21   34  -35   -80  81 308 302 % Fuel Meat Plate  9
cell 2036  2  zirc4    35  -36   -80  81 308 302 % Fuel Clad outer Plate  9
cell 2037  2  h2o      36  -37   -80  81 308 302 % Water between Plates 9 and 10
cell 2038  2  zirc4    37  -38   -80  81 308 302 % Fuel Clad inner Plate  10
cell 2039  2  fuel22   38  -39   -80  81 308 302 % Fuel Meat Plate  10
cell 2040  2  zirc4    39  -40   -80  81 308 302 % Fuel Clad outer Plate  10
cell 2041  2  h2o      40  -41   -80  81 308 302 % Water between Plates 10 and 11
cell 2042  2  zirc4    41  -42   -80  81 308 302 % Fuel Clad inner Plate  11
cell 2043  2  fuel23   42  -43   -80  81 308 302 % Fuel Meat Plate  11
cell 2044  2  zirc4    43  -44   -80  81 308 302 % Fuel Clad outer Plate  11
cell 2045  2  h2o      44  -45   -80  81 308 302 % Water between Plates 11 and 12
cell 2046  2  zirc4    45  -46   -80  81 308 302 % Fuel Clad inner Plate  12
cell 2047  2  fuel24   46  -47   -80  81 308 302 % Fuel Meat Plate  12
cell 2048  2  zirc4    47  -48   -80  81 308 302 % Fuel Clad outer Plate  12

% *** ENE Octant ***
cell 2102  2  zirc4    1   -2   -80  81 -307 305 % Fuel Clad inner Plate  1
cell 2103  2  fuel13   2   -3   -80  81 -307 305 % Fuel Meat Plate  1
cell 2104  2  zirc4    3   -4   -80  81 -307 305 % Fuel Clad outer Plate  1
cell 2105  2  h2o      4   -5   -80  81 -307 305 % Water between Plates 1 and 2
cell 2106  2  zirc4    5   -6   -80  81 -307 305 % Fuel Clad inner Plate  2
cell 2107  2  fuel14   6   -7   -80  81 -307 305 % Fuel Meat Plate  2
cell 2108  2  zirc4    7   -8   -80  81 -307 305 % Fuel Clad outer Plate  2
cell 2109  2  h2o      8   -9   -80  81 -307 305 % Water between Plates 2 and 3
cell 2110  2  zirc4    9  -10   -80  81 -307 305 % Fuel Clad inner Plate  3
cell 2111  2  fuel15  10  -11   -80  81 -307 305 % Fuel Meat Plate  3
cell 2112  2  zirc4   11  -12   -80  81 -307 305 % Fuel Clad outer Plate  3
cell 2113  2  h2o     12  -13   -80  81 -307 305 % Water between Plates 3 and 4
cell 2114  2  zirc4   13  -14   -80  81 -307 305 % Fuel Clad inner Plate  4
cell 2115  2  fuel16  14  -15   -80  81 -307 305 % Fuel Meat Plate  4
cell 2116  2  zirc4   15  -16   -80  81 -307 305 % Fuel Clad outer Plate  4
cell 2117  2  h2o     16  -17   -80  81 -307 305 % Water between Plates 4 and 5
cell 2118  2  zirc4   17  -18   -80  81 -307 305 % Fuel Clad inner Plate  5
cell 2119  2  fuel17  18  -19   -80  81 -307 305 % Fuel Meat Plate  5
cell 2120  2  zirc4   19  -20   -80  81 -307 305 % Fuel Clad outer Plate  5
cell 2121  2  h2o     20  -21   -80  81 -307 305 % Water between Plates 5 and 6
cell 2122  2  zirc4   21  -22   -80  81 -307 305 % Fuel Clad inner Plate  6
cell 2123  2  fuel18  22  -23   -80  81 -307 305 % Fuel Meat Plate  6
cell 2124  2  zirc4   23  -24   -80  81 -307 305 % Fuel Clad outer Plate  6
cell 2125  2  h2o     24  -25   -80  81 -307 305 % Water between Plates 6 and 7
cell 2126  2  zirc4   25  -26   -80  81 -307 305 % Fuel Clad inner Plate  7
cell 2127  2  fuel19  26  -27   -80  81 -307 305 % Fuel Meat Plate  7
cell 2128  2  zirc4   27  -28   -80  81 -307 305 % Fuel Clad outer Plate  7
cell 2129  2  h2o     28  -29   -80  81 -307 305 % Water between Plates 7 and 8
cell 2130  2  zirc4   29  -30   -80  81 -307 305 % Fuel Clad inner Plate  8
cell 2131  2  fuel20  30  -31   -80  81 -307 305 % Fuel Meat Plate  8
cell 2132  2  zirc4   31  -32   -80  81 -307 305 % Fuel Clad outer Plate  8
cell 2133  2  h2o     32  -33   -80  81 -307 305 % Water between Plates 8 and 9
cell 2134  2  zirc4   33  -34   -80  81 -307 305 % Fuel Clad inner Plate  9
cell 2135  2  fuel21  34  -35   -80  81 -307 305 % Fuel Meat Plate  9
cell 2136  2  zirc4   35  -36   -80  81 -307 305 % Fuel Clad outer Plate  9
cell 2137  2  h2o     36  -37   -80  81 -307 305 % Water between Plates 9 and 10
cell 2138  2  zirc4   37  -38   -80  81 -307 305 % Fuel Clad inner Plate  10
cell 2139  2  fuel22  38  -39   -80  81 -307 305 % Fuel Meat Plate  10
cell 2140  2  zirc4   39  -40   -80  81 -307 305 % Fuel Clad outer Plate  10
cell 2141  2  h2o     40  -41   -80  81 -307 305 % Water between Plates 10 and 11
cell 2142  2  zirc4   41  -42   -80  81 -307 305 % Fuel Clad inner Plate  11
cell 2143  2  fuel23  42  -43   -80  81 -307 305 % Fuel Meat Plate  11
cell 2144  2  zirc4   43  -44   -80  81 -307 305 % Fuel Clad outer Plate  11
cell 2145  2  h2o     44  -45   -80  81 -307 305 % Water between Plates 11 and 12
cell 2146  2  zirc4   45  -46   -80  81 -307 305 % Fuel Clad inner Plate  12
cell 2147  2  fuel24  46  -47   -80  81 -307 305 % Fuel Meat Plate  12
cell 2148  2  zirc4   47  -48   -80  81 -307 305 % Fuel Clad outer Plate  12

% *** ESE Octant ***
cell 2202  2  zirc4    1   -2   -80  81 -304 311 % Fuel Clad inner Plate  1
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cell 2203  2  fuel13    2   -3   -80  81 -304 311 % Fuel Meat Plate  1
cell 2204  2  zirc4     3   -4   -80  81 -304 311 % Fuel Clad outer Plate  1
cell 2205  2  h2o       4   -5   -80  81 -304 311 % Water between Plates 1 and 2
cell 2206  2  zirc4     5   -6   -80  81 -304 311 % Fuel Clad inner Plate  2
cell 2207  2  fuel14    6   -7   -80  81 -304 311 % Fuel Meat Plate  2
cell 2208  2  zirc4     7   -8   -80  81 -304 311 % Fuel Clad outer Plate  2
cell 2209  2  h2o       8   -9   -80  81 -304 311 % Water between Plates 2 and 3
cell 2210  2  zirc4     9  -10   -80  81 -304 311 % Fuel Clad inner Plate  3
cell 2211  2  fuel15   10  -11   -80  81 -304 311 % Fuel Meat Plate  3
cell 2212  2  zirc4    11  -12   -80  81 -304 311 % Fuel Clad outer Plate  3
cell 2213  2  h2o      12  -13   -80  81 -304 311 % Water between Plates 3 and 4
cell 2214  2  zirc4    13  -14   -80  81 -304 311 % Fuel Clad inner Plate  4
cell 2215  2  fuel16   14  -15   -80  81 -304 311 % Fuel Meat Plate  4
cell 2216  2  zirc4    15  -16   -80  81 -304 311 % Fuel Clad outer Plate  4
cell 2217  2  h2o      16  -17   -80  81 -304 311 % Water between Plates 4 and 5
cell 2218  2  zirc4    17  -18   -80  81 -304 311 % Fuel Clad inner Plate  5
cell 2219  2  fuel17   18  -19   -80  81 -304 311 % Fuel Meat Plate  5
cell 2220  2  zirc4    19  -20   -80  81 -304 311 % Fuel Clad outer Plate  5
cell 2221  2  h2o      20  -21   -80  81 -304 311 % Water between Plates 5 and 6
cell 2222  2  zirc4    21  -22   -80  81 -304 311 % Fuel Clad inner Plate  6
cell 2223  2  fuel18   22  -23   -80  81 -304 311 % Fuel Meat Plate  6
cell 2224  2  zirc4    23  -24   -80  81 -304 311 % Fuel Clad outer Plate  6
cell 2225  2  h2o      24  -25   -80  81 -304 311 % Water between Plates 6 and 7
cell 2226  2  zirc4    25  -26   -80  81 -304 311 % Fuel Clad inner Plate  7
cell 2227  2  fuel19   26  -27   -80  81 -304 311 % Fuel Meat Plate  7
cell 2228  2  zirc4    27  -28   -80  81 -304 311 % Fuel Clad outer Plate  7
cell 2229  2  h2o      28  -29   -80  81 -304 311 % Water between Plates 7 and 8
cell 2230  2  zirc4    29  -30   -80  81 -304 311 % Fuel Clad inner Plate  8
cell 2231  2  fuel20   30  -31   -80  81 -304 311 % Fuel Meat Plate  8
cell 2232  2  zirc4    31  -32   -80  81 -304 311 % Fuel Clad outer Plate  8
cell 2233  2  h2o      32  -33   -80  81 -304 311 % Water between Plates 8 and 9
cell 2234  2  zirc4    33  -34   -80  81 -304 311 % Fuel Clad inner Plate  9
cell 2235  2  fuel21   34  -35   -80  81 -304 311 % Fuel Meat Plate  9
cell 2236  2  zirc4    35  -36   -80  81 -304 311 % Fuel Clad outer Plate  9
cell 2237  2  h2o      36  -37   -80  81 -304 311 % Water between Plates 9 and 10
cell 2238  2  zirc4    37  -38   -80  81 -304 311 % Fuel Clad inner Plate  10
cell 2239  2  fuel22   38  -39   -80  81 -304 311 % Fuel Meat Plate  10
cell 2240  2  zirc4    39  -40   -80  81 -304 311 % Fuel Clad outer Plate  10
cell 2241  2  h2o      40  -41   -80  81 -304 311 % Water between Plates 10 and 11
cell 2242  2  zirc4    41  -42   -80  81 -304 311 % Fuel Clad inner Plate  11
cell 2243  2  fuel23   42  -43   -80  81 -304 311 % Fuel Meat Plate  11
cell 2244  2  zirc4    43  -44   -80  81 -304 311 % Fuel Clad outer Plate  11
cell 2245  2  h2o      44  -45   -80  81 -304 311 % Water between Plates 11 and 12
cell 2246  2  zirc4    45  -46   -80  81 -304 311 % Fuel Clad inner Plate  12
cell 2247  2  fuel24   46  -47   -80  81 -304 311 % Fuel Meat Plate  12
cell 2248  2  zirc4    47  -48   -80  81 -304 311 % Fuel Clad outer Plate  12

% *** SSE Octant ***
cell 2302  2  zirc4     1   -2   -80  81 -310 302 % Fuel Clad inner Plate  1
cell 2303  2  fuel13    2   -3   -80  81 -310 302 % Fuel Meat Plate  1
cell 2304  2  zirc4     3   -4   -80  81 -310 302 % Fuel Clad outer Plate  1
cell 2305  2  h2o       4   -5   -80  81 -310 302 % Water between Plates 1 and 2
cell 2306  2  zirc4     5   -6   -80  81 -310 302 % Fuel Clad inner Plate  2
cell 2307  2  fuel14    6   -7   -80  81 -310 302 % Fuel Meat Plate  2
cell 2308  2  zirc4     7   -8   -80  81 -310 302 % Fuel Clad outer Plate  2
cell 2309  2  h2o       8   -9   -80  81 -310 302 % Water between Plates 2 and 3
cell 2310  2  zirc4     9  -10   -80  81 -310 302 % Fuel Clad inner Plate  3
cell 2311  2  fuel15   10  -11   -80  81 -310 302 % Fuel Meat Plate  3
cell 2312  2  zirc4    11  -12   -80  81 -310 302 % Fuel Clad outer Plate  3
cell 2313  2  h2o      12  -13   -80  81 -310 302 % Water between Plates 3 and 4
cell 2314  2  zirc4    13  -14   -80  81 -310 302 % Fuel Clad inner Plate  4
cell 2315  2  fuel16   14  -15   -80  81 -310 302 % Fuel Meat Plate  4
cell 2316  2  zirc4    15  -16   -80  81 -310 302 % Fuel Clad outer Plate  4
cell 2317  2  h2o      16  -17   -80  81 -310 302 % Water between Plates 4 and 5
cell 2318  2  zirc4    17  -18   -80  81 -310 302 % Fuel Clad inner Plate  5
cell 2319  2  fuel17   18  -19   -80  81 -310 302 % Fuel Meat Plate  5
cell 2320  2  zirc4    19  -20   -80  81 -310 302 % Fuel Clad outer Plate  5
cell 2321  2  h2o      20  -21   -80  81 -310 302 % Water between Plates 5 and 6
cell 2322  2  zirc4    21  -22   -80  81 -310 302 % Fuel Clad inner Plate  6
cell 2323  2  fuel18   22  -23   -80  81 -310 302 % Fuel Meat Plate  6
cell 2324  2  zirc4    23  -24   -80  81 -310 302 % Fuel Clad outer Plate  6
cell 2325  2  h2o      24  -25   -80  81 -310 302 % Water between Plates 6 and 7
cell 2326  2  zirc4    25  -26   -80  81 -310 302 % Fuel Clad inner Plate  7
cell 2327  2  fuel19   26  -27   -80  81 -310 302 % Fuel Meat Plate  7
cell 2328  2  zirc4    27  -28   -80  81 -310 302 % Fuel Clad outer Plate  7
cell 2329  2  h2o      28  -29   -80  81 -310 302 % Water between Plates 7 and 8
cell 2330  2  zirc4    29  -30   -80  81 -310 302 % Fuel Clad inner Plate  8
cell 2331  2  fuel20   30  -31   -80  81 -310 302 % Fuel Meat Plate  8
cell 2332  2  zirc4    31  -32   -80  81 -310 302 % Fuel Clad outer Plate  8
cell 2333  2  h2o      32  -33   -80  81 -310 302 % Water between Plates 8 and 9
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cell 2334  2  zirc4    33  -34   -80  81 -310 302 % Fuel Clad inner Plate  9
cell 2335  2  fuel21   34  -35   -80  81 -310 302 % Fuel Meat Plate  9
cell 2336  2  zirc4    35  -36   -80  81 -310 302 % Fuel Clad outer Plate  9
cell 2337  2  h2o      36  -37   -80  81 -310 302 % Water between Plates 9 and 10
cell 2338  2  zirc4    37  -38   -80  81 -310 302 % Fuel Clad inner Plate  10
cell 2339  2  fuel22   38  -39   -80  81 -310 302 % Fuel Meat Plate  10
cell 2340  2  zirc4    39  -40   -80  81 -310 302 % Fuel Clad outer Plate  10
cell 2341  2  h2o      40  -41   -80  81 -310 302 % Water between Plates 10 and 11
cell 2342  2  zirc4    41  -42   -80  81 -310 302 % Fuel Clad inner Plate  11
cell 2343  2  fuel23   42  -43   -80  81 -310 302 % Fuel Meat Plate  11
cell 2344  2  zirc4    43  -44   -80  81 -310 302 % Fuel Clad outer Plate  11
cell 2345  2  h2o      44  -45   -80  81 -310 302 % Water between Plates 11 and 12
cell 2346  2  zirc4    45  -46   -80  81 -310 302 % Fuel Clad inner Plate  12
cell 2347  2  fuel24   46  -47   -80  81 -310 302 % Fuel Meat Plate  12
cell 2348  2  zirc4    47  -48   -80  81 -310 302 % Fuel Clad outer Plate  12

% *** SSW Octant ***
cell 2402  2  zirc4     1   -2  -80  81 -301 -307 % Fuel Clad inner Plate  1
cell 2403  2  fuel13    2   -3  -80  81 -301 -307 % Fuel Meat Plate  1
cell 2404  2  zirc4     3   -4  -80  81 -301 -307 % Fuel Clad outer Plate  1
cell 2405  2  h2o       4   -5  -80  81 -301 -307 % Water between Plates 1 and 2
cell 2406  2  zirc4     5   -6  -80  81 -301 -307 % Fuel Clad inner Plate  2
cell 2407  2  fuel14    6   -7  -80  81 -301 -307 % Fuel Meat Plate  2
cell 2408  2  zirc4     7   -8  -80  81 -301 -307 % Fuel Clad outer Plate  2
cell 2409  2  h2o       8   -9  -80  81 -301 -307 % Water between Plates 2 and 3
cell 2410  2  zirc4     9  -10  -80  81 -301 -307 % Fuel Clad inner Plate  3
cell 2411  2  fuel15   10  -11  -80  81 -301 -307 % Fuel Meat Plate  3
cell 2412  2  zirc4    11  -12  -80  81 -301 -307 % Fuel Clad outer Plate  3
cell 2413  2  h2o      12  -13  -80  81 -301 -307 % Water between Plates 3 and 4
cell 2414  2  zirc4    13  -14  -80  81 -301 -307 % Fuel Clad inner Plate  4
cell 2415  2  fuel16   14  -15  -80  81 -301 -307 % Fuel Meat Plate  4
cell 2416  2  zirc4    15  -16  -80  81 -301 -307 % Fuel Clad outer Plate  4
cell 2417  2  h2o      16  -17  -80  81 -301 -307 % Water between Plates 4 and 5
cell 2418  2  zirc4    17  -18  -80  81 -301 -307 % Fuel Clad inner Plate  5
cell 2419  2  fuel17   18  -19  -80  81 -301 -307 % Fuel Meat Plate  5
cell 2420  2  zirc4    19  -20  -80  81 -301 -307 % Fuel Clad outer Plate  5
cell 2421  2  h2o      20  -21  -80  81 -301 -307 % Water between Plates 5 and 6
cell 2422  2  zirc4    21  -22  -80  81 -301 -307 % Fuel Clad inner Plate  6
cell 2423  2  fuel18   22  -23  -80  81 -301 -307 % Fuel Meat Plate  6
cell 2424  2  zirc4    23  -24  -80  81 -301 -307 % Fuel Clad outer Plate  6
cell 2425  2  h2o      24  -25  -80  81 -301 -307 % Water between Plates 6 and 7
cell 2426  2  zirc4    25  -26  -80  81 -301 -307 % Fuel Clad inner Plate  7
cell 2427  2  fuel19   26  -27  -80  81 -301 -307 % Fuel Meat Plate  7
cell 2428  2  zirc4    27  -28  -80  81 -301 -307 % Fuel Clad outer Plate  7
cell 2429  2  h2o      28  -29  -80  81 -301 -307 % Water between Plates 7 and 8
cell 2430  2  zirc4    29  -30  -80  81 -301 -307 % Fuel Clad inner Plate  8
cell 2431  2  fuel20   30  -31  -80  81 -301 -307 % Fuel Meat Plate  8
cell 2432  2  zirc4    31  -32  -80  81 -301 -307 % Fuel Clad outer Plate  8
cell 2433  2  h2o      32  -33  -80  81 -301 -307 % Water between Plates 8 and 9
cell 2434  2  zirc4    33  -34  -80  81 -301 -307 % Fuel Clad inner Plate  9
cell 2435  2  fuel21   34  -35  -80  81 -301 -307 % Fuel Meat Plate  9
cell 2436  2  zirc4    35  -36  -80  81 -301 -307 % Fuel Clad outer Plate  9
cell 2437  2  h2o      36  -37  -80  81 -301 -307 % Water between Plates 9 and 10
cell 2438  2  zirc4    37  -38  -80  81 -301 -307 % Fuel Clad inner Plate  10
cell 2439  2  fuel22   38  -39  -80  81 -301 -307 % Fuel Meat Plate  10
cell 2440  2  zirc4    39  -40  -80  81 -301 -307 % Fuel Clad outer Plate  10
cell 2441  2  h2o      40  -41  -80  81 -301 -307 % Water between Plates 10 and 11
cell 2442  2  zirc4    41  -42  -80  81 -301 -307 % Fuel Clad inner Plate  11
cell 2443  2  fuel23   42  -43  -80  81 -301 -307 % Fuel Meat Plate  11
cell 2444  2  zirc4    43  -44  -80  81 -301 -307 % Fuel Clad outer Plate  11
cell 2445  2  h2o      44  -45  -80  81 -301 -307 % Water between Plates 11 and 12
cell 2446  2  zirc4    45  -46  -80  81 -301 -307 % Fuel Clad inner Plate  12
cell 2447  2  fuel24   46  -47  -80  81 -301 -307 % Fuel Meat Plate  12
cell 2448  2  zirc4    47  -48  -80  81 -301 -307 % Fuel Clad outer Plate  12

% *** WSW Octant ***
cell 2502  2  zirc4     1   -2   -80  81 -304 308 % Fuel Clad inner Plate  1
cell 2503  2  fuel13    2   -3   -80  81 -304 308 % Fuel Meat Plate  1
cell 2504  2  zirc4     3   -4   -80  81 -304 308 % Fuel Clad outer Plate  1
cell 2505  2  h2o       4   -5   -80  81 -304 308 % Water between Plates 1 and 2
cell 2506  2  zirc4     5   -6   -80  81 -304 308 % Fuel Clad inner Plate  2
cell 2507  2  fuel14    6   -7   -80  81 -304 308 % Fuel Meat Plate  2
cell 2508  2  zirc4     7   -8   -80  81 -304 308 % Fuel Clad outer Plate  2
cell 2509  2  h2o       8   -9   -80  81 -304 308 % Water between Plates 2 and 3
cell 2510  2  zirc4     9  -10   -80  81 -304 308 % Fuel Clad inner Plate  3
cell 2511  2  fuel15   10  -11   -80  81 -304 308 % Fuel Meat Plate  3
cell 2512  2  zirc4    11  -12   -80  81 -304 308 % Fuel Clad outer Plate  3
cell 2513  2  h2o      12  -13   -80  81 -304 308 % Water between Plates 3 and 4
cell 2514  2  zirc4    13  -14   -80  81 -304 308 % Fuel Clad inner Plate  4
cell 2515  2  fuel16   14  -15   -80  81 -304 308 % Fuel Meat Plate  4
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cell 2516  2  zirc4    15  -16   -80  81 -304 308 % Fuel Clad outer Plate  4
cell 2517  2  h2o      16  -17   -80  81 -304 308 % Water between Plates 4 and 5
cell 2518  2  zirc4    17  -18   -80  81 -304 308 % Fuel Clad inner Plate  5
cell 2519  2  fuel17   18  -19   -80  81 -304 308 % Fuel Meat Plate  5
cell 2520  2  zirc4    19  -20   -80  81 -304 308 % Fuel Clad outer Plate  5
cell 2521  2  h2o      20  -21   -80  81 -304 308 % Water between Plates 5 and 6
cell 2522  2  zirc4    21  -22   -80  81 -304 308 % Fuel Clad inner Plate  6
cell 2523  2  fuel18   22  -23   -80  81 -304 308 % Fuel Meat Plate  6
cell 2524  2  zirc4    23  -24   -80  81 -304 308 % Fuel Clad outer Plate  6
cell 2525  2  h2o      24  -25   -80  81 -304 308 % Water between Plates 6 and 7
cell 2526  2  zirc4    25  -26   -80  81 -304 308 % Fuel Clad inner Plate  7
cell 2527  2  fuel19   26  -27   -80  81 -304 308 % Fuel Meat Plate  7
cell 2528  2  zirc4    27  -28   -80  81 -304 308 % Fuel Clad outer Plate  7
cell 2529  2  h2o      28  -29   -80  81 -304 308 % Water between Plates 7 and 8
cell 2530  2  zirc4    29  -30   -80  81 -304 308 % Fuel Clad inner Plate  8
cell 2531  2  fuel20   30  -31   -80  81 -304 308 % Fuel Meat Plate  8
cell 2532  2  zirc4    31  -32   -80  81 -304 308 % Fuel Clad outer Plate  8
cell 2533  2  h2o      32  -33   -80  81 -304 308 % Water between Plates 8 and 9
cell 2534  2  zirc4    33  -34   -80  81 -304 308 % Fuel Clad inner Plate  9
cell 2535  2  fuel21   34  -35   -80  81 -304 308 % Fuel Meat Plate  9
cell 2536  2  zirc4    35  -36   -80  81 -304 308 % Fuel Clad outer Plate  9
cell 2537  2  h2o      36  -37   -80  81 -304 308 % Water between Plates 9 and 10
cell 2538  2  zirc4    37  -38   -80  81 -304 308 % Fuel Clad inner Plate  10
cell 2539  2  fuel22   38  -39   -80  81 -304 308 % Fuel Meat Plate  10
cell 2540  2  zirc4    39  -40   -80  81 -304 308 % Fuel Clad outer Plate  10
cell 2541  2  h2o      40  -41   -80  81 -304 308 % Water between Plates 10 and 11
cell 2542  2  zirc4    41  -42   -80  81 -304 308 % Fuel Clad inner Plate  11
cell 2543  2  fuel23   42  -43   -80  81 -304 308 % Fuel Meat Plate  11
cell 2544  2  zirc4    43  -44   -80  81 -304 308 % Fuel Clad outer Plate  11
cell 2545  2  h2o      44  -45   -80  81 -304 308 % Water between Plates 11 and 12
cell 2546  2  zirc4    45  -46   -80  81 -304 308 % Fuel Clad inner Plate  12
cell 2547  2  fuel24   46  -47   -80  81 -304 308 % Fuel Meat Plate  12
cell 2548  2  zirc4    47  -48   -80  81 -304 308 % Fuel Clad outer Plate  12

% *** WNW Octant ***
cell 2602  2  zirc4     1   -2   -80  81 -310 305 % Fuel Clad inner Plate  1
cell 2603  2  fuel13    2   -3   -80  81 -310 305 % Fuel Meat Plate  1
cell 2604  2  zirc4     3   -4   -80  81 -310 305 % Fuel Clad outer Plate  1
cell 2605  2  h2o       4   -5   -80  81 -310 305 % Water between Plates 1 and 2
cell 2606  2  zirc4     5   -6   -80  81 -310 305 % Fuel Clad inner Plate  2
cell 2607  2  fuel14    6   -7   -80  81 -310 305 % Fuel Meat Plate  2
cell 2608  2  zirc4     7   -8   -80  81 -310 305 % Fuel Clad outer Plate  2
cell 2609  2  h2o       8   -9   -80  81 -310 305 % Water between Plates 2 and 3
cell 2610  2  zirc4     9  -10   -80  81 -310 305 % Fuel Clad inner Plate  3
cell 2611  2  fuel15   10  -11   -80  81 -310 305 % Fuel Meat Plate  3
cell 2612  2  zirc4    11  -12   -80  81 -310 305 % Fuel Clad outer Plate  3
cell 2613  2  h2o      12  -13   -80  81 -310 305 % Water between Plates 3 and 4
cell 2614  2  zirc4    13  -14   -80  81 -310 305 % Fuel Clad inner Plate  4
cell 2615  2  fuel16   14  -15   -80  81 -310 305 % Fuel Meat Plate  4
cell 2616  2  zirc4    15  -16   -80  81 -310 305 % Fuel Clad outer Plate  4
cell 2617  2  h2o      16  -17   -80  81 -310 305 % Water between Plates 4 and 5
cell 2618  2  zirc4    17  -18   -80  81 -310 305 % Fuel Clad inner Plate  5
cell 2619  2  fuel17   18  -19   -80  81 -310 305 % Fuel Meat Plate  5
cell 2620  2  zirc4    19  -20   -80  81 -310 305 % Fuel Clad outer Plate  5
cell 2621  2  h2o      20  -21   -80  81 -310 305 % Water between Plates 5 and 6
cell 2622  2  zirc4    21  -22   -80  81 -310 305 % Fuel Clad inner Plate  6
cell 2623  2  fuel18   22  -23   -80  81 -310 305 % Fuel Meat Plate  6
cell 2624  2  zirc4    23  -24   -80  81 -310 305 % Fuel Clad outer Plate  6
cell 2625  2  h2o      24  -25   -80  81 -310 305 % Water between Plates 6 and 7
cell 2626  2  zirc4    25  -26   -80  81 -310 305 % Fuel Clad inner Plate  7
cell 2627  2  fuel19   26  -27   -80  81 -310 305 % Fuel Meat Plate  7
cell 2628  2  zirc4    27  -28   -80  81 -310 305 % Fuel Clad outer Plate  7
cell 2629  2  h2o      28  -29   -80  81 -310 305 % Water between Plates 7 and 8
cell 2630  2  zirc4    29  -30   -80  81 -310 305 % Fuel Clad inner Plate  8
cell 2631  2  fuel20   30  -31   -80  81 -310 305 % Fuel Meat Plate  8
cell 2632  2  zirc4    31  -32   -80  81 -310 305 % Fuel Clad outer Plate  8
cell 2633  2  h2o      32  -33   -80  81 -310 305 % Water between Plates 8 and 9
cell 2634  2  zirc4    33  -34   -80  81 -310 305 % Fuel Clad inner Plate  9
cell 2635  2  fuel21   34  -35   -80  81 -310 305 % Fuel Meat Plate  9
cell 2636  2  zirc4    35  -36   -80  81 -310 305 % Fuel Clad outer Plate  9
cell 2637  2  h2o      36  -37   -80  81 -310 305 % Water between Plates 9 and 10
cell 2638  2  zirc4    37  -38   -80  81 -310 305 % Fuel Clad inner Plate  10
cell 2639  2  fuel22   38  -39   -80  81 -310 305 % Fuel Meat Plate  10
cell 2640  2  zirc4    39  -40   -80  81 -310 305 % Fuel Clad outer Plate  10
cell 2641  2  h2o      40  -41   -80  81 -310 305 % Water between Plates 10 and 11
cell 2642  2  zirc4    41  -42   -80  81 -310 305 % Fuel Clad inner Plate  11
cell 2643  2  fuel23   42  -43   -80  81 -310 305 % Fuel Meat Plate  11
cell 2644  2  zirc4    43  -44   -80  81 -310 305 % Fuel Clad outer Plate  11
cell 2645  2  h2o      44  -45   -80  81 -310 305 % Water between Plates 11 and 12
cell 2646  2  zirc4    45  -46   -80  81 -310 305 % Fuel Clad inner Plate  12
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cell 2647  2  fuel24   46  -47   -80  81 -310 305 % Fuel Meat Plate  12
cell 2648  2  zirc4   47  -48   -80  81 -310 305 % Fuel Clad outer Plate  12

% *** NNW Octant ***
cell 2702  2  zirc4    1   -2  -80  81 311 -301 % Fuel Clad inner Plate  1
cell 2703  2  fuel13   2   -3  -80  81 311 -301 % Fuel Meat Plate  1
cell 2704  2  zirc4    3   -4  -80  81 311 -301 % Fuel Clad outer Plate  1
cell 2705  2  h2o      4   -5  -80  81 311 -301 % Water between Plates 1 and 2
cell 2706  2  zirc4    5   -6  -80  81 311 -301 % Fuel Clad inner Plate  2
cell 2707  2  fuel14   6   -7  -80  81 311 -301 % Fuel Meat Plate  2
cell 2708  2  zirc4    7   -8  -80  81 311 -301 % Fuel Clad outer Plate  2
cell 2709  2  h2o      8   -9  -80  81 311 -301 % Water between Plates 2 and 3
cell 2710  2  zirc4    9  -10  -80  81 311 -301 % Fuel Clad inner Plate  3
cell 2711  2  fuel15  10  -11  -80  81 311 -301 % Fuel Meat Plate  3
cell 2712  2  zirc4   11  -12  -80  81 311 -301 % Fuel Clad outer Plate  3
cell 2713  2  h2o     12  -13  -80  81 311 -301 % Water between Plates 3 and 4
cell 2714  2  zirc4   13  -14  -80  81 311 -301 % Fuel Clad inner Plate  4
cell 2715  2  fuel16  14  -15  -80  81 311 -301 % Fuel Meat Plate  4
cell 2716  2  zirc4   15  -16  -80  81 311 -301 % Fuel Clad outer Plate  4
cell 2717  2  h2o     16  -17  -80  81 311 -301 % Water between Plates 4 and 5
cell 2718  2  zirc4   17  -18  -80  81 311 -301 % Fuel Clad inner Plate  5
cell 2719  2  fuel17  18  -19  -80  81 311 -301 % Fuel Meat Plate  5
cell 2720  2  zirc4   19  -20  -80  81 311 -301 % Fuel Clad outer Plate  5
cell 2721  2  h2o     20  -21  -80  81 311 -301 % Water between Plates 5 and 6
cell 2722  2  zirc4   21  -22  -80  81 311 -301 % Fuel Clad inner Plate  6
cell 2723  2  fuel18  22  -23  -80  81 311 -301 % Fuel Meat Plate  6
cell 2724  2  zirc4   23  -24  -80  81 311 -301 % Fuel Clad outer Plate  6
cell 2725  2  h2o     24  -25  -80  81 311 -301 % Water between Plates 6 and 7
cell 2726  2  zirc4   25  -26  -80  81 311 -301 % Fuel Clad inner Plate  7
cell 2727  2  fuel19  26  -27  -80  81 311 -301 % Fuel Meat Plate  7
cell 2728  2  zirc4   27  -28  -80  81 311 -301 % Fuel Clad outer Plate  7
cell 2729  2  h2o     28  -29  -80  81 311 -301 % Water between Plates 7 and 8
cell 2730  2  zirc4   29  -30  -80  81 311 -301 % Fuel Clad inner Plate  8
cell 2731  2  fuel20  30  -31  -80  81 311 -301 % Fuel Meat Plate  8
cell 2732  2  zirc4   31  -32  -80  81 311 -301 % Fuel Clad outer Plate  8
cell 2733  2  h2o     32  -33  -80  81 311 -301 % Water between Plates 8 and 9
cell 2734  2  zirc4   33  -34  -80  81 311 -301 % Fuel Clad inner Plate  9
cell 2735  2  fuel21  34  -35  -80  81 311 -301 % Fuel Meat Plate  9
cell 2736  2  zirc4   35  -36  -80  81 311 -301 % Fuel Clad outer Plate  9
cell 2737  2  h2o     36  -37  -80  81 311 -301 % Water between Plates 9 and 10
cell 2738  2  zirc4   37  -38  -80  81 311 -301 % Fuel Clad inner Plate  10
cell 2739  2  fuel22  38  -39  -80  81 311 -301 % Fuel Meat Plate  10
cell 2740  2  zirc4   39  -40  -80  81 311 -301 % Fuel Clad outer Plate  10
cell 2741  2  h2o     40  -41  -80  81 311 -301 % Water between Plates 10 and 11
cell 2742  2  zirc4   41  -42  -80  81 311 -301 % Fuel Clad inner Plate  11
cell 2743  2  fuel23  42  -43  -80  81 311 -301 % Fuel Meat Plate  11
cell 2744  2  zirc4   43  -44  -80  81 311 -301 % Fuel Clad outer Plate  11
cell 2745  2  h2o     44  -45  -80  81 311 -301 % Water between Plates 11 and 12
cell 2746  2  zirc4   45  -46  -80  81 311 -301 % Fuel Clad inner Plate  12
cell 2747  2  fuel24  46  -47  -80  81 311 -301 % Fuel Meat Plate  12
cell 2748  2  zirc4   47  -48  -80  81 311 -301 % Fuel Clad outer Plate  12

%  Other materials above and below fuel assembly
cell  577  2  h2o      1   -128     64       % water above fuel assembly
cell  578  2  h2o      1   -128    -65       % water below fuel assembly
%  Upper and lower plates without fuel homogenized
cell 585  2  TopPlat  1  -128   80 -62        % upper end plates
cell 586  2  BotPlat  1  -128  -81  63        % lower end plates
%  Upper and lower end boxes homogenized
cell 587  2  TopBox   1  -128      62 -64     % upper end box
cell 588  2  BotBox   1  -128     -63  65     % lower end box

cell  579  2  al6061   128 -129     80        % pressure vessel above fuel assembly
cell  580  2  al6061   128 -129    -81        % pressure vessel below fuel assembly
cell  581  2  d2o     129          80        % d2o outside PV above fuel assembly
cell  582  2  d2o     129         -81        % d2o outside PV below fuel assembly

% Side plates (fused adjacent plates
cell 590 2 zirc4   1 -48 301 -302  303 -80  81 % N sideplates
cell 591 2 zirc4   1 -48 307 -308  303 -80  81 % NE sideplates
cell 592 2 zirc4   1 -48 304 -305  300 -80  81 % E sideplates
cell 593 2 zirc4   1 -48 310 -311 -303 -80  81 % SE sideplates
cell 594 2 zirc4   1 -48 301 -302 -303 -80  81 % S sideplates
cell 595 2 zirc4   1 -48 307 -308 -303 -80  81 % SW sideplates
cell 596 2 zirc4   1 -48 304 -305 -300 -80  81 % W sideplates
cell 597 2 zirc4   1 -48 310 -311  303 -80  81 % NW sideplates

cell 200 4 d2o  -201  %  large area of d2o.  used for filling lat.

lat 150  4  0 0 2
```

```
1  0. 0.  1
6 34. 0.  2 2 2 2 2 2

cell 181 0 fill 150 -201  202 -203  % inside pressure vessel
%
% ------ Void Outside Core ------
cell 9001 0 outside 201 203 % rest of universe
cell 9002 0 outside 201 -202 % rest of universe
cell 9003 0 outside -201 203 % rest of universe
cell 9004 0 outside -201 -202 % rest of universe
cell 9005 0 outside 201 -203 202 % rest of universe

% ******************************************
% ******** End Of Cell Cards **************
% ******************************************

% ******************************************
% ************ Surface Cards **************
% ******************************************

% *** Fuel Plate Cylindrical surfaces Large Central Location ****
surf  1 cyl  0.0  0.0  9.6000         % Fuel Cld inner Plate  1
surf  2 cyl  0.0  0.0  9.6375         % Fuel Mt inner Plate  1
surf  3 cyl  0.0  0.0  9.6875         % Fuel Mt outer  Plate  1
surf  4 cyl  0.0  0.0  9.7250         % Fuel Cld outer  Plate  1
surf  5 cyl  0.0  0.0  9.9250         % Fuel Cld inner Plate  2
surf  6 cyl  0.0  0.0  9.9625         % Fuel Mt inner Plate  2
surf  7 cyl  0.0  0.0  10.0125        % Fuel Mt outer  Plate  2
surf  8 cyl  0.0  0.0  10.0500        % Fuel Cld outer  Plate  2
surf  9 cyl  0.0  0.0  10.2500        % Fuel Cld inner Plate  3
surf 10 cyl  0.0  0.0  10.2875        % Fuel Mt inner Plate  3
surf 11 cyl  0.0  0.0  10.3375        % Fuel Mt outer  Plate  3
surf 12 cyl  0.0  0.0  10.3750        % Fuel Cld outer  Plate  3
surf 13 cyl  0.0  0.0  10.5750        % Fuel Cld inner Plate  4
surf 14 cyl  0.0  0.0  10.6125        % Fuel Mt inner Plate  4
surf 15 cyl  0.0  0.0  10.6625        % Fuel Mt outer  Plate  4
surf 16 cyl  0.0  0.0  10.7000        % Fuel Cld outer  Plate  4
surf 17 cyl  0.0  0.0  10.9000        % Fuel Cld inner Plate  5
surf 18 cyl  0.0  0.0  10.9375        % Fuel Mt inner Plate  5
surf 19 cyl  0.0  0.0  10.9875        % Fuel Mt outer  Plate  5
surf 20 cyl  0.0  0.0  11.0250        % Fuel Cld outer  Plate  5
surf 21 cyl  0.0  0.0  11.2250        % Fuel Cld inner Plate  6
surf 22 cyl  0.0  0.0  11.2625        % Fuel Mt inner Plate  6
surf 23 cyl  0.0  0.0  11.3125        % Fuel Mt outer  Plate  6
surf 24 cyl  0.0  0.0  11.3500        % Fuel Cld outer  Plate  6
surf 25 cyl  0.0  0.0  11.5500        % Fuel Cld inner Plate  7
surf 26 cyl  0.0  0.0  11.5875        % Fuel Mt inner Plate  7
surf 27 cyl  0.0  0.0  11.6375        % Fuel Mt outer  Plate  7
surf 28 cyl  0.0  0.0  11.6750        % Fuel Cld outer  Plate  7
surf 29 cyl  0.0  0.0  11.8750        % Fuel Cld inner Plate  8
surf 30 cyl  0.0  0.0  11.9125        % Fuel Mt inner Plate  8
surf 31 cyl  0.0  0.0  11.9625        % Fuel Mt outer  Plate  8
surf 32 cyl  0.0  0.0  12.0000        % Fuel Cld outer  Plate  8
surf 33 cyl  0.0  0.0  12.2000        % Fuel Cld inner Plate  9
surf 34 cyl  0.0  0.0  12.2375        % Fuel Mt inner Plate  9
surf 35 cyl  0.0  0.0  12.2875        % Fuel Mt outer  Plate  9
surf 36 cyl  0.0  0.0  12.3250        % Fuel Cld outer  Plate  9
surf 37 cyl  0.0  0.0  12.5250        % Fuel Cld inner Plate 10
surf 38 cyl  0.0  0.0  12.5625        % Fuel Mt inner Plate 10
surf 39 cyl  0.0  0.0  12.6125        % Fuel Mt outer  Plate 10
surf 40 cyl  0.0  0.0  12.6500        % Fuel Cld outer  Plate 10
surf 41 cyl  0.0  0.0  12.8500        % Fuel Cld inner Plate 11
surf 42 cyl  0.0  0.0  12.8875        % Fuel Mt inner Plate 11
surf 43 cyl  0.0  0.0  12.9375        % Fuel Mt outer  Plate 11
surf 44 cyl  0.0  0.0  12.9750        % Fuel Cld outer  Plate 11
surf 45 cyl  0.0  0.0  13.1750        % Fuel Cld inner Plate 12
surf 46 cyl  0.0  0.0  13.2125        % Fuel Mt inner Plate 12
surf 47 cyl  0.0  0.0  13.2625        % Fuel Mt outer  Plate 12
surf 48 cyl  0.0  0.0  13.3000        % Fuel Cld outer  Plate 12

% *** vertical planes separating arcuate assemblies
surf 300 px  0.0
surf 301 px -0.475
surf 302 px  0.475

surf 303 py  0.0
surf 304 py -0.475
surf 305 py  0.475

surf 306 plane  -1.0 1.0 0.0  0.0
```

```
surf 307 plane  -1.0 1.0 0.0 -0.671751442
surf 308 plane  -1.0 1.0 0.0  0.671751442

surf 309 plane   1.0 1.0 0.0  0.0
surf 310 plane   1.0 1.0 0.0 -0.671751442
surf 311 plane   1.0 1.0 0.0  0.671751442

% *** Top and Bottom End Plates ***
surf 80  pz  60.      % Top of fuel meat
surf 81  pz -60.      % Bottom of fuel meat
surf 62  pz  62.      % Top of plates
surf 63  pz -62.      % Bottom of plates
surf 64  pz  82.      % Top of Top End Box
surf 65  pz -82.      % Bottom of Bottom End Box

%  *** Large Test Space Surfaces ***
surf 121 cyl  0.0  0.0  6.35  % Outer surface of flux monitor holder
surf 122 cyl  0.0  0.0  6.95  % Inner surface of pressure tube
surf 123 cyl  0.0  0.0  7.85  % Outer surface of pressure tube
surf 124 cyl  0.0  0.0  7.95  % Inner surface of insulation jacket
surf 125 cyl  0.0  0.0  8.10  % Outer surface of insulation jacket
surf 126 cyl  0.0  0.0  8.70  % Inner surface of Al baffle
surf 127 cyl  0.0  0.0  9.40  % Outer surface of Al baffle
surf 128 cyl  0.0  0.0  13.5  % Inner surface of Pressure boundary Tube
surf 129 cyl  0.0  0.0  14.6  % Outer surface of Pressure boundary Tube

%  *** Small Test Space Surfaces peripheral location ***
surf 220 cyl  0.0  0.0  3.54  % Outer boundary of test space
surf 221 cyl  0.0  0.0  3.70  % Outer surface of flow tube
surf 222 cyl  0.0  0.0  4.00  % Inner surface of pressure tube
surf 223 cyl  0.0  0.0  4.90  % Outer surface of pressure tube
surf 224 cyl  0.0  0.0  5.00  % Inner surface of insulation jacket
surf 225 cyl  0.0  0.0  5.30  % Outer surface of insulation jacket
surf 226 cyl  0.0  0.0  5.80  % Inner surface of safety rod guide tube
surf 227 cyl  0.0  0.0  6.40  % Outer surface of safety rod guide tube
surf 228 cyl  0.0  0.0  7.50  % Inner surface of safety rod follower
surf 229 cyl  0.0  0.0  8.30 % Outer surface of safety rod follower

% *** D2O tank outer boundary ***
surf 201  cyl 0.0 0.0 150.0   %

surf 202 pz -150.
surf 203 pz  150.

% *****************************************
% ********  End Of Surface Cards **********
% *****************************************

% vacuum boundary
set bc 1

% source entropy mesh
set entr [4 4 4 -150. 150. -150. 150. -50. 50. ]

% cross section library path !!!! for Fission machine !!!!
set acelib "/home/popema/SERPENT/SERPENT/data/xsdata_combined"
set declib "/home/popema/SERPENT/SERPENT/data/sss_endfb7.dec"
set nfylib "/home/popema/SERPENT/SERPENT/data/sss_endfb7.nfy"

mesh 3 1000 1000 0 -150 150 -150 150

set power 250.E06
set opti 1
set pop 10000 1000 5 1.2

% ------- Material Cards -------------------------------------------
% ------ Fuel ------
mat fuel1 4.9186E-02      tmp 433.   vol 318.7 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel2 4.9186E-02      tmp 433.   vol 330.9 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel3 4.9186E-02      tmp 433.   vol 343.2 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel4 4.9186E-02      tmp 433.   vol 355.4 burn 1
```

```
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel5 4.9186E-02      tmp 433.   vol 367.7 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel6 4.9186E-02      tmp 433.   vol 379.9 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel7 4.9186E-02      tmp 433.   vol 392.2 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel8 4.9186E-02      tmp 433.   vol 404.4 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel9 4.9186E-02      tmp 433.   vol 416.7 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel10 4.9186E-02     tmp 433.   vol 428.9 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel11 4.9186E-02     tmp 433.   vol 441.2 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel12 4.9186E-02     tmp 433.   vol 453.4 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel13 4.9186E-02     tmp 433.   vol 1951.8 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel14 4.9186E-02     tmp 433.   vol 2026.9 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel15 4.9186E-02     tmp 433.   vol 2101.9 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel16 4.9186E-02     tmp 433.   vol 2177.0 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel17 4.9186E-02     tmp 433.   vol 2252.0 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel18 4.9186E-02     tmp 433.   vol 2327.1 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel19 4.9186E-02     tmp 433.   vol 2402.1 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel20 4.9186E-02     tmp 433.   vol 2477.2 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel21 4.9186E-02     tmp 433.   vol 2552.2 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel22 4.9186E-02     tmp 433.   vol 2627.2 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel23 4.9186E-02     tmp 433.   vol 2702.3 burn 1
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
mat fuel24 4.9186E-02     tmp 433.   vol 2777.3 burn 1
```

```
    92235.03c  7.6963E-03
    92238.03c  3.0882E-02
    42000.03c  1.0608E-02
% ------ H2O Coolant ------
% T=70C, P=2.3 MPa, rho=0.979 g/cc
mat h2o  9.818E-02       moder h2o 1001
     1001.03c  6.545E-02
     8016.03c  3.273E-02
% ------ D2O ------
mat d2o 9.986E-02     moder d2o 1002
     1002.03c  6.657E-02
     8016.03c  3.329E-02
% ------ Al-6061 ------
mat al6061 -2.715       % Al-6061 density 2.715 g/cc
   14000.03c  -0.7   %      0.7   % Si
   26000.03c  -0.6   %      0.60  % Fe
   29000.03c  -0.22  %      0.22  % Cu
   25055.03c  -0.08  %      0.08  % Mn
   12000.03c  -1.0   %      1.0   % Mg
   24000.03c  -0.2   %      0.1   % Cr
   30000.03c  -0.08  %      0.08  % Zn
   22000.03c  -0.03  %      0.03  % Ti
   13027.03c  -97.09 %      97.09 % Al
% ------ Beryllium ------
% assumed 6% by volume H2O
mat be9  1.2188E-01  moder be 4009   % moder be
   4009.03c  1.157E-01
   1001.03c  4.120E-03
   8016.03c  2.060E-03
% ------  SS 304   ------
% Fe-0.08C-2.0Mn-0.045P-0.03S-1.0Si-19Cr-9Ni
mat ss304   -8.0       % ss 304 8g/cc
    6000.03c  -0.08   %     0.08   % C
   25055.03c  -2.0    %     2.0    % Mn
   15031.03c  -0.045  %     0.045  % P
   16000.03c  -0.03   %     0.03   % S
   14000.03c  -0.75   %     0.75   % Si
   24000.03c  -19.    %     19.    % Cr
   28000.03c  -9.25   %     9.25   % Ni
    7014.03c  -0.05   %     0.05   % N
   26000.03c  -68.795 %    68.795  % Fe
% ------ Helium Coolant ------
mat helium 0.0007
     2004.03c  7.0000E-04
% ---- Al/H2O 50/50 mix in test spaces -----
mat AlH2Omix  7.929E-02  moder h2o 1001
     1001.03c  3.270E-02
     8016.03c  1.635E-02
    13027.03c  3.024E-02
% ----- Zircalloy4 -------
mat zirc4  -6.56    tmp 398.
    40000.03c  -98.23   %     98.23 % Zr
    50000.03c  -1.45    %     1.45  % Sn
    26000.03c  -0.21    %     0.21  % Fe
    24000.03c  -0.10    %     0.10  % Cr
    72000.03c  -0.01    %     0.01  % Hf
% ----- Top End Box -------
mix TopBox
  zirc4 0.20
  h2o   0.80
% ----- Bottom End Box -------
mix BotBox
  zirc4 0.20
  h2o   0.80
% ----- Top plate no fuel -------
mix TopPlat
  zirc4 0.39
  h2o   0.61
% ----- Bottom plate no fuel -------
mix BotPlat
  zirc4 0.39
  h2o   0.61

% for installation on Fission
therm h2o lwtr.01t
therm d2o hwtr.01t
therm be  be.01t

dep daytot
0.1 0.5 1.0 2.0 3.5 5.0 10.0 15. 20. 30. 40. 50. 60. 80. 100. 120. 140. 160. 180. 200.
```

```
% TALLIES
% Flux 1MeV cutoff in  test zones
det CTrap dc 140 du 1 dv 432. de 1MeV dx -3.   3.   1  dy  -3.  3.  1  dz -60. 60. 10
det PTrap dc 120 du 2 dv 432. de 1MeV dx 31.  37.   1  dy  -3.  3.  1  dz -60. 60. 10

% Flux broken down into 3.
det FTref1 dc 181  du 0  dv 192. de 1MeV dx  55.4  59.4 1 dy 21.7 25.7 1  dz -60. 60. 10
det FTref2 dc 181  du 0  dv 192. de 1MeV dx  73.8  77.8 1 dy 29.4 33.4 1  dz -60. 60. 10
det FTref3 dc 181  du 0  dv 192. de 1MeV dx  92.3  96.3 1 dy 37.0 41.0 1  dz -60. 60. 10
det FTref4 dc 181  du 0  dv 192. de 1MeV dx 110.8 114.8 1 dy 44.7 48.7 1  dz -60. 60. 10

ene 1MeV   1 1.0E-15 0.625E-06 1.0  20.
```

Appendix B
ATR Core Diagrams

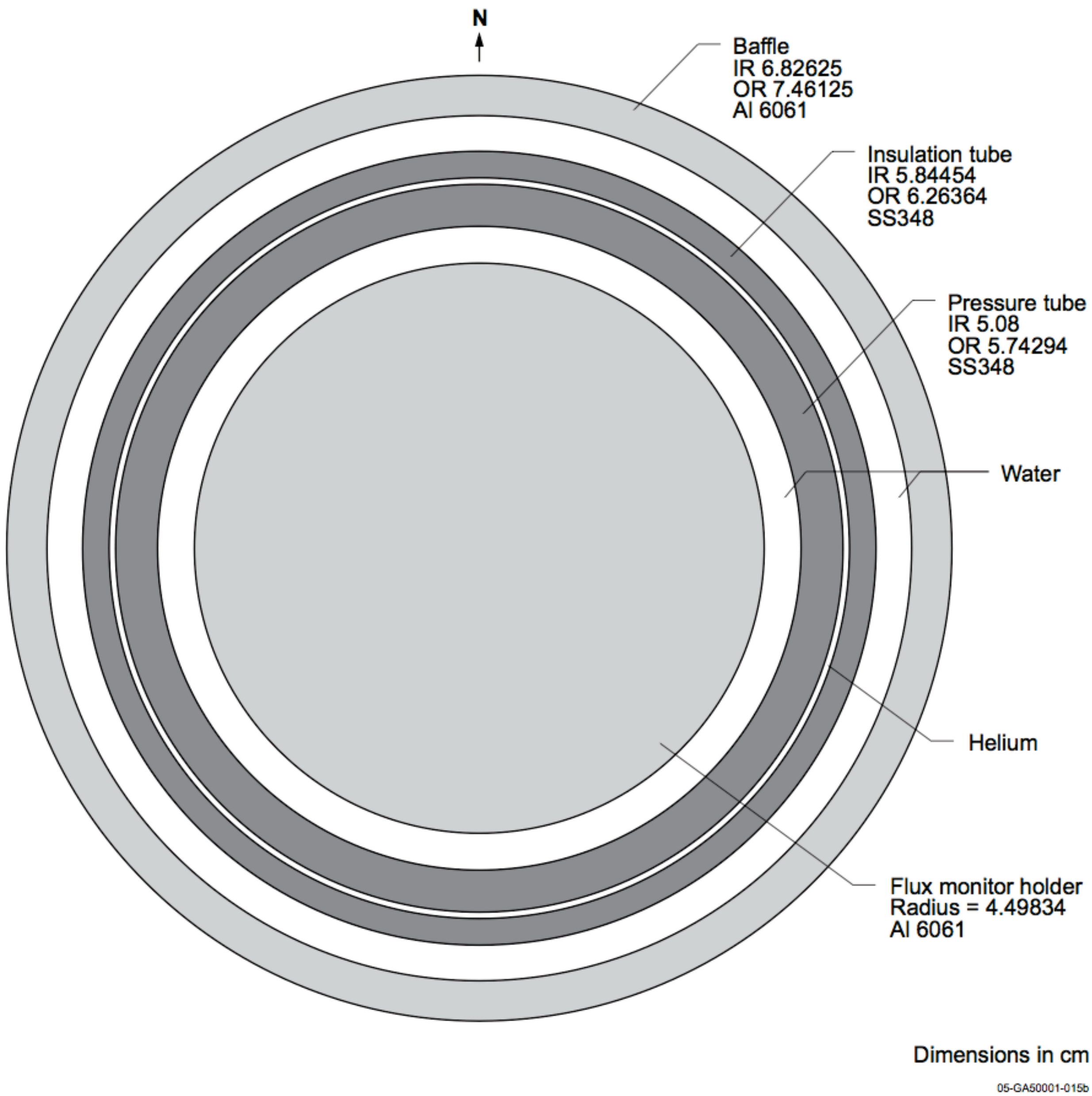

Figure C-1. Diagram of Northwest flux trap in ATR.

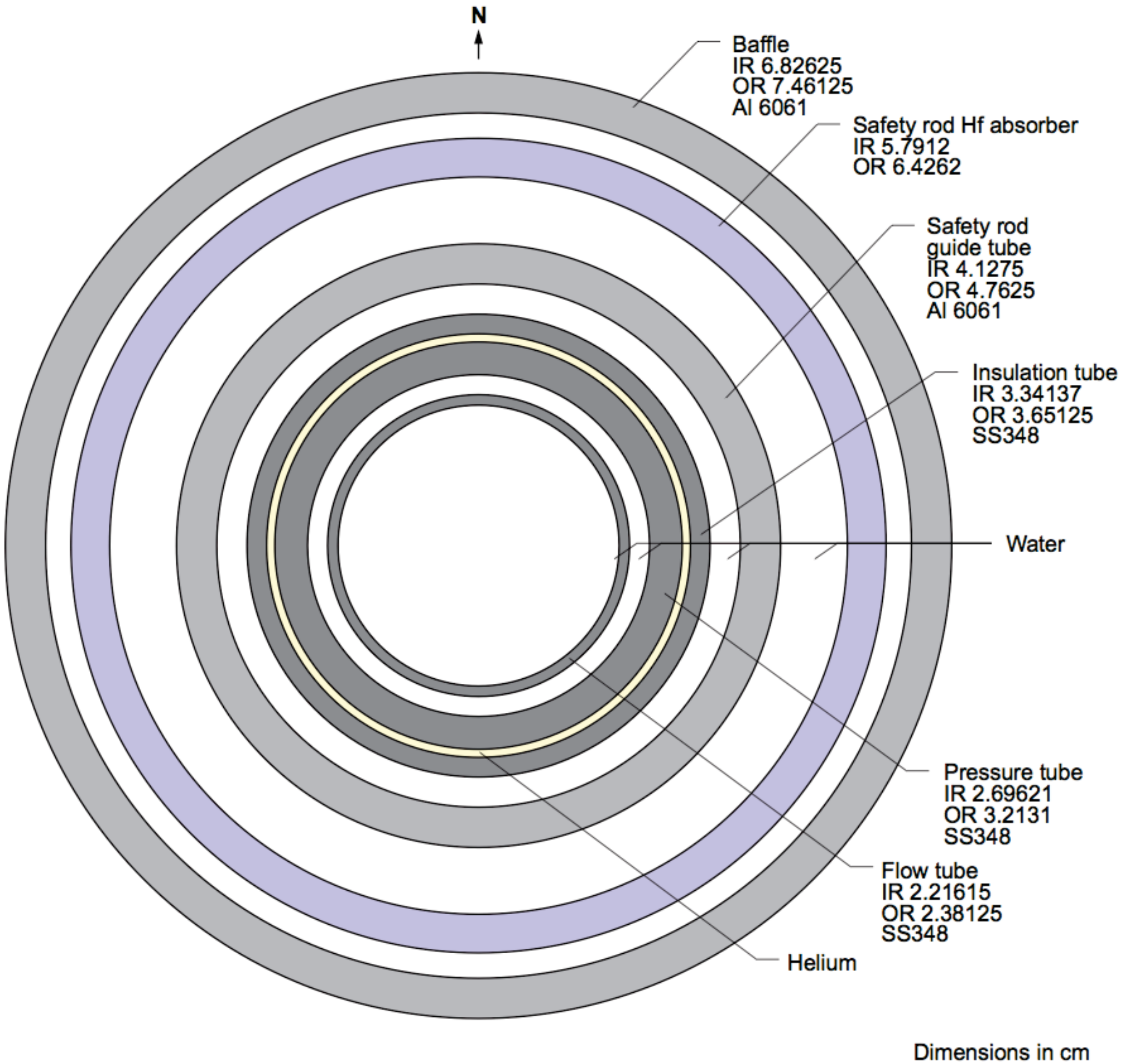

Figure C-2. Diagram of North, West, Southwest, and Southeast flux traps in ATR.

Appendix C
Renderings of Cylindrical MATRIX Concept

Figure C-1. Reactor vessel cut to show core internals.

Figure C-2. Vessel with surrounding D_2O tank.

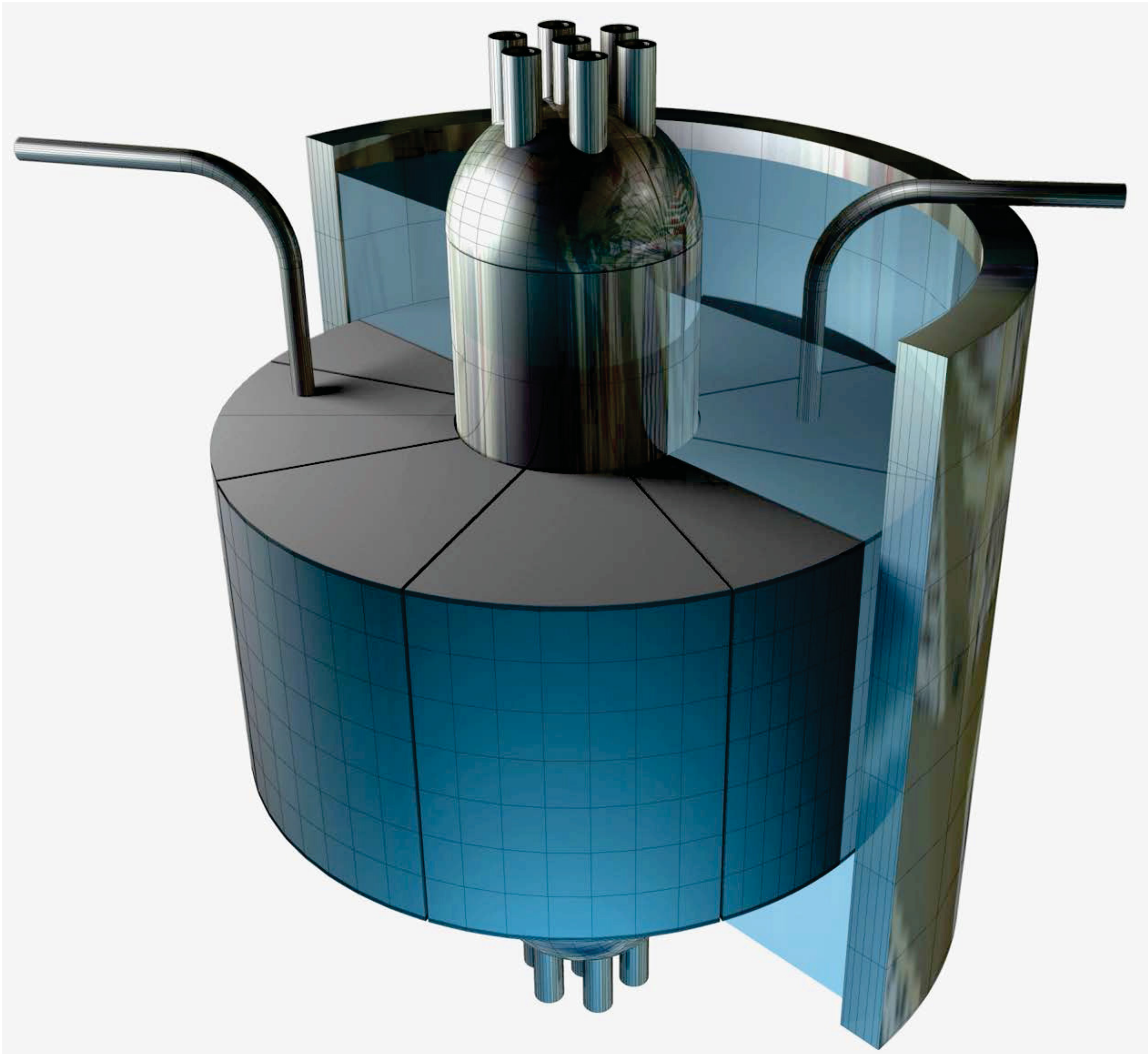

Figure C-3. Vessel with D_2O tanks in water pool.

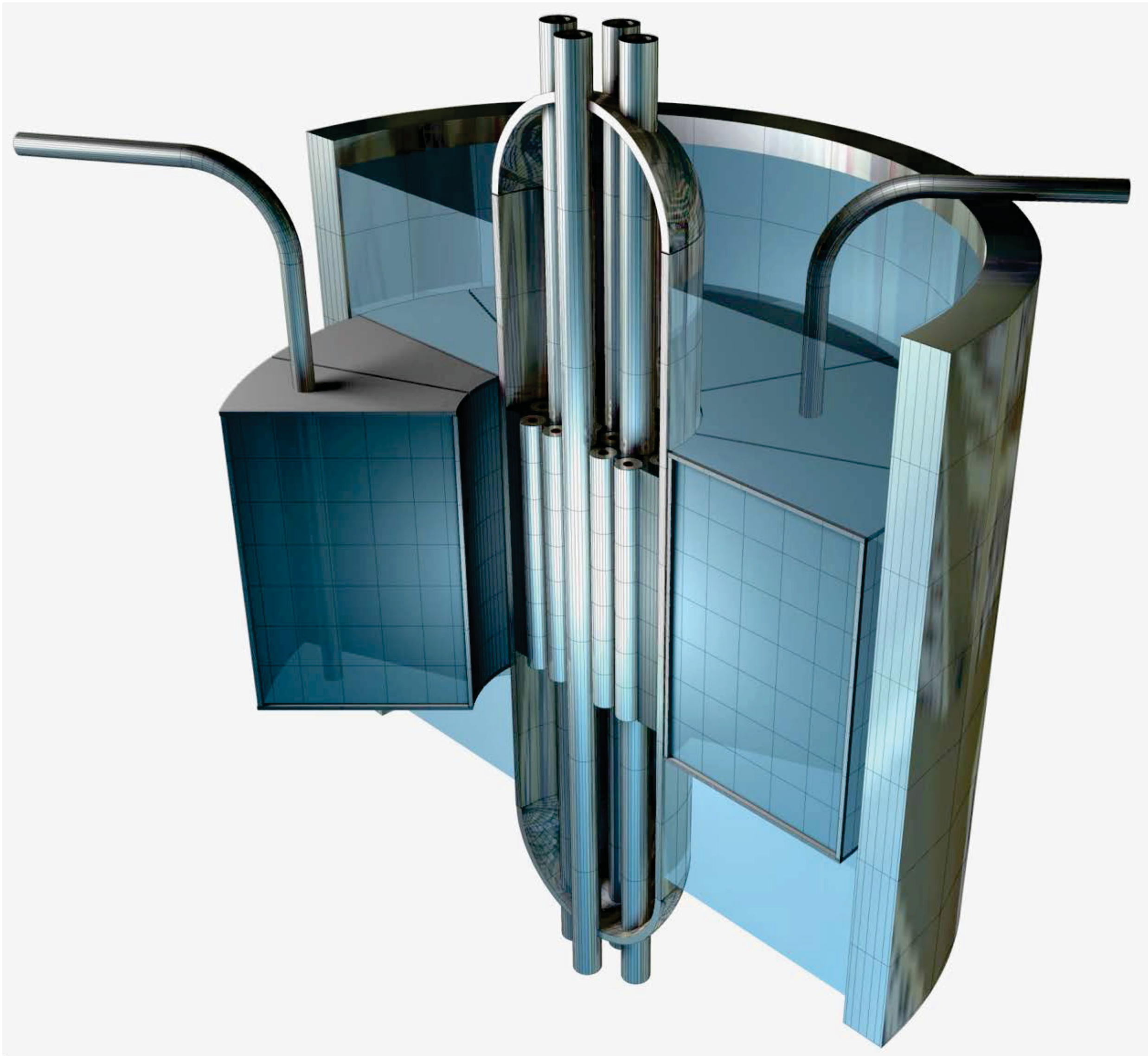

Figure C-4 Vessel with D_2O tanks in water pool, both vessel and D_2O tanks cut.

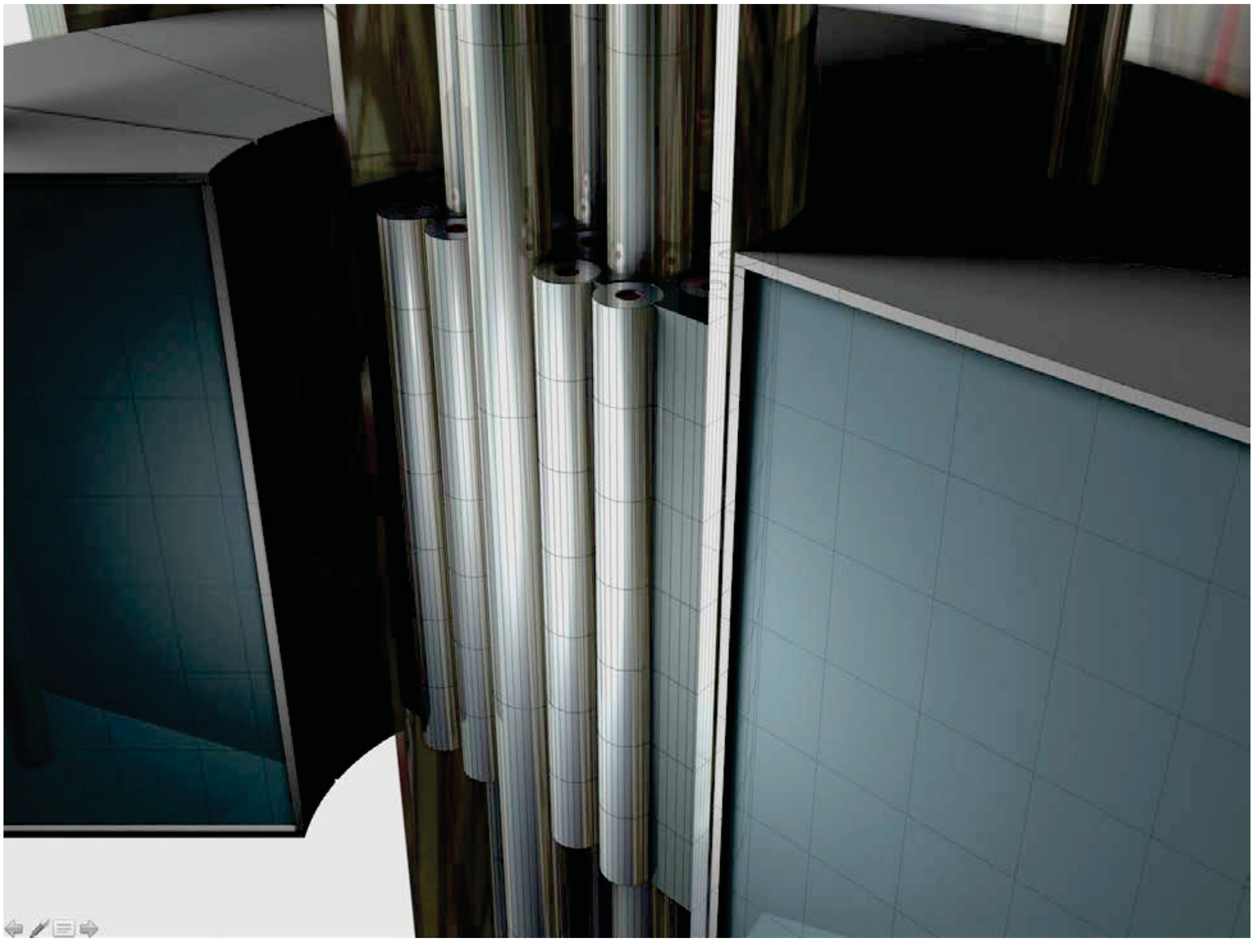

Figure C-5. Expanded view of core with vessel with D_2O tanks in water pool.