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# Criticality Safety Evaluation for the Advanced Test Reactor U-Mo Demonstration Elements

Leland M. Montierth

December 2010

Idaho National Laboratory

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# 1. Introduction

The Reduced Enrichment Research Test Reactors (RERTR) fuel development program is developing a high uranium density fuel based on a (LEU) uranium-molybdenum alloy. Testing of prototypic RERTR fuel elements is necessary to demonstrate integrated fuel performance behavior and scale-up of fabrication techniques. Two RERTR-Full Size Demonstration fuel elements based on the ATR-Reduced YA elements (all but one plate fueled) are to be fabricated for testing in the Advanced Test Reactor (ATR). The two fuel elements will be irradiated in alternating cycles such that only one element is loaded in the reactor at a time. Existing criticality analyses have analyzed Standard (HEU) ATR elements (all plates fueled) from which controls have been derived. This criticality safety evaluation (CSE) documents analysis that determines the reactivity of the Demonstration fuel elements relative to HEU ATR elements and shows that the Demonstration elements are bound by the Standard HEU ATR elements and existing HEU ATR element controls are applicable to the Demonstration elements.

# 2. Description

A brief listing of the various facilities where ATR fuel is present is given in Section 2.1. A description of the HEU ATR elements is given in Section 2.2.1. A description of the Full Size Demonstration elements is given in Section 2.2.2.

## 2.1 Facilities Containing ATR Fuel

ATR fuel is handled and stored at several facilities at the INL. Facilities at the ATR Complex are the ATR, the Advanced Test Reactor Critical (ATRC) Facility and the Nuclear Materials Inspection and Storage (NMIS) Facility. The ATR provides high neutron flux for testing reactor fuels and other materials. ATR fuel is handled and stored at the ATR Facility within the reactor vessel, the working canal, the storage canal and up on the deck. The working canal is directly adjacent to the reactor and is used to transfer fuel, experiments and reactor components between the storage canal and the reactor. The storage canal is used for the storage of fuel, experiments and reactor components. The Advanced Test Reactor Critical (ATRC) Facility is a low power pool version of the high-power ATR core that is used for experimental needs. The NMIS facility is used to store unirradiated and slightly irradiated (< 200mR/hr) fuel. ATR fuel is transferred between the three facilities within the ATR Complex using single and 4-element ATR fresh fuel shipping containers. CSEs have been performed and have derived controls for the handling, storage and transfer of ATR fuel at and between these facilities.

## 2.2 Description of the ATR Fuel

In the history of the ATR, there have been numerous variations of HEU ATR fuel elements. The HEU elements of concern here are the Standard Size non-borated (7F), Standard Size borated where all plates except plates 5 through 15 are borated, and the reduced YA element where all plates except plates 5 through 15 are borated and plate 19 is a “dummy” fuel plate, i.e., it is made entirely of type T-6061 aluminum and contains no fuel. For criticality safety purposes the boron content is conservatively neglected and the Standard elements are identical. This element is referred to here as a “typical” ATR element and bounds the other HEU fuel element variants, including the Mark IV element currently used at ATRC. The Full Size Demonstration elements are based on the ATR Reduced YA elements and also neglect boron for criticality safety purposes.

### 2.2.1 HEU ATR Fuel Elements

A typical ATR fuel element consists of 19 curved aluminum clad uranium aluminide ($UAl_x$) plates containing highly enriched (93±1 wt% U-235) uranium.[1] The highest fissile loading (U-235) of the fresh fuel element is 1075 g.[2] The allowable fuel loading (U-235) uncertainty for each fuel plate is ±1 percent.[1] The allowed fuel element U-235 loading and uncertainty are 1075 ± 10 g, giving a maximum loading of 1085 g for a Standard Sized ATR fuel element. The allowed U-235 loading for the ATR Reduced YA element is 1022.4 ± 10 g as plate 19 is a dummy plate containing no fuel.

Figure 1 presents a simplified view of a typical ATR fuel element. The fuel plates are 49.5 in. long with a fuel zone that is 48 in. long.

The thickness of each plate is 0.05 in. except plates 1 and 19, which are 0.08 in. and 0.1 in., respectively. The fuel matrix section in each plate is 0.02 in. thick. The cladding is made of type T-6061 aluminum. The plates are held in place by aluminum side plates that are 2.549 inches wide, 0.187 in. thick, and 49.5 in. long. The water gap between plates is 0.078 in. thick. When assembled, the angle of curvature of the fuel elements is 45° with inner and outer radii of 2.964 in. and 5.513 in, respectively. The detailed dimensions of each fuel plate and maximum U-235 content are presented in Table 1.

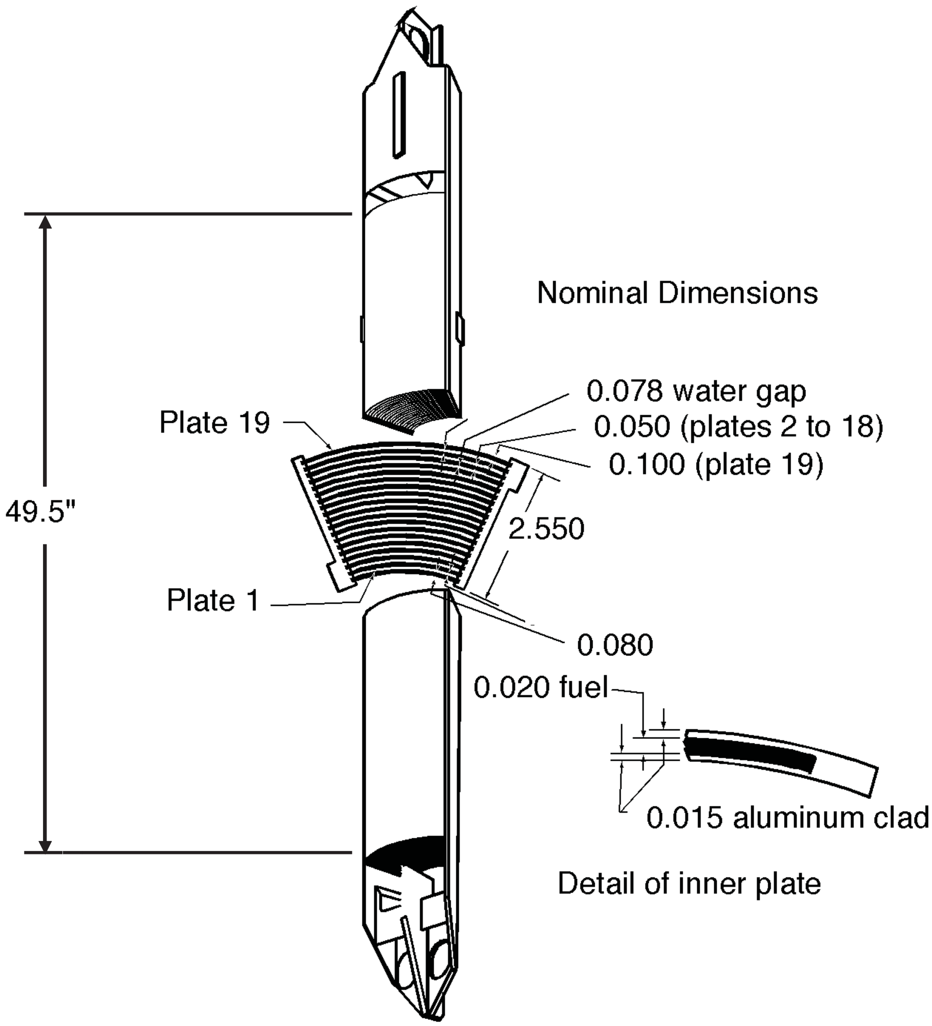



Figure 1. Simplified View of the HEU ATR Fuel Element

Table 1. Dimensions and U-235 Content for Individual Plates in ATR Fuel Element

| Plate Number | Inner Radius (cm) | Outer Radius (cm) | U-235 content (max) (g) |
|---|---|---|---|
| 1 | 7.65810 | 7.86130 | 24.543 |
| 2 | 8.05942 | 8.18642 | 29.391 |
| 3 | 8.38454 | 8.51154 | 39.087 |
| 4 | 8.70966 | 8.83666 | 40.804 |
| 5 | 9.03478 | 9.16178 | 52.621 |
| 6 | 9.35990 | 9.48690 | 55.146 |
| 7 | 9.68502 | 9.81202 | 57.570 |
| 8 | 10.01014 | 10.13714 | 59.994 |
| 9 | 10.33526 | 10.46226 | 62.418 |
| 10 | 10.66038 | 10.78738 | 64.842 |
| 11 | 10.98550 | 11.11250 | 67.266 |
| 12 | 11.31062 | 11.43762 | 69.690 |
| 13 | 11.63574 | 11.76274 | 72.114 |
| 14 | 11.96086 | 12.08786 | 74.538 |
| 15 | 12.28598 | 12.41298 | 77.063 |
| 16 | 12.61110 | 12.73810 | 64.640 |
| 17 | 12.93622 | 13.06322 | 66.559 |
| 18 | 13.26134 | 13.38834 | 54.338 |
| 19[a] | 13.58646 | 13.84046 | 53.126 |
| 19[a] | 13.58646 | 13.84046 | 0. |

a Plate 19 for the ATR-Reduced YA fuel element is a dummy plate and does not contain any fuel.

### 2.2.2 ATR U-10Mo Full Size Demonstration Fuel Elements

The Full Size Demonstration element's physical geometry will remain unchanged from currently approved elements, but the fuel meat in several fuel plates will utilize U-10Mo alloy instead of the standard $UAl_x$ currently used in ATR fuel.[3] Two fuel elements based on the ATR- Reduced YA Element design will be fabricated for testing. The ATR Reduced YA elements consist of 19 total plates including an aluminum dummy plate (plate 19), 11 inner plates with standard $UAl_x$ fuel meats, and plates 1-4 and 16-18 with $UAl_x$ fuel and small amounts of $B_4C$ (burnable poison to suppress power peaking). The RERTR Full-size elements will be identical except that the 11 inner plates (plates 5-15) will be replaced with the U-Mo monolithic fuel design at 19.75% U- 235 enrichment. The plate locations are graphically depicted in Figure 2.

The nominal density of the U-10Mo is given as 16.9 g/cm$^3$, giving a U-235 density of 3.0 g/cm$^3$ for the given enrichment. The fuel meat thickness is 0.013 in., and is surrounded by a thin zirconium layer, 0.001 in. thick, to mitigate interactions between the fuel meat and aluminum cladding. A cross-sectional plot and other details of the U-10Mo plates are shown in Figure 3. Details for the individual fuel plates are given in Table 2. The allowable fuel loading (U-235) uncertainty for each fuel plate is ±1 percent. The total combined HEU and LEU U-235 loading for the Full Size Demonstration element is 1239.1 ± 12 g or a maximum of 1251.1 g.[4]

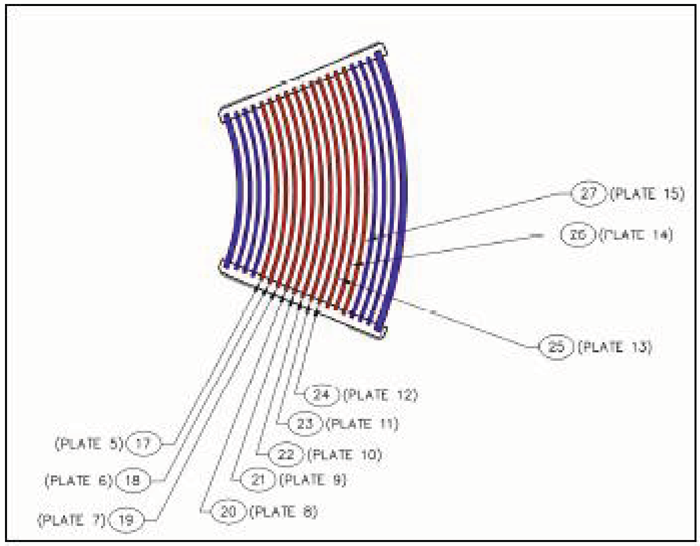



Figure 2. Full Size Demonstration U-10Mo Fuel Element

(Red – U-10Mo, Blue – $UAl_x$; circled numbers are from drawing)

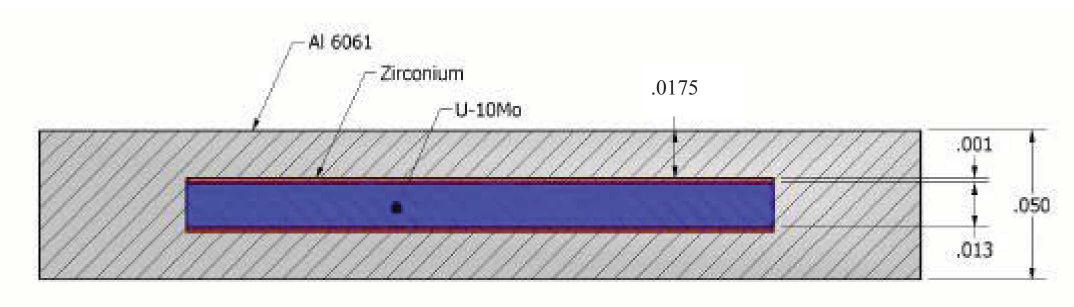



Figure 3. U-10Mo Fuel Plate Cross-section

(dimensions are in inches)

Table 2. Individual Plate Dimensions and U-235 Content for Full Size Demonstration Elements

| Plate Number | Plate Type | Inner Radius (cm) | Outer Radius (cm) | U-235 content (max) (g) |
|---|---|---|---|---|
| 1 | U-$Al_x$ | 7.65810 | 7.86130 | 24.543 |
| 2 | U-$Al_x$ | 8.05942 | 8.18642 | 29.391 |
| 3 | U-$Al_x$ | 8.38454 | 8.51154 | 39.087 |
| 4 | U-$Al_x$ | 8.70966 | 8.83666 | 40.804 |
| 5 | U-10Mo Mono | 9.03478 | 9.16178 | 67.6195 |
| 6 | U-10Mo Mono | 9.35990 | 9.48690 | 72.1241 |
| 7 | U-10Mo Mono | 9.68502 | 9.81202 | 75.3258 |
| 8 | U-10Mo Mono | 10.01014 | 10.13714 | 78.4871 |
| 9 | U-10Mo Mono | 10.33526 | 10.46226 | 81.6888 |
| 10 | U-10Mo Mono | 10.66038 | 10.78738 | 84.8198 |
| 11 | U-10Mo Mono | 10.98550 | 11.11250 | 88.0619 |
| 12 | U-10Mo Mono | 11.31062 | 11.43762 | 91.2131 |
| 13 | U-10Mo Mono | 11.63574 | 11.76274 | 94.4148 |
| 14 | U-10Mo Mono | 11.96086 | 12.08786 | 97.5761 |
| 15 | U-10Mo Mono | 12.28598 | 12.41298 | 100.798 |
| 16 | U-$Al_x$ | 12.61110 | 12.73810 | 64.640 |
| 17 | U-$Al_x$ | 12.93622 | 13.06322 | 66.559 |
| 18 | U-$Al_x$ | 13.26134 | 13.38834 | 54.338 |
| 19 | Al | 13.58646 | 13.84046 | 0. |

# 3. Unique or Special Requirements

There are no unique requirements that are applicable to this evaluation.

# 4. Methodology and Validation

All calculations listed in this report were performed using MCNP5, version 1.40 with the ENDF/B-VI continuous energy cross section library on Sun workstations running the Red Hat Enterprise LINUX Release 4 operating system. MCNP5 and its libraries are installed and maintained in accordance with an approved quality assurance plan.[5]

## 4.1 Methodology

Calculational models were developed for this evaluation. These calculations used the Monte Carlo N-Particle Transport Code (MCNP) computer program[6] and ENDF/B-VI cross sections to determine the criticality potential of ATR fuel types. Validation of the MCNP code is described in this section.

Benchmark experiments containing the same or similar attributes as the evaluated cases analyzed in this CSE are identified and evaluated here.

## 4.2 Validation

### 4.2.1 Validation of HEU ATR Elements

Validation results for the HEU ATR fuel elements are not repeated here as these results have previously been presented elsewhere.[7, 8, 9] In all cases it was not necessary to apply any bias to the results.

### 4.2.2 Validation of U-10Mo Full Size Demonstration Elements

The two different enrichments used in the Full Size Demonstration elements, nominal values of 20% and 93%, complicate the choice of applicable benchmark experiments as there are no known moderated benchmark experiments with these particular enrichments. (Note also that there is no known moderated benchmark experiment containing Mo alloyed with uranium at any enrichment available for validation.) If the fuel in the various plates were mixed together and homogenized, then the effective enrichment would be 25%. The International Criticality Safety Benchmark Evaluation Project (ICSBEP) considers this and 20% to be intermediate enrichments (IEU). Whether the Full Size Demonstration elements are thought of as being homogenized or not, two moderated benchmark experiments with enrichments that bracket 20% and 25% are used to validate the U-10Mo Demonstration elements. One of these benchmark experiments consists of stainless steel clad $U(17)O_2$ fuel rods moderated and reflected by water. The other experiment consists of uranium-polytetrafluoroethylene ($U(30)F_4(CF_2)_n$) and polyethylene ($CH_2$) cubes reflected by paraffin. Brief descriptions of these benchmark experiments are given in this section. The MCNP5 results for these experiments using ENDF/B-VI cross sections are given in Table 3. The last column of this table is the MCNP energy of average neutron lethargy causing fission (EALF).

Stainless steel clad $U(17)O_2$ fuel rods were water moderated and reflected in benchmark experiment IEU-COMP-THERM-002.[10] Experiments were performed in 1970-1973 in the MATR facility at the Institute of Physics and Power Engineering, Obninsk, Russia. The fuel rods were arranged in hexagonal lattices with a pitch of 6.8 cm. Each lattice was comprised of fuel rods containing either no absorber, gadolinium absorber, or cadmium absorber. The lattices were fully reflected on all sides by water. The critical mass was determined for "cold" (~20° C) and "hot" (~200° C) assemblies. Results are presented in the first set of Table 3 only for the cold, no absorber fuel rods case.

Benchmark experiment IEU-COMP-THERM-001 consisted of one-inch cubes of uranium-polytetrafluoroethylene ($U(30)F_4(CF_2)_{n)}$ and polyethylene ($CH_2$) reflected by paraffin.[11, 12] The arrays were assembled with different numbers of the two cube types to vary H/U-235 ratios from 32 to 220. Additional details are given in Table 3. Results are only presented for those benchmark experiments that had EALF values comparable to that of a near-critical array of U-10Mo Demonstration elements, $1.2 \times 10^{-4}$ kev.

Table 3. Results for Moderated Intermediate Enrichment U-235 Benchmark Experiments

| Experiment / MCNP Input File Name | Description | $k_{eff} \pm \sigma$ | EALF [a] (kev) |
|---|---|---|---|
| **IEU-COMP-THERM-002; U(17)$O_2$ fuel rods** | | | |
| CASE_1L | 34 fuel rods at temperature of 22.7° C; no absorber elements | 0.9960 ± 0.0005 | $9.1 \times 10^{-5}$ |
| **IEU-COMP-THERM-001; U-poly cube array results** | | | |
| exp04 | 10x10x8 array size;298 U cubes with 596 $CH_2$ cubes | 0.9998 ± 0.0008 | $2.6 \times 10^{-4}$ |
| exp05 | 16x14x14 array size; 400U cubes with 2800 $CH_2$ cubes | 1.0062 ± 0.0006 | $1.1 \times 10^{-4}$ |
| exp13 | 9x9x11 array size; 302 U cubes with 604 $CH_2$ cubes | 0.9995 ± 0.0008 | $2.6 \times 10^{-4}$ |
| exp14 | 8x8x16 array size; 356 U cubes with 712 $CH_2$ cubes | 1.0000 ± 0.0006 | $2.6 \times 10^{-4}$ |
| exp15 | 8x7x26 array size; 488 U cubes with 976 $CH_2$ cubes | 1.0009 ± 0.0008 | $2.5 \times 10^{-4}$ |
| Average values of k and EALF [b] | | 1.0004 ± 0.0030 | $2.1 \times 10^{-4}$ |

a EALF is the energy of average neutron lethargy causing fission

b The average values of $k_{avg}$ and its corresponding u are determined from the following formulas: $k_{avg} = \Sigma k_i/N$ and $u^2 = \Sigma(k_{avg} - k_i)^2/N$

### 4.2.3 Summary of Validation Results

The range of applicability of the benchmark cases presented in this section is determined by primary physical parameters that characterize a particular fissionable configuration. These physical parameters include material properties, geometry properties and trending parameters such as the EALF or H/X ratio for moderated systems. An area or range of applicability for the benchmark experiments is defined and used to determine the bias for configurations of interest. The choice of the benchmark experiments is typically based on the fissionable element, enrichment, chemical form, configuration geometry and if applicable neutron absorber, moderator material, reflector material, and any other important consideration.

Benchmark applicability to this analysis is determined by fissionable elements, enrichment, geometry, reflection and neutron energy. The critical benchmark experiments used here are applicable to the systems evaluated in this analysis, and the calculated results for the experiments show good correlation with the measured critical results. It will not be necessary, therefore, to apply any bias to the results calculated in this report.

# 5. Process Analysis

This section is not applicable. This CSE does not analyze critical scenarios or develop controls for the storage or handling of ATR fuel elements. This report analyzes the reactivity of the U-10Mo Full Size Demonstration elements relative to the typical HEU ATR element to show that the Full Size Demonstration elements are bound by the Standard HEU ATR elements and existing HEU ATR element controls are applicable to the Full Size Demonstration elements.

# 6. Evaluation & Results

The information provided in Section 2.2 is used to develop the ATR models. The number densities for the materials and uranium isotopics are given in Appendix A. Sample input decks are given in Appendix B. Enrichments of 94% and 20% are used for the ATR HEU and U-10Mo elements, respectively. The HEU ATR plate loadings are given in Table 1 which includes an additional 1% U-235 for each plate giving a total U-235 loading of 1085.75 g. The model U-235 loadings for the U-10Mo plates are given below in Table 4. The maximum plate loadings (specified loading plus 1%) are repeated here from Table 2 and are seen to be less than the model loadings. The model U-235 loadings are determined from the U-10Mo density and the fuel meat volumes, which in turn are determined from the fuel meat thickness, length and average value of the fuel core boundary[13] (this determines the fuel meat width). The total model U-235 loading for the Full Size Demonstration element is 1260.8 g, conservatively larger than the specified maximum of 1251 g. The boron content of the elements is neglected.

Table 4. Maximum Allowed and Model Full Size Demonstration Plate U-235 Loadings

| Plate Number | Plate Type | U-235 Content (max) (g) [a] | Model U-235 Content (g) |
|---|---|---|---|
| 5 | U-10Mo Mono | 67.6195 | 69.949 |
| 6 | U-10Mo Mono | 72.1241 | 73.077 |
| 7 | U-10Mo Mono | 75.3258 | 76.205 |
| 8 | U-10Mo Mono | 78.4871 | 79.333 |
| 9 | U-10Mo Mono | 81.6888 | 82.461 |
| 10 | U-10Mo Mono | 84.8198 | 85.589 |
| 11 | U-10Mo Mono | 88.0619 | 88.717 |
| 12 | U-10Mo Mono | 91.2131 | 91.845 |
| 13 | U-10Mo Mono | 94.4148 | 94.973 |
| 14 | U-10Mo Mono | 97.5761 | 98.100 |
| 15 | U-10Mo Mono | 100.798 | 101.228 |

a These are the maximum loadings as per Reference 4 and are repeated here from Table 2.

The fuel elements are explicitly modeled with 19 curved, aluminum clad fuel plates and aluminum side plates (plate 19 of the Full Size Demonstration element is also aluminum). The non-fueled ends of the ATR elements are ignored, and the element length is 49.5 in.

Results for the HEU ATR elements are given in Section 6.1.1, the U-10Mo Demonstration element results with the dummy plate 19 are given in Section 6.1.2 and the U-10Mo Demonstration element results with plate 19 fueled are given in Section 6.1.3.

For convenience in referring to cases in a given table, groups of cases may be referred to as a “set,” where the set of cases examines variations to a single or limited number of parameters. A preceding header (in bold type) within each table denotes the set.

## 6.1 ATR Reactivity Results

The reactivity of the two fuel types is compared by determining the reactivity of a single element and a near-critical element array for each fuel type. Since the elements are more reactive when moderated, they are modeled with water moderation and reflection. While there are other materials that are better reflectors than water, the use of these materials would not change the results of the comparison presented here. The moderated element configurations are evaluated to be as reactive as reasonably possible. This is done by varying the spacing between elements to find the most reactive configurations.

### 6.1.1 HEU ATR Elements

A previous CSE[8] has evaluated near-critical water moderated and reflected configurations of HEU ATR elements using a previous version of MCNP (probably version MCNP4a, circa 1994, but simply referred to as MCNP) that are seen in Figure 4. The element fuel loading was 1075 g of U-235 with an enrichment of 93% and no boron. Reported values of $k_{eff}$ are 0.984 + 0.002 and 0.985 + 0.003 for the hexagonal array (Configuration A) and circular configuration (Configuration B), respectively. A $k_{eff}$ of 0.444 + 0.002 was also reported for a single water moderated and reflected element.

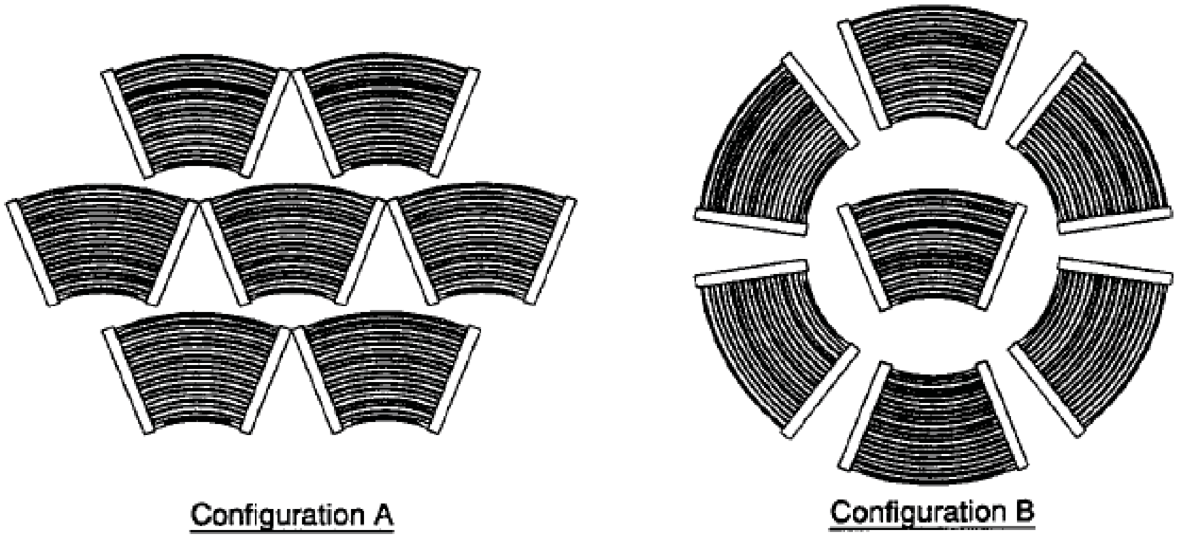


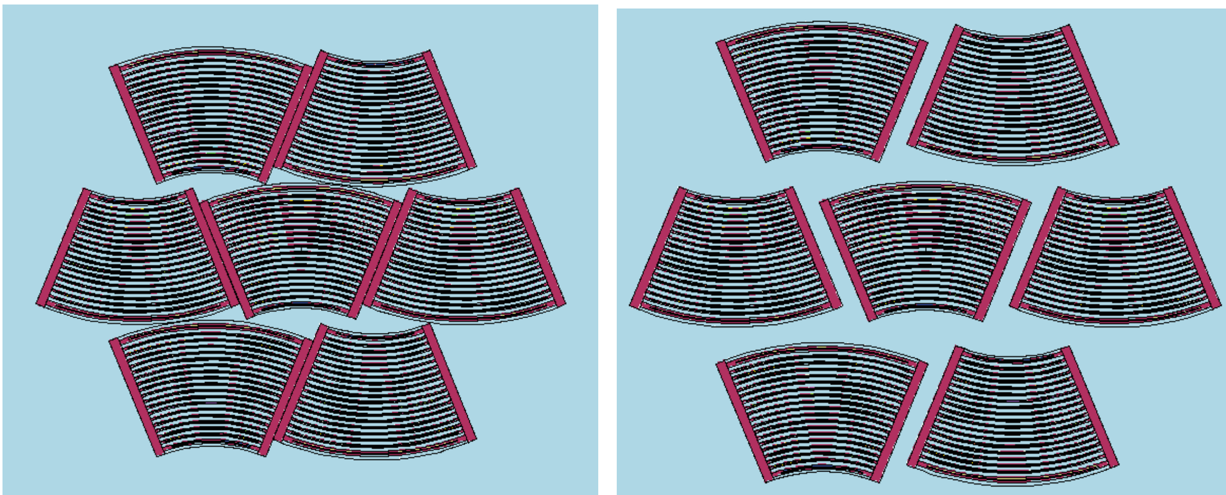

Figure 4. Near-Critical Configurations of (HEU) ATR Elements

(from Figure 3 of Reference 8)

Similar configurations (exact details of the previous configurations are not available) are evaluated with the ATR model used in this CSE to verify that the results are consistent. These results are presented in Appendix C, Table C- 1 and are summarized in this section. The single element result for $k_{eff}$ is 0.4455 ± 0.0006, which agrees with the previous value of $k_{eff}$ from Reference 8 within 1σ (σ from the previous calculation is used). The $k_{eff}$ for a configuration similar to Configuration A in Figure 4 is 0.9887 ± 0.0007. This is just larger than the previous result by 2σ, though is very reasonable considering the slightly higher loading (1085.75g U-235 compared to 1075 g) and enrichment (94% compared to 93%) of the ATR elements and the use of ENDF/B-VI cross sections in this CSE.

A configuration with a more uniform spacing between adjacent side-by-side elements than Configuration A in Figure 4 is used to investigate reactivity changes with increasing space between elements. This configuration is shown in Figure 5. The elements are essentially touching in the first frame of the figure, and the elements are moved in the “conventional” x and y directions as the spacing increases. The most reactive configuration is shown in the second frame where $k_{eff}$ is 0.9952 ± 0.0007. This value is about 0.0065 Δk more reactive than the

Configuration A (Figure 4) case previously discussed. Results for different spacings are given in the third set of Table C- 1.

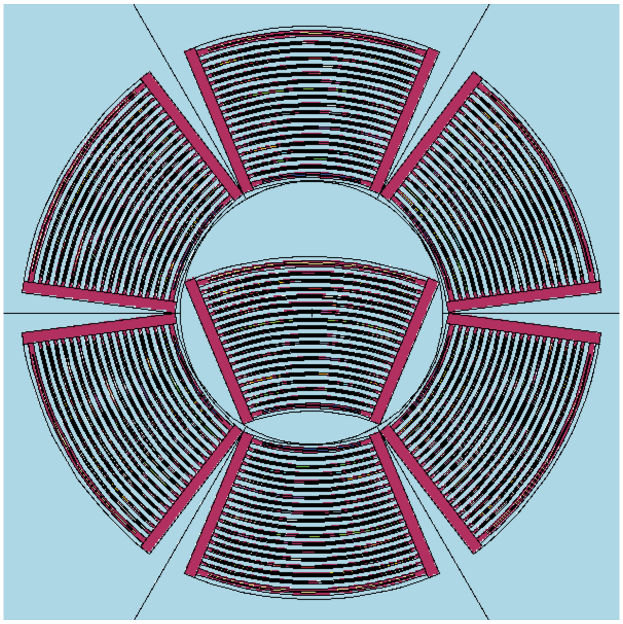


b) This is case heu_7b of Table C- 1 where adjacent elements are essentially touching

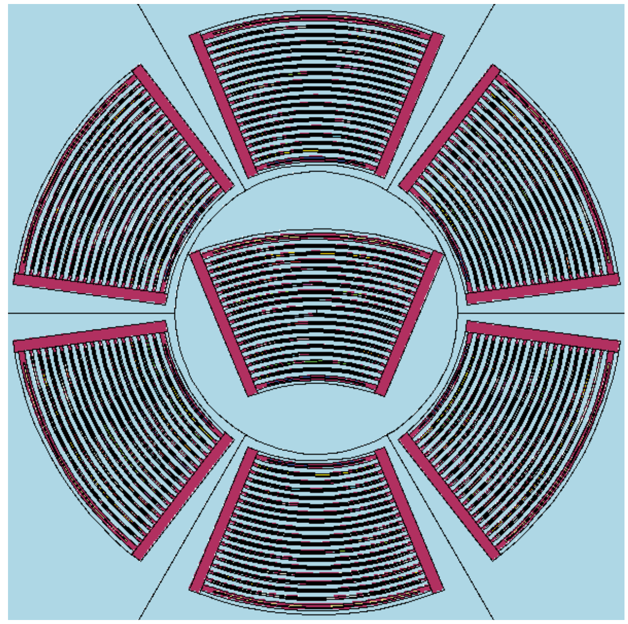
a) This is case heu_7b_1.1 of Table C- 1 where adjacent elements are separated by 1.1 cm

Figure 5. Configurations to Investigate Increased Spacing between Elements

Configurations similar to Figure 4, Configuration B, but with different radial spacing between the center element and the outer ring of elements are shown in Figure 6. The spacing between elements is increased by increasing the radius of the outer ring of elements (azimuthal spacing remains unchanged) while the center element remains fixed. Results for these configurations are given in Appendix C, Table C- 2, and the most reactive case has a $k_{eff}$ of 0.9952 ± 0.0007 which is the same as the most reactive hexagonal array case of Table C- 1. This value is larger than the circular array result of Reference 8 (mentioned above) by 0.01 Δk indicating that the circular configuration used in this CSE is more reactive than that used in Reference 8 and/or the ATR model used here is more reactive. This is further investigated by modifying the Reference 8 model to use the same configuration as that used here which produces a $k_{eff}$ of 0.9950 ± 0.0006, which is essentially identical to the result found here indicating excellent agreement between the two (current and previous) models.



a) This is case heu_7c_ma of Table C- 2 where elements are at closest approach



b) This is case heu_7c_0.2 of Table C- 2 where elements are in most reactive configuration

Figure 6. Circular Configurations to Investigate Increased Spacing between Elements

### 6.1.2 U-10Mo Full Size Demonstration Elements

The U-10Mo Full Size Demonstration elements are evaluated in this section. The configurations evaluated are identical to those in Table C- 1 and Table C- 2 and are the same as shown in Figure 5 and Figure 6, though the most reactive cases occur for slightly different spacings. The results for the Full Size Demonstration elements with different spacings between elements are presented in Appendix C, Table C- 3.

In summary, the most reactive case has a $k_{eff}$ of 0.9624 ± 0.0007 which is less reactive than all the HEU ATR element cases with the exception of a hexagonal array with adjacent elements touching, i.e., it is much less than optimally moderated. The hexagonal array of U-10Mo elements with adjacent elements touching is much less reactive than the equivalent case with HEU ATR elements.

### 6.1.3 U-10Mo Full Size Demonstration Elements with All Plates Fueled

Though there are no current plans for replacing plate 19 of the U-10Mo Full Size Demonstration elements with a fueled plate, results are presented in Appendix C, Table C- 4 for elements with all plates fueled. Plate 19 is assumed to have the same loading as an HEU ATR element, and the total maximum element U-235 loading is 1314.0 g. These results are even more conservative than those presented in Section 6.1.2, but are presented here to demonstrate the reactivity differences of the U10Mo and HEU fuels. The ATR element configurations correspond to those in the previous two sections.

The most reactive case has a $k_{eff}$ of 0.9764 ± 0.0007 which is less reactive than all but three HEU ATR element cases. All cases when compared directly to the HEU ATR element equivalent cases are less reactive. A summary of the most reactive results for the different ATR fueled element models is presented in Section 8.

# 7. Credited Controls and Assumptions

This section is not applicable. This CSE does not develop any new controls for the storage or handling of ATR fuel elements. This CSE demonstrates that existing controls for (HEU) ATR fuel elements are applicable to the U-10Mo Full Size Demonstration Elements.

# 8. Summary & Conclusions

MCNP models have been developed to compare the RETR-Full Size elements to standard HEU ATR elements with the boron content neglected. A summary of the most reactive cases for the HEU ATR fuel elements and the U-10Mo Full Size Demonstration elements is given in Table 5. Results for the Full Size Demonstration element with all plates fueled are not included as they do not affect the conclusions in this CSE.

Table 5. Summary of Most Reactive Results

| Configuration (and Number of Elements) | $k_{eff} + 2\sigma$ (most reactive case) | | Difference $\Delta$k, (HEU – LEU) |
|---|---|---|---|
| | **HEU ATR Elements** | **U-10Mo** Full Size **Demonstration Elements** | |
| **Single ATR element** | 0.4467 | 0.4380 | 0.009 |
| **Hexagonal Array of 7 elements** | 0.9967 | 0.9600 | 0.037 |
| **Circular Configuration of 7 elements** | 0.9965 | 0.9637 | 0.033 |

The $k_{eff}$ for a single HEU ATR element exceeds that of a Full Size Demonstration element by about 0.009 $\Delta$k. For a near-critical configuration of 7 elements, $k_{eff}$ for the HEU elements exceeds that of the Full Size Demonstration elements by an average of 0.035 $\Delta$k. While other array configurations may be slightly more reactive than those evaluated here, this would not affect the conclusion of this CSE. The conclusion of this CSE is that the HEU ATR element bounds the U-10Mo Full Size Demonstration element for criticality calculations and for applying criticality controls. This conclusion remains valid even if the U-10Mo Full Size Demonstration element contained 19 fueled plates.

The Full Size Demonstration elements are bound by the HEU ATR elements, and as such the Full Size Demonstration elements can be handled, stored and transferred using controls established for HEU ATR elements. This also applies to any existing CSI determinations that were derived for HEU ATR elements.

# 9. References

INL documents listed here are available via EDMS by their listed document number.

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7. Stuart, Charles E., III., *Criticality Safety Evaluation for the Analysis of Spacing Between Storage Positions in the New Type ATR Rack in the ATR Canal at the Reactor Technology Complex (RTC),* EDF-8165, Idaho National Laboratory.

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10. Tsiboulia, Anatoli, Yevgeniy Rozhikhin and Vladimir Lependin, *Water-Moderated* $U(17)O_2$ *Annular Fuel Rods Without Absorber and with Gadolinium or Cadmium Absorbers in 6.8-cm-Pitch Hexagonal Lattices at Different Temperatures*, IEU-COMP-THERM-002, NEA/NSC/DOC/(95)03/III, International Handbook of Evaluated Criticality Safety Benchmark Experiments, Volume III.

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12. Putman, V. L., *IFSF Criticality Safety Base Case and Validation*, INEEL/INT-2001-00903, Rev. 0.

13. ATR U-Mo Demonstration Element Assembly, Drawing Number 600200, November 8, 2010.

# Appendix A: Materials & Compositions

atom densities are listed as atoms/(cm·barn)

Table A-1. Material Specifications for $UAl_x$ Plates

| | U-235 | U-234 | U-236 | U-238 | Al |
|---|---|---|---|---|---|
| U Isotopics, → | 94.05% | 1.20% | 0.07% | 4.05% | – |
| Plate Number, ↓ | Number Densities | | | | |
| 1 | 2.6083E-03 | 3.3423E-05 | 1.9331E-05 | 1.1090E-04 | 5.7386E-02 |
| 2 | 2.5277E-03 | 3.2389E-05 | 1.8733E-05 | 1.0747E-04 | 5.7482E-02 |
| 3 | 3.1920E-03 | 4.0902E-05 | 2.3657E-05 | 1.3572E-04 | 5.6693E-02 |
| 4 | 3.1722E-03 | 4.0648E-05 | 2.3510E-05 | 1.3488E-04 | 5.6716E-02 |
| 5 | 3.9035E-03 | 5.0018E-05 | 2.8930E-05 | 1.6597E-04 | 5.5847E-02 |
| 6 | 3.9116E-03 | 5.0122E-05 | 2.8990E-05 | 1.6631E-04 | 5.5837E-02 |
| 7 | 3.9121E-03 | 5.0129E-05 | 2.8994E-05 | 1.6634E-04 | 5.5837E-02 |
| 8 | 3.9127E-03 | 5.0136E-05 | 2.8998E-05 | 1.6636E-04 | 5.5836E-02 |
| 9 | 3.9132E-03 | 5.0143E-05 | 2.9001E-05 | 1.6638E-04 | 5.5835E-02 |
| 10 | 3.9136E-03 | 5.0149E-05 | 2.9005E-05 | 1.6640E-04 | 5.5835E-02 |
| 11 | 3.9141E-03 | 5.0154E-05 | 2.9008E-05 | 1.6642E-04 | 5.5834E-02 |
| 12 | 3.9145E-03 | 5.0159E-05 | 2.9011E-05 | 1.6644E-04 | 5.5834E-02 |
| 13 | 3.9149E-03 | 5.0164E-05 | 2.9014E-05 | 1.6645E-04 | 5.5833E-02 |
| 14 | 3.9152E-03 | 5.0169E-05 | 2.9017E-05 | 1.6647E-04 | 5.5833E-02 |
| 15 | 3.9207E-03 | 5.0239E-05 | 2.9057E-05 | 1.6670E-04 | 5.5827E-02 |
| 16 | 3.1885E-03 | 4.0857E-05 | 2.3631E-05 | 1.3557E-04 | 5.6697E-02 |
| 17 | 3.1861E-03 | 4.0827E-05 | 2.3613E-05 | 1.3547E-04 | 5.6699E-02 |
| 18 | 2.5631E-03 | 3.2843E-05 | 1.8996E-05 | 1.0898E-04 | 5.7440E-02 |
| 19 | 2.5633E-03 | 3.2846E-05 | 1.8998E-05 | 1.0899E-04 | 5.7440E-02 |

Table A-2. Material Specifications for U-10Mo

| Element / Isotope | Isotopics | Number Density |
|---|---|---|
| U-235 | 20% | 7.7940E-03 |
| U-238 | 79.726% | 3.0677E-02 |
| U-234 | 0.112% | 4.3834E-05 |
| U-236 | 0.162% | 6.2864E-05 |
| Mo | – | 1.0608E-02 |
| density = 16.9 $g/cm^3$ | | |

Table A-3. Material Specifications for Zr Cladding

| Isotope | Number Density |
|---|---|
| Zr-90 | 2.2077E-02 |
| Zr-91 | 4.8145E-03 |
| Zr-92 | 7.3590E-03 |
| Zr-94 | 7.4577E-03 |
| Zr-96 | 1.2015E-03 |
| density = 6.5 g/cm$^3$ | |

Table A-4. Material Specifications for Water

| Element | Moles of Element/ Mole of Compound | Number Density, [atom/(cm·b)] |
|---|---|---|
| H | 2 | 6.6856E-02 |
| O | 1 | 3.3428E-02 |
| density = 1.0 g/cm$^3$ | | |

Table A-5. Material Specifications for Al-6061

| Element / Isotope | Atom density |
|---|---|
| Mg | 6.7060E-04 |
| Si-28 | 3.2114E-04 |
| Si-29 | 1.6261E-05 |
| Si-30 | 1.0794E-05 |
| Fe-54 | 1.1952E-05 |
| Fe-56 | 1.8745E-04 |
| Fe-57 | 4.3312E-06 |
| Fe-58 | 5.7205E-07 |
| Al | 5.9018E-02 |
| density = 2.7065 g/cm$^3$ | |

# Appendix B: Typical Input Listings

Sample Input Deck #1, Case heu_7b_1.1 from Table C- 1

MCNP Listing for HEU ATR Near-Critical Hexagonal Array

```
HEU ATR element
c LEE: note this uses average "B" values
c      cell cards for ATR assembly
601    5 0.100311          600 -601 -680 -681              u=1  imp:n=1
602    101 6.017874E-02   602 -603 -682 -683 -692 693      u=1  imp:n=1
603    20  6.024110E-02   601 -604 -680 -681 #602          u=1  imp:n=1
604    5 0.100311          604 -605 -680 -681              u=1  imp:n=1
c      plate 2
605    102 6.017685E-02   606 -607 -684 -685 -692 693      u=1  imp:n=1
606    20  6.024110E-02   605 -608 -680 -681 #605          u=1  imp:n=1
607    5 0.100311          608 -609 -680 -681              u=1  imp:n=1
c      plate 3
608    103 6.009507E-02   610 -611 -684 -685 -692 693      u=1  imp:n=1
609    20  6.024110E-02   609 -612 -680 -681 #608          u=1  imp:n=1
610    5 0.100311          612 -613 -680 -681              u=1  imp:n=1
c     plate 4
611    104 6.009671E-02   614 -615 -684 -685 -692 693      u=1  imp:n=1
612    20  6.024110E-02   613 -616 -680 -681 #611          u=1  imp:n=1
613    5 0.100311          616 -617 -680 -681              u=1  imp:n=1
c     plate 5
614    105 6.000722E-02   618 -619 -684 -685 -692 693      u=1  imp:n=1
615    20  6.024110E-02   617 -620 -680 -681 #614          u=1  imp:n=1
616    5 0.100311          620 -621 -680 -681              u=1  imp:n=1
c     plate 6
617   106 6.000587E-02    622 -623 -684 -685 -692 693      u=1  imp:n=1
618   20  6.024110E-02    621 -624 -680 -681 #617          u=1  imp:n=1
619   5 0.100311           624 -625 -680 -681              u=1  imp:n=1
c     plate 7
620   107 6.000534E-02    626 -627 -684 -685 -692 693      u=1  imp:n=1
 621   20  6.024110E-02    625 -628 -680 -681  #620         u=1  imp:n=1
622   5 0.100311           628 -629 -680 -681              u=1  imp:n=1
c     plate 8
623   108 6.000448E-02    630 -631 -684 -685 -692 693      u=1  imp:n=1
624   20  6.024110E-02    629 -632 -680 -681 #623          u=1  imp:n=1
625   5 0.100311           632 -633 -680 -681              u=1  imp:n=1
c     plate 9
626   109 6.000431E-02    634 -635 -684 -685 -692 693      u=1  imp:n=1
627   20  6.024110E-02    633 -636 -680 -681 #626          u=1  imp:n=1
628   5 0.100311           636 -637 -680 -681              u=1  imp:n=1
c     plate 10
629  110 6.000392E-02     638 -639 -684 -685 -692 693      u=1  imp:n=1
630  20  6.024110E-02     637 -640 -680 -681 #629          u=1  imp:n=1
631   5 0.100311           640 -641 -680 -681              u=1  imp:n=1
c     plate 11
632  111 6.000321E-02     642 -643  -684 -685 -692 693     u=1  imp:n=1
633  20  6.024110E-02     641 -644 -680 -681  #632         u=1  imp:n=1
634   5 0.100311           644 -645 -680 -681              u=1  imp:n=1
c     plate 12
635   112 6.000329E-02    646 -647 -684 -685 -692 693      u=1  imp:n=1
636   20  6.024110E-02    645 -648 -680 -681 #635          u=1  imp:n=1
637   5 0.100311           648 -649 -680 -681              u=1  imp:n=1
c      plate 13
638   113 6.000216E-02    650 -651 -684 -685 -692 693      u=1  imp:n=1
639   20  6.024110E-02    649 -652 -680 -681 #638          u=1  imp:n=1
```

```
640   5 0.100311          652 -653 -680 -681              u=1  imp:n=1
c      plate 14
641   114 6.000182E-02    654 -655 -684 -685 -692 693      u=1  imp:n=1
642   20  6.024110E-02    653 -656 -680 -681  #641        u=1  imp:n=1
643   5 0.100311          656 -657 -680 -681              u=1  imp:n=1
c     plate 15
644   115 6.000168E-02    658 -659 -684 -685 -692 693      u=1  imp:n=1
645   20  6.024110E-02    657 -660 -680 -681 #644         u=1  imp:n=1
646   5 0.100311          660 -661 -680 -681              u=1  imp:n=1
c     plate 16
647   116 6.009189E-02    662 -663 -684 -685 -692 693      u=1  imp:n=1
648   20  6.024110E-02    661 -664 -680 -681 #647         u=1  imp:n=1
649   5 0.100311          664 -665 -680 -681              u=1  imp:n=1
c     plate 17
650   117 6.009204E-02    666 -667 -684 -685 -692 693      u=1  imp:n=1
651   20  6.024110E-02    665 -668 -680 -681  #650        u=1  imp:n=1
652   5 0.100311          668 -669 -680 -681              u=1  imp:n=1
c     plate 18
653   118 6.017003E-02    670 -671 -686 -687 -692 693      u=1  imp:n=1
654   20  6.024110E-02    669 -672 -680 -681 #653         u=1  imp:n=1
655   5 0.100311          672 -673 -680 -681              u=1  imp:n=1
c     plate 19
656   119 6.017359E-02    674 -675 -682 -683 -692 693      u=1  imp:n=1
657   20  6.024110E-02    673 -676 -680 -681 #656         u=1  imp:n=1
658   5 0.100311          676 -677 -680 -681              u=1  imp:n=1
c      side plates
659   20 6.024110E-02    (-600:677:680:681)              u=1  imp:n=1
c     cut-out elements and move
60    0    697 -698 -678 -679 -690 691 fill=1
                     trcl=(0  -10.5  0)          imp:n=1  $ at center, fixed location
61    0    697 -698 -678 -679 -690 691 fill=1
                     trcl=1                    imp:n=1  $ center, right
62    0    697 -698 -678 -679 -690 691 fill=1
                     trcl=2                    imp:n=1  $ center, left
63    0    697 -698 -678 -679 -690 691 fill=1
                     trcl=3                    imp:n=1  $ up, right
64    0    697 -698 -678 -679 -690 691 fill=1
                     trcl=(-5.27 -2.40   0)       imp:n=1  $ up, left, subtract dx/2, add dy
65    0    697 -698 -678 -679 -690 691 fill=1
                     trcl=4                    imp:n=1  $ down, right
66    0    697 -698 -678 -679 -690 691 fill=1
                     trcl=(-5.27 -18.70   0)       imp:n=1  $ down, left, subtract dx/2, subtract dy
104 5 0.100311   -110  111  -112  113 -114   115
                #60 #61 #62 #63 #64 #65 #66
                          imp:n=1
105  0            110:-111:112:-113:114:-115   imp:n=0

c ******************************************************************
C     SURFACE SPECIFICATIONS
c     surface cards
600    cz 7.52855
c     radius for fuel plates
c     plate 1
601    cz 7.6581    $plate 1 inner radius
602    cz 7.7343    $plate 1 fuel meat inner
603    cz 7.7851    $plate 1 fuel meat outer
604    cz 7.8613    $plate 1 outer radius
c     plate 2
605    cz 8.05942   $plate 2 inner radius
606    cz 8.09752   $plate 2 fuel meat inner
607    cz 8.14832   $plate 2 fuel meat outer
```

```
608   cz 8.18642   $plate 2 outer radius
c     plate 3
609   cz 8.38454   $plate 3 inner radius
610   cz 8.42264   $plate 3 fuel meat inner
611   cz 8.47344   $plate 3 fuel meat outer
612   cz 8.51154   $plate 3 outer radius
c     plate 4
613   cz 8.70966   $plate 4 inner radius
614   cz 8.74776   $plate 4 fuel meat inner
615   cz 8.79856   $plate 4 fuel meat outer
616   cz 8.83666   $plate 4 outer radius
c     plate 5
617   cz 9.03478   $plate 5 inner radius
618   cz 9.07288   $plate 5 fuel meat inner
619   cz 9.12368   $plate 5 fuel meat outer
620   cz 9.16178   $plate 5 outer radius
c     plate 6
621   cz 9.3599    $plate 6 inner radius
622   cz 9.398     $plate 6 fuel meat inner
623   cz 9.4488    $plate 6 fuel meat outer
624   cz 9.4869    $plate 6 outer radius
c     plate 7
625   cz 9.68502   $plate 7 inner radius
626   cz 9.72312   $plate 7 fuel meat inner
627   cz 9.77392   $plate 7 fuel meat outer
628   cz 9.81202   $plate 7 outer radius
c     plate 8
629   cz 10.01014  $plate 8 inner radius
630   cz 10.04824  $plate 8 fuel meat inner
631   cz 10.09904  $plate 8 fuel meat outer
632   cz 10.13714  $plate 8 outer radius
c     plate 9
633   cz 10.33526  $plate 9 inner radius
634   cz 10.37336  $plate 9 fuel meat inner
635   cz 10.42416  $plate 9 fuel meat outer
636   cz 10.46226  $plate 9 outer radius
c     plate 10
637   cz 10.66038  $plate 10 inner radius
638   cz 10.69848  $plate 10 fuel meat inner
639   cz 10.74928  $plate 10 fuel meat outer
640   cz 10.78738  $plate 10 outer radius
c     plate 11
641   cz 10.9855   $plate 11 inner radius
642   cz 11.02360  $plate 11 fuel meat inner
643   cz 11.07440  $plate 11 fuel meat outer
644   cz 11.1125   $plate 11 outer radius
c     plate 12
645   cz 11.31062  $plate 12 inner radius
646   cz 11.34872  $plate 12 fuel meat inner
647   cz 11.39952  $plate 12 fuel meat outer
648   cz 11.43762  $plate 12 outer radius
c     plate 13
649   cz 11.63574  $plate 13 inner radius
650   cz 11.67384  $plate 13 fuel meat inner
651   cz 11.72464  $plate 13 fuel meat outer
652   cz 11.76274  $plate 13 outer radius
c     plate 14
653   cz 11.96086  $plate 14 inner radius
654   cz 11.99896  $plate 14 fuel meat inner
655   cz 12.04976  $plate 14 fuel meat outer
656   cz 12.08786  $plate 14 outer radius
```

```
c      plate 15
657    cz 12.28598  $plate 15 inner radius
658    cz 12.32408  $plate 15 fuel meat inner
659    cz 12.37488  $plate 15 fuel meat outer
660    cz 12.41298  $plate 15 outer radius
c      plate 16
661    cz 12.6111   $plate 16 inner radius
662    cz 12.64920  $plate 16 fuel meat inner
663    cz 12.70000  $plate 16 fuel meat outer
664    cz 12.7381   $plate 16 outer radius
c      plate 17
665    cz 12.93622  $plate 17 inner radius
666    cz 12.97432  $plate 17 fuel meat inner
667    cz 13.02512  $plate 17 fuel meat outer
668    cz 13.06322  $plate 17 outer radius
c      plate 18
669    cz 13.26134  $plate 18 inner radius
670    cz 13.29944  $plate 18 fuel meat inner
671    cz 13.35024  $plate 18 fuel meat outer
672    cz 13.38834  $plate 18 outer radius
c      plate 19
673    cz 13.58646  $plate 19 inner radius
674    cz 13.68806  $plate 19 fuel meat inner
675    cz 13.73886  $plate 19 fuel meat outer
676    cz 13.84046  $plate 19 outer radius
677    cz 14.01317  $outer diameter of element
c     surfaces for sides of plate and fuel region
678   p -2.414214 -1 0 0          $outside boundary of Al plate
679   p  2.414214 -1 0 0          $outside boundary of Al plate
680   p -2.414214 -1 0 -1.241183  $inside boundary of Al plate
681   p  2.414214 -1 0 -1.241183  $inside boundary of Al plate
682   p -2.414214 -1 0 -2.535464  $plate 1 and 19 fuel meat boundary
683   p  2.414214 -1 0 -2.535464  $plate 1 and 19 fuel meat boundary
684   p -2.414214 -1 0 -1.871730  $plate 2 through 17 fuel meat boundary
685   p  2.414214 -1 0 -1.871730  $plate 2 through 17 fuel meat boundary
686   p -2.414214 -1 0 -2.004477  $plate 18 fuel meat boundary
687   p  2.414214 -1 0 -2.004477  $plate 18 fuel meat boundary
690   pz  62.8650   $top of fuel element, 49.5" total
691   pz -62.8650   $bottom of fuel element
692   pz  60.960    $top of fuel meat, 48" total
693   pz -60.960    $bottom of fuel meat
697   cz  7.52856   $inner radius of element
698   cz 14.00302   $outer radius of element
160   cz  10000.    $just a big surface
c ***************************************************************
*110  px  65.2630                    $ storage rack
*111  px -65.2630
*112  py  44.8468
*113  py -44.8468
114  pz  100.0                       $ water reflector
115  pz -100.0

mode n
C     WATER  dens=1.0000 g/cc  $   atm. den.:   .100284
m5     1001.62c   6.6874E-02  $ H
       8016.62c   3.3437E-02  $ O
mt5   lwtr.60t
c     fuel plates
m101    92235.69c   2.4472E-03
        92238.69c   1.0405E-04
        92234.69c   3.1358E-05
```

```
        92236.69c   1.8137E-05
        13027.62c   5.7578E-02
m102    92235.69c   2.4586E-03
        92238.69c   1.0453E-04
        92234.69c   3.1504E-05
        92236.69c   1.8221E-05
        13027.62c   5.7564E-02
m103    92235.69c   3.1090E-03
        92238.69c   1.3219E-04
        92234.69c   3.9839E-05
        92236.69c   2.3042E-05
        13027.62c   5.6791E-02
m104    92235.69c   3.0936E-03
        92238.69c   1.3154E-04
        92234.69c   3.9641E-05
        92236.69c   2.2928E-05
        13027.62c   5.6809E-02
m105    92235.69c   3.8111E-03
        92238.69c   1.6204E-04
        92234.69c   4.8835E-05
        92236.69c   2.8245E-05
        13027.62c   5.5957E-02
m106    92235.69c   3.8230E-03
        92238.69c   1.6255E-04
        92234.69c   4.8988E-05
        92236.69c   2.8334E-05
        13027.62c   5.5943E-02
m107    92235.69c   3.8272E-03
        92238.69c   1.6273E-04
        92234.69c   4.9042E-05
        92236.69c   2.8365E-05
        13027.62c   5.5938E-02
m108    92235.69c   3.8311E-03
        92238.69c   1.6289E-04
        92234.69c   4.9092E-05
        92236.69c   2.8394E-05
        13027.62c   5.5933E-02
m109    92235.69c   3.8347E-03
        92238.69c   1.6305E-04
        92234.69c   4.9138E-05
        92236.69c   2.8420E-05
        13027.62c   5.5929E-02
m110    92235.69c   3.8381E-03
        92238.69c   1.6319E-04
        92234.69c   4.9180E-05
        92236.69c   2.8445E-05
        13027.62c   5.5925E-02
m111    92235.69c   3.8412E-03
        92238.69c   1.6332E-04
        92234.69c   4.9220E-05
        92236.69c   2.8468E-05
        13027.62c   5.5921E-02
m112    92235.69c   3.8441E-03
        92238.69c   1.6344E-04
        92234.69c   4.9257E-05
        92236.69c   2.8489E-05
        13027.62c   5.5918E-02
m113    92235.69c   3.8468E-03
        92238.69c   1.6356E-04
        92234.69c   4.9292E-05
        92236.69c   2.8509E-05
```

```
        13027.62c   5.5914E-02
m114    92235.69c   3.8493E-03
        92238.69c   1.6367E-04
        92234.69c   4.9324E-05
        92236.69c   2.8528E-05
        13027.62c   5.5911E-02
m115    92235.69c   3.8567E-03
        92238.69c   1.6398E-04
        92234.69c   4.9420E-05
        92236.69c   2.8583E-05
        13027.62c   5.5903E-02
m116    92235.69c   3.1380E-03
        92238.69c   1.3342E-04
        92234.69c   4.0210E-05
        92236.69c   2.3257E-05
        13027.62c   5.6757E-02
m117    92235.69c   3.1372E-03
        92238.69c   1.3339E-04
        92234.69c   4.0199E-05
        92236.69c   2.3251E-05
        13027.62c   5.6758E-02
m118    92235.69c   2.5171E-03
        92238.69c   1.0702E-04
        92234.69c   3.2254E-05
        92236.69c   1.8655E-05
        13027.62c   5.7495E-02
m119    92235.69c   2.4894E-03
        92238.69c   1.0584E-04
        92234.69c   3.1899E-05
        92236.69c   1.8449E-05
        13027.62c   5.7528E-02
c     material for cladding and support (Al6061)
m20    13027.62c 5.9018E-02 $ Al +Zn impurity
       12000.62c 6.7060e-04 $ Mg
       14028.62c 3.2114E-04 $ Si
       14029.62c 1.6261E-05
       14030.62c 1.0794E-05 $ Si
       26054.62c 1.1952E-05 $ Fe
       26056.62c 1.8745E-04
       26057.62c 4.3312E-06
       26058.62c 5.7205E-07 $ Fe
c  $ Cu
c  $ Cr
c  $ Mn
c  $ Ti
c                              RC
c
c
c add dx, dy=0 always
*tr1   9.67 10.18   0  180. 270.0 90.  90. 180. 90.  90. 90.  0.
c subtract dx, dy=0 always
*tr2  -9.67 10.18   0  180. 270.0 90.  90. 180. 90.  90. 90.  0.
c add dx/2, add dy
*tr3   4.45 18.40   0  180. 270.0 90.  90. 180. 90.  90. 90.  0.
c add dx/2, subtract dy
*tr4   4.45  2.11   0  180. 270.0 90.  90. 180. 90.  90. 90.  0.
kcode  6500  1.0  55  290
c
ksrc  0.2    -2.8     0.00  -0.2    -2.8     0.0
      3.7     2.6     0.00  -3.7     2.6     0.0
      2.7    -1.1     0.00  -2.7    -1.1     0.0
```

```
     2.1    -2.6     0.00  -2.1    -2.6     0.0
print
```

Sample Input Deck #2, Case heu_7c_0.2 from Table C- 2

MCNP Listing for HEU ATR Near-Critical Circular Configuration

```
HEU ATR element
c LEE: note this uses average "B" values
c      cell cards for ATR assembly
601    5 0.100311         600 -601 -680 -681              u=1  imp:n=1
602    101 6.017874E-02   602 -603 -682 -683 -692 693      u=1  imp:n=1
603    20  6.024110E-02   601 -604 -680 -681 #602         u=1  imp:n=1
604    5 0.100311         604 -605 -680 -681              u=1  imp:n=1
c      plate 2
605    102 6.017685E-02   606 -607 -684 -685 -692 693      u=1  imp:n=1
606    20  6.024110E-02   605 -608 -680 -681 #605         u=1  imp:n=1
607    5 0.100311         608 -609 -680 -681              u=1  imp:n=1
c      plate 3
608    103 6.009507E-02   610 -611 -684 -685 -692 693      u=1  imp:n=1
609    20  6.024110E-02   609 -612 -680 -681 #608         u=1  imp:n=1
610    5 0.100311         612 -613 -680 -681              u=1  imp:n=1
c     plate 4
611    104 6.009671E-02   614 -615 -684 -685 -692 693      u=1  imp:n=1
612    20  6.024110E-02   613 -616 -680 -681 #611         u=1  imp:n=1
613    5 0.100311         616 -617 -680 -681              u=1  imp:n=1
c     plate 5
614    105 6.000722E-02   618 -619 -684 -685 -692 693      u=1  imp:n=1
615    20  6.024110E-02   617 -620 -680 -681 #614         u=1  imp:n=1
616    5 0.100311         620 -621 -680 -681              u=1  imp:n=1
c     plate 6
617   106 6.000587E-02    622 -623 -684 -685 -692 693      u=1  imp:n=1
618   20  6.024110E-02    621 -624 -680 -681 #617         u=1  imp:n=1
619   5 0.100311          624 -625 -680 -681              u=1  imp:n=1
c     plate 7
620   107 6.000534E-02    626 -627 -684 -685 -692 693      u=1  imp:n=1
621   20  6.024110E-02    625 -628 -680 -681  #620        u=1  imp:n=1
622   5 0.100311          628 -629 -680 -681              u=1  imp:n=1
c     plate 8
623   108 6.000448E-02    630 -631 -684 -685 -692 693      u=1  imp:n=1
624   20  6.024110E-02    629 -632 -680 -681 #623         u=1  imp:n=1
625   5 0.100311          632 -633 -680 -681              u=1  imp:n=1
c     plate 9
626   109 6.000431E-02    634 -635 -684 -685 -692 693      u=1  imp:n=1
627   20  6.024110E-02    633 -636 -680 -681 #626         u=1  imp:n=1
628   5 0.100311          636 -637 -680 -681              u=1  imp:n=1
c     plate 10
629  110 6.000392E-02     638 -639 -684 -685 -692 693      u=1  imp:n=1
630  20  6.024110E-02     637 -640 -680 -681 #629         u=1  imp:n=1
631   5 0.100311          640 -641 -680 -681              u=1  imp:n=1
c     plate 11
632  111 6.000321E-02     642 -643  -684 -685 -692 693     u=1  imp:n=1
633  20  6.024110E-02     641 -644 -680 -681  #632        u=1  imp:n=1
634   5 0.100311          644 -645 -680 -681              u=1  imp:n=1
c     plate 12
635   112 6.000329E-02    646 -647 -684 -685 -692 693      u=1  imp:n=1
636   20  6.024110E-02    645 -648 -680 -681 #635         u=1  imp:n=1
637   5 0.100311          648 -649 -680 -681              u=1  imp:n=1
c      plate 13
638   113 6.000216E-02    650 -651 -684 -685 -692 693      u=1  imp:n=1
639   20  6.024110E-02    649 -652 -680 -681 #638         u=1  imp:n=1
```

```
640   5 0.100311          652 -653 -680 -681              u=1  imp:n=1
c     plate 14
641   114 6.000182E-02    654 -655 -684 -685 -692 693     u=1  imp:n=1
642   20  6.024110E-02    653 -656 -680 -681  #641        u=1  imp:n=1
643   5 0.100311          656 -657 -680 -681              u=1  imp:n=1
c     plate 15
644   115 6.000168E-02    658 -659 -684 -685 -692 693     u=1  imp:n=1
645   20  6.024110E-02    657 -660 -680 -681 #644         u=1  imp:n=1
646   5 0.100311          660 -661 -680 -681              u=1  imp:n=1
c     plate 16
647   116 6.009189E-02    662 -663 -684 -685 -692 693     u=1  imp:n=1
648   20  6.024110E-02    661 -664 -680 -681 #647         u=1  imp:n=1
649   5 0.100311          664 -665 -680 -681              u=1  imp:n=1
c     plate 17
650   117 6.009204E-02    666 -667 -684 -685 -692 693     u=1  imp:n=1
651   20  6.024110E-02    665 -668 -680 -681  #650        u=1  imp:n=1
652   5 0.100311          668 -669 -680 -681              u=1  imp:n=1
c     plate 18
653   118 6.017003E-02    670 -671 -686 -687 -692 693     u=1  imp:n=1
654   20  6.024110E-02    669 -672 -680 -681 #653         u=1  imp:n=1
655   5 0.100311          672 -673 -680 -681              u=1  imp:n=1
c     plate 19
656   119 6.017359E-02    674 -675 -682 -683 -692 693     u=1  imp:n=1
657   20  6.024110E-02    673 -676 -680 -681 #656         u=1  imp:n=1
658   5 0.100311          676 -677 -680 -681              u=1  imp:n=1
c     side plates
659   20 6.024110E-02    (-600:677:680:681)               u=1  imp:n=1
c     cut-out elements and move
59    0    697 -698 -678 -679 -690 691 fill=1 trcl=(0 -1.3 0)  u=3  imp:n=1
60    5 0.100311    #59                              u=3  imp:n=1
61    0    -160                    fill=3 trcl=1          u=31 imp:n=1
62    0    -160                    fill=3 trcl=2          u=32 imp:n=1
63    0    -160                    fill=3 trcl=3          u=33 imp:n=1
64    0    -160                    fill=3 trcl=4          u=34 imp:n=1
65    0    -160                    fill=3 trcl=5          u=35 imp:n=1
66    0    697 -698 -678 -679 -690 691 fill=1 trcl=(0 -10.5 0) u=2 imp:n=1
102   5 0.100311 -180 #66                         u=2  imp:n=1
104   5 0.100311  180           171 -172 fill=3    u=2  imp:n=1
105   5 0.100311  180           170  172 fill=31   u=2  imp:n=1
106   5 0.100311  180          -170  171 fill=32   u=2  imp:n=1
103   5 0.100311  180          -171 172  fill=33   u=2  imp:n=1
107   5 0.100311  180          -170 -172 fill=34   u=2  imp:n=1
108   5 0.100311  180           170 -171 fill=35   u=2  imp:n=1
109   0   -110 111 -112 113 -114 115 fill=2                  imp:n=1
110  0             110:-111:112:-113:114:-115   imp:n=0

c *******************************************************************
C     SURFACE SPECIFICATIONS
c     surface cards
600    cz 7.52855
c     radius for fuel plates
c     plate 1
601    cz 7.6581    $plate 1 inner radius
602    cz 7.7343    $plate 1 fuel meat inner
603    cz 7.7851    $plate 1 fuel meat outer
604    cz 7.8613    $plate 1 outer radius
c     plate 2
605    cz 8.05942   $plate 2 inner radius
606    cz 8.09752   $plate 2 fuel meat inner
607    cz 8.14832   $plate 2 fuel meat outer
608    cz 8.18642   $plate 2 outer radius
```

```
c     plate 3
609   cz 8.38454   $plate 3 inner radius
610   cz 8.42264   $plate 3 fuel meat inner
611   cz 8.47344   $plate 3 fuel meat outer
612   cz 8.51154   $plate 3 outer radius
c     plate 4
613   cz 8.70966   $plate 4 inner radius
614   cz 8.74776   $plate 4 fuel meat inner
615   cz 8.79856   $plate 4 fuel meat outer
616   cz 8.83666   $plate 4 outer radius
c     plate 5
617   cz 9.03478   $plate 5 inner radius
618   cz 9.07288   $plate 5 fuel meat inner
619   cz 9.12368   $plate 5 fuel meat outer
620   cz 9.16178   $plate 5 outer radius
c     plate 6
621   cz 9.3599    $plate 6 inner radius
622   cz 9.398     $plate 6 fuel meat inner
623   cz 9.4488    $plate 6 fuel meat outer
624   cz 9.4869    $plate 6 outer radius
c     plate 7
625   cz 9.68502   $plate 7 inner radius
626   cz 9.72312   $plate 7 fuel meat inner
627   cz 9.77392   $plate 7 fuel meat outer
628   cz 9.81202   $plate 7 outer radius
c     plate 8
629   cz 10.01014  $plate 8 inner radius
630   cz 10.04824  $plate 8 fuel meat inner
631   cz 10.09904  $plate 8 fuel meat outer
632   cz 10.13714  $plate 8 outer radius
c     plate 9
633   cz 10.33526  $plate 9 inner radius
634   cz 10.37336  $plate 9 fuel meat inner
635   cz 10.42416  $plate 9 fuel meat outer
636   cz 10.46226  $plate 9 outer radius
c     plate 10
637   cz 10.66038  $plate 10 inner radius
638   cz 10.69848  $plate 10 fuel meat inner
639   cz 10.74928  $plate 10 fuel meat outer
640   cz 10.78738  $plate 10 outer radius
c     plate 11
641   cz 10.9855   $plate 11 inner radius
642   cz 11.02360  $plate 11 fuel meat inner
643   cz 11.07440  $plate 11 fuel meat outer
644   cz 11.1125   $plate 11 outer radius
c     plate 12
645   cz 11.31062  $plate 12 inner radius
646   cz 11.34872  $plate 12 fuel meat inner
647   cz 11.39952  $plate 12 fuel meat outer
648   cz 11.43762  $plate 12 outer radius
c     plate 13
649   cz 11.63574  $plate 13 inner radius
650   cz 11.67384  $plate 13 fuel meat inner
651   cz 11.72464  $plate 13 fuel meat outer
652   cz 11.76274  $plate 13 outer radius
c     plate 14
653   cz 11.96086  $plate 14 inner radius
654   cz 11.99896  $plate 14 fuel meat inner
655   cz 12.04976  $plate 14 fuel meat outer
656   cz 12.08786  $plate 14 outer radius
c     plate 15
```

```
657   cz 12.28598  $plate 15 inner radius
658   cz 12.32408  $plate 15 fuel meat inner
659   cz 12.37488  $plate 15 fuel meat outer
660   cz 12.41298  $plate 15 outer radius
c     plate 16
661   cz 12.6111   $plate 16 inner radius
662   cz 12.64920  $plate 16 fuel meat inner
663   cz 12.70000  $plate 16 fuel meat outer
664   cz 12.7381   $plate 16 outer radius
c     plate 17
665   cz 12.93622  $plate 17 inner radius
666   cz 12.97432  $plate 17 fuel meat inner
667   cz 13.02512  $plate 17 fuel meat outer
668   cz 13.06322  $plate 17 outer radius
c     plate 18
669   cz 13.26134  $plate 18 inner radius
670   cz 13.29944  $plate 18 fuel meat inner
671   cz 13.35024  $plate 18 fuel meat outer
672   cz 13.38834  $plate 18 outer radius
c     plate 19
673   cz 13.58646  $plate 19 inner radius
674   cz 13.68806  $plate 19 fuel meat inner
675   cz 13.73886  $plate 19 fuel meat outer
676   cz 13.84046  $plate 19 outer radius
677   cz 14.01317  $outer diameter of element
c    surfaces for sides of plate and fuel region
678   p -2.414214 -1 0 0          $outside boundary of Al plate
679   p  2.414214 -1 0 0          $outside boundary of Al plate
680   p -2.414214 -1 0 -1.241183  $inside boundary of Al plate
681   p  2.414214 -1 0 -1.241183  $inside boundary of Al plate
682   p -2.414214 -1 0 -2.535464  $plate 1 and 19 fuel meat boundary
683   p  2.414214 -1 0 -2.535464  $plate 1 and 19 fuel meat boundary
684   p -2.414214 -1 0 -1.871730  $plate 2 through 17 fuel meat boundary
685   p  2.414214 -1 0 -1.871730  $plate 2 through 17 fuel meat boundary
686   p -2.414214 -1 0 -2.004477  $plate 18 fuel meat boundary
687   p  2.414214 -1 0 -2.004477  $plate 18 fuel meat boundary
690   pz  62.8650   $top of fuel element, 49.5" total
691   pz -62.8650   $bottom of fuel element
692   pz  60.960    $top of fuel meat, 48" total
693   pz -60.960    $bottom of fuel meat
697   cz  7.52856   $inner radius of element
698   cz 14.00302   $outer radius of element
160   cz  10000.    $just a big surface
170   py      0.    $ horizontal line
171   p  1.73205081    1   0  0
172   p  1.73205081   -1   0  0
180   cz 5.94
c ***************************************************************
*110  px  65.2630                    $ storage rack
*111  px -65.2630
*112  py  44.8468
*113  py -44.8468
114  pz  100.0                       $ water reflector
115  pz -100.0

mode n
C     WATER  dens=1.0000 g/cc  $   atm. den.:   .100284
m5     1001.62c   6.6874E-02  $ H
       8016.62c   3.3437E-02  $ O
mt5   lwtr.60t
c     fuel plates
```

```
m101    92235.69c   2.4472E-03
        92238.69c   1.0405E-04
        92234.69c   3.1358E-05
        92236.69c   1.8137E-05
        13027.62c   5.7578E-02
m102    92235.69c   2.4586E-03
        92238.69c   1.0453E-04
        92234.69c   3.1504E-05
        92236.69c   1.8221E-05
        13027.62c   5.7564E-02
m103    92235.69c   3.1090E-03
        92238.69c   1.3219E-04
        92234.69c   3.9839E-05
        92236.69c   2.3042E-05
        13027.62c   5.6791E-02
m104    92235.69c   3.0936E-03
        92238.69c   1.3154E-04
        92234.69c   3.9641E-05
        92236.69c   2.2928E-05
        13027.62c   5.6809E-02
m105    92235.69c   3.8111E-03
        92238.69c   1.6204E-04
        92234.69c   4.8835E-05
        92236.69c   2.8245E-05
        13027.62c   5.5957E-02
m106    92235.69c   3.8230E-03
        92238.69c   1.6255E-04
        92234.69c   4.8988E-05
        92236.69c   2.8334E-05
        13027.62c   5.5943E-02
m107    92235.69c   3.8272E-03
        92238.69c   1.6273E-04
        92234.69c   4.9042E-05
        92236.69c   2.8365E-05
        13027.62c   5.5938E-02
m108    92235.69c   3.8311E-03
        92238.69c   1.6289E-04
        92234.69c   4.9092E-05
        92236.69c   2.8394E-05
        13027.62c   5.5933E-02
m109    92235.69c   3.8347E-03
        92238.69c   1.6305E-04
        92234.69c   4.9138E-05
        92236.69c   2.8420E-05
        13027.62c   5.5929E-02
m110    92235.69c   3.8381E-03
        92238.69c   1.6319E-04
        92234.69c   4.9180E-05
        92236.69c   2.8445E-05
        13027.62c   5.5925E-02
m111    92235.69c   3.8412E-03
        92238.69c   1.6332E-04
        92234.69c   4.9220E-05
        92236.69c   2.8468E-05
        13027.62c   5.5921E-02
m112    92235.69c   3.8441E-03
        92238.69c   1.6344E-04
        92234.69c   4.9257E-05
        92236.69c   2.8489E-05
        13027.62c   5.5918E-02
m113    92235.69c   3.8468E-03
```

```
       92238.69c   1.6356E-04
       92234.69c   4.9292E-05
       92236.69c   2.8509E-05
       13027.62c   5.5914E-02
m114    92235.69c   3.8493E-03
       92238.69c   1.6367E-04
       92234.69c   4.9324E-05
       92236.69c   2.8528E-05
       13027.62c   5.5911E-02
m115    92235.69c   3.8567E-03
       92238.69c   1.6398E-04
       92234.69c   4.9420E-05
       92236.69c   2.8583E-05
       13027.62c   5.5903E-02
m116    92235.69c   3.1380E-03
       92238.69c   1.3342E-04
       92234.69c   4.0210E-05
       92236.69c   2.3257E-05
       13027.62c   5.6757E-02
m117    92235.69c   3.1372E-03
       92238.69c   1.3339E-04
       92234.69c   4.0199E-05
       92236.69c   2.3251E-05
       13027.62c   5.6758E-02
m118    92235.69c   2.5171E-03
       92238.69c   1.0702E-04
       92234.69c   3.2254E-05
       92236.69c   1.8655E-05
       13027.62c   5.7495E-02
m119    92235.69c   2.4894E-03
       92238.69c   1.0584E-04
       92234.69c   3.1899E-05
       92236.69c   1.8449E-05
       13027.62c   5.7528E-02
c     material for cladding and support (Al6061)
m20    13027.62c 5.9018E-02 $ Al +Zn impurity
      12000.62c 6.7060e-04 $ Mg
      14028.62c 3.2114E-04 $ Si
      14029.62c 1.6261E-05
      14030.62c 1.0794E-05 $ Si
      26054.62c 1.1952E-05 $ Fe
      26056.62c 1.8745E-04
      26057.62c 4.3312E-06
      26058.62c 5.7205E-07 $ Fe
c  $ Cu
c  $ Cr
c  $ Mn
c  $ Ti
c                              RC
c
*tr1  0  0  0  60. 150. 90. 330.  60. 90. 90. 90. 0.
*tr2  0  0  0 120. 210. 90.  30. 120. 90. 90. 90. 0.
*tr3  0  0  0 180. 270. 90.  90. 180. 90. 90. 90. 0.
*tr4  0  0  0 240. 330. 90. 150. 240. 90. 90. 90. 0.
*tr5  0  0  0 300.  30. 90. 210. 300. 90. 90. 90. 0.
kcode  6500  1.0  55  290
c
ksrc  0.2    -2.8     0.00  -0.2    -2.8     0.0
      3.7     2.6     0.00  -3.7     2.6     0.0
      2.7    -1.1     0.00  -2.7    -1.1     0.0
      2.1    -2.6     0.00  -2.1    -2.6     0.0
```

print

## Sample Input Deck #3, Case leu-1_7c_0.4 from Table C- 3

MCNP Listing for Demonstration U-10Mo

```
LEU ATR Demonstration element
c LEE: note this uses average "B" values
c      cell cards for ATR assembly
601    5 0.100311         600 -601 -680 -681              u=1  imp:n=1
602    101 6.017874E-02   602 -603 -682 -683 -692 693      u=1  imp:n=1
603    20  6.024110E-02   601 -604 -680 -681 #602         u=1  imp:n=1
604    5 0.100311         604 -605 -680 -681              u=1  imp:n=1
c      plate 2
605    102 6.017685E-02   606 -607 -684 -685 -692 693      u=1  imp:n=1
606    20  6.024110E-02   605 -608 -680 -681 #605         u=1  imp:n=1
607    5 0.100311         608 -609 -680 -681              u=1  imp:n=1
c      plate 3
608    103 6.009507E-02   610 -611 -684 -685 -692 693      u=1  imp:n=1
609    20  6.024110E-02   609 -612 -680 -681 #608         u=1  imp:n=1
610    5 0.100311         612 -613 -680 -681              u=1  imp:n=1
c     plate 4
611    104 6.009671E-02   614 -615 -684 -685 -692 693      u=1  imp:n=1
612    20  6.024110E-02   613 -616 -680 -681 #611         u=1  imp:n=1
613    5 0.100311         616 -617 -680 -681              u=1  imp:n=1
c     plate 5
614   515 4.918570E-02    618 -619 -684 -685 -692 693      u=1  imp:n=1
6141  30  4.290970E-02   6171 -618 -684 -685 -692 693      u=1  imp:n=1
6142  30  4.290970E-02   619 -6191 -684 -685 -692 693      u=1  imp:n=1
615   20  6.024110E-02    617 -620 -680 -681
                       (-6171:6191:692:-693:684:685)     u=1  imp:n=1
616   5 0.100311          620 -621 -680 -681              u=1  imp:n=1
c     plate 6
617   515 4.918570E-02    622 -623 -684 -685 -692 693      u=1  imp:n=1
6171  30  4.290970E-02   6211 -622 -684 -685 -692 693      u=1  imp:n=1
6172  30  4.290970E-02   623 -6231 -684 -685 -692 693      u=1  imp:n=1
618   20  6.024110E-02    621 -624 -680 -681
                       (-6211:6231:692:-693:684:685)     u=1  imp:n=1
619   5 0.100311          624 -625 -680 -681              u=1  imp:n=1
c     plate 7
620   515 4.918570E-02    626 -627 -684 -685 -692 693      u=1  imp:n=1
6201  30  4.290970E-02   6251 -626 -684 -685 -692 693      u=1  imp:n=1
6202  30  4.290970E-02   627 -6271 -684 -685 -692 693      u=1  imp:n=1
621   20  6.024110E-02    625 -628 -680 -681
                       (-6251:6271:692:-693:684:685)     u=1  imp:n=1
622   5 0.100311          628 -629 -680 -681              u=1  imp:n=1
c     plate 8
623   515 4.918570E-02    630 -631 -684 -685 -692 693      u=1  imp:n=1
6231  30  4.290970E-02   6291 -630 -684 -685 -692 693      u=1  imp:n=1
6232  30  4.290970E-02   631 -6311 -684 -685 -692 693      u=1  imp:n=1
624   20  6.024110E-02    629 -632 -680 -681
                       (-6291:6311:692:-693:684:685)     u=1  imp:n=1
625   5 0.100311          632 -633 -680 -681              u=1  imp:n=1
c     plate 9
626   515 4.918570E-02    634 -635 -684 -685 -692 693      u=1  imp:n=1
6261  30  4.290970E-02   6331 -634 -684 -685 -692 693      u=1  imp:n=1
6262  30  4.290970E-02   635 -6351 -684 -685 -692 693      u=1  imp:n=1
627   20  6.024110E-02    633 -636 -680 -681
                       (-6331:6351:692:-693:684:685)     u=1  imp:n=1
628   5 0.100311          636 -637 -680 -681              u=1  imp:n=1
c     plate 10
```

```
629   515 4.918570E-02    638 -639 -684 -685 -692 693      u=1  imp:n=1
6291  30  4.290970E-02   6371 -638 -684 -685 -692 693      u=1  imp:n=1
6292  30  4.290970E-02   639 -6391 -684 -685 -692 693      u=1  imp:n=1
630   20  6.024110E-02    637 -640 -680 -681
                    (-6371:6391:692:-693:684:685)      u=1  imp:n=1
631   5 0.100311          640 -641 -680 -681               u=1  imp:n=1
c     plate 11
632   515 4.918570E-02    642 -643  -684 -685 -692 693     u=1  imp:n=1
6321  30  4.290970E-02   6411 -642 -684 -685 -692 693      u=1  imp:n=1
6322  30  4.290970E-02   643 -6431 -684 -685 -692 693      u=1  imp:n=1
633   20  6.024110E-02    641 -644 -680 -681
                    (-6411:6431:692:-693:684:685)      u=1  imp:n=1
634   5 0.100311          644 -645 -680 -681               u=1  imp:n=1
c     plate 12
635   515 4.918570E-02    646 -647 -684 -685 -692 693      u=1  imp:n=1
6351  30  4.290970E-02   6451 -646 -684 -685 -692 693      u=1  imp:n=1
6352  30  4.290970E-02   647 -6471 -684 -685 -692 693      u=1  imp:n=1
636   20  6.024110E-02    645 -648 -680 -681
                    (-6451:6471:692:-693:684:685)      u=1  imp:n=1
637   5 0.100311          648 -649 -680 -681               u=1  imp:n=1
c      plate 13
638   515 4.918570E-02    650 -651 -684 -685 -692 693      u=1  imp:n=1
6381  30  4.290970E-02   6491 -650 -684 -685 -692 693      u=1  imp:n=1
6382  30  4.290970E-02   651 -6511 -684 -685 -692 693      u=1  imp:n=1
639   20  6.024110E-02    649 -652 -680 -681
                    (-6491:6511:692:-693:684:685)      u=1  imp:n=1
640   5 0.100311          652 -653 -680 -681               u=1  imp:n=1
c      plate 14
641   515 4.918570E-02    654 -655 -684 -685 -692 693      u=1  imp:n=1
6411  30  4.290970E-02   6531 -654 -684 -685 -692 693      u=1  imp:n=1
6412  30  4.290970E-02   655 -6551 -684 -685 -692 693      u=1  imp:n=1
642   20  6.024110E-02    653 -656 -680 -681
                    (-6531:6551:692:-693:684:685)      u=1  imp:n=1
643   5 0.100311          656 -657 -680 -681               u=1  imp:n=1
c     plate 15
644   515 4.918570E-02    658 -659 -684 -685 -692 693      u=1  imp:n=1
6441  30  4.290970E-02   6571 -658 -684 -685 -692 693      u=1  imp:n=1
6442  30  4.290970E-02   659 -6591 -684 -685 -692 693      u=1  imp:n=1
645   20  6.024110E-02    657 -660 -680 -681
                    (-6571:6591:692:-693:684:685)      u=1  imp:n=1
646   5 0.100311          660 -661 -680 -681               u=1  imp:n=1
c     plate 16
647   116 6.009189E-02    662 -663 -684 -685 -692 693      u=1  imp:n=1
648   20  6.024110E-02    661 -664 -680 -681 #647          u=1  imp:n=1
649   5 0.100311          664 -665 -680 -681               u=1  imp:n=1
c     plate 17
650   117 6.009204E-02    666 -667 -684 -685 -692 693      u=1  imp:n=1
651   20  6.024110E-02    665 -668 -680 -681  #650         u=1  imp:n=1
652   5 0.100311          668 -669 -680 -681               u=1  imp:n=1
c     plate 18
653   118 6.017003E-02    670 -671 -686 -687 -692 693      u=1  imp:n=1
654   20  6.024110E-02    669 -672 -680 -681 #653          u=1  imp:n=1
655   5 0.100311          672 -673 -680 -681               u=1  imp:n=1
c     plate 19
c 656   119 6.017359E-02    674 -675 -682 -683 -692 693      u=1  imp:n=1
c 657   20  6.024110E-02    673 -676 -680 -681 #656          u=1  imp:n=1
657   20  6.024110E-02    673 -676 -680 -681               u=1  imp:n=1
658   5 0.100311          676 -677 -680 -681               u=1  imp:n=1
c      side plates
659   20 6.024110E-02    (-600:677:680:681)               u=1  imp:n=1
c     cut-out elements and move
```

```
59    0    697 -698 -678 -679 -690 691 fill=1 trcl=(0 -1.1 0)  u=3  imp:n=1
60    5 0.100311    #59                              u=3  imp:n=1
61    0    -160                     fill=3 trcl=1          u=31 imp:n=1
62    0    -160                     fill=3 trcl=2          u=32 imp:n=1
63    0    -160                     fill=3 trcl=3          u=33 imp:n=1
64    0    -160                     fill=3 trcl=4          u=34 imp:n=1
65    0    -160                     fill=3 trcl=5          u=35 imp:n=1
66    0    697 -698 -678 -679 -690 691 fill=1 trcl=(0 -10.5 0) u=2 imp:n=1
102   5 0.100311 -180 #66                        u=2  imp:n=1
104   5 0.100311  180           171 -172 fill=3    u=2  imp:n=1
105   5 0.100311  180           170  172 fill=31   u=2  imp:n=1
106   5 0.100311  180          -170  171 fill=32   u=2  imp:n=1
103   5 0.100311  180          -171 172  fill=33   u=2  imp:n=1
107   5 0.100311  180          -170 -172 fill=34   u=2  imp:n=1
108   5 0.100311  180           170 -171 fill=35   u=2  imp:n=1
109   0    -110 111 -112 113 -114 115 fill=2                   imp:n=1
110  0             110:-111:112:-113:114:-115   imp:n=0

c ******************************************************************
C     SURFACE SPECIFICATIONS
c     surface cards
600    cz 7.52855
c     radius for fuel plates
c     plate 1
601    cz 7.6581    $plate 1 inner radius
602    cz 7.7343    $plate 1 fuel meat inner
603    cz 7.7851    $plate 1 fuel meat outer
604    cz 7.8613    $plate 1 outer radius
c     plate 2
605    cz 8.05942   $plate 2 inner radius
606    cz 8.09752   $plate 2 fuel meat inner
607    cz 8.14832   $plate 2 fuel meat outer
608    cz 8.18642   $plate 2 outer radius
c     plate 3
609    cz 8.38454   $plate 3 inner radius
610    cz 8.42264   $plate 3 fuel meat inner
611    cz 8.47344   $plate 3 fuel meat outer
612    cz 8.51154   $plate 3 outer radius
c     plate 4
613    cz 8.70966   $plate 4 inner radius
614    cz 8.74776   $plate 4 fuel meat inner
615    cz 8.79856   $plate 4 fuel meat outer
616    cz 8.83666   $plate 4 outer radius
c     plate 5
617    cz 9.03478   $plate 5 inner radius
6171   cz 9.07923   $plate 5 inner Zr clad radius
618    cz 9.08177   $plate 5 fuel meat inner
619    cz 9.11479   $plate 5 fuel meat outer
6191   cz 9.11733   $plate 5 outer Zr clad radius
620    cz 9.16178   $plate 5 outer radius
c     plate 6
621    cz 9.3599    $plate 6 inner radius
6211   cz 9.40435   $plate 6 inner Zr clad radius
622    cz 9.40689   $plate 6 fuel meat inner
623    cz 9.43991   $plate 6 fuel meat outer
6231   cz 9.44245   $plate 6 outer Zr clad radius
624    cz 9.4869    $plate 6 outer radius
c     plate 7
625    cz 9.68502   $plate 7 inner radius
6251   cz 9.72947   $plate 7 inner Zr clad radius
626    cz 9.73201   $plate 7 fuel meat inner
```

```
627    cz 9.76503   $plate 7 fuel meat outer
6271   cz 9.76757   $plate 7 outer Zr clad radius
628    cz 9.81202   $plate 7 outer radius
c      plate 8
629    cz 10.01014  $plate 8 inner radius
6291   cz 10.05459  $plate 8 inner Zr clad radius
630    cz 10.05713  $plate 8 fuel meat inner
631    cz 10.09015  $plate 8 fuel meat outer
6311   cz 10.09269  $plate 8 outer Zr clad radius
632    cz 10.13714  $plate 8 outer radius
c      plate 9
633    cz 10.33526  $plate 9 inner radius
6331   cz 10.37971  $plate 9 inner Zr clad radius
634    cz 10.38225  $plate 9 fuel meat inner
635    cz 10.41527  $plate 9 fuel meat outer
6351   cz 10.41781  $plate 9 outer Zr clad radius
636    cz 10.46226  $plate 9 outer radius
c      plate 10
637    cz 10.66038  $plate 10 inner radius
6371   cz 10.70483  $plate 10 inner Zr clad radius
638    cz 10.70737  $plate 10 fuel meat inner
639    cz 10.74039  $plate 10 fuel meat outer
6391   cz 10.74293  $plate 10 outer Zr clad radius
640    cz 10.78738  $plate 10 outer radius
c      plate 11
641    cz 10.9855   $plate 11 inner radius
6411   cz 11.02995  $plate 11 inner Zr clad radius
642    cz 11.03249  $plate 11 fuel meat inner
643    cz 11.06551  $plate 11 fuel meat outer
6431   cz 11.06805  $plate 11 outer Zr clad radius
644    cz 11.1125   $plate 11 outer radius
c      plate 12
645    cz 11.31062  $plate 12 inner radius
6451   cz 11.35507  $plate 12 inner Zr clad radius
646    cz 11.35761  $plate 12 fuel meat inner
647    cz 11.39063  $plate 12 fuel meat outer
6471   cz 11.39317  $plate 12 outer Zr clad radius
648    cz 11.43762  $plate 12 outer radius
c      plate 13
649    cz 11.63574  $plate 13 inner radius
6491   cz 11.68019  $plate 13 inner Zr clad radius
650    cz 11.68273  $plate 13 fuel meat inner
651    cz 11.71575  $plate 13 fuel meat outer
6511   cz 11.71829  $plate 13 outer Zr clad radius
652    cz 11.76274  $plate 13 outer radius
c      plate 14
653    cz 11.96086  $plate 14 inner radius
6531   cz 12.00531  $plate 14 inner Zr clad radius
654    cz 12.00785  $plate 14 fuel meat inner
655    cz 12.04087  $plate 14 fuel meat outer
6551   cz 12.04341  $plate 14 outer Zr clad radius
656    cz 12.08786  $plate 14 outer radius
c      plate 15
657    cz 12.28598  $plate 15 inner radius
6571   cz 12.33043  $plate 15 inner Zr clad radius
658    cz 12.33297  $plate 15 fuel meat inner
659    cz 12.36599  $plate 15 fuel meat outer
6591   cz 12.36853  $plate 15 outer Zr clad radius
660    cz 12.41298  $plate 15 outer radius
c      plate 16
661    cz 12.6111   $plate 16 inner radius
```

```
662    cz 12.64920  $plate 16 fuel meat inner
663    cz 12.70000  $plate 16 fuel meat outer
664    cz 12.7381   $plate 16 outer radius
c      plate 17
665    cz 12.93622  $plate 17 inner radius
666    cz 12.97432  $plate 17 fuel meat inner
667    cz 13.02512  $plate 17 fuel meat outer
668    cz 13.06322  $plate 17 outer radius
c      plate 18
669    cz 13.26134  $plate 18 inner radius
670    cz 13.29944  $plate 18 fuel meat inner
671    cz 13.35024  $plate 18 fuel meat outer
672    cz 13.38834  $plate 18 outer radius
c      plate 19
673    cz 13.58646  $plate 19 inner radius
674    cz 13.68806  $plate 19 fuel meat inner
675    cz 13.73886  $plate 19 fuel meat outer
676    cz 13.84046  $plate 19 outer radius
677    cz 14.01317  $outer diameter of element
c     surfaces for sides of plate and fuel region
678   p -2.414214 -1 0 0          $outside boundary of Al plate
679   p  2.414214 -1 0 0          $outside boundary of Al plate
680   p -2.414214 -1 0 -1.241183  $inside boundary of Al plate
681   p  2.414214 -1 0 -1.241183  $inside boundary of Al plate
682   p -2.414214 -1 0 -2.535464  $plate 1 and 19 fuel meat boundary
683   p  2.414214 -1 0 -2.535464  $plate 1 and 19 fuel meat boundary
684   p -2.414214 -1 0 -1.871730  $plate 2 through 17 fuel meat boundary
685   p  2.414214 -1 0 -1.871730  $plate 2 through 17 fuel meat boundary
686   p -2.414214 -1 0 -2.004477  $plate 18 fuel meat boundary
687   p  2.414214 -1 0 -2.004477  $plate 18 fuel meat boundary
690   pz  62.8650   $top of fuel element, 49.5" total
691   pz -62.8650   $bottom of fuel element
692   pz  60.960    $top of fuel meat, 48" total
693   pz -60.960    $bottom of fuel meat
697   cz  7.52856   $inner radius of element
698   cz 14.00302   $outer radius of element
160   cz  10000.    $just a big surface
170   py      0.    $ horizontal line
171   p  1.73205081    1   0  0
172   p  1.73205081   -1   0  0
180   cz 5.94
c ****************************************************************
*110  px  65.2630                          $ storage rack
*111  px -65.2630
*112  py  44.8468
*113  py -44.8468
114  pz  100.0                             $ water reflector
115  pz -100.0

mode n
C     WATER  dens=1.0000 g/cc  $   atm. den.:   .100284
m5     1001.62c   6.6874E-02  $ H
      8016.62c   3.3437E-02  $ O
mt5   lwtr.60t
c     fuel plates
m101    92235.69c   2.4472E-03
        92238.69c   1.0405E-04
        92234.69c   3.1358E-05
        92236.69c   1.8137E-05
        13027.62c   5.7578E-02
m102    92235.69c   2.4586E-03
```

```
        92238.69c   1.0453E-04
        92234.69c   3.1504E-05
        92236.69c   1.8221E-05
        13027.62c   5.7564E-02
m103    92235.69c   3.1090E-03
        92238.69c   1.3219E-04
        92234.69c   3.9839E-05
        92236.69c   2.3042E-05
        13027.62c   5.6791E-02
m104    92235.69c   3.0936E-03
        92238.69c   1.3154E-04
        92234.69c   3.9641E-05
        92236.69c   2.2928E-05
        13027.62c   5.6809E-02
m105    92235.69c   3.8111E-03
        92238.69c   1.6204E-04
        92234.69c   4.8835E-05
        92236.69c   2.8245E-05
        13027.62c   5.5957E-02
m106    92235.69c   3.8230E-03
        92238.69c   1.6255E-04
        92234.69c   4.8988E-05
        92236.69c   2.8334E-05
        13027.62c   5.5943E-02
m107    92235.69c   3.8272E-03
        92238.69c   1.6273E-04
        92234.69c   4.9042E-05
        92236.69c   2.8365E-05
        13027.62c   5.5938E-02
m108    92235.69c   3.8311E-03
        92238.69c   1.6289E-04
        92234.69c   4.9092E-05
        92236.69c   2.8394E-05
        13027.62c   5.5933E-02
m109    92235.69c   3.8347E-03
        92238.69c   1.6305E-04
        92234.69c   4.9138E-05
        92236.69c   2.8420E-05
        13027.62c   5.5929E-02
m110    92235.69c   3.8381E-03
        92238.69c   1.6319E-04
        92234.69c   4.9180E-05
        92236.69c   2.8445E-05
        13027.62c   5.5925E-02
m111    92235.69c   3.8412E-03
        92238.69c   1.6332E-04
        92234.69c   4.9220E-05
        92236.69c   2.8468E-05
        13027.62c   5.5921E-02
m112    92235.69c   3.8441E-03
        92238.69c   1.6344E-04
        92234.69c   4.9257E-05
        92236.69c   2.8489E-05
        13027.62c   5.5918E-02
m113    92235.69c   3.8468E-03
        92238.69c   1.6356E-04
        92234.69c   4.9292E-05
        92236.69c   2.8509E-05
        13027.62c   5.5914E-02
m114    92235.69c   3.8493E-03
        92238.69c   1.6367E-04
```

```
       92234.69c   4.9324E-05
       92236.69c   2.8528E-05
       13027.62c   5.5911E-02
m115    92235.69c   3.8567E-03
       92238.69c   1.6398E-04
       92234.69c   4.9420E-05
       92236.69c   2.8583E-05
       13027.62c   5.5903E-02
m116    92235.69c   3.1380E-03
       92238.69c   1.3342E-04
       92234.69c   4.0210E-05
       92236.69c   2.3257E-05
       13027.62c   5.6757E-02
m117    92235.69c   3.1372E-03
       92238.69c   1.3339E-04
       92234.69c   4.0199E-05
       92236.69c   2.3251E-05
       13027.62c   5.6758E-02
m118    92235.69c   2.5171E-03
       92238.69c   1.0702E-04
       92234.69c   3.2254E-05
       92236.69c   1.8655E-05
       13027.62c   5.7495E-02
m119    92235.69c   2.4894E-03
       92238.69c   1.0584E-04
       92234.69c   3.1899E-05
       92236.69c   1.8449E-05
       13027.62c   5.7528E-02
m515    92235.69c   7.7940E-03
       92238.69c   3.0677E-02
       92234.69c   4.3834E-05
       92236.69c   6.2864E-05
       42000.66c   1.0608E-02
c     material for cladding and support (Al6061)
m20    13027.62c 5.9018E-02 $ Al +Zn impurity
      12000.62c 6.7060e-04 $ Mg
      14028.62c 3.2114E-04 $ Si
      14029.62c 1.6261E-05
      14030.62c 1.0794E-05 $ Si
      26054.62c 1.1952E-05 $ Fe
      26056.62c 1.8745E-04
      26057.62c 4.3312E-06
      26058.62c 5.7205E-07 $ Fe
c
m30   40090.66c  2.2077E-02
     40091.66c  4.8145E-03
     40092.66c  7.3590E-03
     40094.66c  7.4577E-03
     40096.66c  1.2015E-03
c                              RC
c
*tr1  0  0  0  60. 150. 90. 330.  60. 90. 90. 90. 0.
*tr2  0  0  0 120. 210. 90.  30. 120. 90. 90. 90. 0.
*tr3  0  0  0 180. 270. 90.  90. 180. 90. 90. 90. 0.
*tr4  0  0  0 240. 330. 90. 150. 240. 90. 90. 90. 0.
*tr5  0  0  0 300.  30. 90. 210. 300. 90. 90. 90. 0.
kcode  6500  1.0  55  290
c
ksrc  0.2    -2.8     0.00  -0.2    -2.8     0.0
     3.7     2.6     0.00  -3.7     2.6     0.0
     2.7    -1.1     0.00  -2.7    -1.1     0.0
```

```
    2.1    -2.6     0.00  -2.1    -2.6     0.0
print
```

# Appendix C: Fuel Element Array Results

The results in Table C- 1 are for the HEU ATR elements. The water moderated and reflected single element results are given in the first set of the table. The comparison case (from Reference 8) results are given in the second set. Results for the hexagonal array shown in Figure 5 with different spacings are given in the third set of the table.

Table C- 1. Results for HEU ATR Element Configurations

| Case (MCNP Input File) | Description | $k_{eff} \pm \sigma$ | $k_{eff} + 2\sigma$ |
|---|---|---|---|
| **A single water moderated and reflected ATR element** | | | |
| heu_1a | Single water moderated and reflected ATR element | 0.4455 ± 0.0006 | 0.4467 |
| **A hexagonal array of 7 ATR elements like Configuration A in Figure 4** | | | |
| heu_7a | Elements are water moderated and flooded | 0.9887 ± 0.0007 | 0.9901 |
| **A hexagonal array of 7 ATR elements to investigate element spacing, see Figure 5** | | | |
| heu_7b | Adjacent elements are touching; see Figure 5a | 0.9602 ± 0.0007 | 0.9615 |
| heu_7b_.2 | Previous case, but spacing between elements is 0.2 cm | 0.9725 ± 0.0007 | 0.9739 |
| heu_7b_.4 | Case heu_7b, but spacing between elements is 0.4 cm | 0.9806 ± 0.0007 | 0.9821 |
| heu_7b_.6.o | Case heu_7b, but spacing between elements is 0.6 cm | 0.9872 ± 0.0007 | 0.9886 |
| heu_7b_.8 | Case heu_7b, but spacing between elements is 0.8 cm | 0.9914 ± 0.0008 | 0.9929 |
| heu_7b_.9 | Case heu_7b, but spacing between elements is 0.9 cm | 0.9911 ± 0.0008 | 0.9926 |
| heu_7b_1 | Case heu_7b, but spacing between elements is 1.0 cm | 0.9944 ± 0.0007 | 0.9958 |
| heu_7b_1.1 | Previous case, but spacing is 1.1 cm; see Figure 5b | 0.9952 ± 0.0007 | 0.9967 |
| heu_7b_1.2 | Case heu_7b, but spacing between elements is 1.2 cm | 0.9916 ± 0.0007 | 0.9930 |
| heu_7b_1.4 | Case heu_7b, but spacing between elements is 1.4 cm | 0.9907 ± 0.0007 | 0.9920 |
| heu_7b_1.6 | Case heu_7b, but spacing between elements is 1.6 cm | 0.9887 ± 0.0007 | 0.9900 |
| heu_7b_1.8 | Case heu_7b, but spacing between elements is 1.8 cm | 0.9831 ± 0.0007 | 0.9844 |
| heu_7b_2 | Case heu_7b, but spacing between elements is 2.0 cm | 0.9759 ± 0.0007 | 0.9772 |

Results for the circular configuration shown in Figure 6 with different spacings are given in Table C- 2.

Table C- 2. Results for HEU ATR Elements in Circular Configurations

| Case (MCNP Input File) | Description | $k_{eff} \pm \sigma$ | $k_{eff} + 2\sigma$ |
|---|---|---|---|
| **Elements in circular configuration with varying spacing** | | | |
| heu_7c_ma | Elements are at closest approach, see Figure 6a | 0.9818 ± 0.0007 | 0.9832 |
| heu_7c_0 | Similar to previous case, but center element is moved upwards towards the center, and radius of outer ring is increased slightly | 0.9942 ± 0.0007 | 0.9956 |
| heu_7c_0.1 | Case heu_7c_0, but outer radius is increased by 0.1 cm | 0.9949 ± 0.0007 | 0.9963 |
| heu_7c_0.2 | Case heu_7c_0, but outer radius is increased by 0.2 cm, see Figure 6b | 0.9952 ± 0.0007 | 0.9965 |
| heu_7c_0.3 | Case heu_7c_0, but outer radius is increased by 0.3 cm | 0.9948 ± 0.0007 | 0.9962 |
| heu_7c_0.4 | Case heu_7c_0, but outer radius is increased by 0.4 cm | 0.9937 ± 0.0007 | 0.9951 |
| heu_7c_0.6 | Case heu_7c_0, but outer radius is increased by 0.6 cm | 0.9898 ± 0.0007 | 0.9912 |
| heu_7c_0.8 | Case heu_7c_0, but outer radius is increased by 0.8 cm | 0.9855 ± 0.0007 | 0.9868 |
| heu_7c_1.0 | Case heu_7c_0, but outer radius is increased by 1.0 cm | 0.9802 ± 0.0007 | 0.9815 |

Results similar to those given in Table C- 1 and Table C- 2 are given in Table C- 3 for the U-10Mo Demonstration elements with the aluminum (dummy) plate 19 and the boron content neglected.

Table C- 3. Results for U-10Mo Full Size Demonstration ATR Element Configurations

| Case (MCNP Input File) | Description | $k_{eff} \pm \sigma$ | $k_{eff} + 2\sigma$ |
|---|---|---|---|
| **A single water moderated and reflected ATR Demonstration element** | | | |
| leu-1_1a | Single water moderated and reflected ATR element | 0.4370 ± 0.0005 | 0.4380 |
| **A hexagonal array of 7 U-10Mo elements like Configuration A in Figure 4** | | | |
| leu-1_7a | Elements are water moderated and flooded | 0.9540 ± 0.0007 | 0.9553 |
| **A hexagonal array of 7 U-10Mo elements to investigate element spacing, see Figure 5** | | | |
| leu-1_7b | Adjacent elements are touching; see Figure 5a | 0.9218 ± 0.0008 | 0.9234 |
| leu-1_7b_.2 | Previous case, but spacing between elements is 0.2 cm | 0.9333 ± 0.0007 | 0.9348 |
| leu-1_7b_.4 | Case leu-1_7b, but spacing between elements is 0.4 cm | 0.9442 ± 0.0006 | 0.9455 |
| leu-1_7b_.6 | Case leu-1_7b, but spacing between elements is 0.6 cm | 0.9504 ± 0.0006 | 0.9517 |
| leu-1_7b_.8 | Case leu-1_7b, but spacing between elements is 0.8 cm | 0.9546 ± 0.0007 | 0.9560 |
| leu-1_7b_.9 | Case leu-1_7b, but spacing between elements is 0.9 cm | 0.9568 ± 0.0007 | 0.9582 |
| leu-1_7b_1 | Case leu-1_7b, but spacing between elements is 1.0 cm | 0.9585 ± 0.0008 | 0.9600 |
| leu-1_7b_1.1 | Case leu-1_7b, but spacing between elements is 1.1 cm | 0.9585 ± 0.0007 | 0.9599 |
| leu-1_7b_1.2 | Case leu-1_7b, but spacing between elements is 1.2 cm | 0.9574 ± 0.0007 | 0.9589 |
| leu-1_7b_1.4 | Case leu-1_7b, but spacing between elements is 1.4 cm | 0.9571 ± 0.0007 | 0.9585 |
| leu-1_7b_1.6 | Case leu-1_7b, but spacing between elements is 1.6 cm | 0.9543 ± 0.0007 | 0.9558 |
| leu-1_7b_1.8 | Case leu-1_7b, but spacing between elements is 1.8 cm | 0.9499 ± 0.0007 | 0.9512 |
| leu-1_7b_2 | Case leu-1_7b, but spacing between elements is 2.0 cm | 0.9435 ± 0.0007 | 0.9448 |
| **Elements in circular configuration with varying spacing** | | | |
| leu-1_7c_ma | Elements are at closest approach, see Figure 6a | 0.9416 ± 0.0007 | 0.9431 |
| leu-1_7c_0 | Similar to previous case, but center element is moved upwards towards the center, and radius of outer ring is increased slightly | 0.9579 ± 0.0007 | 0.9594 |
| leu-1_7c_0.1 | Case leu-1_7c_0, but outer radius is increased by 0.1 cm | 0.9596 ± 0.0007 | 0.9611 |
| leu-1_7c_0.2 | Case leu-1_7c_0, but outer radius is increased by 0.2 cm | 0.9607 ± 0.0007 | 0.9621 |
| leu-1_7c_0.3 | Case leu-1_7c_0, but outer radius is increased by 0.3 cm | 0.9606 ± 0.0006 | 0.9619 |
| leu-1_7c_0.4 | Case leu-1_7c_0, but outer radius is increased by 0.4 cm | 0.9624 ± 0.0007 | 0.9637 |
| leu-1_7c_0.6 | Case leu-1_7c_0, but outer radius is increased by 0.6 cm | 0.9597 ± 0.0006 | 0.9610 |
| leu-1_7c_0.8 | Case leu-1_7c_0, but outer radius is increased by 0.8 cm | 0.9572 ± 0.0007 | 0.9585 |
| leu-1_7c_1.0 | Case leu-1_7c_0, but outer radius is increased by 1.0 cm | 0.9533 ± 0.0007 | 0.9547 |

The results in Table C- 4 are the equivalent results as those given in Table C- 3 except all 19 plates are fueled and the boron content is neglected. The fuel loading in plate 19 is assumed to be the same as that of plate 19 of the HEU ATR element.

Table C- 4. Results for U-10Mo Full Size Demonstration ATR Elements with all Plates Fueled

| Case (MCNP Input File) | Description | $k_{eff} \pm \sigma$ | $k_{eff} + 2\sigma$ |
|---|---|---|---|
| **A single water moderated and reflected ATR Demonstration element** | | | |
| leu_1a | Single water moderated and reflected ATR element | 0.4490 ± 0.0006 | 0.4501 |
| **A hexagonal array of 7 U-10Mo (all plates fueled) elements like Configuration A in Figure 4** | | | |
| leu_7a | Elements are water moderated and flooded | 0.9701 ± 0.0007 | 0.9715 |
| **A hexagonal array of 7 U-10Mo (all plates fueled) elements to investigate element spacing, see Figure 5** | | | |
| leu_7b | Adjacent elements are touching; see Figure 5a | 0.9342 ± 0.0007 | 0.9356 |
| leu_7b_.2 | Previous case, but spacing between elements is 0.2 cm | 0.9464 ± 0.0006 | 0.9476 |
| leu_7b_.4 | Case leu_7b, but spacing between elements is 0.4 cm | 0.9558 ± 0.0007 | 0.9571 |
| leu_7b_.6 | Case leu_7b, but spacing between elements is 0.6 cm | 0.9640 ± 0.0007 | 0.9654 |
| leu_7b_.8 | Case leu_7b, but spacing between elements is 0.8 cm | 0.9702 ± 0.0007 | 0.9716 |
| leu_7b_1 | Case leu_7b, but spacing between elements is 1.0 cm | 0.9739 ± 0.0007 | 0.9752 |
| leu_7b_1.2 | Case leu_7b, but spacing between elements is 1.2 cm | 0.9764 ± 0.0006 | 0.9777 |
| leu_7b_1.4 | Case leu_7b, but spacing between elements is 1.4 cm | 0.9740 ± 0.0006 | 0.9753 |
| leu_7b_1.6 | Case leu_7b, but spacing between elements is 1.6 cm | 0.9734 ± 0.0006 | 0.9746 |
| leu_7b_1.8 | Case leu_7b, but spacing between elements is 1.8 cm | 0.9706 ± 0.0006 | 0.9719 |
| leu_7b_2 | Case leu_7b, but spacing between elements is 2.0 cm | 0.9644 ± 0.0007 | 0.9658 |
| **Elements in circular configuration with varying spacing** | | | |
| leu_7c_ma | Elements are at closest approach, see Figure 6a | 0.9556 ± 0.0007 | 0.9569 |
| leu_7c_0 | Similar to previous case, but center element is moved upwards towards the center, and radius of outer ring is increased slightly | 0.9739 ± 0.0007 | 0.9753 |
| leu_7c_0.1 | Case leu_7c_0, but outer radius is increased by 0.1 cm | 0.9753 ± 0.0007 | 0.9766 |
| leu_7c_0.2 | Case leu_7c_0, but outer radius is increased by 0.2 cm | 0.9760 ± 0.0007 | 0.9774 |
| leu_7c_0.3 | Case leu_7c_0, but outer radius is increased by 0.3 cm | 0.9762 ± 0.0007 | 0.9777 |
| leu_7c_0.4 | Case leu_7c_0, but outer radius is increased by 0.4 cm | 0.9764 ± 0.0007 | 0.9778 |
| leu_7c_0.6 | Case leu_7c_0, but outer radius is increased by 0.6 cm | 0.9739 ± 0.0006 | 0.9751 |
| leu_7c_0.8 | Case leu_7c_0, but outer radius is increased by 0.8 cm | 0.9713 ± 0.0007 | 0.9727 |
| leu_7c_1.0 | Case leu_7c_0, but outer radius is increased by 1.0 cm | 0.9679 ± 0.0007 | 0.9692 |