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# PRELIMINARY ENERGY DEPOSITION CALCULATIONS FOR GRIST-2 TESTS IN THE TREAT UPGRADE







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IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

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# PRELIMINARY ENERGY DEPOSITION CALCULATIONS FOR GRIST-2 TESTS IN THE TREAT UPGRADE

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# ABSTRACT

Preliminary studies have been made to estimate the energy deposition in GRIST-2 tests irradiated in the proposed TREAT Upgrade reactor. The objective of the GRIST-2 project is to test GCFR (gas cooled fast reactor) fuel under conditions of hypothetical core disruptive accidents (HCDA). Test requirements are (1) an energy deposition in the test of approximately 2500 J/g or higher, (2) a pin-to-pin variation in energy deposition of less than 10% and (3) the variation in the energy deposition across any pin (at a given axial position) should be less than 10%. Calculations performed by EG&G Idaho were made for 7 and 37-pin tests using one-dimensional transport theory. These yield average energy deposition rates in the test at the axial peak which are in the 5000-5500 J/g range for the 37-pin test and are in the 8500-9000 J/g range for the 7-pin test. These values are obtained with a cadmium thermal neutron filter (TNF) surrounding the test. This hardens the flux to meet the third requirement. The central test pin is fully enriched $UO_2$, with the outer pins having lower enrichments to satisfy requirement 2. Addition of the TNF reduces the energy deposition by about 10%.

The results in the above calculations are also compared with the Monte Carlo results computed by ANL-West personnel.

SUMMARY

Calculations of the energy deposition for GRIST-2 tests represented in the TREAT Upgrade reactor have been made using a 33-group ring (cylindrical) model and one-dimensional $S_n$ transport theory. Seven and thirty-seven pin tests have been examined. Comparisons are made between resonance self-shielded and infinite dilute data sets and between the EG&G results and ANL Monte Carlo results. The ANL results were transmitted to EG&G by letter (1,2).

In general, there is agreement between the calculated results to within about 10%. This is good agreement, considering the differences that exist in the reactor models, in the test models, in the calculational methods, and in the cross section data sets. The test energies calculated by EG&G and ANL are approximately 10% higher for the 37-pin test and 20% higher for the 7-pin test, than those estimated by extrapolation of existing LMFBR results[(3)]. The calculated average energy deposition rates in the test at the axial maximum are in the 5000-5500 J/g range for the 37-pin test and in the 8500-9000 J/g range for the 7-pin test. This is well above the minimum test requirements of approximately 2500 J/g in the test[(4)].

There are further test requirements of ± 10% in pin-to-pin power flatness and a power variation across each pin of less than 10% at a given axial position[(4)]. The first of these is easily met by grading the enrichments between pins. The second is shown to be roughly met by use of a cadmium thermal neutron filter (TNF). The TNF reduces the energy deposition by about 10% but appreciably flattens the power in the outer ring of test pins.

## 1.0 INTRODUCTION

The Gas Reactor In-pile Safety Test (GRIST-2) test loop is a helium cooled in-pile tube for use in testing gas cooled reactor fuel under loss-of-flow (LOF) and transient overpower (TOP) accident conditions with failure to scram. It is to be constructed in the Transient Reactor Test Facility (TREAT) Upgrade Reactor at ANL-West.

Since these tests model hypothetical core disruptive accidents (HCDA), relatively high energy depositions are required. Test requirements of approximately 2500 J/g have been established for the test pins(4). Fully enriched fuel is allowed in meeting this requirement. However, pin-to-pin power variations are to be within ± 10%, so the outer pins in the test have lowered enrichments to accomplish this. A further requirement is a uniform energy deposition across each pin to within 10% at a given axial position. A thermal neutron filter (TNF) hardens the incoming spectrum to help achieve this requirement.

Extrapolation of existing LMFBR results(3) for the proposed TREAT Upgrade reactor indicates that it is the best choice among available reactors to accommodate the GRIST-2 tests. The studies described here are an initial estimate of the test energy deposition for the GRIST-2/TREAT Upgrade combination.

The general method employed by EG&G was to model the reactor and test using one dimensional $S_n$ transport theory methods. The cross section development is described in Section 2, the reactor model and results are described in Section 3, and some conclusions are given in Section 4.

## 2.0 CROSS SECTION DEVELOPMENT

The cross section data used were derived from the ENDF/B-IV data file using the data processing codes ETOP(5) and FLANGE(6). ETOP and FLANGE process the ENDF data for use in the EG&G multigroup spectrum codes PHROG(7) and INCITE(8). All calculations were made for ambient temperatures. Two 33-group cross section sets were produced with PHROG and INCITE, one infinite dilute and one with resonance self-shielded cross sections. The group structure is shown in Table I. There are 23 fast and 10 thermal groups (with upscatter) with the break point at 2.38 eV.

## 2.1 Infinite Dilute Cross Sections

The infinite dilute cross section set was produced using PHROG and INCITE. The PHROG resonance calculation was made for a homogeneous medium, namely the original TREAT fuel. Spectrum calculations, made with both PHROG and INCITE in the B-1 approximation, were used to collapse the cross sections to the desired 33-group structure. The infinite dilute cross sections are microscopic data.

## 2.2 Self-Shielded Cross Sections

The resonance self-shielded cross section set will be denoted as the SCRABL cross sections. To produce this set, 90-group cross sections are first produced by PHROG and INCITE, following the methods used above, except for U-235 and U-238 over the resonance range (groups 19-68). These data were produced by the resonance code RABBLE(9), which is incorporated in the SCRABL(10) code. The geometry represented in the RABBLE resolved resonance calculation is shown in Figure 1. In this calculation the major portion of the reactor is treated as a single cell, with the modified zones of the TREAT Upgrade combined somewhat due to size limitations of the code. The resolved resonance calculation is valid for the geometry represented in RABBLE, with the ring model (vs discrete pins) introducing a degree of uncertainty. The unresolved calculation by SCRABL, incorporating the PHROG algorithms, is more limited, being modeled by a single pin within a moderator. For this problem, an average enrichment and a zero Dancoff correction were used. One would expect this to give cross sections over the unresolved range that are slightly too high. The resonance treatment is under further investigation.

The resultant 90-group microscopic data library was used to produce a coalesced 33-group macroscopic library using the SCAMP* transport code, which is also incorporated in SCRABL. While it would be preferable to use the RABBLE model (Fig. 1) or a full core model to produce coalescing spectra, this is beyond the capacity of the computer for 90 groups. Thus, a series of 6-region coalescing runs were made. Each run used, in order, a TREAT fuel region, two modified zone regions, a region to represent the pressure boundaries and thermal neutron filter (TNF), a region to represent the outer (18-pin) ring of test pins, and finally a region representing one of the inner test pin rings or the center test pin. These coalescing calculations were made in slab geometry with the $S_4$ approximation, producing 33-group macroscopic cross sections. The attempt in the coalescing runs was to properly represent the influence of adjacent regions on the spectrum in a given region.

In all calculations in the following section the cross sections used for the original TREAT fuel are the infinite dilute values.

## 3.0 TEST PIN ENRICHMENT STUDIES AND ENERGY DEPOSITION CALCULATIONS

### 3.1 Reactor Model and Methods

Reactor calculations were made for the TREAT Upgrade reactor with 7 and 37-pin GRIST-2 tests, using 33-group, one dimensional transport theory. The ring model used is similar to that used in the RABBLE calculation, but more detailed. It includes the complete reactor with the cladding, voids and various cylindrical shells of the test loop represented explicitly. The TREAT fuel includes control-type elements and followers. The models are summarized in Tables II to IV, which list geometry and isotopic concentrations

*SCAMP is a multigroup version of the TOPIC[11] $S_n$ code with slab, cylindrical and spherical geometry options.

of the materials. The mutiple regions in each of the test pin rings and TREAT fuel were introduced to provide more useful output edits. Approximations from $S_4$ to $S_8$ were used. Differences in results between the angular approximations were found to be negligible.

The energy depositions in the tests were calculated on the basis that the driver core would be pushed to its operating limits. This corresponds to temperature limits of 873 K (600°C) for the TREAT fuel, 1375 K (1102°C) for the modified (converter) zones, and 1125 K (852°C) for the outer row of the converter. The first of these has proven to be the limiting condition. A value of 180 calories per gram is used as the heat necessary to raise the temperature of TREAT fuel from room temperature to 873 K. This was obtained from by numerical integration of a table of specific heats of graphite[12] and independently from enthalpy tables of ANL-6034[13]. Since the transport code provides power depositions per unit volume, the 180 calories per gram is converted to 1125.9 Joules per cubic centimeter by multiplying by the density of the fuel (1.72 $g/cm^3$) and its volume fraction in the fuel region (.87) and by 4.18 J/cal. Then, the energy per unit volume in the test can be obtained from a simple proportion using the power edits from the transport code.

$$\frac{\text{J/cm}^3 \text{ in test}}{\text{J/cm}^3 \text{ at TREAT peak (1125.9)}} = \frac{\text{Power/vol in Test from code}}{\text{Power/vol at TREAT peak from code}}$$

Finally, to convert the $J/cm^3$ in the test to Joules per gram, the $J/cm^3$ are divided by 9.83 $g/cm^3$, the density of the test $UO_2$. This yields

$$\text{Joules/gram in test fuel} = 114.5363 \left[\frac{\text{Power/vol in test from code}}{\text{Power/vol at TREAT peak from code}}\right].$$

3.2 Calculational Results

The results of these calculations are summarized in Tables V and VI. All of the energy deposition rates listed have been reduced by 7% from the calculated value to account for the hodoscope slot[1]. They have been further reduced by 10% to allow for possible reactivity insertions due to fuel relocation[12]. This should be conservative, the reference suggests an 8% derating for a somewhat larger test. A list of conclusions from Tables V and VI follows.

1. The energy deposition rates calculated are in the 5000-5500 Joules per gram range for the 37-pin test and in the 8400-9200 Joules per gram range for the 7-pin test, when using a thermal neutron filter. These rates are above those extrapolated from LMFBR calculations[3] by about 10% for the 37-pin test and by about 20% for the 7-pin test. This must be regarded as tentative, pending further converter core design changes and further refinement of the calculations.
2. Addition of a thermal neutron filter (TNF) reduces the energy deposition for the 37-pin test by approximately 10%. The reduction for the 7-pin test is about 13%. However, this will be somewhat compensated for because the energy deposition will subsequently increase when the enrichments in the outer test ring, for the shielded SCRABL cross section case, are increased to improve power flatness.
3. Power flatness across the outer test ring is improved by use of the TNF, and meets "within 10%" requirement, for the definition given in Table VI.
4. The ring-to-ring enrichments (93-89-79-60% and 93-79% for the 37-pin and 7-pin tests, respectively) which were determined using the dilute cross sections, must be increased in the outer rings to achieve flatness when using the shielded SCRABL cross sections. This will increase the energy deposition rates somewhat.

### 3.3 Comparison with ANL Calculations

Table IV also includes energy deposition rates calculated by ANL. The ANL calculation used enrichments of 93-90-82 and 73% in the test rings vs the 93-89-79-60% used in the EG&G calculations. The ANL model of the converter is also different, generally using somewhat lower enrichments in the inner converter zones. The ANL number densities, volume averaged to the same zones as used in the EG&G calculations, are given in Table VII.

Overall, the agreement between results is quite good, with the values grouped between 5000 and 5500 Joules per gram for the 37-pin test with filter. This is probably a bit fortuitous, since the differences in the test and converter between the EG&G and the Argonne models produce results that tend to cancel each other.

The Monte Carlo calculations were made with the pins explicitly shown, using dilute cross sections and a hodoscope slot. All of the ANL results have been adjusted to the same assumptions used in the EG&G calculations, namely, the energy necessary to raise the TREAT fuel to 873 K (600°C) is assumed to be 180 calories per gram and a 10% back off for possible reactivity insertions due to fuel relocation is assumed.

The energy deposition for the 37-pin Monte Carlo calculation is 7% under the EG&G SCRABL result. To examine what part of this is due to different number densities vs that which is due to the $S_n$-Monte Carlo differences, the ANL number densities were inserted into the EG&G $S_n$ ring model, using dilute cross sections. This gave an energy deposition of 5455 J/g vs 5150 J/g for the EG&G dilute data in the ring model, or about 6% more. This difference can be ascribed to the different number densities in the tests and converters of the two models. With this in mind, it appears that the Monte Carlo model predicts a smaller energy deposition than the $S_n$ ring model.

The seven-pin results are not as complete. The $S_n$ ring calculations with dilute cross sections are straightforward but the SCRABL cross sections for the 6-pin ring are from an inner ring of the 37-pin calculation and are thus coalesced over too hard a spectrum. This is apparent in the flatness across the 6-pin ring in Table VI. The ANL 7-pin result[(2)] uses 90% enriched fuel in the outer (6-pin) ring, which is probably too high, and also has poor statistics (8.4% standard deviation). Overall, the 7-pin results agree to within about 10% but this must be considered tentative in view of the limited nature of the calculations.

## 4.0 CONCLUSIONS AND DISCUSSION

The studies reported here represent a first estimate of the energy deposition rates for the GRIST-2 tests in the TREAT upgrade reactor. Considering that a number of methods have been used, the energy deposition rates appear to be reasonably well established.

The TNF also appears to be relatively effective. This performance can be further improved by addition of a certain amount of resonance absorber, if this is desired. There will be a trade-off of energy deposition for power flatness. Present thinking would combine gadolinium for the thermal absorber with hafnium for the resonance region, both of these having high melting points.

With refinements in methods and changes in design, adjustments in the test enrichments and a reduction in calculational uncertainties can be expected. Changes of enrichments can be expected as we proceed from the ring model of the test to pin-by-pin detail, since this will allow direct streaming of neutrons into the inner pins of the test. The effect of the hodoscope slot can also be evaluated. At the present time, an evaluation of the resonance treatment used in cross section preparation is underway. Finally, changes can be expected as the upgrade core design evolves.

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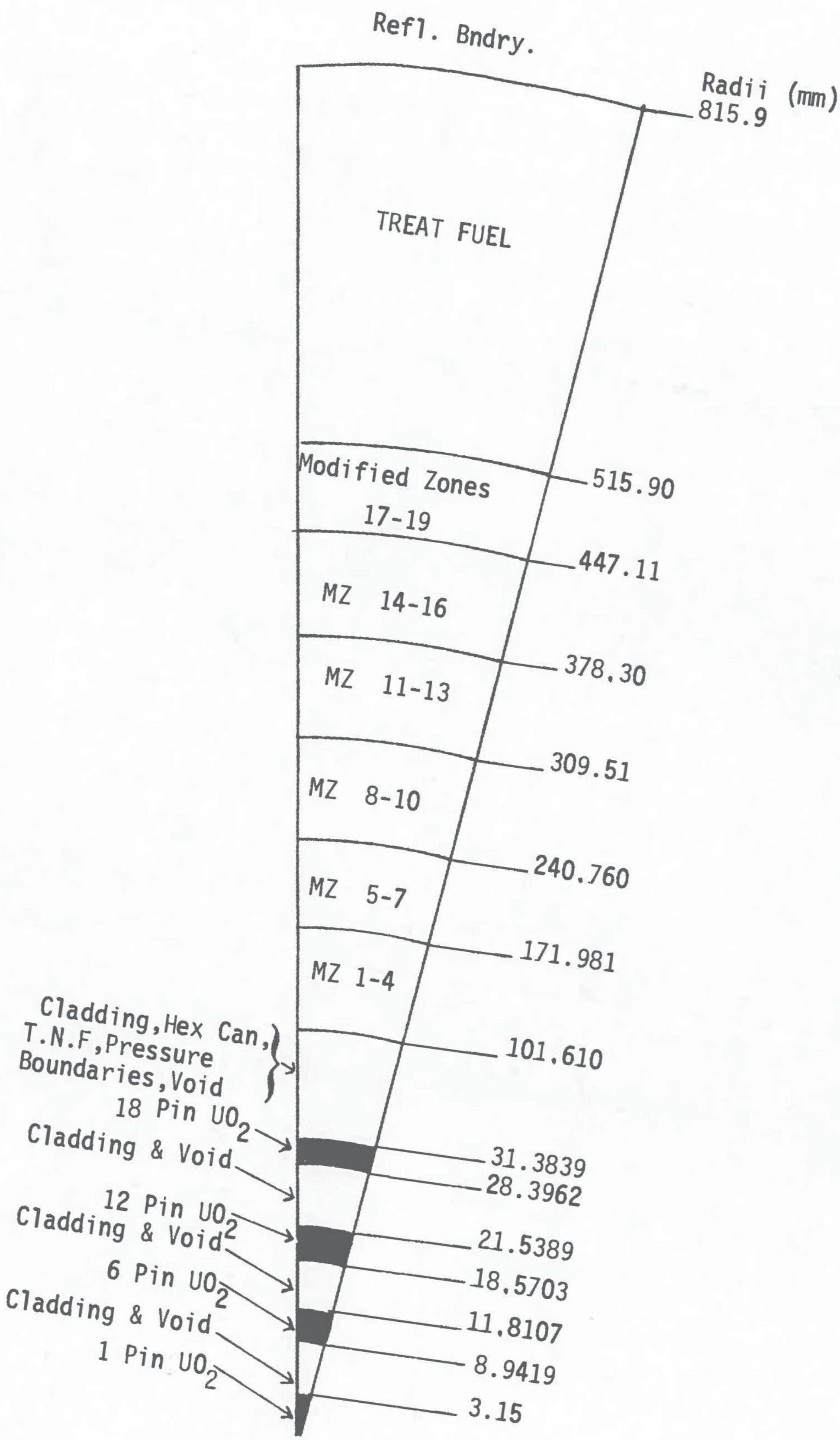


Figure 1: RABBLE Model.

TABLE I

GROUP STRUCTURE OF THE 90 AND 33-GROUP CROSS SECTION SETS

| Group | | Upper Energy(eV) |
|---|---|---|
| 1 | 1 | 1.0000E 07 |
| | 2 | 7.7880E 06 |
| 2 | 3 | 6.0653E 06 |
| | 4 | 4.7237E 06 |
| 3 | 5 | 3.6788E 06 |
| | 6 | 2.8650E 06 |
| 4 | 7 | 2.2313E 06 |
| | 8 | 1.7377E 06 |
| 5 | 9 | 1.3534E 06 |
| | 10 | 1.0540E 06 |
| 6 | 11 | 8.2085E 05 |
| | 12 | 6.3928E 05 |
| 7 | 13 | 4.9787E 05 |
| | 14 | 3.8774E 05 |
| 8 | 15 | 3.0197E 05 |
| | 16 | 2.3518E 05 |
| 9 | 17 | 1.8316E 05 |
| | 18 | 1.4264E 05 |
| 10 | 19 | 1.1109E 05 |
| | 20 | 8.6517E 04 |
| 11 | 21 | 6.7379E 04 |
| | 22 | 5.2475E 04 |
| 12 | 23 | 4.0867E 04 |
| | 24 | 3.1828E 04 |
| 13 | 25 | 2.4787E 04 |
| | 26 | 1.9304E 04 |
| 14 | 27 | 1.5034E 04 |
| | 28 | 1.1709E 04 |
| 15 | 29 | 9.1188E 03 |
| | 30 | 7.1017E 03 |
| 16 | 31 | 5.5308E 03 |
| | 32 | 4.3074E 03 |
| | 33 | 3.3546E 03 |
| | 34 | 2.6126E 03 |
| 17 | 35 | 2.0347E 03 |
| | 36 | 1.5846E 03 |
| | 37 | 1.2341E 03 |
| | 38 | 9.6111E 02 |
| 18 | 39 | 7.4851E 02 |
| | 40 | 5.8294E 02 |
| | 41 | 4.5399E 02 |
| | 42 | 3.5357E 02 |
| 19 | 43 | 2.7536E 02 |
| | 44 | 2.1445E 02 |
| | 45 | 1.6702E 02 |
| | 46 | 1.3007E 02 |
| 20 | 47 | 1.0130E 02 |
| | 48 | 7.8892E 01 |
| | 49 | 6.1441E 01 |
| | 50 | 4.7851E 01 |
| 21 | 51 | 3.7266E 01 |
| | 52 | 2.9023E 01 |
| | 53 | 2.2603E 01 |
| | 54 | 1.7603E 01 |
| 22 | 55 | 1.3709E 01 |
| | 56 | 1.0677E 01 |
| | 57 | 8.3152E 00 |
| | 58 | 6.4759E 00 |
| 23 | 59 | 5.0434E 00 |
| | 60 | 3.9278E 00 |
| | 61 | 3.0590E 00 |
| 24 | 62 | 2.3823E 00 |
| 25 | 63 | 1.8554E 00 |
| | 64 | 1.4450E 00 |
| | 65 | 1.1253E 00 |
| 26 | 66 | 8.7641E-01 |
| | 67 | 6.8255E-01 |
| 27 | 68 | 5.3157E-01 |
| 28 | 69 | 4.1399E-01 |
| | 70 | 3.8000E-01 |
| | 71 | 3.6000E-01 |
| | 72 | 3.3000E-01 |
| | 73 | 3.1000E-01 |
| | 74 | 3.0000E-01 |
| | 75 | 2.9000E-01 |
| | 76 | 2.8000E-01 |
| | 77 | 2.6000E-01 |
| | 78 | 2.4000E-01 |
| | 79 | 2.2000E-01 |
| 29 | 80 | 1.8000E-01 |
| | 81 | 1.6000E-01 |
| | 82 | 1.4000E-01 |
| | 83 | 1.0000E-01 |
| | 84 | 8.0000E-02 |
| 30 | 85 | 6.0000E-02 |
| | 86 | 4.0000E-02 |
| 31 | 87 | 2.5300E-02 |
| 32 | 88 | 1.5000E-02 |
| | 89 | 7.0000E-03 |
| 33 | 90 | 4.0000E-03 |

TABLE II: RING TRANSPORT MODEL OF 37-PIN GRIST-2 TEST IN TREAT UPGRADE

(Dimensions in Centimeters)

| REGION NUMBER | MATERIAL NUMBER | NUMBER OF INTERVALS | INNER RADIUS | OUTER RADIUS | REGION WIDTH | MESH SPACING |
|---|---|---|---|---|---|---|
| 1 | 1 | 4 | 0. | 1.8186500E-01 | 1.8186500E-01 | 4.5466250E-02 |
| 2 | 1 | 4 | 1.8186500E-01 | 2.5719600E-01 | 7.5331000E-02 | 1.8832750E-02 |
| 3 | 1 | 4 | 2.5719600E-01 | 3.1500000E-01 | 5.7804000E-02 | 1.4451000E-02 |
| 4 | 2 | 1 | 3.1500000E-01 | 3.5884000E-01 | 4.3840000E-02 | 4.3840000E-02 |
| 5 | 3 | 1 | 3.5884000E-01 | 8.5148000E-01 | 4.9264000E-01 | 4.9264000E-01 |
| 6 | 2 | 1 | 8.5148000E-01 | 8.9418500E-01 | 4.2705000E-02 | 4.2705000E-02 |
| 7 | 4 | 4 | 8.9418500E-01 | 9.9900800E-01 | 1.0482300E-01 | 2.6205750E-02 |
| 8 | 4 | 4 | 9.9900800E-01 | 1.0938310E+00 | 9.4823000E-02 | 2.3705750E-02 |
| 9 | 4 | 4 | 1.0938310E+00 | 1.1810660E+00 | 8.7235000E-02 | 2.1808750E-02 |
| 10 | 2 | 1 | 1.1810660E+00 | 1.2237710E+00 | 4.2705000E-02 | 4.2705000E-02 |
| 11 | 3 | 1 | 1.2237710E+00 | 1.8128380E+00 | 5.8906700E-01 | 5.8906700E-01 |
| 12 | 2 | 1 | 1.8128380E+00 | 1.8570290E+00 | 4.4191000E-02 | 4.4191000E-02 |
| 13 | 5 | 4 | 1.8570290E+00 | 1.9609840E+00 | 1.0395500E-01 | 2.5988750E-02 |
| 14 | 5 | 4 | 1.9609840E+00 | 2.0596980E+00 | 9.8714000E-02 | 2.4678500E-02 |
| 15 | 5 | 4 | 2.0596980E+00 | 2.1538930E+00 | 9.4195000E-02 | 2.3548750E-02 |
| 16 | 2 | 1 | 2.1538930E+00 | 2.1980840E+00 | 4.4191000E-02 | 4.4191000E-02 |
| 17 | 3 | 1 | 2.1980840E+00 | 2.7951460E+00 | 5.9706200E-01 | 5.9706200E-01 |
| 18 | 2 | 1 | 2.7951460E+00 | 2.8396210E+00 | 4.4475000E-02 | 4.4475000E-02 |
| 19 | 6 | 4 | 2.8396210E+00 | 2.9425830E+00 | 1.0296200E-01 | 2.5740500E-02 |
| 20 | 6 | 4 | 2.9425830E+00 | 3.0420600E+00 | 9.9477000E-02 | 2.4869250E-02 |
| 21 | 6 | 4 | 3.0420600E+00 | 3.1383880E+00 | 9.6328000E-02 | 2.4082000E-02 |
| 22 | 2 | 1 | 3.1383880E+00 | 3.1828630E+00 | 4.4475000E-02 | 4.4475000E-02 |
| 23 | 3 | 1 | 3.1828630E+00 | 3.5980000E+00 | 4.1513700E-01 | 4.1513700E-01 |
| 24 | 2 | 1 | 3.5980000E+00 | 3.8600000E+00 | 2.6200000E-01 | 2.6200000E-01 |
| 25 | 3 | 2 | 3.8600000E+00 | 4.5500000E+00 | 6.9000000E-01 | 3.4500000E-01 |
| 26 | 2 | 2 | 4.5500000E+00 | 4.9000000E+00 | 3.5000000E-01 | 1.7500000E-01 |
| 27 | 3 | 2 | 4.9000000E+00 | 5.8750000E+00 | 9.7500000E-01 | 4.8750000E-01 |
| 28 | 2 | 4 | 5.8750000E+00 | 7.1250000E+00 | 1.2500000E+00 | 3.1250000E-01 |
| 29 | 3 | 1 | 7.1250000E+00 | 7.3650000E+00 | 2.4000000E-01 | 2.4000000E-01 |
| 30 | 7 | 28 | 7.3650000E+00 | 7.4300000E+00 | 6.5000000E-02 | 2.3214286E-03 |
| 31 | 3 | 3 | 7.4300000E+00 | 9.1500000E+00 | 1.7200000E+00 | 5.7333333E-01 |
| 32 | 2 | 3 | 9.1500000E+00 | 1.0100000E+01 | 9.5000000E-01 | 3.1666667E-01 |
| 33 | 3 | 1 | 1.0100000E+01 | 1.0161000E+01 | 6.1000000E-02 | 6.1000000E-02 |
| 34 | 8 | 3 | 1.0161000E+01 | 1.2507000E+01 | 2.3460000E+00 | 7.8200000E-01 |
| 35 | 9 | 3 | 1.2507000E+01 | 1.4853000E+01 | 2.3460000E+00 | 7.8200000E-01 |
| 36 | 10 | 3 | 1.4853000E+01 | 1.7198100E+01 | 2.3451000E+00 | 7.8170000E-01 |
| 37 | 11 | 6 | 1.7198100E+01 | 2.4076000E+01 | 6.8779000E+00 | 1.1463167E+00 |
| 38 | 12 | 6 | 2.4076000E+01 | 3.0951000E+01 | 6.8750000E+00 | 1.1458333E+00 |
| 39 | 13 | 6 | 3.0951000E+01 | 3.7830000E+01 | 6.8790000E+00 | 1.1465000E+00 |
| 40 | 14 | 5 | 3.7830000E+01 | 4.4711000E+01 | 6.8810000E+00 | 1.3762000E+00 |
| 41 | 15 | 5 | 4.4711000E+01 | 5.1590000E+01 | 6.8790000E+00 | 1.3758000E+00 |
| 42 | 16 | 5 | 5.1590000E+01 | 6.1500000E+01 | 9.9100000E+00 | 1.9820000E+00 |
| 43 | 16 | 5 | 6.1500000E+01 | 7.0500000E+01 | 9.0000000E+00 | 1.8000000E+00 |
| 44 | 16 | 5 | 7.0500000E+01 | 7.9500000E+01 | 9.0000000E+00 | 1.8000000E+00 |
| 45 | 16 | 5 | 7.9500000E+01 | 8.8500000E+01 | 9.0000000E+00 | 1.8000000E+00 |
| 46 | 16 | 5 | 8.8500000E+01 | 9.7500000E+01 | 9.0000000E+00 | 1.8000000E+00 |
| 47 | 16 | 5 | 9.7500000E+01 | 1.0650000E+02 | 9.0000000E+00 | 1.8000000E+00 |
| 48 | 17 | 25 | 1.0650000E+02 | 1.7700000E+02 | 7.0500000E+01 | 2.8200000E+00 |

TABLE III: RING MODEL OF 7-PIN GRIST-2 TEST IN TREAT UPGRADE

(Dimensions in Centimeters)

| REGION NUMBER | MATERIAL NUMBER | NUMBER OF INTERVALS | INNER RADIUS | OUTER RADIUS | REGION WIDTH | MESH SPACING |
|---|---|---|---|---|---|---|
| 1 | 1 | 7 | 0. | 1.8186500E-01 | 1.8186500E-01 | 2.5980714E-02 |
| 2 | 1 | 7 | 1.8186500E-01 | 2.5719600E-01 | 7.5331000E-02 | 1.0761571E-02 |
| 3 | 1 | 7 | 2.5719600E-01 | 3.1500000E-01 | 5.7804000E-02 | 8.2577143E-03 |
| 4 | 2 | 2 | 3.1500000E-01 | 3.5884000E-01 | 4.3840000E-02 | 2.1920000E-02 |
| 5 | 3 | 1 | 3.5884000E-01 | 8.5148000E-01 | 4.9264000E-01 | 4.9264000E-01 |
| 6 | 2 | 2 | 8.5148000E-01 | 8.9418500E-01 | 4.2705000E-02 | 2.1352500E-02 |
| 7 | 5 | 7 | 8.9418500E-01 | 9.9900800E-01 | 1.0482300E-01 | 1.4974714E-02 |
| 8 | 5 | 7 | 9.9900800E-01 | 1.0938310E+00 | 9.4823000E-02 | 1.3546143E-02 |
| 9 | 5 | 7 | 1.0938310E+00 | 1.1810660E+00 | 8.7235000E-02 | 1.2462143E-02 |
| 10 | 2 | 2 | 1.1810660E+00 | 1.2237710E+00 | 4.2705000E-02 | 2.1352500E-02 |
| 11 | 3 | 1 | 1.2237710E+00 | 1.6150000E+00 | 3.9122900E-01 | 3.9122900E-01 |
| 12 | 2 | 1 | 1.6150000E+00 | 1.8770000E+00 | 2.6200000E-01 | 2.6200000E-01 |
| 13 | 3 | 2 | 1.8770000E+00 | 2.8730000E+00 | 9.9600000E-01 | 4.9800000E-01 |
| 14 | 2 | 2 | 2.8730000E+00 | 3.2230000E+00 | 3.5000000E-01 | 1.7500000E-01 |
| 15 | 3 | 3 | 3.2230000E+00 | 5.8750000E+00 | 2.6520000E+00 | 8.8400000E-01 |
| 16 | 2 | 6 | 5.8750000E+00 | 7.1250000E+00 | 1.2500000E+00 | 2.0833333E-01 |
| 17 | 3 | 1 | 7.1250000E+00 | 7.3650000E+00 | 2.4000000E-01 | 2.4000000E-01 |
| 18 | 7 | 28 | 7.3650000E+00 | 7.4300000E+00 | 6.5000000E-02 | 2.3214286E-03 |
| 19 | 3 | 3 | 7.4300000E+00 | 9.1500000E+00 | 1.7200000E+00 | 5.7333333E-01 |
| 20 | 2 | 3 | 9.1500000E+00 | 1.0100000E+01 | 9.5000000E-01 | 3.1666667E-01 |
| 21 | 3 | 1 | 1.0100000E+01 | 1.0161000E+01 | 6.1000000E-02 | 6.1000000E-02 |
| 22 | 8 | 3 | 1.0161000E+01 | 1.2507000E+01 | 2.3460000E+00 | 7.8200000E-01 |
| 23 | 9 | 3 | 1.2507000E+01 | 1.4853000E+01 | 2.3460000E+00 | 7.8200000E-01 |
| 24 | 10 | 3 | 1.4853000E+01 | 1.7198100E+01 | 2.3451000E+00 | 7.8170000E-01 |
| 25 | 11 | 6 | 1.7198100E+01 | 2.4076000E+01 | 6.8779000E+00 | 1.1463167E+00 |
| 26 | 12 | 6 | 2.4076000E+01 | 3.0951000E+01 | 6.8750000E+00 | 1.1458333E+00 |
| 27 | 13 | 6 | 3.0951000E+01 | 3.7830000E+01 | 6.8790000E+00 | 1.1465000E+00 |
| 28 | 14 | 5 | 3.7830000E+01 | 4.4711000E+01 | 6.8810000E+00 | 1.3762000E+00 |
| 29 | 15 | 5 | 4.4711000E+01 | 5.1590000E+01 | 6.8790000E+00 | 1.3758000E+00 |
| 30 | 16 | 5 | 5.1590000E+01 | 6.1500000E+01 | 9.9100000E+00 | 1.9820000E+00 |
| 31 | 16 | 5 | 6.1500000E+01 | 7.0500000E+01 | 9.0000000E+00 | 1.8000000E+00 |
| 32 | 16 | 5 | 7.0500000E+01 | 7.9500000E+01 | 9.0000000E+00 | 1.8000000E+00 |
| 33 | 16 | 5 | 7.9500000E+01 | 8.8500000E+01 | 9.0000000E+00 | 1.8000000E+00 |
| 34 | 16 | 5 | 8.8500000E+01 | 9.7500000E+01 | 9.0000000E+00 | 1.8000000E+00 |
| 35 | 16 | 5 | 9.7500000E+01 | 1.0650000E+02 | 9.0000000E+00 | 1.8000000E+00 |
| 36 | 17 | 25 | 1.0650000E+02 | 1.7700000E+02 | 7.0500000E+01 | 2.8200000E+00 |

TABLE IV: NUMBER DENSITIES FOR 37-PIN TEST AND TREAT UPGRADE REACTOR[a]

| Mat. No. | 1 | 2 | 4[b] | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Material | Center Pin 93% | 316 S.S. | 6-Pin 89% | 12-Pin 79% | 18-Pin 60% | TNF | (L)1 | MZ-2 |
| Isotope | | | | | | | | |
| C | | | | | | | 6.8570-2 | 6.8660-2 |
| O | 4.4292-2 | | 4.4292-2 | 4.4292-2 | 4.4292-2 | | 2.522-4 | 2.0730-4 |
| B-10 | | | | | | | | |
| B-11 | | | | | | | | |
| Cr | | 1.581-2 | | | | | 5.1250-4 | 5.1250-4 |
| Mn | | 1.760-3 | | | | | 1.3500-5 | 1.3500-5 |
| Fe | | 5.973-2 | | | | | 2.0681-3 | 2.0681-3 |
| Al | | 9.880-3 | | | | | 1.0990-4 | 1.0990-4 |
| Ni | | | | | | | 1.2500-5 | 1.2500-5 |
| Zr | | | | | | | | |
| Cd | | | | | | 2.0-2 | | |
| U-235 | 2.0596-2 | | 1.9710-2 | 1.7495-2 | 1.3287-2 | | 1.1870-4 | 9.6490-5 |
| U-238 | 1.5500-3 | | 2.4360-3 | 4.6510-3 | 8.8590-3 | | 8.9320-6 | 7.2550-6 |

| Mat. No. | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|
| Material | MZ 3-4 | MZ 5-7 | MZ 8-10 | MZ 11-13 | MZ 14-16 | MZ 17-19 | TREAT Fuel | REFL. |
| Isotope | | | | | | | | |
| C | 6.8680-2 | 7.301-2 | 7.307-2 | 7.312-2 | 7.321-2 | 7.324-2 | 7.600-2 | 8.370-2 |
| O | 1.7700-4 | 1.400-4 | 1.130-4 | 8.933-5 | 5.511-5 | 3.662-5 | 1.6414-5 | |
| B-10 | | | | | | | 1.2317-7 | 3.517-8 |
| B-11 | | | | | | | 5.2850-1 | 1.509-7 |
| Cr | 5.1250-4 | 4.193-4 | | | | | 5.3213-8 | |
| Mn | 1.3500-5 | 1.110-5 | | | | | | |
| Fe | 2.0681-3 | 1.692-3 | | | | | 1.4607-5 | 1.801-5 |
| Al | 1.0990-4 | 8.991-5 | | | | | | |
| Ni | 1.2500-5 | 1.026-5 | | | | | 7.8540-9 | |
| Zr | | | | | | | 1.6481-3 | |
| Cd | | | | | | | | |
| U-235 | 8.2300-5 | 6.510-5 | 5.255-5 | 4.154-5 | 2.563-5 | 1.703 | 7.6545-6 | |
| U-238 | 6.1940-6 | 4.900-6 | 3.955-6 | 3.127 | 1.929-6 | 1.282 | 5.5497-7 | |

(a) No Densities in atoms/b-cm.
(b) Material 3 is a void.

TABLE V: AVERAGE POWER DEPOSITION AT AXIAL PEAK IN TEST

| Calculational Method | Cross Section Set | Test Size (Pins) | TNF | Energy Deposition (J/g) |
|---|---|---|---|---|
| Ring-Transport | Dilute-EG&G | 37 | Yes | 5150 |
| Ring-Transport | Dilute-EG&G | 37 | No | 5743 |
| Ring-Transport | SCRABL | 37 | Yes | 5445 |
| Ring-Transport | SCRABL | 37 | No | 6164 |
| Ring-Transport | Dilute | 7 | Yes | 9160 |
| Ring-Transport | Dilute | 7 | No | 10528 |
| Ring-Transport | SCRABL[a] | 7 | Yes | 8514 |
| Monte Carlo-ANL | Dilute-ANL | 7 | Yes | 8404 |
| Monte Carlo-ANL | Dilute-ANL | 37 | Yes | 5057 |
| Ring-Transport-ANL No. Densities | Dilute-EG&G | 37 | Yes | 5455 |

[a] The outer ring here was collapsed as an inner ring in the 37-pin calculation and thus on too hard a spectrum.

TABLE VI: POWER FLATTENING IN TEST-TRANSPORT RING MODEL

| | Pins in Test | Cross Section Set | TNF | 1-Pin | Ring 6-Pin | 12-Pin | 18-Pin |
|---|---|---|---|---|---|---|---|
| Relative Power Density in Ring (a) | 37 | Dilute | Yes | 1.0 | 1.014 | 1.024 | .993 |
| | 37 | Dilute | No | 1.0 | 1.02 | 1.05 | 1.09 |
| | 37 | SCRABL | Yes | 1.0 | .971 | .953 | .908 |
| | 37 | SCRABL | No | 1.0 | .976 | .975 | .987 |
| | 7 | Dilute | Yes | 1.0 | .994 | --- | --- |
| | 7 | Dilute | No | 1.0 | 1.05 | --- | --- |
| | 7 | SCRABL | Yes | 1.0 | .914 | --- | --- |
| Flatness Across Ring (b) | 37 | Dilute | Yes | 1.04 | 1.06 | 1.10 | 1.19 |
| | 37 | Dilute | No | 1.04 | 1.06 | 1.13 | 1.29 |
| | 37 | SCRABL | Yes | 1.03 | 1.03 | 1.05 | 1.09 |
| | 37 | SCRABL | No | 1.03 | 1.04 | 1.07 | 1.17 |
| | 7 | Dilute | Yes | 1.09 | 1.16 | --- | --- |
| | 7 | Dilute | No | 1.12 | 1.25 | --- | --- |
| | 7 | SCRABL | Yes | 1.05 | 1.06 | | |

[a] The relative power density in a ring is the ratio of the power density in the ring to that in the center pin.

[b] Flatness across ring is the ratio of the power in the outer third of the ring to that in the inner third.

TABLE VII: NUMBER DENSITIES USED FOR ANL-WEST MODEL[a] OF THE UPGRADED TREAT

| Mat. No. | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|
| Material | MZ-1 | MZ-2 | MZ-3,4 | MZ 5-7 | MZ 8-10 | MZ 11-13 | MZ 14-16 | MZ 17-19 | TREAT Fuel |
| Isotope | | | | | | | | | |
| C | 6.8584-2 | 6.8665-2 | 6.8716-2 | 7.3042-2 | 7.3089-2 | 7.3133-2 | 7.3201-2 | 7.3239-2 | 7.6210-2 |
| O | 2.2815-4 | 1.8914-4 | 1.6394-4 | 1.3333-4 | 1.1001-4 | 8.8865-5 | 5.5540-5 | 3.7410-5 | 1.6460-5 |
| B-10 | | | | | | | | | 1.2230-7 |
| B-11 | | | | | | | | | 5.2480-7 |
| Cr | 5.1579-4 | | | 4.2201-4 | | | | | 5.2200-8 |
| Mn | 1.3566-5 | | | 1.1100-5 | | | | | |
| Fe | 2.0820-3 | | | 1.7034-3 | | | | | 1.4450-5 |
| Al | 1.1052-4 | | | 9.0423-5 | | | | | |
| Ni | 1.2692-5 | | | 1.0384-5 | | | | | 7.7050-9 |
| Zr | | | | | | | | | 9.8600-4 |
| U-235 | 1.0666-4 | 8.8420-5 | 7.6645-5 | 6.2332-5 | 5.1430-5 | 4.1451-5 | 2.5965-5 | 1.7489-5 | 7.6761-6 |
| U-238 | 7.4149-6 | 6.1469-6 | 5.3283-6 | 4.3332-6 | 3.5754-6 | 2.8817-6 | 1.8051-6 | 1.2158-6 | 5.5653-7 |

[a] atoms-barn/cm