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# Validation of SCALE for High Temperature Gas-Cooled Reactor Analysis

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# Validation of SCALE for High Temperature Gas-Cooled Reactor Analysis

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# ABSTRACT

This report documents verification and validation studies carried out to assess the performance of the SCALE code system methods and nuclear data for modeling and analysis of High Temperature Gas-Cooled Reactor (HTGR) configurations. Validation data were available from the *International Handbook of Evaluated Reactor Physics Benchmark Experiments (IRPhE Handbook),* prepared by the International Reactor Physics Experiment Evaluation Project, for two different HTGR designs: prismatic and pebble bed. SCALE models have been developed for HTTR, a prismatic fuel design reactor operated in Japan and HTR-10, a pebble bed reactor operated in China. The models were based on benchmark specifications included in the 2009, 2010, and 2011 releases of the *IRPhE Handbook*. SCALE models for the HTR-PROTEUS pebble bed configuration at the PROTEUS critical facility in Switzerland have also been developed, based on benchmark specifications included in a 2009 IRPhE draft benchmark. The development of the SCALE models has involved a series of investigations to identify particular issues associated with modeling the physics of HTGRs and to understand and quantify the effect of particular modeling assumptions on calculation-to-experiment comparisons.

# FOREWORD

To assess the capability of the SCALE code system to accurately model High Temperature Gas-Cooled Reactors (HTGRs), verification and validation studies were performed using validation data from the *International Handbook of Evaluated Reactor Physics Benchmark Experiments (IRPhE Handbook)*. SCALE models have been developed for HTTR, a prismatic fuel design reactor operated in Japan; HTR-10, a pebble bed reactor operated in China; and the HTR-PROTEUS pebble bed configuration at the PROTEUS critical facility in Switzerland. The development of the SCALE models has involved a series of investigations to identify particular issues associated with modeling the physics of HTGRs and to understand and quantify the effect of particular modeling assumptions on calculation-to-experiment comparisons.

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| 1-D | one dimensional |
| 2-D | two dimensional |
| 3-D | three dimensional |
| ANL | Argonne National Laboratory |
| BOC | beginning of cycle |
| BP | burnable poison |
| C/E | calculated to experimental |
| CE | continuous energy |
| DOE | U.S. Department of Energy |
| EBC | equivalent boron content |
| EFPD | effective full power days |
| EOC | end of cycle |
| FS | flat standard |
| HTGR | high temperature gas-cooled reactor |
| HTR | high temperature reactor |
| HTTR | High Temperature Engineering Test Reactor |
| IAEA | International Atomic Energy Agency |
| IRPhE | International Reactor Physics Benchmark Experiments |
| JAERI | Japanese Atomic Energy Research Institute |
| $k_{eff}$ | effective multiplication factor |
| $k_{inf}$ | infinite medium multiplication factor |
| LWR | light water reactor |
| MG | multigroup |
| MTU | metric ton uranium ($10^6$ grams) |
| NRC | U.S. Nuclear Regulatory Commission |
| ORNL | Oak Ridge National Laboratory |
| PBR | pebble bed reactor |
| ppm | parts per million |
| PSI | Paul Scherrer Institute |
| PWR | pressurized water reactor |
| SCALE | Standardized Computer Analyses for Licensing Evaluations |
| TRISO | tristructural isotropic |
| $UO_2$ | uranium dioxide |

# 1. INTRODUCTION

The development of advanced methods and computational tools for the analysis of High Temperature Gas-Cooled Reactor (HTGR) configurations has been a research area of renewed interest for the international community. HTGR configurations are potential candidates for future deployment throughout the world—a type of reactor system that would meet the increased requirements of efficiency, safety, and proliferation resistance and would support other applications such as process heat applications, hydrogen production, or nuclear waste recycling. Only two HTGRs are now operating: the High Temperature Engineering Test Reactor (HTTR) in Japan and the High Temperature Reactor–10 (HTR-10) in China. HTTR has a prismatic fuel assembly design, whereas HTR-10 is a Pebble Bed Reactor (PBR). In the United States, both the prismatic and the pebble bed designs are being considered for future deployment by the Next Generation Nuclear Plant (NGNP) Program [1].

The primary challenge in the design and analysis of HTGR configurations is the modeling of the fuel, which has characteristics very different from those of conventional light water reactor (LWR) fuel. HTGR fuel is composed of a large number of tiny tristructural-isotropic (TRISO) fuel particles embedded in a graphite matrix and shaped into spherical or cylindrical fuel elements. Each fuel particle has a spherical fuel kernel with a radius of approximately 0.025 cm that is covered by carbon-based layers for a total radius of approximately 0.045 cm. The inherent double heterogeneity of such a fuel makes it more difficult to model and requires methods different from those used for a typical LWR fuel. The first level of heterogeneity concerns the random distribution of the large number of fuel particles inside the cylindrical or spherical fuel element. The second level of heterogeneity refers to the distribution of the fuel pebbles inside the reactor core for a PBR or of the fuel elements in fuel assemblies placed in the core for a prismatic HTGR. The movement of the fuel pebbles during the reactor operation of a PBR adds another level of complexity.

Recent improvements in the SCALE [2] code system, developed and maintained by Oak Ridge National Laboratory (ORNL), have focused on addressing the particular needs for the design and analysis of HTGR configurations. As discussed in a later section, improved physics approximations and numerical techniques for performing resonance self-shielding of the cross sections and for treating doubly heterogeneous systems [3] were introduced in the 5.1 release of SCALE. Later, this cross-section processing methodology was folded into the 6.0 version of the SCALE/TRITON depletion sequence [4] to permit burnup simulation of doubly heterogeneous fuels [5]. In addition to the development work, there has been an ongoing effort to qualify and validate the SCALE models, methodologies, and associated nuclear data for use with doubly heterogeneous configurations.

This report documents verification and validation studies carried out to assess the performance of the SCALE methods and data for analysis of HTGR configurations. The experimental data used for validation was acquired from the *International Handbook of Evaluated Reactor Physics Benchmark Experiments* (*IRPhE Handbook*) prepared by the International Reactor Physics Experiment Evaluation Project for both the prismatic and the pebble bed designs. SCALE models have been developed for HTTR and the HTR-10 based on benchmark specifications and experimental data included in the 2009, 2010, and 2011 editions of the *IRPhE Handbook* [6,7,8,9,10]. SCALE models for the HTR-PROTEUS pebble bed configuration at the PROTEUS critical facility in Switzerland have been developed based on benchmark specifications included in a 2009 IRPhE draft benchmark; this draft benchmark has yet to be included as a final version in the *IRPhE Handbook* released by the time of the publication of the present report. The development of the SCALE models has involved a series of investigations to identify the particular issues associated with modeling the physics of the HTGRs and to understand and quantify the effect of particular modeling assumptions on calculation-to-experiment comparisons.

As described in the HTGR NRC Research Plan (ML110310182) [12], the assessed SCALE code modules employ key elements of the SCALE/TRITON lattice physics sequence recently adapted by ORNL to enable the PARCS [13], AGREE [14], and MELCOR [15] codes to simulate thermally coupled HTGR core physics (i.e., computed core maps of neutron flux, fission power, decay power, fuel burnup, nuclide inventories, etc.) during normal power operations, transients, and accidents. The initial benchmark validation studies described in this report have been performed against measured data from clean, zero-power, room-temperature critical configurations in HTTR, HTR-10, and HTR-PROTEUS. The report thus documents an early step in a code assessment process intended to eventually include benchmarking of the NRC's HTGR core simulation code suite (i.e., PARCS-AGREE with SCALE/TRITON lattice physics) against startup data, power operating data, and transient test data from existing HTGR tests such as for HTTR and HTR-10.

# 2. SCALE VALIDATION FOR HTGRs—PEBBLE BED FUEL DESIGN

This section summarizes the verification and validation studies performed to evaluate the SCALE performance for analysis of PBR configurations. Studies to assess the accuracy of SCALE cross sections used in the analysis of the PBRs are discussed. Reactor models for validation against experimental data for the HTR-10 first critical core are presented in detail. Analysis of PBR configurations from the experimental program carried out at the PROTEUS critical facility at the Paul Scherrer Institute (PSI) is also included.

## 2.1 SCALE CROSS SECTIONS FOR PBR ANALYSIS

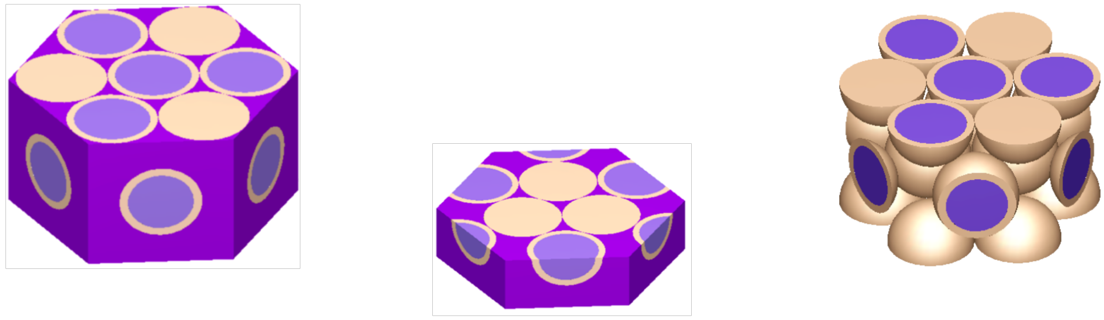
As a first step, investigations were carried out on simple models to assess the capabilities of SCALE to provide accurate cross sections for analyses of PBR configurations [16]. Establishing the accuracy of the cross sections are fundamental for understanding the accuracy of the calculations at the reactor core level. Different configurations representative of HTR-10 fuel were analyzed and two operating conditions were considered—one corresponding to the initial critical core and the other to the full power operating core of the HTR-10.

### 2.1.1 Computational Models

#### 2.1.1.1 Configuration typical of HTR-10 first critical core fuel

The configuration typical of HTR-10 first critical core fuel was modeled as a hexagonal prism containing a mixture of fuel and moderator pebbles in a 53:47 ratio, characteristic of the first critical core, with saturated air surrounding the fuel and moderator pebbles. The material composition and geometry data are based on the benchmark specifications for the HTR-10 initial core as included in the IRPhE Handbook [10]. The fuel pebble has an inner region of 2.5 cm radius and a graphite shell of 0.5 cm thickness. The pebble inner region contains 8,335 fuel particles embedded in a graphite matrix. The packing fraction of the fuel and moderator pebbles in the reactor core is 61%. Each fuel particle has a 0.025 cm radius kernel that contains uranium dioxide ($UO_2$) and is surrounded by four carbon-based layers, for a total outer radius of 0.0455 cm.

The configuration was modeled with both the Monte Carlo transport code MCNP5 [17] using continuous energy cross sections and with the SCALE/KENO-VI Monte Carlo transport code using 238-group cross-section libraries. In both cases, the libraries were based on ENDF/B-VII data at 300 K. The SCALE/KENO-VI model of the hexagonal fuel cell is illustrated in Fig. 2.1, which shows the whole cell, the cell at half height, and the arrangement of the pebbles in three layers inside the hexagonal prism. The SCALE/KENO-VI model served as a building block to represent the fuel zone in the three-dimensional (3-D) model of the HTR-10, as discussed later in this report. The MCNP model of the hexagonal fuel cell is similar to the model used by Seker and Colak [18]. A cross-sectional view of the MCNP5 model at half height of the cell is illustrated in Fig. 2.2. The MCNP5 model explicitly represents the fuel particles inside the fuel pebbles using a lattice representation that ensures the fuel particles do not intersect the interface of the graphite matrix with the pebble shell. The fuel particles are not explicitly modeled with SCALE/KENO-VI. However, the doubly heterogeneous nature of the fuel is accounted for through the method of calculating the cross sections of the fuel zone inside the pebble, as discussed later in this report.



(a) hexagonal fuel cell (b) half of fuel cell (c) pebbles' arrangement

**Fig. 2.1. SCALE/KENO-VI model of hexagonal fuel cell.**

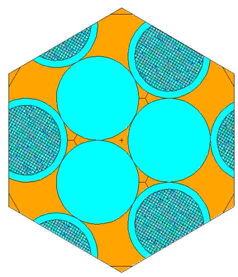


**Fig. 2.2. MCNP model of hexagonal fuel cell—cross section at half height.**

#### 2.1.1.2 Configuration typical of HTR-10 full power core fuel

At nominal power operating condition, the fuel core includes only fuel pebbles. A configuration consisting of a unit cell with a single fuel pebble surrounded by coolant was considered for this condition. This configuration was analyzed with MCNP5 and SCALE for a fresh fuel composition at operating temperature. To assess the temperature dependence of the results, the same unit cell was also studied at a temperature of 300 K.

The model for the configuration typical of HTR-10 full power core fuel consists of a spherical cell that includes a single fuel pebble surrounded by helium coolant. The radius of the spherical cell, 3.53735 cm, was calculated to correspond to the 61% packing fraction of the fuel pebbles in the core, knowing that there are 27,000 fuel pebbles and no moderator pebbles [19] in the full power core. The geometry and material data for the fuel pebble were the same as those used for the HTR-10 first critical core [10]. However, in this case the saturated air coolant was replaced by helium at 861.05 K temperature [19]; the helium atomic density was calculated based on temperature and pressure (3 MPa) values [20].

The single pebble unit cell models are illustrated in Fig. 2.3. In the MCNP5 model, the fuel particles were modeled as used in Ref. 18, in a lattice structure that avoids the intersection of the particles with the pebble shell inner surface. The SCALE model accounts for double heterogeneity of the fuel through the method of processing the cross sections for the fuel zone. The cross sections for fuel pebble materials are considered at 1200 K, and the cross sections for the coolant at 900 K, to facilitate a comparison of the results obtained with the two codes. These two temperatures were selected to be close to the actual operating temperatures reported in literature and to be consistent with the temperatures for which cross-section data are available with MCNP5.

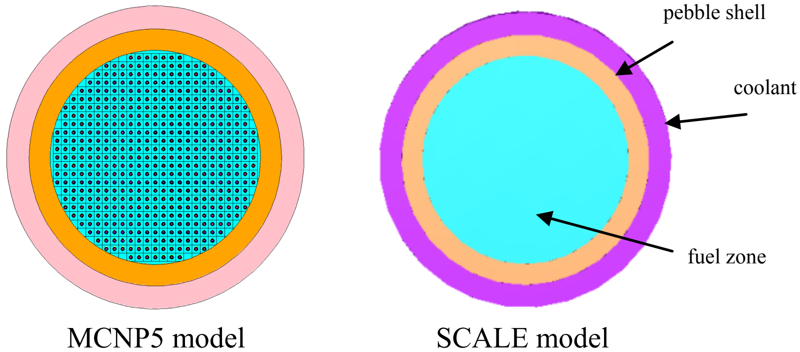



**Fig. 2.3. Pebble unit cell models.**

### 2.1.2 Modeling Doubly Heterogeneous Fuel in SCALE

Double heterogeneity of fuel can be modeled in SCALE using the DOUBLEHET option for cross-section processing, which combines the treatment of the first level of heterogeneity (fuel particles in the fuel compact—either sphere or cylinder) with the treatment of the second level of heterogeneity (pebbles inside the core for a PBR or cylindrical fuel compacts inside a prismatic fuel assembly for a prismatic HTGR). Though the fuel particles inside the fuel pebble are not explicitly modeled in the pebble unit cell shown in Fig. 2.3, the doubly heterogeneous nature of the fuel is accounted for through the method of calculating the cross sections for the fuel zone inside the pebble, which is illustrated in Fig. 2.4.

Problem-dependent multigroup cross sections for transport calculations are determined in SCALE using the CENTRM/PMC cross-section processing methodology. For fuels with no double heterogeneity, the CENTRM code solves the one-dimensional (1-D) neutron transport equation for a simple building block (such as a fuel pin in an LWR assembly) using pointwise cross sections and calculates the flux solution on a fine grid (about 50,000 to 70,000 points). This flux is used by the PMC code to weight pointwise cross sections for obtaining self-shielded multigroup cross sections for transport calculations with the XSDRNPM 1-D, NEWT two-dimensional (2-D), or KENO 3-D transport codes available in SCALE. For doubly heterogeneous fuel, the DOUBLEHET option sequentially applies the CENTRM/PMC methodology to the two levels of heterogeneity of such a fuel. On the first level of heterogeneity, the fuel particles inside the pebble (see Fig. 2.4), pointwise flux disadvantage factors are calculated and used to generate zone-weighted pointwise cross sections for the homogenized fuel region inside the pebble (radius 2.5 cm). These pointwise cross sections are used on the second level of heterogeneity calculations, the pebble in a lattice of pebbles, to determine with CENTRM the flux distribution, which is used then by PMC to determine multigroup problem-dependent cross-section data for the fuel element (i.e., pebble or cylinder).

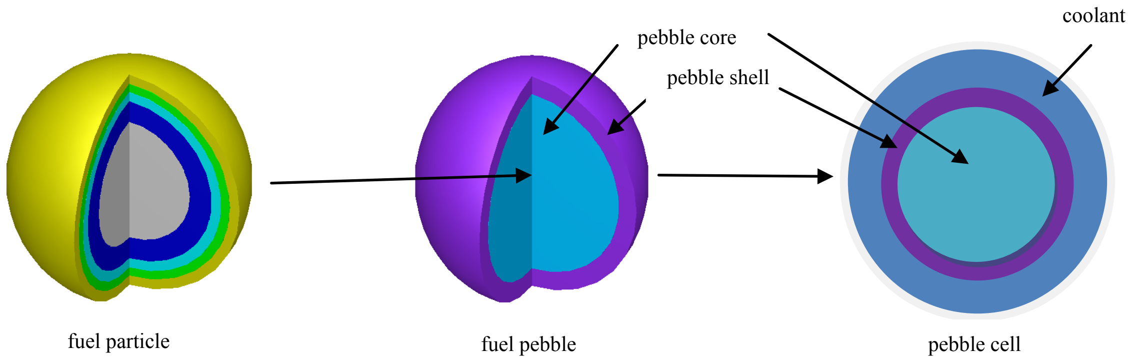



**Fig. 2.4. Double-heterogeneity model for cross-section processing in SCALE.**

### 2.1.3 Results

Relevant parameters for the configurations presented in Section 2.1.1 were calculated with SCALE and compared to corresponding data calculated with MCNP5. The values of the infinite medium multiplication factor ($k_{inf}$) for the hexagonal prism fuel cell models illustrated in Figs. 2.1 and 2.2, as calculated with SCALE/KENO-VI and MCNP5, are presented in Table 2.1. As seen, the SCALE/KENO-VI $k_{inf}$ value is within 2 mk (or 0.1%) of the MCNP5 value.

**Table 2.1. Comparison of $k_{inf}$ values for a hexagonal prism fuel cell**

| Code | Cross-section data | $k_{inf}$ | σ[a] | Difference (mk[b]) |
|---|---|---|---|---|
| **MCNP5** | CE[c] ENDF/B-VII | 1.74949 | 0.00028 | |
| **SCALE/KENO-VI** | 238-group ENDF/B-VII | 1.75138 | 0.00017 | 1.9 ± 0.3 |

[a] Standard deviation.
[b] 1 mk = $10^{-3}$.
[c] Continuous energy data.

The following spectral indices were calculated for the pebble unit cells illustrated in Fig. 2.3: fast-to-thermal $^{238}U$ capture ratio ($\rho_{28}$), fast-to-thermal $^{235}U$ fission ratio ($\delta_{25}$), ratio of $^{238}U$ fissions to $^{235}U$ fissions ($\delta_{28}$), and $^{238}U$ capture to $^{235}U$ fission ratio (C*). The spectral indices were calculated as follows:

$$\rho_{28} = \frac{\int_{cell} dV \int_{E>0.625eV} dE\Sigma_a^{238}(E)\Phi(E)}{\int_{cell} dV \int_{E<0.625eV} dE\Sigma_a^{238}(E)\Phi(E)} \qquad \delta_{25} = \frac{\int_{cell} dV \int_{E>0.625eV} dE\Sigma_f^{235}(E)\Phi(E)}{\int_{cell} dV \int_{E<0.625eV} dE\Sigma_f^{235}(E)\Phi(E)}$$

$$\delta_{28} = \frac{\int_{cell} dV \int dE\Sigma_f^{238}(E)\Phi(E)}{\int_{cell} dV \int dE\Sigma_f^{235}(E)\Phi(E)} \qquad C^* = \frac{\int_{cell} dV \int dE\Sigma_a^{238}(E)\Phi(E)}{\int_{cell} dV \int dE\Sigma_f^{235}(E)\Phi(E)}$$

where $E$ is neutron energy, $V$ is volume of the configuration considered, Φ is neutron flux, $\Sigma_a$ is macroscopic absorption cross section, and $\Sigma_f$ is macroscopic fission cross section. The cross sections from the unit cell calculation were collapsed to a two-group structure to determine the spectral indices, with the group boundary between thermal and fast at 0.625 eV.

A comparison of the spectral indices and $k_{inf}$ for the pebble cell unit models for the case where all cross sections were considered at 300 K is presented in Table 2.2. The SCALE values shown in this table were obtained using a 1-D spherical geometry transport calculation for the flux and eigenvalue solution in the pebble unit cell; however, the multigroup cross sections in the 1-D transport calculation accounted for the double heterogeneity of the fuel as the DOUBLEHET option was used for cross-section self-shielding. Compared with the 3-D detailed MCNP model, the 1-D SCALE model performs remarkably well and, inherent to the approach used for neutron transport, is very fast, requiring about 2 minutes to complete on a single processor vs. the 9 hours required to run MCNP in parallel on 10 processors. The differences of the spectral indices calculated with SCALE compared to the MCNP values as a reference are less than 2% in this case.

**Table 2.2. Spectral indices for single fuel pebble cell (at 300 K)**

| Parameter | Significance | MCNP5 [a] | SCALE | Diff [b] (%) |
|---|---|---|---|---|
| $\rho_{28}$ | Fast-to-thermal $^{238}$U capture ratio | 8.028 (0.004) | 8.159 | 1.6 |
| $\delta_{25} \times 10^2$ | Fast-to-thermal $^{235}$U fission ratio | 11.081 (0.004) | 11.048 | -0.3 |
| $\delta_{28} \times 10^4$ | $^{238}$U fission to $^{235}$U fission ratio | 14.117 (0.005) | 13.890 | -1.6 |
| $C^*$ | $^{238}$U capture to $^{235}$U fission ratio | 0.196 (0.0001) | 0.199 | 1.5 |
| $k_{inf}$ | Multiplication constant | 1.6596 (0.0001) | 1.6553 | -0.3 |

[a] Value in parentheses represents the standard deviation.
[b] Calculated as 100*(value$_{SCALE}$ - value$_{MCNP}$)/value$_{MCNP}$.

The pebble unit cell total, fission, and absorption microscopic cross sections for $^{235}$U and $^{238}$U in a four-group structure are shown in Tables 2.3 and 2.4. The four-group structure is the same as used in the VSOP code [21]. The $^{235}$U cross sections are estimated by SCALE within 1% of the corresponding MCNP reference values, except for the cross sections in group 3. The fission cross section in group 3 is underestimated by about 1.7%; note, however, that this group contributes only 4% to the total number of fissions in the system. The largest difference for $^{238}$U absorption cross sections is seen for group 2, of 2.2%; note that the absorption in this group accounts for about 34% of total absorptions in $^{238}$U.

**Table 2.3. $^{235}$U cross sections for single fuel pebble cell (at 300 K)**

| Group | Upper energy (eV) | Total cross section (b) | | | | Fission cross section (b) | | | | Absorption cross section (b) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MCNP | $\sigma^a_{MCNP}$ (%) | SCALE | Diff[b] (%) | MCNP | $\sigma_{MCNP}$ (%) | SCALE | Diff (%) | MCNP | $\sigma_{MCNP}$ (%) | SCALE | Diff (%) |
| 1 | $2\times10^7$ | 8.86 | 0.01 | 8.80 | -0.7 | 1.31 | 0.01 | 1.30 | -1.0 | 1.49 | 0.01 | 1.47 | -0.8 |
| 2 | $1\times10^5$ | 29.39 | 0.01 | 29.36 | -0.1 | 11.81 | 0.02 | 11.81 | 0.0 | 17.79 | 0.02 | 17.78 | 0.0 |
| 3 | 29.0 | 73.39 | 0.02 | 72.38 | -1.4 | 35.41 | 0.03 | 34.81 | -1.7 | 61.91 | 0.03 | 60.95 | -1.5 |
| 4 | 1.87 | 342.80 | 0.03 | 341.22 | -0.5 | 280.27 | 0.03 | 278.98 | -0.5 | 328.62 | 0.03 | 327.13 | -0.5 |

[a] Standard deviation
[b] Calculated as 100*(value$_{SCALE}$ – value$_{MCNP}$)/value$_{MCNP}$

**Table 2.4. $^{238}$U cross sections for single fuel pebble cell (at 300 K)**

| Group | Upper energy (eV) | Total cross section (b) | | | | Fission cross section (b) | | | | Absorption cross section (b) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MCNP | $\sigma^a_{MCNP}$ (%) | SCALE | Diff[b] (%) | MCNP | $\sigma_{MCNP}$ (%) | SCALE | Diff (%) | MCNP | $\sigma_{MCNP}$ (%) | SCALE | Diff (%) |
| 1 | $2\times10^7$ | 9.04 | 0.01 | 9.05 | 0.1 | 1.5E-1 | 0.03 | 1.5E-1 | -3.2 | 0.26 | 0.02 | 0.25 | -2.2 |
| 2 | $1\times10^5$ | 23.64 | 0.03 | 23.98 | 1.4 | 2.5E-4 | 0.28 | 2.5E-4 | 0.5 | 3.96 | 0.06 | 4.05 | 2.2 |
| 3 | 29.0 | 33.78 | 0.06 | 33.89 | 0.3 | 2.4E-5 | 0.10 | 2.4E-5 | 1.3 | 21.29 | 0.08 | 21.37 | 0.4 |
| 4 | 1.87 | 10.46 | 0.03 | 10.40 | -0.6 | 8.9E-6 | 0.03 | 8.9E-6 | -0.5 | 1.43 | 0.03 | 1.43 | -0.5 |

[a] Standard deviation.
[b] Calculated as 100*(value$_{SCALE}$ – value$_{MCNP}$)/value$_{MCNP}$.

For assessing the effect of accuracy in the multigroup cross-section data on the system behavior, the contributions of particular groups to the system capture, fission, etc. are listed in Table 2.5. This information was estimated with the MCNP model illustrated in Fig. 2.2. It facilitates estimating the effect of uncertainty in the cross section for a particular energy group and nuclide on the uncertainty in the reaction rates for the analyzed system. For example, as the largest contribution to the fission rate in the system is due to thermal neutrons (group 4) fission in $^{235}$U (as expected, as this is a thermal system), it is desirable to estimate the fission cross section in this group as accurately as possible. Regarding the contribution of $^{238}U$ to the total capture in the system, it is seen that the largest contribution is due to neutrons in the intermediate energy range (groups 2 and 3).

**Table 2.5. Group contributions to reaction rates in U—single fuel pebble cell (at 300 K)**

| Group | Upper energy (eV) | Total reaction rate in U | | Fission rate in U [a] | Capture rate in U | |
|---|---|---|---|---|---|---|
| | | $^{235}U$ (%) | $^{238}U$ (%) | $^{235}U$ (%) | $^{235}U$ (%) | $^{238}U$ (%) |
| 1 | 2 x $10^7$ | 1.1 | 1.2 | 0.3 | 0.1 | 0.1 |
| 2 | 1 x $10^5$ | 6.9 | 5.5 | 4.1 | 8.4 | 5.6 |
| 3 | 29.0 | 5.0 | 2.3 | 3.6 | 10.9 | 8.7 |
| 4 | 1.87 | 75.6 | 2.3 | 92.0 | 64.2 | 1.9 |
| | total | 88.7 | 11.3 | 100.0 | 83.7 | 16.3 |

[a] Fission rate in $^{238}U$ contributes less than 0.1% to the fission rate in U.

A comparison of the results obtained with SCALE and MCNP5 for the single pebble unit cell at operating temperatures is shown in Table 2.6 for spectral indices and in Tables 2.7 and 2.8 for the unit cell cross sections of $^{235}U$ and $^{238}U$, respectively. The differences observed for $k_{inf}$ and spectral indices in this case are consistent with those seen for the same configuration at 300 K. The differences in spectral indices are practically the same at the two temperature conditions, with the exception of $\delta_{28}$, for which the difference is 1.6% larger at operating temperature compared to 300 K. This latter difference is mainly due to the increased underestimation of the $^{238}U$ fission cross section in the fast energy range at operating temperature compared to 300 K; note that this increased underestimation does not significantly impact the total fission in the system, as the $^{238}U$ contribution to the total fission rate in the system is less than 0.1%.

**Table 2.6. Spectral indices for single fuel pebble cell (operating temperatures)**

| Parameter | Significance | MCNP5 [a] | SCALE | Diff [b] (%) |
|---|---|---|---|---|
| $\boldsymbol{\rho_{28}}$ | Fast-to-thermal $^{238}U$ capture ratio | 10.218 (0.006) | 10.414 | 1.9 |
| $\boldsymbol{\delta_{25} \times 10^2}$ | Fast-to-thermal $^{235}U$ fission ratio | 12.319 (0.004) | 12.279 | -0.3 |
| $\boldsymbol{\delta_{28} \times 10^4}$ | $^{238}U$ fission to $^{235}U$ fission ratio | 14.519 (0.005) | 14.058 | -3.2 |
| $\mathbf{C^*}$ | $^{238}U$ capture to $^{235}U$ fission ratio | 0.254 (0.0001) | 0.258 | 1.7 |
| $\mathbf{k_{inf}}$ | Multiplication constant | 1.6081 (0.0002) | 1.6034 | -0.3 |

[a] Value in parentheses represents the standard deviation.
[b] Calculated as 100*($value_{SCALE}$ – $value_{MCNP}$)/$value_{MCNP}$.

With respect to the comparison of cross sections at 300K (Tables 2.3 and 2.4) and at operating temperatures (Tables 2.7 and 2.8), the only cases for which the absolute difference between the SCALE and the MCNP values changes by more than 0.5% are $^{235}U$ fission in group 1 and $^{238}U$ fission in group 1 and absorption in groups 1 and 3. As the contribution of $^{235}U$ fission or $^{238}U$ absorption in group 1 to the total fission or absorption rate in the system is negligible, a slightly increased underestimation or overestimation of the corresponding cross sections would not have significant effect on the system properties. In the case of the $^{238}U$ absorption cross section in group 3, given that the absorption rate in this group contributes approximately 9% to the total absorption rate in the system, an increased overestimation of this cross section would have some effect on the system behavior. However, the magnitude of the overestimation (SCALE vs. MCNP) is not large (1.2%).

**Table 2.7. $^{235}$U cross sections for single fuel pebble cell (operating temperatures)**

| Group | Upper energy (eV) | Total cross-section (b) | | | | Fission cross-section (b) | | | | Absorption cross-section (b) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MCNP | $\sigma^a_{MCNP}$ (%) | SCALE | Diff[b] (%) | MCNP | $\sigma_{MCNP}$ (%) | SCALE | Diff (%) | MCNP | $\sigma_{MCNP}$ (%) | SCALE | Diff (%) |
| 1 | $2\times10^7$ | 8.87 | 0.01 | 8.71 | -1.8 | 1.31 | 0.01 | 1.29 | -2.1 | 1.49 | 0.01 | 1.46 | -1.9 |
| 2 | $1\times10^5$ | 29.39 | 0.01 | 29.34 | -0.2 | 11.81 | 0.02 | 11.79 | -0.2 | 17.79 | 0.02 | 17.75 | -0.2 |
| 3 | 29.0 | 73.26 | 0.02 | 72.24 | -1.4 | 35.50 | 0.03 | 34.86 | -1.8 | 61.81 | 0.03 | 60.79 | -1.6 |
| 4 | 1.87 | 242.09 | 0.04 | 244.08 | -0.8 | 192.47 | 0.04 | 194.20 | 0.9 | 228.00 | 0.04 | 229.97 | 0.9 |

[a] Standard deviation.
[b] Calculated as 100*(value$_{SCALE}$ – value$_{MCNP}$)/value$_{MCNP}$.

**Table 2.8. $^{238}$U cross sections for single fuel pebble cell (operating temperatures)**

| Group | Upper energy (eV) | Total cross-section (b) | | | | Fission cross-section (b) | | | | Absorption cross-section (b) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MCNP | $\sigma^a_{MCNP}$ (%) | SCALE | Diff[b] (%) | MCNP | $\sigma_{MCNP}$ (%) | SCALE | Diff (%) | MCNP | $\sigma_{MCNP}$ (%) | SCALE | Diff (%) |
| 1 | $2\times10^7$ | 9.04 | 0.01 | 8.95 | -1.0 | 1.5E-1 | 0.03 | 1.4E-1 | -5.2 | 0.26 | 0.02 | 0.25 | -3.8 |
| 2 | $1\times10^5$ | 26.46 | 0.03 | 26.78 | 1.2 | 2.6E-4 | 0.20 | 2.6E-4 | -0.3 | 4.95 | 0.06 | 5.03 | 1.8 |
| 3 | 29.0 | 42.26 | 0.06 | 42.69 | 1.0 | 3.2E-5 | 0.08 | 3.3E-5 | 1.8 | 28.27 | 0.07 | 28.61 | 1.2 |
| 4 | 1.87 | 10.13 | 0.03 | 10.16 | 0.3 | 6.4E-6 | 0.04 | 6.5E-6 | 0.8 | 1.04 | 0.03 | 1.06 | 0.8 |

[a] Standard deviation.
[b] Calculated as 100*(value$_{SCALE}$ - value$_{MCNP}$)/value$_{MCNP}$.

## 2.2 ANALYSIS OF THE HTR-10 FIRST CRITICAL CORE

The HTR-10 reactor is a test reactor intended to serve in the development of the technology for construction of PBRs in China. It is a small reactor, with a diameter and height of the cylindrical core of 180 and 197 cm, respectively. HTR-10 is helium cooled, graphite moderated, and operated at 10 MW thermal power. The reactor main design features [10] are listed in Table 2.9.

**Table 2.9. HTR-10 design features**

| Parameter | Value |
|---|---|
| Thermal power (MW) | 10 |
| Core diameter (cm) | 180 |
| Core height (cm) | 197 |
| Primary coolant pressure (MPa) | 3 |
| Coolant inlet temperature (°C) | 250 |
| Coolant outlet temperature (°C) | 700 |
| Fuel type | $UO_2$ |
| Number of fuel elements in equilibrium core | 27,000 |
| Heavy metal loading per fuel element (g) | 5 |
| Initial fuel enrichment (wt % $^{235}$U) | 17 |
| Number of control rods in side reflector | 10 |
| Number of absorber ball units in side reflector | 7 |
| Fuel loading mode | multipass |

The first core of HTR-10 reached criticality in 2000. A set of benchmark specifications for the HTR-10 initial critical core experiment was released before the actual experiment took place, for a benchmark exercise coordinated by the International Atomic Energy Agency (IAEA). The actual configuration for the first criticality was different than the pre-experiment specifications, leading to a new set of benchmark specifications that was provided later. Both the initial and an updated set of benchmark specifications, along with results obtained with different codes by the participants to the IAEA benchmark exercise, were presented in IAEA TECDOC-1382 [22]. The post-experiment benchmark specifications were included and presented in detail in the 2009 release of the IRPhE Handbook [10].

### 2.2.1 HTR-10 Full Core SCALE Model

A full 3-D model for the HTR-10 reactor has been developed using the SCALE/KENO-VI Monte Carlo transport code [23]. The core configuration is based on the IRPhE benchmark description [10] used for the evaluation of the initial critical configuration of the HTR-10. A vertical cutaway view of the SCALE/KENO-VI model for HTR-10 is illustrated in Fig. 2.5. The reactor has a cylindrical active core region located above a conical pebble discharge tube and a cylindrical discharge tube. For the initial critical configuration, there were a total of 16,890 fuel and moderator pebbles in the active core region (9,627 fuel pebbles and 7,263 moderator pebbles), for a 57:43 fuel-to-moderator pebble ratio. The conical and cylindrical discharge tubes beneath the active core region were filled with moderator pebbles only, with a packing fraction of 61%. The reflector region surrounding the active core region and the discharge tubes are zones with varying material densities of carbon, natural boron, and coolant components.

The uranium load in each fuel pebble is 5 g, and the fuel enrichment is 17 wt% $^{235}$U. Each fuel pebble contains 8,335 fuel particles. Each fuel particle includes a spherical $UO_2$ kernel surrounded by four carbon-based layers. The IRPhE benchmark specifications [10] for the fuel particle data and material data for pebbles and moderator that were used to develop the HTR-10 core model are summarized in Tables 2.10 and 2.11.

**Table 2.10. Fuel particle data for HTR-10 fuel**

| Zone description | Material | Density ($g/cm^3$) | Outer radius (mm) |
|---|---|---|---|
| Fuel kernel | $UO_2$ | 10.4 | 0.250 |
| Buffer layer | Graphite | 1.1 | 0.350 |
| Inner pyrolitic carbon layer | Graphite | 1.9 | 0.390 |
| SiC layer | Silicon carbide | 3.18 | 0.425 |
| Outer pyrolitic carbon layer | Graphite | 1.9 | 0.465 |
| Matrix | Graphite | 1.73 | N/A |

**Table 2.11. Material data for pebbles and reflector in HTR-10**

| Parameter | Value |
|---|---|
| Uranium mass per pebble (g) | 5 |
| Uranium enrichment (wt % $^{235}U$) | 17 |
| Equivalent boron in uranium (ppm) | 4 |
| Density of graphite in fuel pebble shell ($g/cm^3$) | 1.73 |
| Density of graphite in moderator pebble ($g/cm^3$) | 1.84 |
| Density of graphite reflector ($g/cm^3$) | 1.76 |
| Equivalent boron in graphite moderator pebble (ppm) | 0.125 |
| Equivalent boron in graphite of fuel particle coatings (ppm) | 1.3 |
| Equivalent boron in graphite reflector (ppm) | 4.8366 |

The pre-experiment set of benchmark (IAEA) specifications [22] considered that both the graphite in the dummy pebbles and the graphite in the fuel pebble outer shell had the same density, 1.73 $g/cm^3$. Later, in the IRPhE benchmark, the graphite density in the moderator (dummy) pebble was modified to 1.84 $g/cm^3$. In addition, the equivalent boron specified in the IRPhE for the moderator pebbles was much lower than in the pre-experiment specifications: 0.125 ppm vs. 1.3 ppm. The actual experiment was conducted under atmospheric air at 15 °C [10] instead of helium as stated in the pre-experiment benchmark specifications [22]. For the work documented in this report, only the IRPhE benchmark specifications were used for developing the core models.

Two sets of benchmark specifications are included in the IRPhE Handbook for HTR-10, called Simplified Model and High-Fidelity Model, respectively. The difference between these two models is the level of detail for the structures in the reflector region. The specifications for all the other regions in the reactor are the same in both models. In the High-Fidelity Model, 20 coolant flow channels, 13 control rod/irradiations channels, 7 small absorber ball channels, and one hot gas duct are explicitly modeled in the reflector region. In the Simplified Model, the ducts and borings in the reflector region are homogenized with the reflector material. The dimensions and locations for these regions were used as provided in Table 3.2 of Ref. [10].

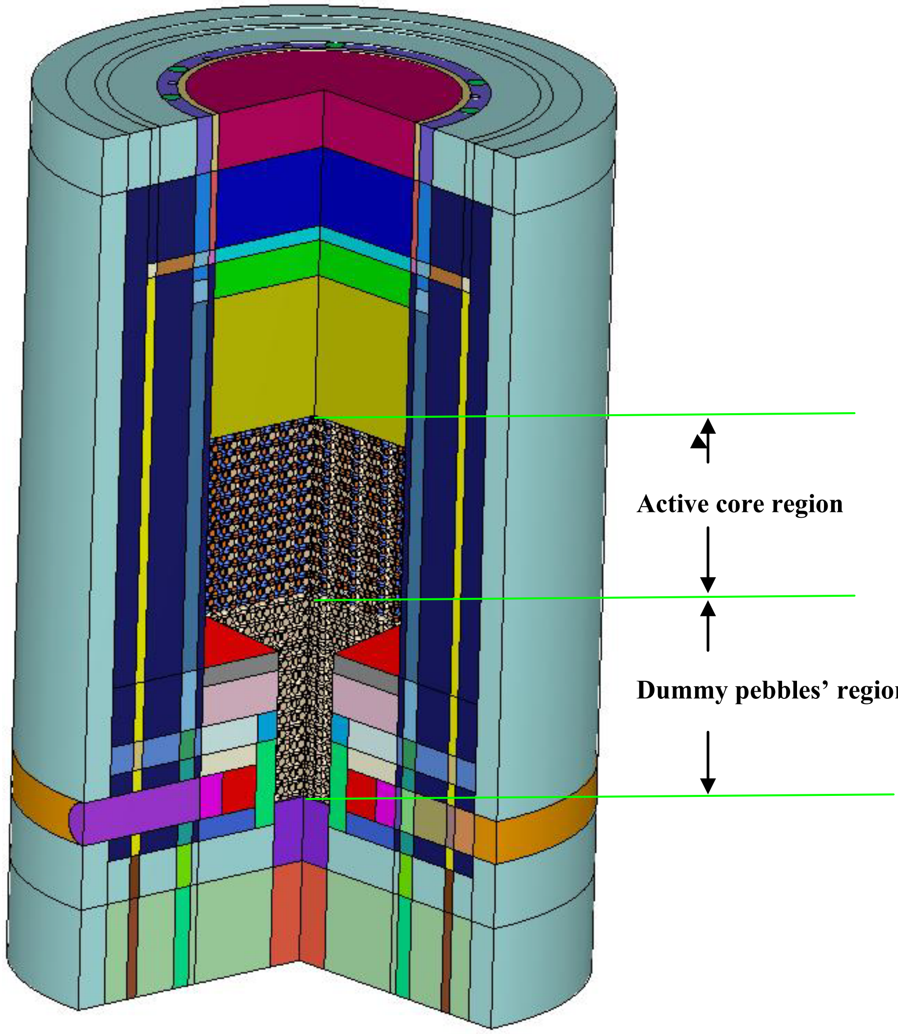



**Fig. 2.5. SCALE/KENO-VI model for HTR-10 first core.**

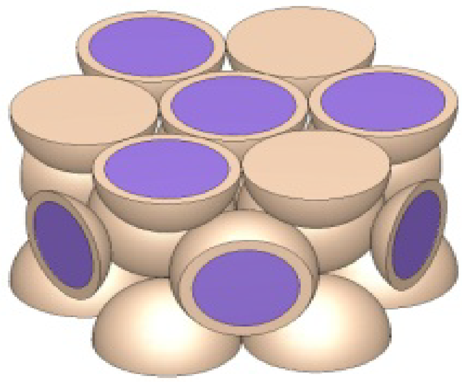
### 2.2.1.1 Active core region

The active core region contains fuel and moderator pebbles, with a 57:43 ratio of the fuel-to-moderator pebble numbers. The fuel and moderator pebbles are explicitly represented in the SCALE model using a hexagonal prism unit cell as a building block. Albeit the fuel particles inside each of the fuel pebbles are not explicitly modeled with SCALE, the double-heterogeneous structure is taken into account through the way the cross sections for the fuel zone inside the fuel pebble are calculated, as described in Section 2.1.2.

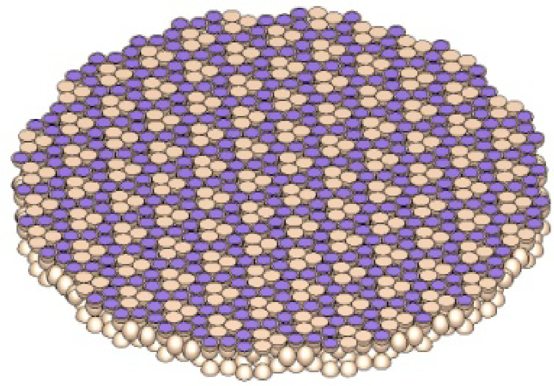
The geometry of the hexagonal unit cell is illustrated in Fig. 2.6 (a). The different colors used in this figure signify the presence of different materials. The dimensions of this unit cell are calculated to ensure that both the packing fraction of the pebbles in the active core region and the fuel-to-moderator pebble ratio are conserved as specified in the benchmark, to 61% and 57:43, respectively. The hexagonal unit cells are packed into layers, as illustrated in Fig. 2.6 (b), and these layers are stacked vertically to form the detailed active core region. The height for the active core is 123.574 cm.

To preserve the total number of fuel and moderator pebbles in the active core region, addition of the pebbles and the stacks of pebble layers when building the active core model needs be done in a manner that would ensure a minimal clipping of fuel and moderator pebbles by the cylindrical boundary of the core. The building of the core model as described above resulted (see Table 2.12) in a number of

16,885 fuel and moderator pebbles in the active core region, similar to the number reported in Ref. 18. The difference of five fuel pebbles, compared to the benchmark specifications [10], would correspond to a reduction of 0.05% in the total mass of uranium in the core.



(a) hexagonal prism unit cell



(b) pebble layer in active core region

**Fig. 2.6. Modeling of active core region.**

**Table 2.12. Number of fuel and moderator pebbles in the active core region**

| | Total number of pebbles | Number of fuel pebbles | Number of moderator pebbles | Fuel-to-moderator pebble ratio |
|---|---|---|---|---|
| SCALE/KENO-VI model | 16,885 | 9,622 | 7,263 | 56.99 : 43.01 |
| Benchmark specifications [7] | 16,890 | 9,627 | 7,263 | 57.00 : 43.00 |
| Difference | 5 | 5 | 0 | – |

The number of fuel and moderator pebbles in the SCALE/KENO-VI model for the active core region was verified by comparing the calculated volumes of the unique material regions in the active core region to the volumes corresponding to the expected number of pebbles modeled in this region. The volume calculation was performed using two different methods: (1) stochastic calculation within SCALE/KENO-VI using the random sampling option for volume calculation and (2) analytical calculation with Keno3D, the 3-D visualization software designed for interactively viewing SCALE/KENO-VI geometry models on Windows computers. The results of the comparison are shown in Table 2.13. The comparison shows that the underestimation of the total volume of graphite material in the active core region is less than 0.2%, whereas the total volume of the fuel mixture in the fuel pebbles is exactly conserved (corresponds to 9,622 fuel pebbles). The modeling of the pebbles in the active core region is illustrated in Fig 2.7, which also shows the pebbles in the dummy pebbles regions.

**Table 2.13. Volume verification for the active core region**

| Material in active core | Expected volume ($10^5$ cm$^3$) | Keno3D calculated volume ($10^5$ cm$^3$) | Calculated-to-expected volume ratio |
|---|---|---|---|
| Fuel mixture in fuel pebble | 6.2976 | 6.2976 | 1.0000 |
| Graphite shell of fuel pebble | 4.5856 | 4.5736 | 0.9974 |
| Graphite in moderator pebbles | 8.2139 | 8.2056 | 0.9990 |

#### 2.2.1.2 Dummy pebbles region

The dummy pebbles region located underneath the active core region, which contains only graphite pebbles, was also modeled in detail in the SCALE/KENO-VI model, as illustrated in Fig. 2.7. The volume occupied by the graphite material in this region was calculated with Keno3D to verify that the packing of the graphite pebbles in this region is consistent with the expected value of 61%. The calculated packing fraction was 60.5%, in good agreement with the expected value. The very small difference of 0.5% in the total graphite volume is due to the inherent clipping of the graphite pebbles at the outer surfaces of the cylindrical and conical portions of the discharge tube.

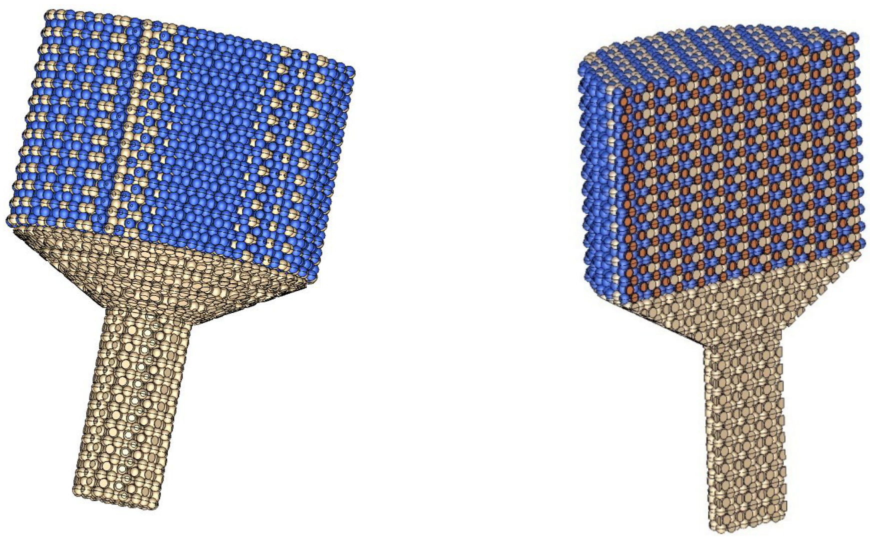
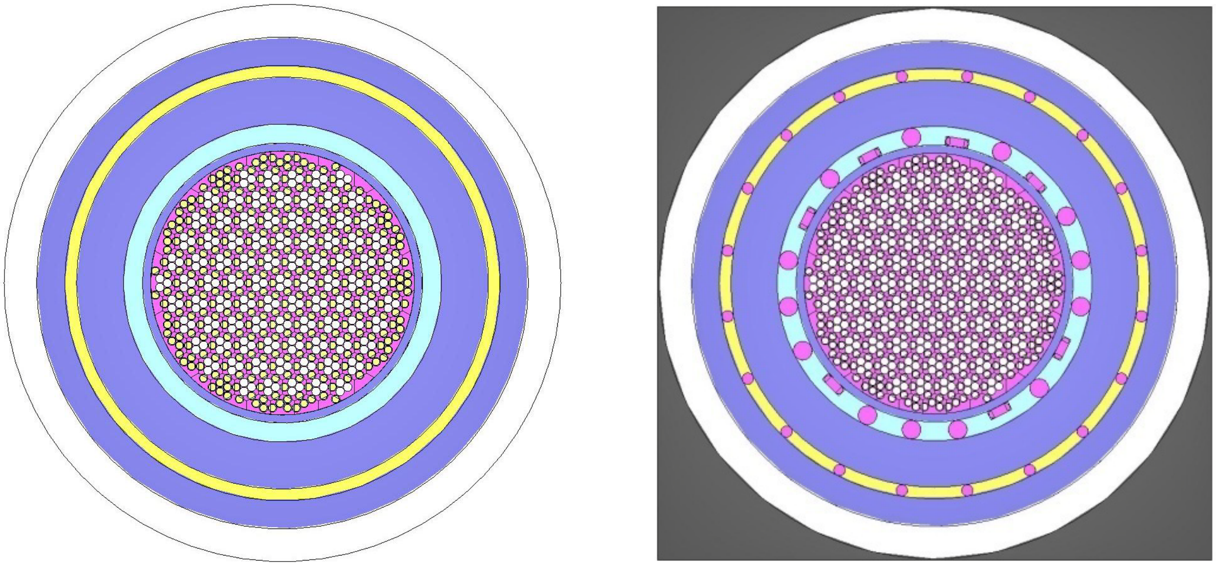


**Fig. 2.7. Modeling of pebbles in active core region and dummy pebbles region.**

#### 2.2.1.3 Reflector region

The IRPhE benchmark description [10] for the High-Fidelity Model includes explicit representation of the ducts and borings in the reflector: small absorber ball channels, coolant channels, control rod and irradiation channels, and the hot gas duct. The benchmark description for the Simplified Model [10] represents the radial zones containing borings as azimuthally homogenized. The difference between the High-Fidelity and Simplified models is illustrated in Fig. 2.8, which shows a radial view of the core, as modeled with SCALE/KENO-VI. Details of the channels in the reflector in the SCALE/KENO-VI model are presented in Fig. 2.9.

The volumes of the ducts and borings in the reflector region were analytically calculated based on the provided geometry specifications and also calculated within SCALE/KENO-VI to ensure that the modeled geometry is consistent with the actual specifications. The volume comparison in Table 2.14 shows a very good agreement. The very small differences can be explained by uncertainty in the stochastic volume calculation with KENO-VI.



Simplified model High-Fidelity model

**Fig. 2.8. Comparison of Simplified and High-Fidelity models—radial view.**

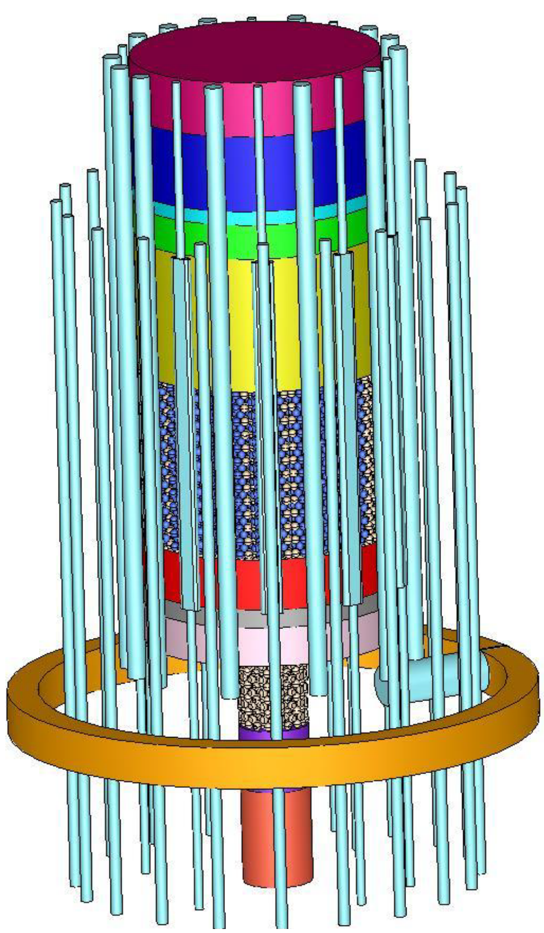


**Fig. 2.9. High-Fidelity model—channels in reflector region.**

**Table 2.14. Volume verification for the reflector region**

| Region in reflector | Expected volume ($10^5$ cm$^3$) | Keno-VI calculated volume ($10^5$ cm$^3$) | Calculated-to-expected volume ratio |
|---|---|---|---|
| Coolant channels | 5.0768 | 5.0772 | 1.0001 |
| Control rod/irradiation channels | 7.7648 | 7.7646 | 1.0000 |
| KLAK channels | 2.2941 | 2.2929 | 0.9995 |
| Hot gas duct | 0.7069 | 0.7066 | 0.9996 |

#### 2.2.1.4 Cross-section data

Calculations for the HTR-10 full core SCALE/KENO-VI model were carried out using the SCALE 238-group ENDF/B-VII cross sections.

### 2.2.2 Comparison with MCNP

The IRPhE Handbook [10] provides calculation results for the HTR-10 first core benchmark as obtained with an MCNP model. Though no information is provided on the nuclear cross-section libraries used for calculating the reported $k_{eff}$ value, it was noted that the MCNP input file included in an appendix of the IRPhE Handbook shows ENDF/B-V (release unknown) data as being used in the model. This MCNP input file, corresponding to the high-fidelity benchmark, was used by ORNL to repeat calculations with different sets of continuous energy cross-section libraries. Both ENDF/B-V.0-based libraries and ENDF/B-VII.0-based libraries were employed to try reproducing the IRPhE-reported results and to ensure a consistent comparison with the SCALE results that were obtained with ENDF/B-VII libraries.

A few modifications were made to the provided MCNP input for complete consistency with the benchmark data, as it was observed that some values for material densities in the input were slightly different from the provided benchmark specifications. The thermal scattering data $S(\alpha,\beta)$ for graphite that were used in the MCNP calculations were taken from dataset *endf70sab* for ENDF/B-VII.0 and from dataset *tmccs* for ENDF/B.V.0. [17]

The MCNP model was used to study the sensitivity of the effective multiplication factor ($k_{eff}$) results to the cross-section library data and to the boron isotopic composition data. Two sets of data were used for the boron isotopic composition: (1) 19.9% $^{10}$B and 80.1% $^{11}$B, as specified in the IRPhE benchmark [10]; and (2) 19.8% $^{10}$B and 80.2% $^{11}$B, as specified in the *Nuclear Wallet Card 2005* [24]. The sensitivity of $k_{eff}$ results to the boron isotopic composition are presented in Table 2.15, which shows practically no impact, irrespective of the cross-section dataset used. On the other hand, the effect of the ENDF/B library on $k_{eff}$ is significant, of the order of 300 pcm, as shown in Table 2.16.

**Table 2.15. Sensitivity of $k_{eff}$ to the boron isotopic composition**

| Cross section data | Boron isotopic composition | $k_{eff}$ | $\sigma(k_{eff})$ | $k_{eff}$ difference (pcm) |
|---|---|---|---|---|
| ENDF/B-V.0 | 19.8% $^{10}$B 80.2% $^{11}$B | 1.01187 | 0.00022 | 21 ± 30 |
| | 19.9% $^{10}$B 80.1% $^{11}$B | 1.01166 | 0.00021 | |
| ENDF/B-VII.0 | 19.8% $^{10}$B 80.2% $^{11}$B | 1.01472 | 0.00021 | 1 ± 30 |
| | 19.9% $^{10}$B 80.1% $^{11}$B | 1.01473 | 0.00021 | |

**Table 2.16. Sensitivity of $k_{eff}$ to the cross-section data**

| Boron isotopic composition | Cross section data | $k_{eff}$ | $\sigma(k_{eff})$ | $k_{eff}$ difference (pcm) |
|---|---|---|---|---|
| 19.8% $^{10}B$ 80.2% $^{11}B$ | ENDF/B-V.0<br>ENDF/B-VII.0 | 1.01187<br>1.01472 | 0.00022<br>0.00021 | 285 ± 30 |
| 19.9% $^{10}B$ 80.1% $^{11}B$ | ENDF/B-V.0<br>ENDF/B-VII.0 | 1.01166<br>1.01473 | 0.00021<br>0.00021 | 307 ± 30 |

### 2.2.3 Results

The $k_{eff}$ value calculated with the SCALE/KENO-VI model for the simplified benchmark model is compared in Table 2.17 to the corresponding MCNP-calculated value and the expected benchmark value as reported in Ref. 10. The difference between the two calculated $k_{eff}$ values is approximately 300 pcm. Both MCNP and SCALE overestimate the expected benchmark value by 1.2% and 1.5%, respectively.

**Table 2.17. $k_{eff}$ results for simplified benchmark model**

| | Cross-section data | $k_{eff}$ | $\sigma(k_{eff})$ | $k_{eff}$ difference (pcm)[a] |
|---|---|---|---|---|
| Expected benchmark value (Ref. 9) | | 1.0131 | 0.0037 | |
| SCALE/KENO-VI | ENDF/B-VII.0 | 1.02804 | 0.00027 | 304 ± 34 |
| MCNP5 (Ref. 9) | N/A[b] | 1.02500 | 0.00021 | |

[a] Calculated as $10^5 \times (k_{SCALE} - k_{MCNP})$.
[b] Not available.

The $k_{eff}$ value calculated with SCALE/KENO-VI for the High-Fidelity Model is compared to the corresponding MCNP-calculated value reported in Ref. 10 and to the experimental result in Table 2.18. The SCALE-calculated value was obtained using 238-group ENDF/B-VII cross sections, whereas the MCNP-calculated value was obtained using continuous energy (CE) ENDF/B-VII cross sections. As observed, there is a relatively good agreement between SCALE and MCNP, with a difference in the calculated $k_{eff}$ of 162 ± 33 pcm. However, both MCNP and SCALE overestimate the experimental values, by 1.5% and 1.3%, respectively.

**Table 2.18. $k_{eff}$ results for high-fidelity benchmark model**

| | Cross-section data | $k_{eff}$ | $\sigma(k_{eff})$ | $k_{eff}$ difference (pcm)[a] |
|---|---|---|---|---|
| Expected benchmark value (experiment) | | 1.0000 | 0.0037 | |
| SCALE/KENO-VI | ENDF/B-VII.0 | 1.01311 | 0.00025 | -162 ± 33 |
| MCNP5 (calculated by ORNL) | ENDF/B-VII.0 | 1.01473 | 0.00021 | |

[a] Calculated as $10^5 \times (k_{SCALE} - k_{MCNP})$.

One possible source of the difference between the calculated and experimental $k_{eff}$ values may be due to possible uncertainties in the benchmark specifications that were not included in the IRPhE description [10]. As specified in Ref. 10, the sources of information used to develop the benchmark specifications do not contain a complete set of data on the uncertainties or tolerances of all relevant parameters. Sensitivity studies on various parameters such as variations in boron concentration in the fuel element, density of graphite matrix in the fuel pebble, or dimensions of the core and fuel that were presented in Ref. 10 showed that part of the difference may be related to uncertainties in these parameters. A large contributor in the observed code bias might be uncertainty in the carbon capture cross section for graphite-rich reactor systems. A Japanese study [25] showed that a new evaluation of the carbon capture cross section that was used in the recent release of the Japanese JENDL 4.0 data led to significantly better agreement between calculated and experimental reactivity for HTTR annular cores compared to other evaluations. The reactivity for three HTTR annular cores calculated using ENDF/B-VII data for the carbon capture cross section overestimated the experimental values by 0.8 to 1.7%; whereas when JENDL 4.0 data were used the calculated reactivity agreed within 0.3% with the experiment [25].

## 2.3 ANALYSIS OF THE HTR-PROTEUS BENCHMARK EXPERIMENTS

PROTEUS is a zero-power research reactor facility located at the Paul Scherrer Institut in Switzerland. This facility has been used over the years to carry out experiments relevant to different types of reactor configurations. PROTEUS has a cylindrical graphite annulus with a central cavity for which the content can be changed according to the type of reactor being investigated. Though it has been used mostly to study light water reactors, the facility was configured as a pebble bed reactor critical facility from 1992 to 1996 and designated as HTR-PROTEUS. During this period, 13 critical configurations were assembled and various reactor physics experiments were conducted [11]. This section includes a summary of the experiments as described in Ref. 11, along with the description of the SCALE models developed for the corresponding configurations and the results obtained with these models.

### 2.3.1 HTR-PROTEUS Experiments Overview

PROTEUS consists of a graphite cylinder of 3.26 m diameter and 3.30 m height and has a central polygonal cavity that can be approximated as a cylinder with a 1.25 m effective radius [11]. Thirteen critical PBR configurations were studied with HTR-PROTEUS. In ten of these configurations, the pebbles were manually arranged in the core in a fixed lattice arrangement, whereas in the other three configurations the pebbles were randomly arranged. Only the cores with a deterministic lattice arrangement are addressed in this report. The HTR-PROTEUS configuration is illustrated in Fig. 2.10, which shows one of the models developed with SCALE/KENO-VI.

The main characteristics of the configurations with deterministic pebble arrangements are summarized in Table 2.19, which is a simplified version of Table 1.2 in the IRPhE draft benchmark [11]. The identifiers are as used in the original PSI documentation [26,27]. These configurations can be placed in two main groups depending on the pebble arrangement in the configuration: (1) cores 1 to 3 have a hexagonal-closed-packed (HCP) pebble arrangement and (2) cores 5 to 10 have a columnar hexagonal point-on-point (CHPOP) packing arrangement. The number 4 core that is missing from the table (in the sequence from 1 to 10) corresponds to a random arrangement of the pebbles in the core (not modeled here). For cores 1a, 5, and 9, more than one state was considered, and named as such in the original documents. The original naming may not be necessarily associated with large changes in configurations.

Differences among core configurations can relate to

- Total number of layers of pebbles in the configuration.
- Fuel-to-moderator pebble ratio in all or most of the layers in a configuration. In some configurations, the end layer is much different than the other layers, e.g., the 23$^{rd}$ layer in cores 5 and 8 or the 28$^{th}$ layer in core 9 state 2.
- Type and number of control rods.
- Presence of polyethylene rods in the core and/or the cross-sectional shape of these rods—cylindrical vs. triangular.

The differences between these configurations will be discussed in detail further in this section.

The HTR-PROTEUS experiments included, in addition to criticality experiments, measurements of differential and integral control rod and safety rod worths and reaction rates ratios. These later measurements were not evaluated in the IRPhE draft benchmark [11], but compiled data were included. Only the criticality experiments are addressed in the current report.

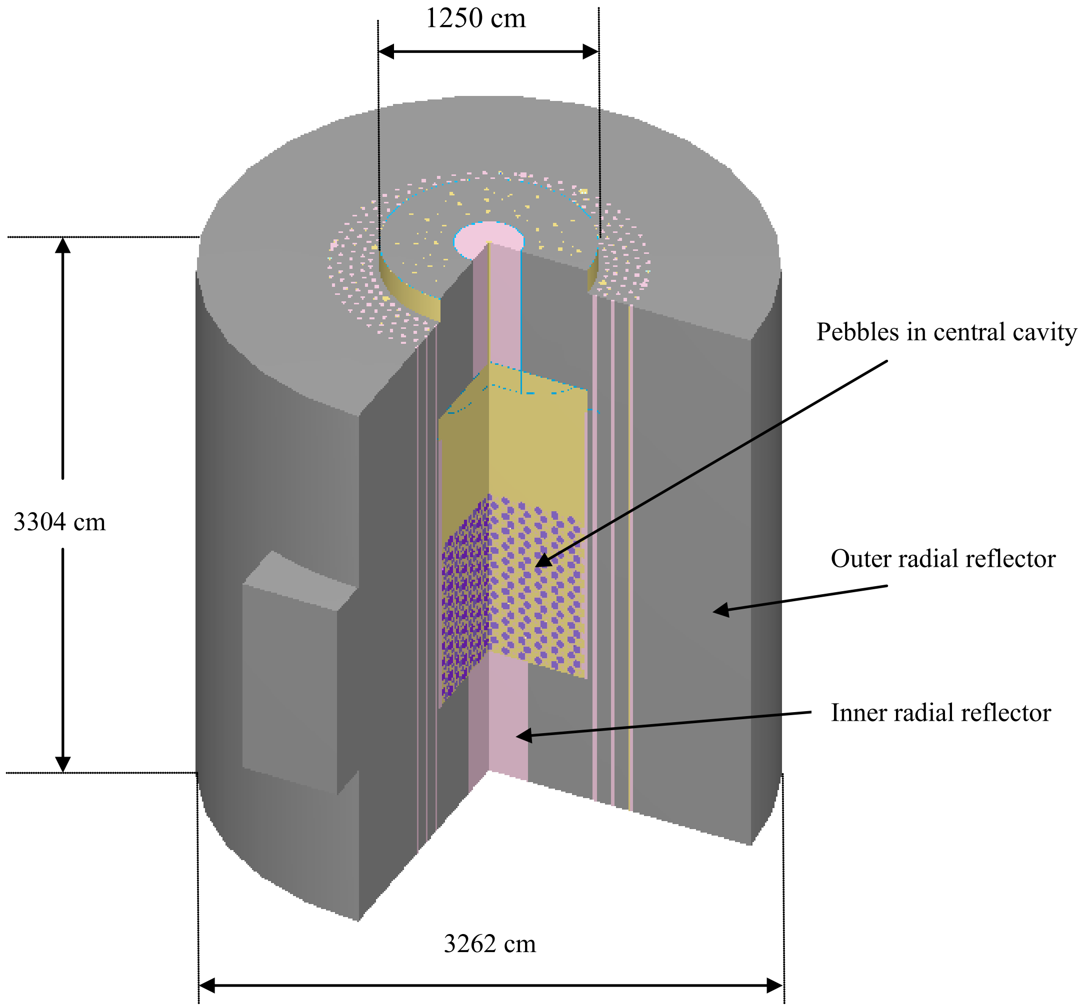



**Fig. 2.10. HTR-PROTEUS illustration—SCALE/KENO-VI model.**

**Table 2.19. HTR-PROTEUS configurations**

| Core Identifier | Date | Packing[a] | Pebble Configuration Detail | Fuel-to-Moderator Pebble Ratio |
|---|---|---|---|---|
| 1<br>State 1 | July 1992 | HCP | 22 layers | 2.00425 |
| 1A<br>State 1<br>State 2 | June 1993<br>Feb. 1994 | HCP | 21 layers<br>As State 1, but slightly different locations for control rods | 2.00445 |
| 2<br>State 1 | Aug 1993 | HCP | 16 layers<br>17th layer | 2.00425<br>Moderator pebbles only |
| 3<br>State 1 | Oct 1993 | HCP | 17 layers<br>18th layer is partially filled<br>327 cylindrical polyethylene rods | 2.0045 |
| 5<br>State 1<br>State 2<br>State 3 | July 1994<br>July 1994<br>Nov 1995 | CHPOP | 22 layers<br>23rd layer<br>Same pebble arrangement in all three states, but small differences in bottom reflector or/and small changes in control rod positioning | 2.000378<br>0.6188 |
| 6<br>State 1 | April 1995 | CHPOP | 21 layers<br>22nd layer<br>654 triangular polyethylene rods | 2.0000<br>0.5628 |
| 7<br>State 1 | May 1995 | CHPOP | 17 layers<br>18th layer<br>654 triangular polyethylene rods | 1.99951<br>0.5628 |
| 8<br>State 1 | Jan 1996 | CHPOP | 22 layers<br>23rd layer<br>654 triangular polyethylene rods | 2.00378<br>0.6188 |
| 9<br>State 1<br>State 2 | Feb 1996<br>Feb 1996 | CHPOP | 27 layers<br>State 2 has 28th layer pure moderator | 0.998565<br>0.929744 in State 2 |
| 10<br>State 1 | May 1996 | CHPOP | 27 layers<br>654 cylindrical polyethylene rods | 0.998565 |

[a] HCP = hexagonal closed packing; CHPOP = columnar hexagonal point-on-point.

### 2.3.2 Computational Models for HTR-PROTEUS Configurations

#### 2.3.2.1 Modeling data

Data used to develop the computational models for the HTR-PROTEUS configurations were taken to large extent from the IRPhE draft benchmark. [11] Other references were used or assumptions were made in the cases where the information in Ref. 11 was inconsistent or incomplete. Data of most relevance will be discussed in this report. For more details the reader is encouraged to consult the references provided.

All HTR-PROTEUS configurations included both fuel and moderator pebbles, arranged in different lattices, as summarized in Table 2.19. The uranium load in each fuel pebble is ~ 6 g and the fuel enrichment is 16.7 wt % $^{235}U$. Each fuel pebble contains a 2.35-cm-radius spherical fuel region with 9,394 fuel particles and a graphite shell with a total radius of 3.0 cm. Each fuel particle includes a spherical $UO_2$ kernel surrounded by four carbon-based layers. The IRPhE draft benchmark specifications [11] for the fuel particle data and material data for pebbles and moderator that were used to develop the HTR-PROTEUS core models are summarized in Tables 2.20 and 2.21.

**Table 2.20. Fuel particle data for HTR-PROTEUS fuel**

| Zone description | Material | Density ($g/cm^3$) | Outer radius (mm) |
|---|---|---|---|
| Fuel kernel | $UO_2$ | 10.88 | 0.2510 |
| Buffer layer | Graphite | 1.10 | 0.3425 |
| Inner pyrolitic carbon layer | Graphite | 1.90 | 0.3824 |
| SiC layer | Silicon carbide | 3.18 | 0.4177 |
| Outer pyrolitic carbon layer | Graphite | 1.89 | 0.4577 |
| Matrix | Graphite | 1.73 | N/A |

**Table 2.21. Material data for pebbles and reflector in HTR-PROTEUS**

| Parameter | Value |
|---|---|
| Uranium mass per pebble (g) | 5.97 |
| Uranium enrichment (wt % $^{235}U$) | 16.7 |
| Density of graphite in fuel pebble shell ($g/cm^3$) | 1.73 |
| Density of graphite in moderator pebble ($g/cm^3$) | 1.68 |
| Density of graphite reflector ($g/cm^3$) | 1.76 |
| Equivalent boron in graphite of moderator pebble (ppm) | 1.7149 |
| Equivalent boron in graphite of fuel pebble (ppm) | 0.3883 |

There are a large number of borings in the reflector near the core, as seen in Fig. 2.10, which are arranged in rings, some containing control elements. A variety of control rods were used in the studied configurations: Cd/Al ZEBRA-type rods, an automatic control rod, withdrawable stainless steel control rods, safety/shutdown rods, and static measurement rods [11]. The ZEBRA-type rods were used only in Core 1.

#### 2.3.2.2 Modeling assumptions

The specifications in the HTR-PROTEUS IRPhE draft benchmark [11] are not a complete set—there are cases with missing information or cases containing conflicting information. Assumptions were necessary in order to generate the data needed in computational models in these cases, such as assumptions about reflector structure and graphite composition, details of the polyethylene rods, or details on control rods.

The modeling assumptions used for creating the reflector model are as follows:

1. *Type of graphite used in different zones of the graphite reflector.* Based on data provided in Table 1.7 and Figure 4.2 of Ref. 11, it was assumed that the graphite spacers used in the cores, the graphite rods filling the borings in the radial reflector, the filled pieces for the ZEBRA rod borings in Core 1, the graphite plug for the axial neutron source, and the central section of the axial reflectors utilized the so-called "axial graphite" composition, while all other parts of the reflector, including the top 12 cm, and the other filler rods utilized the so-named "radial" graphite.
2. *Effect of external structures.* The effect of external structure on the core reactivity was assumed of minimal importance. This is supported by results in Ref. 28, which indicate that this effect amounts to less than a 100 pcm change in the multiplication factor.
3. *Elevation of the central graphite plug in the upper reflector.* It was assumed 14.9 cm, though no consistency exist for this data in figures of Ref. 11.
4. *Status of holes in the upper axial reflector.* The assumption in Ref. 11 that the 34 holes in the upper axial reflector plug were kept opened was used, though it is different than that used in other sources [29].
5. *Height of graphite spacers used to transform the central cavity into a 12-sided polygonal prism.* This was inferred from figures provided in Ref. 11 as 174.4 cm, reaching the bottom of the upper reflector.

Polyethylene rods were used in some of the cores to increase moderation. The following modeling assumptions were used for these rods:

1. Data on the type of rods used in Core 7 were inconsistent between Table 1.2 and Table 1.29 of Ref. 11. Since the information in Table 1.2 was moderately vague, the rod information in Table 1.29 was used.
2. The precise locations of polyethylene rods in Core 8 were not available. The rods were specified as only 12 cm long for this case, but their precise position was not mentioned. As Table 1.30 in Ref. 11 indicated that the goal for this core was to simulate high water loading at the bottom of the core, it was assumed that the rods were placed at the bottom of the core cavity.

Assumptions made about the control rods included:

1. *Level of full insertion.* It was assumed that the full insertion level for cores 2 to 9 was when the entirety of the withdrawable control rod or the copper wedge for the autorod was contained within the upper graphite reflector. This assumption was based on Fig. 3.14 in Ref. 11, which shows the withdrawn shutdown rod. More detailed information was available for control rods in Core 1, so in this later case a more accurate model was possible.
2. *Radial location of withdrawable control rods.* Since Table 1.21 in Ref. 11 indicated that the withdrawable control rods were inserted in the 5$^{th}$ boring ring and no other indication of radial location was ever given, all withdrawable control rods were assumed to be located in the 5$^{th}$ ring.
3. *Status of unused withdrawable control rod channels and ZEBRA rod channels.* Based on Fig. 4.3 of Ref. 11, it was assumed that the unused withdrawable control rod channels and ZEBRA rod channels were filled with graphite, although the safety/shutdown rod channels were left empty.

#### 2.3.2.3 Models for Cores 1 to 3

Four of the HTR-PROTEUS configurations used an HCP arrangement of the pebbles in the core. These configurations, as specified in Table 2.19, were identified as 1, 1a, 2, and 3. The theoretical packing fraction of the pebbles is 0.7045 for this arrangement, though it cannot be achieved in the actual core volume because of the unoccupied spaces in the proximity of the inner cavity outer boundary. The building block used to model the HCP core configurations consisted of a hexagonal prism designed to preserve the geometry and moderator-to-fuel pebble ratio of a given core arrangement, as illustrated in Fig. 2.11. Though the TRISO particles in each fuel pebble were not explicitly modeled, the double heterogeneity of the fuel was accounted for by using the DOUBLEHET option for cross-section processing within SCALE, as described in Section 2.1.2.

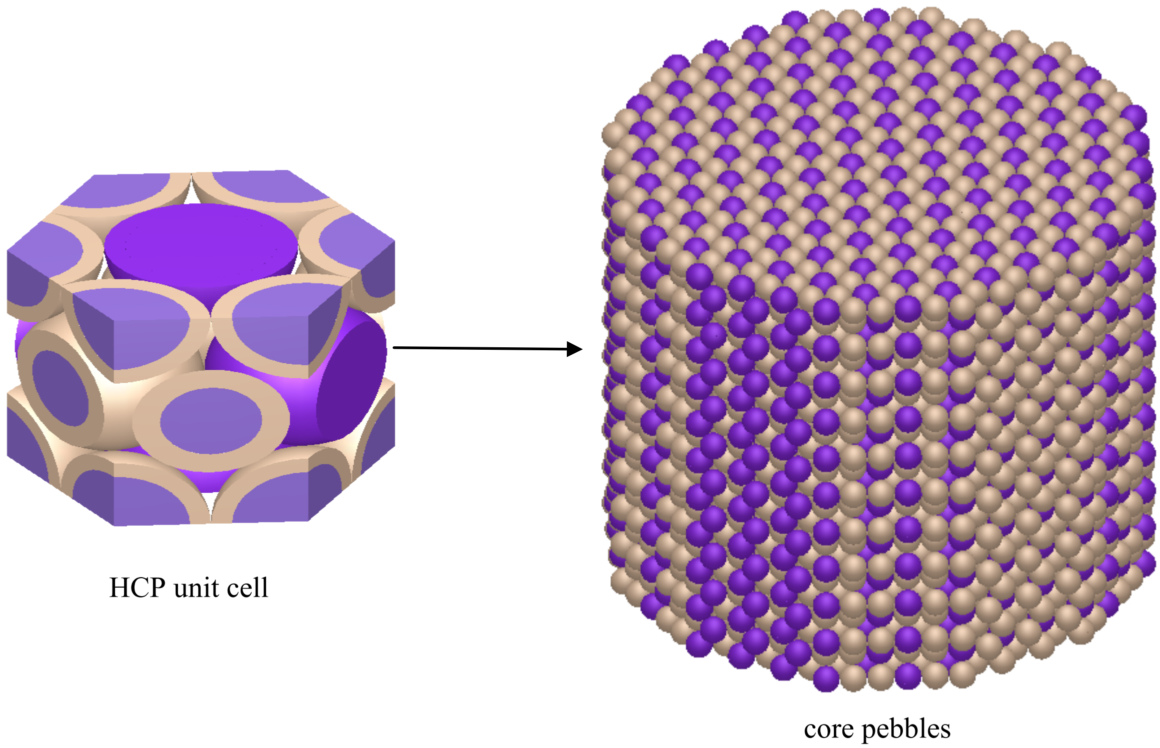



**Fig. 2.11. Core modeling for HCP pebble arrangements.**

Cores 1 and 1a had 22 and 21 pebble layers, respectively, each of the layers with a pebble ratio (fuel-to-moderator) of 2.0. Cores 2 and 3 had 17 and 18 layers of pebbles; the most top layer consisted of only moderator pebbles for Core 2, whereas for Core 3 the topmost layer was partially filled, as illustrated in Fig. 2.12. Another difference between Core 3 and the other three HCP cores is the presence of polyethylene rods inserted vertically in the interstices between pebbles, as shown in Fig 2.12. The purpose in this experiment was to study the effect of water ingress by means of the hydrogen in the polyethylene.

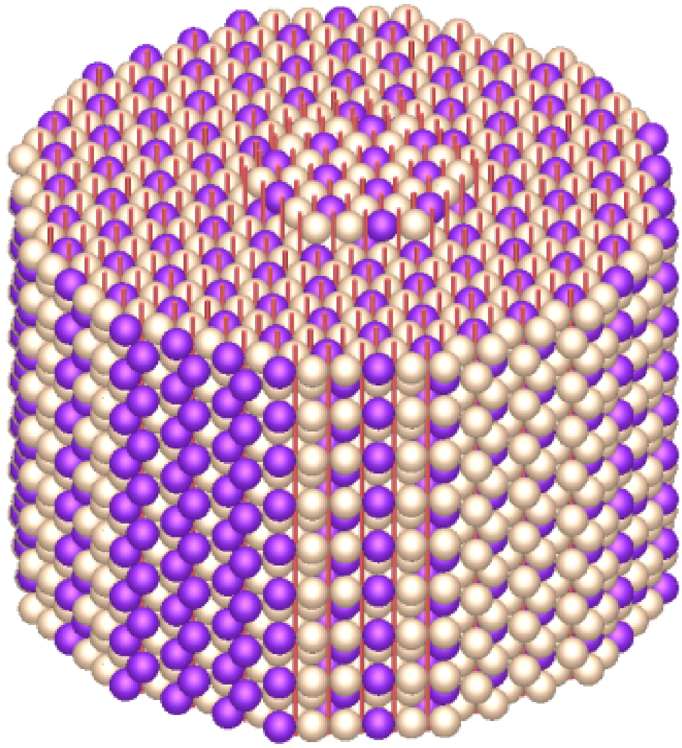


**Fig. 2.12. Pebble modeling for Core 3.**

#### 2.3.2.4 Models for Cores 5 to 10

Cores 5 to 10 used a CHPOP arrangement of the pebbles in the core. The theoretical packing fraction of the pebbles is 0.6046 for this arrangement, though it cannot be achieved in the actual core volume because of the unoccupied spaces in the proximity of the inner cavity outer boundary. The building block used to model the CHPOP core configurations consisted of a hexagonal prism designed to preserve the geometry and moderator-to-fuel pebble ratio of a given core arrangement, as illustrated in Fig. 2.13. The modeling of the top and bottom of the core, as well as of pebbles in proximity to the core boundary, was handled separately. Cores 5 to 8 had more moderator pebbles than fuel pebbles in the topmost pebble layer, as shown in Fig. 2.13 for Core 5. Cores 6, 7, 8, and 10 included polyethylene rods inserted axially between the pebbles. There were differences in dimensions and shapes for the polyethylene rods in these cores. Core 9 in particular was more challenging to model than the others, as it contained seven different types of layer arrangements, as illustrated in Fig. 2.14.

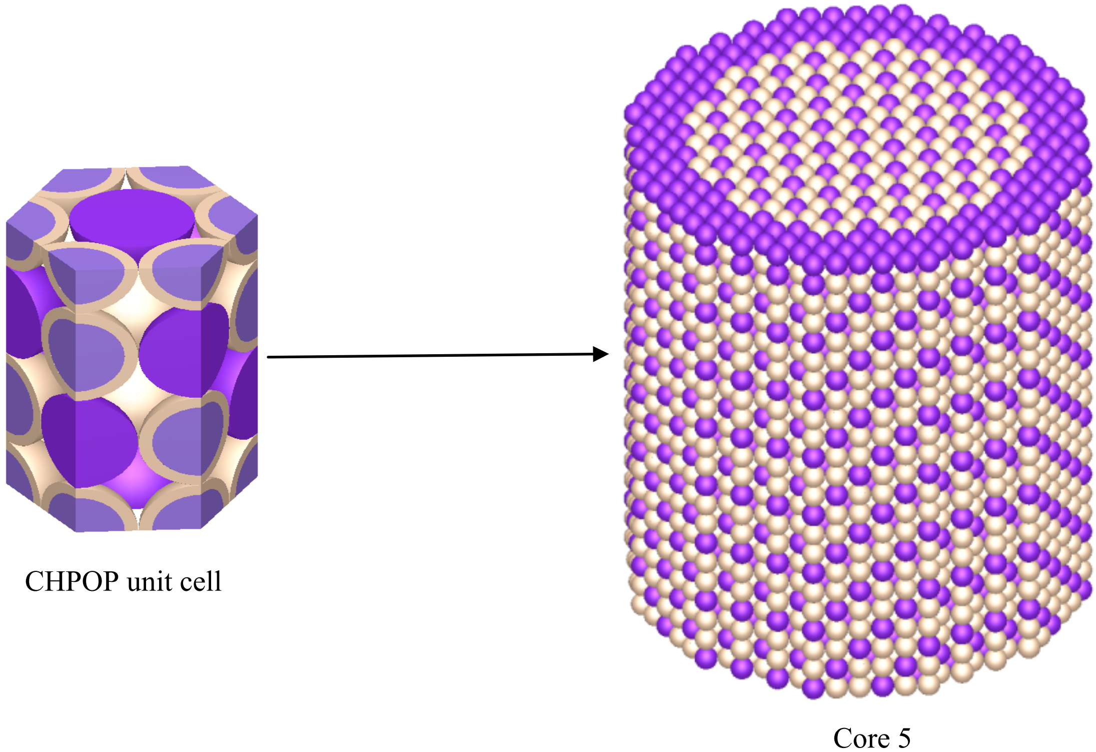



**Fig. 2.13. Core modeling for CHPOP arrangements.**

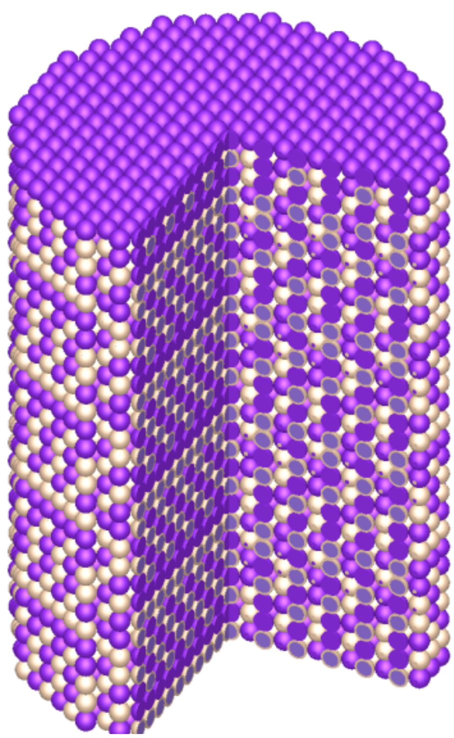


**Fig. 2.14. Pebble modeling for Core 9 state 2.**

### 2.3.3 Comparison with MCNP

The IRPhE draft benchmark provides calculation results for the critical configurations as obtained with MCNP models. [11] Though the MCNP models are not included in the draft benchmark, it is mentioned that the cross sections used with these models were continuous-energy cross sections from ENDF-B/V and ENDF/B-VI. The provided MCNP results for $k_{eff}$ are used for comparison with the corresponding results obtained for the current report with SCALE models.

### 2.3.4 Results

The SCALE/KENO-VI models for the HTR-PROTEUS configurations were used to calculate the $k_{eff}$ values. The results are compared to the MCNP results [11] in Tables 2.22 and 2.23 for the configurations with HCP and CHPOP pebble arrangements, respectively. The SCALE results shown in these tables were obtained using 238-group ENDF/B-VI cross sections, for better consistency with the data that were used with MCNP. The average difference between SCALE and MCNP results for configurations with HCP packing of the pebbles is 252 ± 93 pcm. The average difference between SCALE and MCNP results for configurations with CHPOP packing of the pebbles is 422 ± 93 pcm.

The comparison of SCALE-calculated $k_{eff}$ values to the experimental data provided in Ref. 11 is presented in Tables 2.24 and 2.25. The SCALE results were obtained in these cases using the most recent 238-group ENDF/B-VII cross sections available in SCALE. The average difference between the calculated and benchmark $k_{eff}$ data shown in Tables 2.24 and 2.25 is 797 pcm.

**Table 2.22. $k_{eff}$ results for PROTEUS cores with HCP pebble arrangements**

| | **Core ID** | **1** | **1A (1)** | **1A (2)**[e] | **2** | **3** |
|---|---|---|---|---|---|---|
| SCALE/KENO-VI (ORNL) [a] | $k_{eff}$ | 1.00900 | 1.01078 | 1.00969 | 1.01078 | 1.01145 |
| | $\sigma(k_{eff})$[c] | 0.00120 | 0.00081 | 0.00080 | 0.00099 | 0.00075 |
| MCNP5 (IRPhE) [b] | $k_{eff}$ | 1.00767 | 1.00725 | 1.00753 | 1.00845 | 1.00818 |
| | $\sigma(k_{eff})$ | 0.00022 | 0.00021 | 0.00017 | 0.00023 | 0.00022 |
| $k_{eff}$ difference | $\Delta k_{eff}$ [pcm] [d] | 133 | 353 | 216 | 233 | 327 |
| | $\sigma(\Delta k_{eff})$ [pcm] | 122 | 84 | 82 | 102 | 78 |
| | $\Delta k_{eff}$ [%] | 0.1 | 0.3 | 0.2 | 0.2 | 0.3 |

[a] Used 238-group ENDF/B-VI cross sections.
[b] Used continuous-energy ENDF/B-V or ENDF/B-VI cross sections.
[c] Standard deviation of calculated $k_{eff}$ value.
[d] $\Delta(k_{eff}) = (k^{SCALE} - k^{MCNP})$ ; 1 pcm = $10^{-5}$.
[e] Core identified 1A (see Table 2.19) had two states.

**Table 2.23. $k_{eff}$ results for PROTEUS cores with CHPOP pebble arrangements**

| | Core ID [e] | 5 (1) | 5 (2) | 5 (3) | 6 | 7 | 8 | 9 (1) | 9 (2) | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| SCALE | $k_{eff}$ | 1.00932 | 1.00750 | 1.00715 | 1.01343 | 1.00880 | 1.00841 | 1.00460 | 1.00910 | 1.00697 |
| (ORNL) [a] | $\sigma(k_{eff})$ [c] | 0.00091 | 0.00083 | 0.00079 | 0.00080 | 0.00071 | 0.00088 | 0.00100 | 0.00140 | 0.00088 |
| MCNP5 | $k_{eff}$ | 1.00338 | 1.00286 | 1.00333 | 1.00676 | 1.00678 | 1.00370 | 1.00299 | 1.00325 | 1.00426 |
| (IRPhE) [b] | $\sigma(k_{eff})$ | 0.00018 | 0.00019 | 0.00021 | 0.00017 | 0.00017 | 0.00019 | 0.00019 | 0.00019 | 0.00018 |
| $k_{eff}$ | $\Delta k_{eff}$ [pcm] [d] | 594 | 464 | 382 | 667 | 202 | 471 | 161 | 585 | 271 |
| difference | $\sigma(\Delta k_{eff})$ [pcm] | 93 | 85 | 82 | 82 | 73 | 90 | 102 | 141 | 90 |
| | $\Delta k_{eff}$ [%] | 0.6 | 0.5 | 0.6 | 0.7 | 0.2 | 0.5 | 0.2 | 0.6 | 0.3 |

[a] Used 238-group ENDF/B-VI cross sections.
[b] Used continuous-energy ENDF/B-V or ENDF/B-VI cross sections.
[c] Standard deviation of calculated $k_{eff}$ value.
[d] $\Delta(k_{eff}) = (k^{SCALE} - k^{MCNP})$ ; 1 pcm = $10^{-5}$.
[e] Core 5 had three states and core 9 had two states (see Table 2.19).

**Table 2.24. Comparison of SCALE-calculated $k_{eff}$ to benchmark data for PROTEUS cores with HCP pebble arrangements**

| | Core ID | 1 | 1A (1) | 1A (2) [e] | 2 | 3 |
|---|---|---|---|---|---|---|
| SCALE/KENO-VI | $k_{eff}$ | 1.01117 | 1.01060 | 1.01165 | 1.00998 | 1.00847 |
| (ORNL) [a] | $\sigma(k_{eff})$ [c] | 0.00082 | 0.00099 | 0.00081 | 0.00094 | 0.00079 |
| Benchmark | $k_{eff}$ | 1.00316 | 1.00291 | 1.00371 | 1.00243 | 1.00054 |
| (IRPhE) [b] | $\sigma(k_{eff})$ | 0.00022 | 0.00024 | 0.00072 | 0.00022 | 0.00018 |
| | $\Delta k_{eff}$ [pcm] [d] | 801 | 769 | 794 | 755 | 793 |
| $k_{eff}$ difference | $\sigma(\Delta k_{eff})$ [pcm] | 85 | 102 | 108 | 97 | 81 |
| | $\Delta k_{eff}$ [%] | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |

[a] Used 238-group ENDF/B-VII cross sections.
[b] As reported in Ref. 17.
[c] Standard deviation of calculated $k_{eff}$ value.
[d] $\Delta(k_{eff}) = (k^{SCALE} - k^{MCNP})$ ; 1 pcm = $10^{-5}$.
[e] Core identified 1A (see Table 2.19) had two states.

**Table 2.25. Comparison of SCALE-calculated $K_{eff}$ to benchmark data for PROTEUS cores with CHPOP pebble arrangements**

| | Core ID [e] | 5 (1) | 5 (2) | 5 (3) | 6 | 7 | 8 | 9 (1) | 9 (2) | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| SCALE | $k_{eff}$ | 1.00816 | 1.00748 | 1.00798 | 1.01355 | 1.00945 | 1.00964 | 1.00530 | 1.00868 | 1.00894 |
| (ORNL) [a] | $\sigma(k_{eff})$ [c] | 0.00079 | 0.00083 | 0.00085 | 0.00077 | 0.00088 | 0.00085 | 0.00100 | 0.00079 | 0.00089 |
| Benchmark | $k_{eff}$ | 1.00071 | 1.00071 | 1.00071 | 1.00053 | 1.00053 | 1.00071 | 1.00108 | 1.00108 | 1.00073 |
| (IRPhE) [b] | $\sigma(k_{eff})$ | 0.00014 | 0.00014 | 0.00014 | 0.00024 | 0.00024 | 0.00014 | 0.00024 | 0.00024 | 0.00014 |
| $k_{eff}$ | $\Delta k_{eff}$ [pcm] [d] | 745 | 677 | 727 | 1302 | 892 | 893 | 422 | 760 | 821 |
| difference | $\sigma(\Delta k_{eff})$ [pcm] | 80 | 84 | 86 | 81 | 91 | 86 | 103 | 83 | 90 |
| | $\Delta k_{eff}$ [%] | 0.7 | 0.7 | 0.7 | 1.3 | 0.9 | 0.9 | 0.4 | 0.8 | 0.8 |

[a] Used 238-group ENDF/B-VII cross sections.
[b] As reported in Ref. 17.
[c] Standard deviation of calculated $k_{eff}$ value.
[d] $\Delta(k_{eff}) = (k^{SCALE} - k^{MCNP})$ ; 1 pcm = $10^{-5}$.
[e] Core 5 had three states and core 9 had two states (see Table 2.19).

# 3. SCALE VALIDATION FOR HTGRs—PRISMATIC FUEL DESIGN

Verification and validation studies performed to evaluate the SCALE analysis of HTGRs with prismatic fuel design was carried out to large extent using experimental data available for the HTTR. The documentation describing the measurements performed at HTTR is available from reactor physics benchmarks that were published in the IRPhE in 2009, 2010, and 2011 [6, 7, 8, 9].

The HTTR is a 30 MWth, prismatic core, graphite-moderated, helium-cooled reactor that was built by the Japan Atomic Energy Agency (JAEA). The first criticality of the HTTR was achieved with an annular core on November 10, 1998, while full core criticality was attained on December 16, 1998. At full power, the reactor can supply 950 °C helium that can be further used for high temperature applications. The 950 °C coolant temperature was first achieved on April 19, 2004, for a short time. At the beginning of 2010, the reactor was operated at 950 °C for a period of 50 days. Each of these maximum designed high temperature operations were preceded by 850 °C full power tests (achieved for a short time on December 7, 2001, and then for a period of 30 days in 2007). The core of this reactor consists of prismatic fuel blocks that use TRISO fuel with 12 different fuel enrichments, between 3.4 and 9.9 wt % $^{235}$U.

The analyses performed for an HTTR prismatic fuel block are first discussed in this section, including a few modeling considerations for the annular fuel pin that is characteristic of the HTTR design. Then the analyses and results obtained for the HTTR critical and subcritical configurations are presented in detail.

## 3.1 ANALYSIS OF HTTR FUEL BLOCK

### 3.1.1 Description of the HTTR Fuel Block

The HTTR fuel blocks are hexagonal prisms that can contain either 31 or 33 pins. The fuel block analyzed in this section was a 33-pin block with TRISO fuel at 6.3 wt % $^{235}$U enrichment and containing burnable poison (BP) rods with 2.5% $^{10}$B content. Only the main characteristics of the fuel block considered for analysis are summarized in Table 3.1. Detailed specifications for the HTTR fuel blocks can be found in Ref. 6.

**Table 3.1. Fuel block main characteristics**

| Parameter | Value |
|---|---|
| Shape | Hexagonal prism |
| Height (cm) | 58 |
| Side to side distance (cm) | 36 |
| Number of fuel pins | 31 or 33 |
| Fuel pin inner radius (cm) | 0.5 |
| Fuel pin outer radius (cm) | 1.3 |
| Fuel pin pitch—triangular (cm) | 5.15 |
| Fuel pin height (cm) | 54.6 |
| Number of burnable poison pins | 2 |
| Burnable poison pin radius (cm) | 0.7 |
| Mass of uranium per fuel pin (g) | 188.58 |

Each of the 33 fuel pins is annular and contains 12,987 TRISO fuel particles embedded in a graphite matrix, for a total mass of 188.58 ± 5.66 g of uranium per pin. Each fuel pin is enclosed in a graphite sleeve, with helium circulated outside this sleeve. There are 14 annular TRISO fuel compacts, each 3.9 cm high, stacked on top of each other in a fuel pin, for a total fuel pin height of 54.6 cm. The TRISO fuel particle is made of a relatively large, spherical fuel kernel with 0.03 cm radius that is surrounded by four layers of carbon or silicon carbide. The dimensions of the different layers of the TRISO fuel grains are listed in Table 3.2. The isotopic material composition for all the materials used in the fuel block model, as obtained from Ref. 6, are summarized in Table 3.3.

**Table 3.2. Fuel particle data for HTTR**

| Zone Description | Material | Outer Radius (μm) |
|---|---|---|
| Fuel kernel | $UO_2$ | 300 |
| Buffer layer | Graphite | 360 |
| Inner pyrolitic carbon layer | Graphite | 390 |
| SiC layer | Silicon carbide | 415 |
| Outer pyrolitic carbon layer | Graphite | 460 |
| Matrix | Graphite | N/A |

**Table 3.3. Material data for 6.3 wt % $^{235}$U enriched HTTR fuel block**

| Component | Material | Composition | Number density (atoms cm$^{-1}$ b$^{-1}$) | Density (g/cm$^3$) |
|---|---|---|---|---|
| Fuel kernel (6.3 wt % $^{235}$U) | $UO_2$ | $^{234}$U<br>$^{235}$U<br>$^{236}$U<br>O<br>$^{10}$B | 1.1293 x 10$^{-5}$<br>1.4783 x 10$^{-3}$<br>2.1699 x 10$^{-2}$<br>4.6343 x 10$^{-2}$<br>1.7276 x 10$^{-7}$ | 10.39 |
| Buffer layer | graphite | C<br>$^{10}$B | 5.5153 x 10$^{-2}$<br>1.8290 x 10$^{-8}$ | 1.1 |
| IPyC layer | graphite | C<br>$^{10}$B | 9.2758 x 10$^{-2}$<br>3.0761 x 10$^{-8}$ | 1.85 |
| SiC layer | SiC | C<br>Si<br>$^{10}$B | 4.8061 x 10$^{-2}$<br>4.8061 x 10$^{-2}$<br>5.3208 x 10$^{-8}$ | 3.2 |
| OPyC layer | graphite | C<br>$^{10}$B | 9.2758 x 10$^{-2}$<br>3.0761 x 10$^{-8}$ | 1.85 |
| Graphite compact [a] | graphite | C<br>$^{10}$B | 8.5237 x 10$^{-2}$<br>1.5452 x 10$^{-8}$ | 1.7 |
| Graphite (IG-110) in fuel block | graphite | C<br>$^{10}$B | 8.8243 x 10$^{-2}$<br>7.8036 x 10$^{-9}$ | 1.74 |
| Burnable poison pin (2.5 wt %) | $B_4C$ in graphite | C<br>$^{10}$B<br>$^{11}$B | 8.7995 x 10$^{-2}$<br>4.9882 x 10$^{-4}$<br>2.0078 x 10$^{-5}$ | 1.247 |
| Helium coolant | He | He | 2.4616 x 10$^{-5}$ | 0.000164 |

[a] Values included in Ref. 6 are 0.5% smaller; the model used in Ref. 6 does not include the fuel handling positions, but it accounts for them using a 0.5% reduction in the nominal graphite density.

### 3.1.2 Computational Model for the HTTR Fuel Block

A 3-D model of the HTTR fuel block described previously was developed with SCALE/KENO-VI. Cross sectional and axial views of this model are illustrated in Fig. 3.1. In this report, the locations of the fuel and burnable absorber pins in the cross-sectional view of the fuel block are identified using the format *mn*, with *m* identifying the row from the bottom to the top in Fig. 3.1(a) and *n* identifying the position on the row from left to right (e.g., “11” identifies the BP pin in the lower left corner; “12” is the fuel pin to its right; “44” is the handling hole; and “47” is the empty BP location).

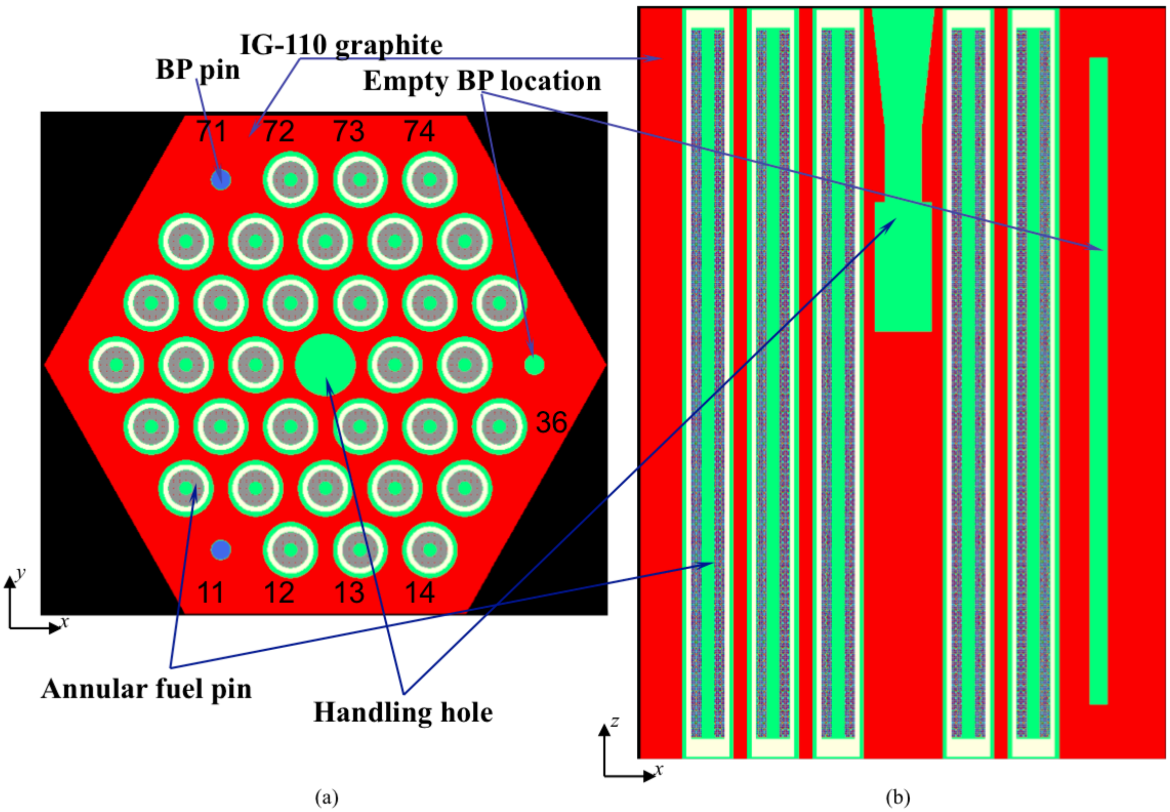



**Fig. 3.1. (a) Cross-sectional and (b) vertical views of the HTTR fuel block.**

One important feature of the HTTR fuel block design is the spatial double heterogeneity. The first level of heterogeneity consists of the distribution of the TRISO particles inside the fuel compact, while the second level is represented by the lattice of fuel pins in the fuel block. In modeling the first level of heterogeneity, the parameter that primarily needs to be conserved is the amount of fuel per fuel pin, which is 188.58 ± 5.66 g uranium for fresh HTTR fuel [6].

### 3.1.2.1 Fuel pin modeling for continuous-energy calculations

A fuel block model was developed to represent fuel particles in detail and treat the neutron transport using continuous-energy (CE) cross-section data with SCALE/KENO-VI. The distribution of the fuel particles was modeled using a regular lattice representation. One method to conserve the fuel mass in a lattice representation of the fuel particles would be to fully include the lattice of fuel grains within the fuel pin. In using this approach, however, the lattice model must have a smaller pitch than the actual value to avoid the clipping of the TRISO particles at the boundaries of the fuel pin. This will create a different spatial distribution (and different local packing fraction) of the TRISO particles, with the regions near the boundaries of the pin containing no TRISO particles. A rigorous random placement (not based on a lattice) of the individual TRISO particles within the fuel pin that also preserves the mass of fuel can be used and has been previously demonstrated [30]. However, because the number of TRISO particles is very large (~5 million per fuel block in this case), this latter modeling approach is computationally feasible only for small configurations (e.g., single fuel compact).

An alternative approach was proposed by Ilas and Gehin to mitigate the above-mentioned modeling concerns [31], which conjectured to conserve the mass in a fuel pin in a statistical sense, while also preserving the uniform spatial distribution by shifting the lattice using a random vector with components smaller than half the size of the lattice pitch. This is the approach used for the CE model in this report.

This approach alleviates the error due to the shift of the lattice of grains within the fuel pin boundaries, an error that was pointed out by Žáková and Talamo [32].

#### 3.1.2.2 Fuel pin modeling for multigroup calculations

A fuel block SCALE/KENO-VI model was developed for use in calculations with a multigroup cross-section library. The double heterogeneity of the fuel was accounted for in this model through the use of the DOUBLEHET option in SCALE for cross-section processing. Details about this cross-section processing approximation are included in Section 2.1.2 of this report. In this approximation, both the mass of fuel and its uniform spatial distribution are rigorously preserved. Availability of a multigroup model is very important for depletion simulations, sensitivity/uncertainty problems, or simply as a replacement for the more rigorous but longer-running continuous energy models. The multigroup option is at this time the only available option in SCALE for sensitivity/uncertainty analysis and for depletion calculations.

The DOUBLEHET treatment in SCALE, however, is presently available only for solid cylindrical pins. Therefore, for annular cylindrical pins as characteristic to the HTTR core, additional geometry approximations [31] need to be made before a double-heterogeneous treatment can be applied to the generation of the multigroup cross-section libraries for use with SCALE/KENO-VI. The approximation used in this report consisted of transforming the annular pin into a solid cylindrical pin by homogenizing the graphite matrix in the fuel regions with the inside and the outside helium regions. This approximation is used both for applying the double-heterogeneous treatment to the cross-section processing and in the transport geometry model of the problem input.

### 3.1.3 Results for the HTTR Fuel Block

The results obtained with SCALE/KENO-VI for both continuous energy and multigroup models are compared to corresponding results obtained with MCNP5 for eigenvalue and fission source distribution. The fuel block configuration illustrated in Fig. 3.1 was modeled with both SCALE/KENO-VI and MCNP5. Because the double-heterogeneity procedure for cross-section processing does not support annular pins as noted above, the annular fuel was homogenized with the central hole to form a solid cylindrical pin for the multigroup option in SCALE/KENO-VI. To assess the possible uncertainty introduced by this homogenization, the same configurations with homogenized pins were modeled with continuous energy SCALE/KENO-VI.

#### 3.1.3.1 Multiplication constant

The values obtained for the multiplication constant $k_{eff}$ are presented in Table 3.4. As seen, there is an excellent agreement between the SCALE/KENO-VI CE and MCNP5 models, with a difference in $k_{eff}$ of 85 ± 35 pcm. The $k_{eff}$ difference between the MG and CE SCALE/KENO-VI models is 336 ± 37 pcm. The homogenization of the fuel pins with their central holes (see cases 1 and 4 in Table 3.4) leads to a small overestimation of the $k_{eff}$ result, of 68 ± 37 pcm. The axial homogenization of the central handling hole has virtually no effect on the multiplication constant (see cases 1 and 5 in Table 3.4), the difference being 22 ± 35 pcm.

The last column of Table 3.4 compares the CPU time for each calculation. The MCNP5 code used the OpenMPI-compiled parallel version. Both the SCALE/KENO-VI and the MCNP5 simulations used 11 million particles, with 110 generations (cycles), first 10 generations skipped, and 100,000 particles per generation. As seen, the multigroup version of SCALE/KENO-VI is more than three times faster than the continuous energy version for the same number of particles simulated.

**Table 3.4. Multiplication constants for different models of the HTTR fuel block**

| Case # | Description [a] | $k_{eff}$ | $\sigma_k$ [b] | CPU time [c] (hours) |
|---|---|---|---|---|
| 1 | SCALE/KENO-VI CE | 1.33186 | 0.00027 | 14.0 |
| 2 | SCALE/KENO-VI MG | 1.32850 | 0.00025 | 4.3 |
| 3 | MCNP5 CE | 1.33101 | 0.00024 | 142.5* |
| 4 | SCALE/KENO-VI CE with homogenized pins | 1.33254 | 0.00026 | 13.8 |
| 5 | SCALE/KENO-VI CE with homogenized handling hole | 1.33164 | 0.00022 | 14.0 |
| 6 | SCALE/KENO-VI CE with periodic boundary conditions | 1.32325 | 0.00033 | 14.0 |

[a] CE = continuous energy cross sections; MG = 238-group cross sections.
[b] Standard deviation in $k_{eff}$.
[c] SCALE cases were run on single processor (CPU) using the prelease version of SCALE 6.1. MCNP5 version 1.51 was run on a parallel cluster and included fuel pin mesh tally computations.

Calculations for cases 1 through 5 in Table 3.4 were performed using reflective boundary conditions on the outer boundary, in accordance with the current lattice level methodology for light water reactors. The application of a white boundary condition (results not shown) has virtually no effect on the multiplication constant, as expected. The use of a periodic boundary condition (case 6 in Table 3.4), however, seems to have a relatively large effect; the multiplication constant in this case is with 861 ± 43 pcm lower than that for the case when a reflective boundary condition was used (case 2 in Table 3.4). This difference is due to the different virtual positions of the BP pins around the fuel block when the periodic boundary condition is used as opposed to the reflective boundary condition.

### 3.1.3.2 Fission density distribution

Pin fission density distributions were calculated using three models: (1) MCNP5 CE, (2) SCALE/KENO-VI CE, and (3) SCALE/KENO-VI MG. In all three cases, a reflective boundary condition was used on the outer boundary.

The 3-D distribution of the fission density in all 33 fuel pins, as calculated with the SCALE/KENO-VI MG model and illustrated using the Keno3D plotting software, is shown in Fig. 3.2. Each axial zone corresponds to a fuel compact, in which the fission density was averaged. The color-coded values for fission density clearly suggest that the distribution peaks at the top and bottom of the pins furthest from the BP pins.

The radial-azimuthal distribution of the calculated fission density in each pin for each of the three models is illustrated in Fig. 3.3. The symmetry of the fuel block was taken into account to reduce the number of distinct pins from 33 to 19. In accord with the pin numbering convention introduced in Section 3.1.2, each decade on the abscissa axis in Fig. 3.3 corresponds to a row of pins in Fig. 3.1, from row 1 to row 4.

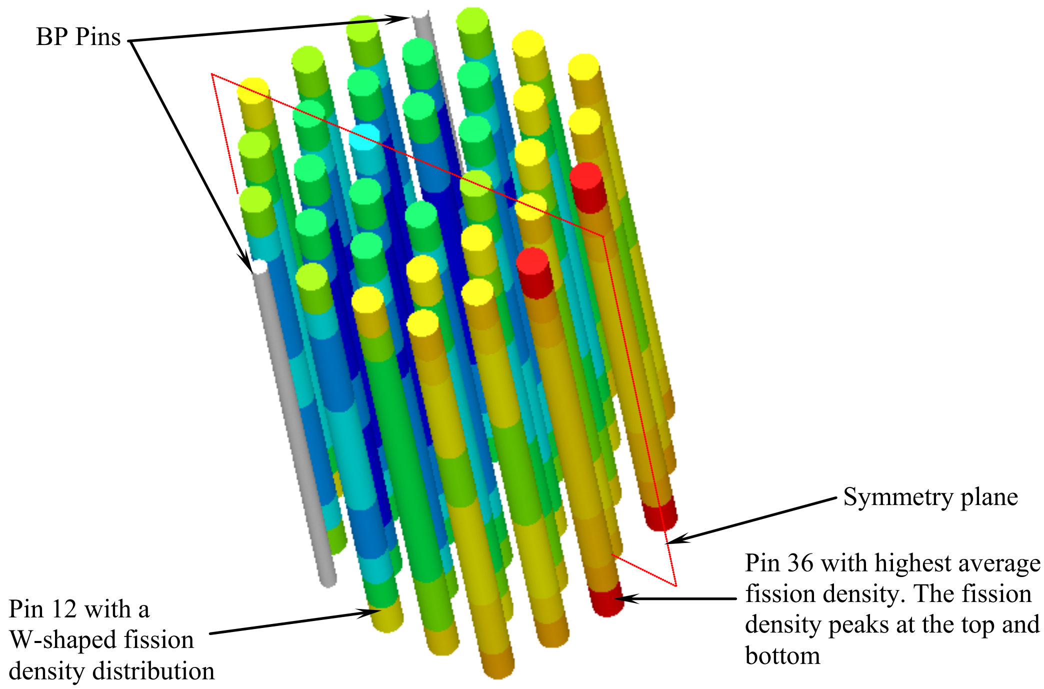



**Fig. 3.2. Three-dimensional pin fission density distribution in the HTTR fuel block with SCALE/KENO MG.**

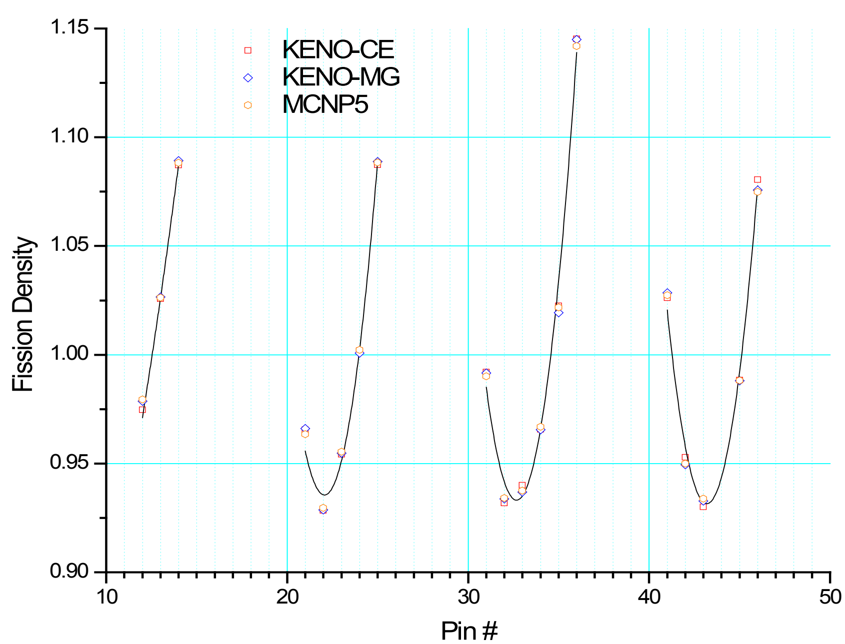



**Fig. 3.3. Pin fission density distribution in the HTTR fuel block with three models.**

As seen in Fig. 3.3, the three models listed above show an excellent agreement in calculated pin fission density. The differences in data obtained with these models are small, below 1% between their predictions for all the pins, and are hardly visible on the plot. The statistical errors are negligibly small (~0.1%) and are not shown. The fission density peaks in pin 36, which is the furthest from the BP pins. It is interesting to notice the parabolic shape of the fission density distribution in each row of pins; a parabolic fit of the data points resulted in a goodness-of-fit coefficient ($R^2$ value) better than 0.99. The parabolic shape distribution of the fission source density is important, as it provides grounds for the use of a (second-order) polynomial function in *x* and *y* to describe the neutron flux in a nodal code. Fig. 3.3 shows the fitting parabolas for the SCALE/KENO-VI CE values only; the shapes for the other two models are similar.

The axial fission density distribution takes a cosine shape with a minimum at the middle of the pin (as opposed to an LWR fission density distribution, which usually peaks at the middle) when the fuel pin is far from the BP pins. However, the fission density is "W" shaped for fuel pins near the BP pin as a result of the graphite region in the middle of the BP pins, as illustrated in Fig. 3.4 for pin 12 (symmetric with pin 72), which is located near the BP pin. The same good agreement (differences no larger than 1%) between SCALE/KENO-VI values and MCNP values as seen axially was also observed radially.

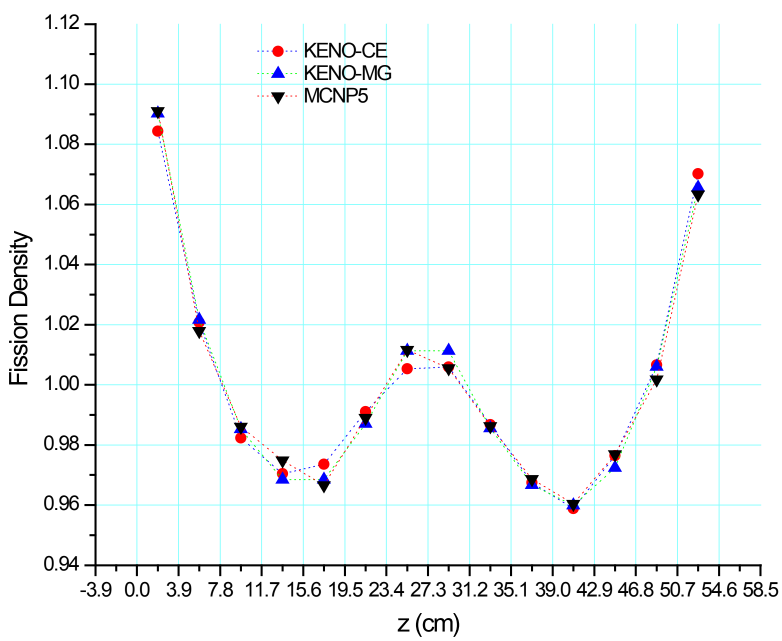



**Fig. 3.4. Axial fission density distribution in pin 12 of the HTTR fuel block.**

As seen for the multiplication constant, the use of a periodic boundary condition instead of a reflective one leads to large changes in fission density distribution, by as much as 7% for pin 36, which is near the empty BP location. For a periodic boundary condition, the fission density has almost equal values in pins 13, 36, and 41. Also, this boundary condition leads to a flatter pin fission density distribution throughout the fuel block. The large differences in fission density distribution, together with the large difference in the multiplication eigenvalue predicted with the periodic boundary condition, demonstrate the importance of using the correct boundary conditions for the fuel block calculations.

## 3.2 ANALYSIS OF CONFIGURATIONS CONTAINING HTTR FUEL BLOCKS

A number of core configurations built with HTTR-like fuel blocks were analyzed with SCALE/KENO-VI to assess the effect on $k_{eff}$ of gradual changes in these configurations, from simpler to more complex cores. It also served in assessing the effect on $k_{eff}$ results of SCALE/KENO-VI modeling assumptions as a function of core complexity. The considered cores consisted of four quasi–2-D problems (labeled "Core 1" through "Core 4" and described below) that resemble one-block layers of the HTTR core.

### 3.2.1 Core 1

This problem consisted of 6.3% enriched identical HTTR fuel blocks arranged in five rings (counting also the central block as a ring), surrounded by one ring of radial reflector blocks as shown in Fig. 3.5. All the fuel blocks had the same rotational orientation. Vacuum boundary conditions were assumed for the lateral surfaces, and reflective boundary conditions were used for the top and bottom surfaces. This configuration would be a difficult problem for a diffusion code because of the large lateral leakage.

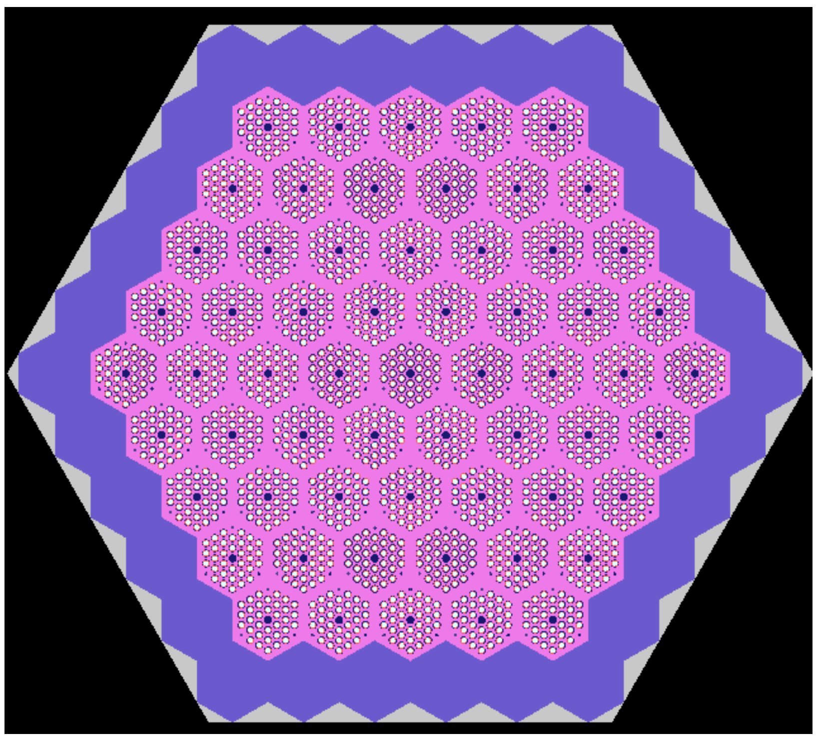


**Fig. 3.5. Horizontal layout of Core 1.**

The multiplication constants obtained for this configuration with the multigroup and continuous energy SCALE/KENO-VI models are shown in Table 3.5. As seen, the difference between the multigroup and the continuous energy models is

$\Delta k = k_{MG} - k_{CE} = -219 \pm 38$ pcm .

**Table 3.5. Multiplication constants for Core 1**

| Model[a] | $k_{eff}$ | $\sigma^b$ |
|---|---|---|
| SCALE/KENO-VI MG | 1.21715 | 0.00023 |
| SCALE/KENO-VI CE | 1.21934 | 0.00030 |

[a] MG = multigroup; CE = continuous energy.
[b] Standard deviation of $k_{eff}$.

### 3.2.2 Core 2

The Core 2 problem is similar to the Core 1 problem, but contains four rings of fuel blocks and two rings of radial graphite blocks, as illustrated in Fig. 3.6. This configuration, therefore, diminishes the lateral neutron leakage by increasing the amount of reflector graphite, compared to Core 1. Vacuum boundary conditions are used on the outer lateral surfaces, and reflective boundary conditions are applied at the top and bottom of the configuration. The multiplication constants obtained for this configuration, for which both continuous energy and multigroup models were created, are shown in Table 3.6. The difference between the multigroup and the continuous energy models is

$\Delta k = k_{MG} - k_{CE} = -294 \pm 36$ pcm .

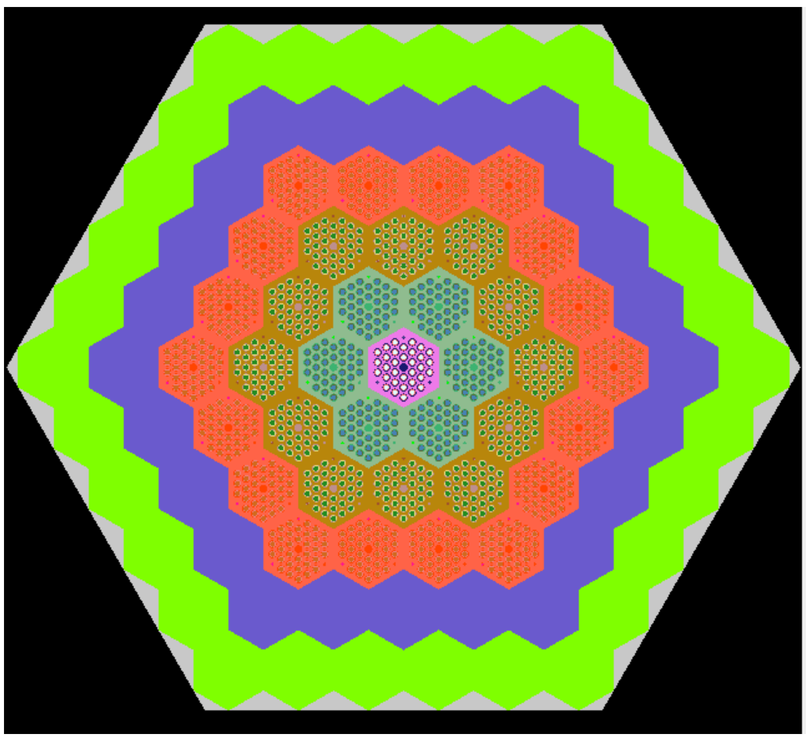


**Fig. 3.6. Horizontal layout of Core 2 showing the radial tally regions.**

**Table 3.6. Multiplication constants for Core 2**

| Model[a] | $k_{eff}$ | $\sigma^b$ |
|---|---|---|
| SCALE/KENO-VI MG | 1.20879 | 0.00024 |
| SCALE/KENO-VI CE | 1.21173 | 0.00027 |

[a] MG = multigroup; CE = continuous energy.
[b] Standard deviation of $k_{eff}$.

In addition to the multiplication constants, the radial distribution of the neutron scalar flux in 23 groups was calculated for this configuration. The flux results are presented in Table 3.7 and illustrated in Fig. 3.7. For the purpose of this calculation, the test problem was divided into seven concentric rings (see Fig. 3.6)—a central fuel block, three fuel rings numbered 1 to 3, two reflector rings, and the outer void. Each column of Table 3.7 and each curve on the plot in Fig. 3.7 correspond to one of these regions. The SCALE/KENO-VI transport calculation was performed using a 238-group cross-section library, and the obtained 238-group fluxes were later collapsed to 23 groups.

The neutron spectrum in the central fuel block is almost identical with that in the first ring blocks and therefore is barely distinguishable on Fig. 3.7. As observed, the 23-group spectrum in the four radial regions that contain fuel is fairly constant. The highest thermal spectrum is obtained in the first ring of radial reflector. The flux decreases rapidly, by about one order of magnitude, outside the core (the void region, made up of the triangular regions just outside of the radial reflector).

**Table 3.7. Flux spectrum in 23-group structure for Core 2**

| Group # | Upper Energy (eV) | Center Fuel Block | Ring 1 Fuel | Ring 2 Fuel | Ring 3 Fuel | Reflector Ring 1 | Reflector Ring 2 | Outer Void |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.00E+07 | 1.48E-13 | 1.40E-13 | 1.20E-13 | 9.36E-14 | 1.06E-14 | 5.37E-16 | 1.01E-16 |
| 2 | 3.00E+06 | 5.08E-12 | 4.79E-12 | 4.12E-12 | 3.16E-12 | 3.78E-13 | 1.30E-14 | 1.54E-15 |
| 3 | 1.36E+06 | 1.48E-11 | 1.40E-11 | 1.20E-11 | 9.00E-12 | 1.28E-12 | 4.46E-14 | 3.47E-15 |
| 4 | 5.00E+05 | 4.29E-11 | 4.05E-11 | 3.48E-11 | 2.54E-11 | 4.19E-12 | 1.56E-13 | 9.10E-15 |
| 5 | 1.00E+05 | 1.24E-10 | 1.17E-10 | 1.00E-10 | 7.19E-11 | 1.33E-11 | 5.32E-13 | 2.98E-14 |
| 6 | 6.00E+04 | 3.38E-10 | 3.19E-10 | 2.74E-10 | 1.93E-10 | 4.00E-11 | 1.75E-12 | 8.90E-14 |
| 7 | 9.50E+03 | 3.31E-09 | 3.12E-09 | 2.68E-09 | 1.83E-09 | 4.56E-10 | 2.55E-11 | 1.30E-12 |
| 8 | 3.05E+02 | 1.11E-07 | 1.05E-07 | 8.98E-08 | 6.01E-08 | 1.93E-08 | 1.53E-09 | 8.79E-11 |
| 9 | 4.00E+00 | 2.72E-06 | 2.56E-06 | 2.18E-06 | 1.46E-06 | 5.69E-07 | 5.64E-08 | 3.31E-09 |
| 10 | 1.50E+00 | 5.45E-06 | 5.16E-06 | 4.39E-06 | 2.95E-06 | 1.16E-06 | 1.22E-07 | 8.11E-09 |
| 11 | 1.10E+00 | 6.61E-06 | 6.24E-06 | 5.31E-06 | 3.57E-06 | 1.42E-06 | 1.52E-07 | 9.35E-09 |
| 12 | 1.05E+00 | 7.11E-06 | 6.70E-06 | 5.70E-06 | 3.83E-06 | 1.53E-06 | 1.65E-07 | 9.63E-09 |
| 13 | 9.75E-01 | 7.93E-06 | 7.47E-06 | 6.36E-06 | 4.28E-06 | 1.72E-06 | 1.86E-07 | 1.16E-08 |
| 14 | 8.50E-01 | 1.15E-05 | 1.09E-05 | 9.23E-06 | 6.22E-06 | 2.52E-06 | 2.84E-07 | 1.77E-08 |
| 15 | 5.00E-01 | 1.82E-05 | 1.71E-05 | 1.46E-05 | 9.80E-06 | 4.08E-06 | 4.77E-07 | 3.24E-08 |
| 16 | 4.00E-01 | 2.28E-05 | 2.16E-05 | 1.83E-05 | 1.24E-05 | 5.25E-06 | 6.34E-07 | 4.32E-08 |
| 17 | 3.50E-01 | 2.77E-05 | 2.62E-05 | 2.22E-05 | 1.51E-05 | 6.57E-06 | 8.30E-07 | 6.01E-08 |
| 18 | 3.00E-01 | 3.55E-05 | 3.35E-05 | 2.84E-05 | 1.93E-05 | 9.01E-06 | 1.27E-06 | 9.38E-08 |
| 19 | 2.50E-01 | 5.76E-05 | 5.43E-05 | 4.60E-05 | 3.24E-05 | 1.86E-05 | 3.79E-06 | 3.45E-07 |
| 20 | 1.75E-01 | 9.52E-05 | 8.92E-05 | 7.57E-05 | 5.60E-05 | 4.12E-05 | 1.10E-05 | 1.09E-06 |
| 21 | 1.50E-01 | 1.58E-04 | 1.49E-04 | 1.27E-04 | 1.01E-04 | 9.80E-05 | 3.14E-05 | 3.33E-06 |
| 22 | 1.00E-01 | 3.04E-04 | 2.86E-04 | 2.44E-04 | 2.19E-04 | 3.06E-04 | 1.14E-04 | 1.22E-05 |
| 23 | 5.00E-02 | 2.71E-04 | 2.55E-04 | 2.19E-04 | 2.29E-04 | 4.72E-04 | 1.95E-04 | 2.09E-05 |

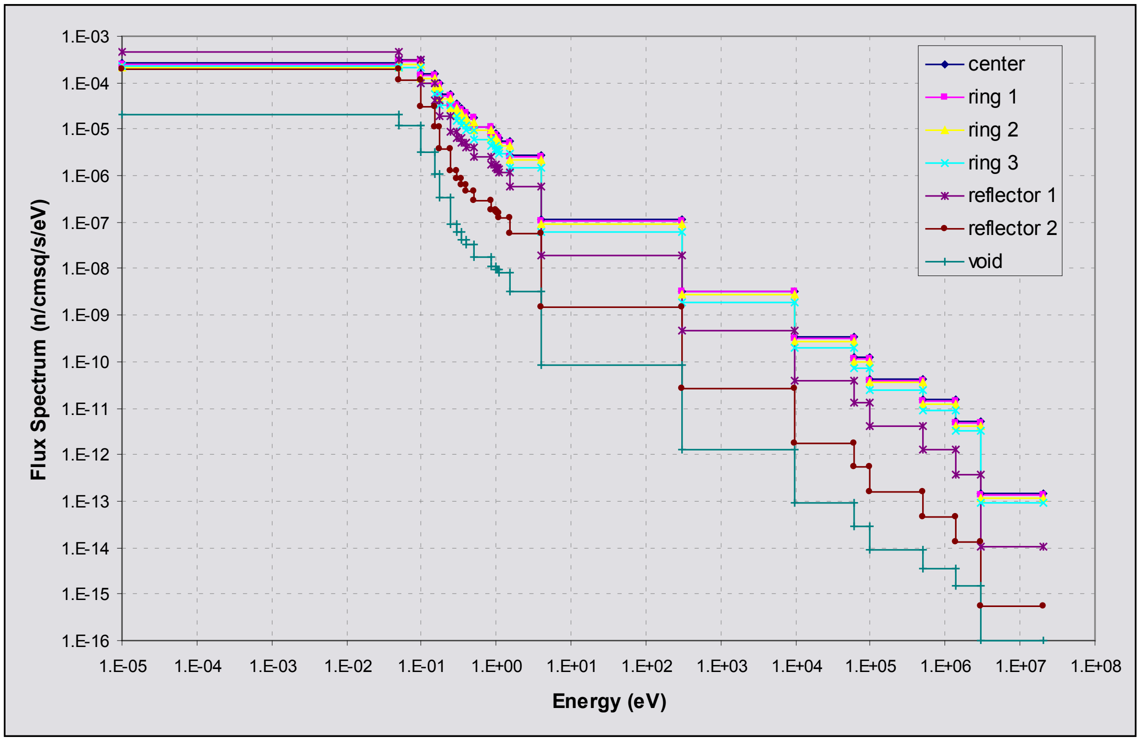



**Fig. 3.7. Flux distribution (23-group) in radial regions of Core 2.**

### 3.2.3 Core 3

The Core 3 problem represents the same fuel block distribution as in the midplane of the actual HTTR core, but has two rings of radial graphite. The control rod blocks in the real HTTR midplane were replaced with graphite blocks. This configuration, therefore, adds an additional level of heterogeneity over the previous Core 2. As for the previous cases, vacuum boundary conditions were iused on the lateral surface and reflective boundary conditions at the top and bottom of the configuration.

This configuration was used to assess the importance of a correct modeling of the fuel block orientation on the $k_{eff}$ results for the core. As illustrated in Fig 3.8, two cases were studied: (1) a case labeled "rotated" that corresponds to the actual arrangement of the fuel blocks at the middle of the HTTR core and (2) a case labeled "not rotated" that corresponds to a hypothetical arrangement of the fuel blocks, in which these have a fixed orientation.

The results for the multiplication constants for the two cases, each case assessed with both the multigroup and the continuous energy models, are presented in Table 3.8. As observed, the "not rotated" setup leads to a significant increase, of approximately 1% (or 1000 pcm), in the multiplication constant. The difference between the multigroup and the continuous energy models for the correct configuration ("rotated") is

$\Delta k = k_{MG} - k_{CE} = -351 \pm 39$ pcm .

The difference between the "rotated" and the "not rotated" cases is significant. The large difference between these two cases can be explained by carefully inspecting the corresponding input files and configurations details. As seen in the detailed configuration in Fig. 3.9, there are four instances in the "not rotated" case in which the boron pin (BP) positions (marked with a red circle, as opposed to the empty position, which is yellow) are close to each other. This creates a "shadowing" effect between the two BP pins, which reduces their effectiveness as a neutron absorber. In other words, the two neighbors compete for the same thermal neutrons. This leads to a decrease in the absorption rate and, consequently, to an increase in $k_{eff}$ for the "not rotated" case.

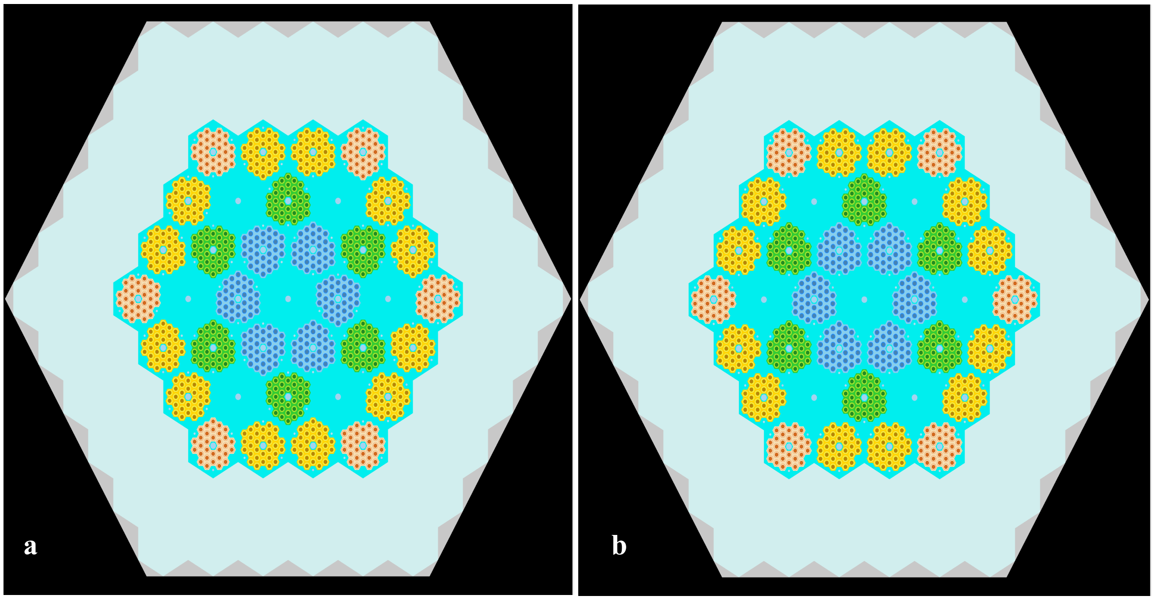



**Fig. 3.8. Horizontal layout of Core 3 with (a) "rotated" and (b) "not rotated" configurations.**

**Table 3.8. Multiplication constants for Core 3**

| Model [a] | Rotated blocks | | Not rotated blocks | |
|---|---|---|---|---|
| | $k_{eff}$ | $\sigma$[b] | $k_{eff}$ | $\sigma$[b] |
| SCALE/KENO-VI MG | 1.17700 | 0.00024 | 1.18843 | 0.00027 |
| SCALE/KENO-VI CE | 1.18051 | 0.00031 | 1.19117 | 0.00031 |

[a] MG = multigroup; CE = continuous energy.
[b] Standard deviation of $k_{eff}$.

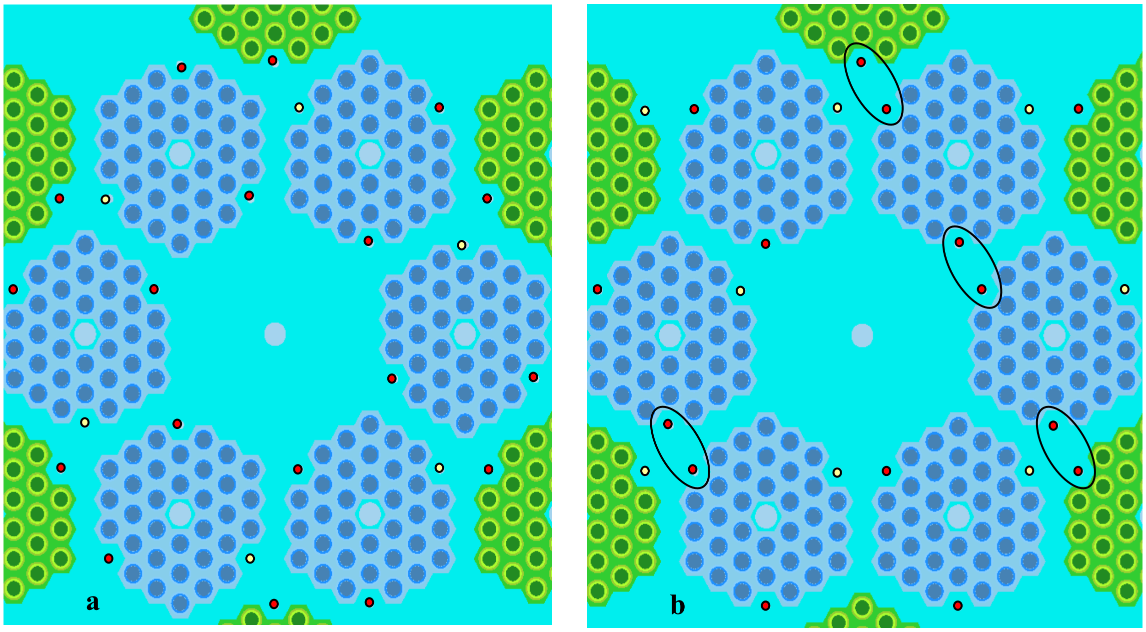



**Fig. 3.9. Detail of Core 3 for (a) "rotated" and (b) "not rotated" setups.**

### 3.2.4 Core 4

The Core 4 problem, illustrated in Fig. 3.10, represents the same fuel block distribution as in the midplane of the real HTTR core, with two rings of radial graphite. Compared to Core 3, the control rod blocks as in the real HTTR midplane were explicitly modeled. This configuration, therefore, further adds a level of heterogeneity over the previous Core 3. As for the previous cases, vacuum boundary conditions were applied on the lateral surface and reflective boundary conditions at the top and bottom of the configuration.

The multiplication constants obtained for Core 4 for two cases—with control rods in and control rods out, for which both continuous energy and multigroup models were created—are presented in Table 3.9. The difference between the multigroup and the continuous energy models is

$\Delta k = k_{MG} - k_{CE}$ = -307 ± 35 pcm (control rods out) ,
$\Delta k = k_{MG} - k_{CE}$ = -268 ± 38 pcm (control rods in) .

The data for control rods reactivity insertions, ρ, are presented in Table 3.10. The value for ρ was calculated as

$$\rho = \frac{k_{eff}^{CRin} - k_{eff}^{CRout}}{k_{eff}^{CRin} k_{eff}^{CRout}}$$

The difference in reactivity calculated with multigroup and continuous energy models is Δρ = 0.00158 or 0.5%.

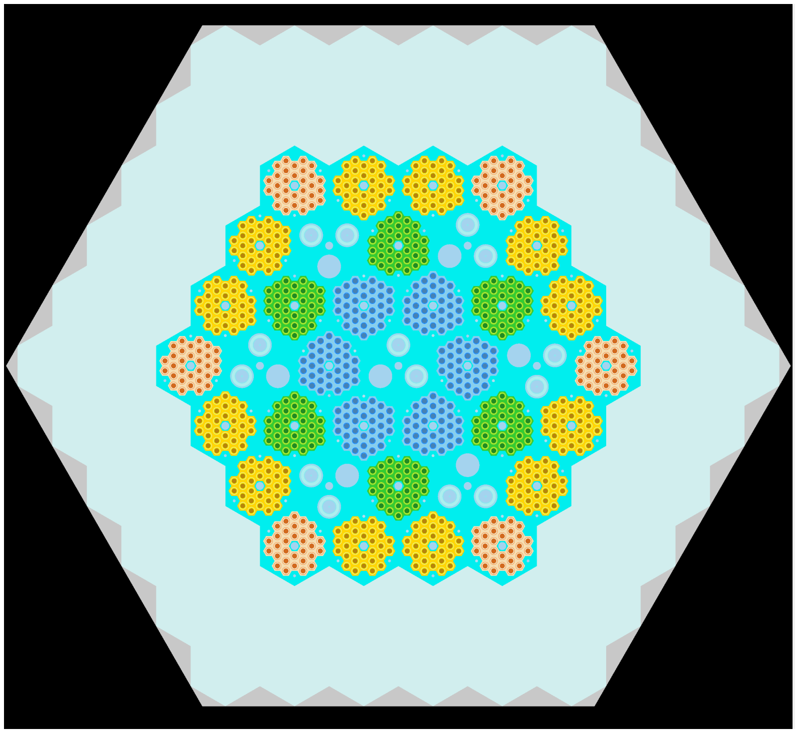


**Fig. 3.10. Horizontal layout of Core 4 (with control rods in).**

**Table 3.9. Multiplication constants for Core 4**

| Model [a] | Control Rods Out | | Control Rods In | |
|---|---|---|---|---|
| | $k_{eff}$ | $\sigma$[b] | $k_{eff}$ | $\sigma$ |
| SCALE/KENO-VI MG | 1.16964 | 0.00023 | 0.83638 | 0.00021 |
| SCALE/KENO-VI CE | 1.17271 | 0.00027 | 0.83906 | 0.00032 |

[a] MG = multigroup; CE = continuous energy.
[b] Standard deviation of $k_{eff}$.

**Table 3.10. Control rods reactivity for Core 4**

| Model[a] | Reactivity |
|---|---|
| SCALE/KENO-VI MG | -0.34066 |
| SCALE/KENO-VI CE | -0.33908 |

[a] MG = multigroup; CE = continuous energy.
[b] Standard deviation of reactivity.

For the two Core 4 configurations, with control rods out and control rods in, the flux spectrum was evaluated on a radial meshing similar with the one used for Core 2—that is, concentric rings. The calculated 238-group flux was collapsed to a 23-group structure and volume-averaged over the concentric rings. The flux results are shown in Table 3.11 and illustrated in Fig. 3.11 for the case with control rods out. The data for the case with the control rods fully inserted are shown in Table 3.12 and illustrated in Fig. 3.12.

**Table 3.11. Flux spectrum (23-group) for radial regions of Core 4 (control rods out)**

| Group # | Upper Energy (eV) | Center Fuel Block | Ring 1 Fuel | Ring 2 Fuel | Ring 3 Fuel | Reflector Ring 1 | Reflector Ring 2 | Outer Void |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.00E+07 | 6.59E-14 | 1.41E-13 | 1.01E-13 | 1.15E-13 | 1.26E-14 | 6.25E-16 | 1.14E-16 |
| 2 | 3.00E+06 | 2.39E-12 | 4.75E-12 | 3.50E-12 | 3.87E-12 | 4.54E-13 | 1.54E-14 | 1.62E-15 |
| 3 | 1.36E+06 | 7.82E-12 | 1.36E-11 | 1.04E-11 | 1.08E-11 | 1.52E-12 | 5.39E-14 | 4.34E-15 |
| 4 | 5.00E+05 | 2.54E-11 | 3.88E-11 | 3.11E-11 | 3.01E-11 | 5.02E-12 | 1.86E-13 | 1.22E-14 |
| 5 | 1.00E+05 | 7.98E-11 | 1.10E-10 | 9.16E-11 | 8.40E-11 | 1.60E-11 | 6.34E-13 | 3.68E-14 |
| 6 | 6.00E+04 | 2.36E-10 | 2.98E-10 | 2.56E-10 | 2.22E-10 | 4.80E-11 | 2.10E-12 | 1.09E-13 |
| 7 | 9.50E+03 | 2.58E-09 | 2.88E-09 | 2.58E-09 | 2.07E-09 | 5.47E-10 | 3.04E-11 | 1.54E-12 |
| 8 | 3.05E+02 | 1.02E-07 | 9.80E-08 | 9.25E-08 | 6.75E-08 | 2.31E-08 | 1.83E-09 | 1.04E-10 |
| 9 | 4.00E+00 | 2.80E-06 | 2.45E-06 | 2.40E-06 | 1.66E-06 | 6.82E-07 | 6.77E-08 | 4.06E-09 |
| 10 | 1.50E+00 | 5.64E-06 | 4.98E-06 | 4.84E-06 | 3.36E-06 | 1.40E-06 | 1.47E-07 | 9.10E-09 |
| 11 | 1.10E+00 | 6.84E-06 | 6.06E-06 | 5.85E-06 | 4.05E-06 | 1.70E-06 | 1.81E-07 | 1.07E-08 |
| 12 | 1.05E+00 | 7.35E-06 | 6.50E-06 | 6.31E-06 | 4.38E-06 | 1.83E-06 | 1.99E-07 | 1.27E-08 |
| 13 | 9.75E-01 | 8.20E-06 | 7.28E-06 | 7.04E-06 | 4.89E-06 | 2.05E-06 | 2.23E-07 | 1.36E-08 |
| 14 | 8.50E-01 | 1.20E-05 | 1.06E-05 | 1.02E-05 | 7.09E-06 | 3.02E-06 | 3.40E-07 | 2.15E-08 |
| 15 | 5.00E-01 | 1.91E-05 | 1.69E-05 | 1.63E-05 | 1.13E-05 | 4.89E-06 | 5.74E-07 | 3.62E-08 |
| 16 | 4.00E-01 | 2.43E-05 | 2.14E-05 | 2.06E-05 | 1.42E-05 | 6.28E-06 | 7.58E-07 | 5.19E-08 |
| 17 | 3.50E-01 | 3.02E-05 | 2.62E-05 | 2.53E-05 | 1.73E-05 | 7.89E-06 | 1.00E-06 | 6.50E-08 |
| 18 | 3.00E-01 | 3.95E-05 | 3.40E-05 | 3.30E-05 | 2.24E-05 | 1.08E-05 | 1.55E-06 | 1.15E-07 |
| 19 | 2.50E-01 | 6.98E-05 | 5.80E-05 | 5.66E-05 | 3.85E-05 | 2.28E-05 | 4.69E-06 | 4.31E-07 |
| 20 | 1.75E-01 | 1.29E-04 | 1.02E-04 | 1.01E-04 | 6.93E-05 | 5.14E-05 | 1.37E-05 | 1.43E-06 |
| 21 | 1.50E-01 | 2.52E-04 | 1.89E-04 | 1.89E-04 | 1.31E-04 | 1.24E-04 | 3.96E-05 | 4.16E-06 |
| 22 | 1.00E-01 | 6.27E-04 | 4.27E-04 | 4.43E-04 | 3.11E-04 | 3.95E-04 | 1.44E-04 | 1.53E-05 |
| 23 | 5.00E-02 | 7.90E-04 | 4.62E-04 | 5.15E-04 | 3.53E-04 | 6.17E-04 | 2.46E-04 | 2.63E-05 |

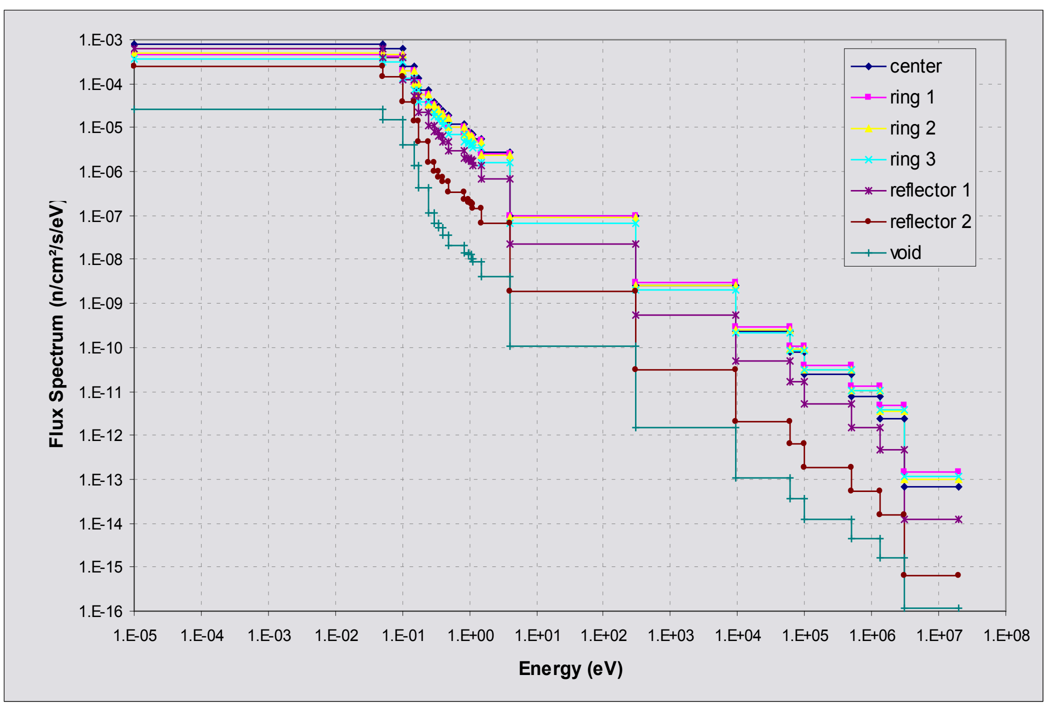



**Fig. 3.11. Flux distribution (23-group) in radial regions of Core 4 (control rods out).**

**Table 3.12. Flux spectrum (23-group) for radial regions of Core 4 (control rods in)**

| Group # | Upper Energy (eV) | Center Fuel Block | Ring 1 Fuel | Ring 2 Fuel | Ring 3 Fuel | Reflector Ring 1 | Reflector Ring 2 | Outer Void |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.00E+07 | 3.82E-14 | 1.05E-13 | 8.15E-14 | 1.30E-13 | 1.61E-14 | 7.81E-16 | 1.47E-16 |
| 2 | 3.00E+06 | 1.41E-12 | 3.54E-12 | 2.81E-12 | 4.37E-12 | 5.84E-13 | 1.96E-14 | 2.03E-15 |
| 3 | 1.36E+06 | 4.94E-12 | 1.01E-11 | 8.58E-12 | 1.22E-11 | 1.96E-12 | 6.90E-14 | 5.86E-15 |
| 4 | 5.00E+05 | 1.62E-11 | 2.90E-11 | 2.57E-11 | 3.37E-11 | 6.40E-12 | 2.40E-13 | 1.47E-14 |
| 5 | 1.00E+05 | 5.12E-11 | 8.26E-11 | 7.58E-11 | 9.34E-11 | 2.03E-11 | 8.18E-13 | 4.49E-14 |
| 6 | 6.00E+04 | 1.47E-10 | 2.23E-10 | 2.09E-10 | 2.45E-10 | 6.05E-11 | 2.69E-12 | 1.42E-13 |
| 7 | 9.50E+03 | 1.46E-09 | 2.15E-09 | 2.01E-09 | 2.23E-09 | 6.79E-10 | 3.91E-11 | 1.99E-12 |
| 8 | 3.05E+02 | 4.31E-08 | 7.13E-08 | 6.19E-08 | 6.90E-08 | 2.80E-08 | 2.32E-09 | 1.27E-10 |
| 9 | 4.00E+00 | 9.86E-07 | 1.72E-06 | 1.43E-06 | 1.61E-06 | 8.16E-07 | 8.59E-08 | 5.20E-09 |
| 10 | 1.50E+00 | 1.90E-06 | 3.44E-06 | 2.82E-06 | 3.21E-06 | 1.66E-06 | 1.86E-07 | 1.14E-08 |
| 11 | 1.10E+00 | 2.26E-06 | 4.16E-06 | 3.41E-06 | 3.85E-06 | 2.03E-06 | 2.30E-07 | 1.18E-08 |
| 12 | 1.05E+00 | 2.44E-06 | 4.48E-06 | 3.64E-06 | 4.15E-06 | 2.17E-06 | 2.50E-07 | 1.58E-08 |
| 13 | 9.75E-01 | 2.73E-06 | 4.98E-06 | 4.05E-06 | 4.62E-06 | 2.45E-06 | 2.82E-07 | 1.68E-08 |
| 14 | 8.50E-01 | 3.87E-06 | 7.20E-06 | 5.82E-06 | 6.66E-06 | 3.59E-06 | 4.29E-07 | 2.88E-08 |
| 15 | 5.00E-01 | 6.03E-06 | 1.13E-05 | 9.11E-06 | 1.04E-05 | 5.79E-06 | 7.19E-07 | 4.66E-08 |
| 16 | 4.00E-01 | 7.65E-06 | 1.43E-05 | 1.14E-05 | 1.31E-05 | 7.43E-06 | 9.52E-07 | 6.15E-08 |
| 17 | 3.50E-01 | 9.40E-06 | 1.74E-05 | 1.39E-05 | 1.59E-05 | 9.31E-06 | 1.25E-06 | 9.31E-08 |
| 18 | 3.00E-01 | 1.20E-05 | 2.23E-05 | 1.77E-05 | 2.04E-05 | 1.28E-05 | 1.92E-06 | 1.45E-07 |
| 19 | 2.50E-01 | 1.98E-05 | 3.65E-05 | 2.88E-05 | 3.41E-05 | 2.64E-05 | 5.63E-06 | 5.17E-07 |
| 20 | 1.75E-01 | 3.36E-05 | 6.11E-05 | 4.80E-05 | 5.95E-05 | 5.88E-05 | 1.61E-05 | 1.59E-06 |
| 21 | 1.50E-01 | 5.94E-05 | 1.06E-04 | 8.27E-05 | 1.10E-04 | 1.40E-04 | 4.61E-05 | 4.88E-06 |
| 22 | 1.00E-01 | 1.29E-04 | 2.18E-04 | 1.70E-04 | 2.53E-04 | 4.42E-04 | 1.67E-04 | 1.79E-05 |
| 23 | 5.00E-02 | 1.42E-04 | 2.15E-04 | 1.72E-04 | 2.85E-04 | 6.87E-04 | 2.84E-04 | 3.05E-05 |

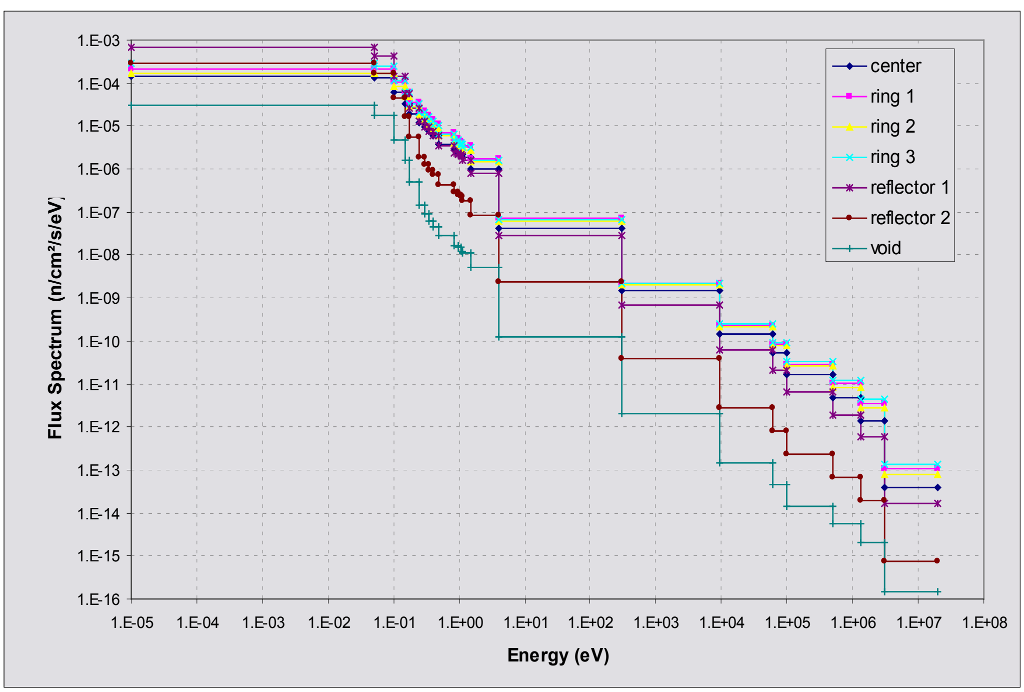



**Fig. 3.12. Flux distribution (23-group) in radial regions of Core 4 (control rods in).**

## 3.3 ANALYSIS OF HTTR FULL CORE BENCHMARK EXPERIMENTS

### 3.3.1 Description of the HTTR Core

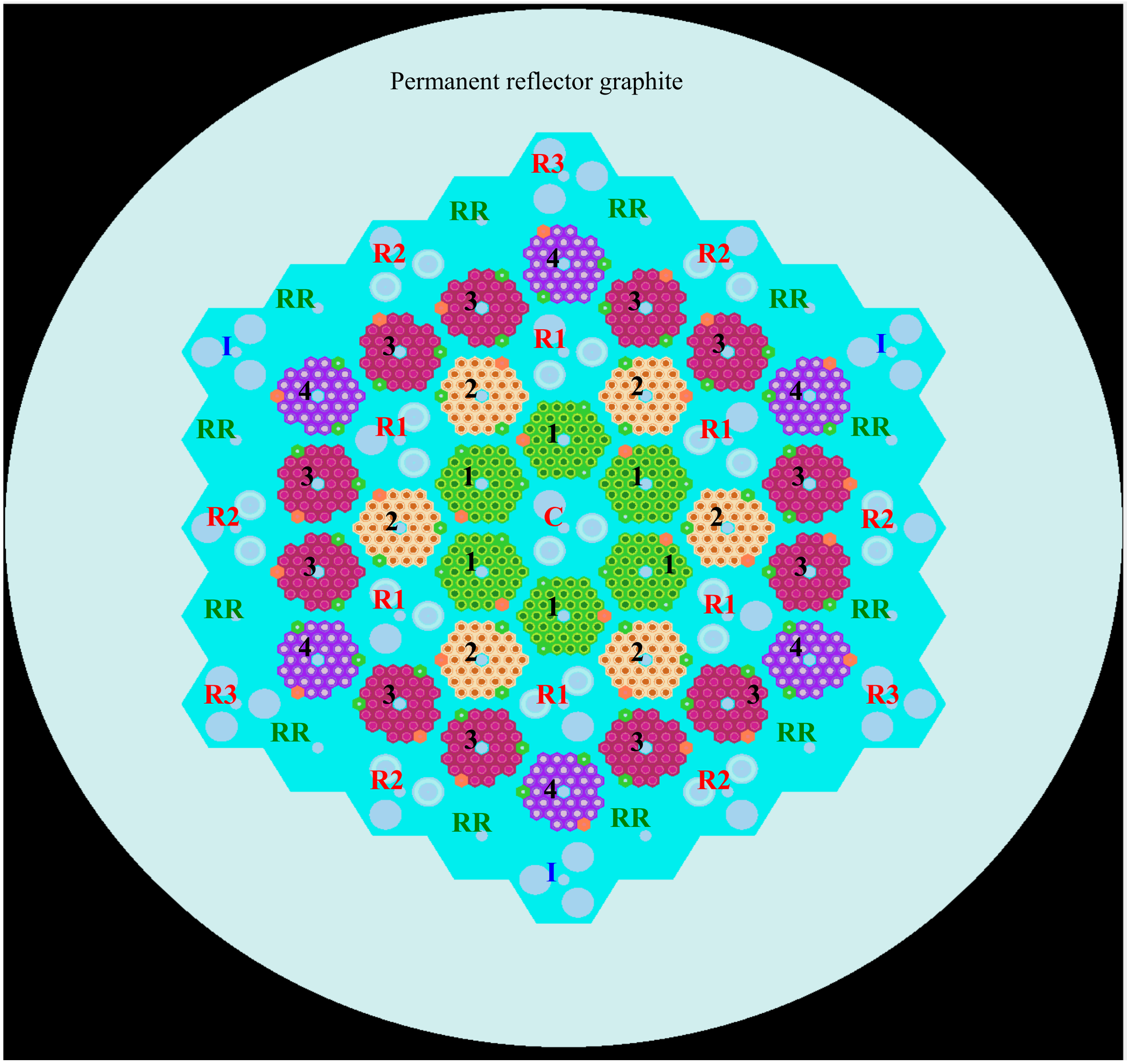
The HTTR core consists of fuel blocks that use TRISO fuel with 12 different fuel enrichments, between 3.4 and 9.9 wt % $^{235}U$, grouped into four fuel zones. These fuel blocks are arranged axially in five-block columns for a total active height of 290 cm. The four fuel zones are intermixed with control rod columns and are surrounded by reflector blocks, as illustrated in Fig. 3.13 that shows a cross-sectional view of the HTTR fully loaded core (30 fuel columns).

The control rods, made of $B_4C$, are operated in pairs. Each pair of control rods occupies two of the three available channels in each control rod guide column. There are a total of 16 pairs of control rods in the HTTR core. The third hollow position in each of the control rod guide columns can be used as a reserved shutdown pellet insertion hole. These pellets, also made of $B_4C$, can be released into the holes under gravity as a backup mechanism for emergency shutdown.

In addition to the fuel and control blocks, the active core also contains three columns reserved for irradiation tests and 12 replaceable reflector columns.

The IG-110 graphite used in the fabrication of the fuel blocks, control rod blocks, irradiation blocks, and replaceable reflector blocks is a high purity graphite with an equivalent boron content (EBC) less than 1 ppm. The EBC of the PGX graphite that is used for the permanent reflector is under 5 ppm. During the approach to criticality, dummy graphite blocks are also used to replace the fuel blocks. These blocks are fabricated from IG-11 graphite, which also has an EBC under 5 ppm.

The main characteristics of the HTTR core are summarized in Table 3.13. Details about the fuel type and fuel assembly have been included in Tables 3.1 and 3.2 of this report.




Fuel zones: **1**, **2**, **3**, **4**

Control rods: **C** central

**R1** ring 1

**R2** ring 2

**R3** ring 3

**I** Instrumentation column

**RR** Replaceable reflector column

**Fig. 3.13. Fully loaded HTTR core configuration.**

**Table 3.13. Main characteristics of the HTTR core**

| Parameter | Value |
|---|---|
| Thermal power (MW) | 30 |
| Inlet temperature (°C) | 395 |
| Maximum outlet temperature (°C) | 950 |
| Fuel type | TRISO in prismatic blocks |
| Number of fuel columns | 30 |
| Number of fuel blocks per column | 5 |
| Fuel enrichment (wt % $^{235}$U) | 3.4 to 9.9 |
| Moderator | Graphite |
| Coolant | Helium |

### 3.3.2 Experimental Data

The experimental data used for validation in this report were taken from the HHTR benchmarks included in the IRPhE Handbook [6,7,8,9]. The following data were analyzed in this report:

- Criticality measurements for fully loaded (30 fuel columns) or partially loaded (19–27 fuel columns) critical core configurations
- Criticality measurements for full core subcritical configuration (30 fuel columns, all control rods fully inserted)
- Shutdown margin
- Excess reactivity
- Control rod worths
- Isothermal reactivity coefficients

Details about the measured data are provided in the section discussing the calculation-to-experiment comparison.

### 3.3.3 Computational Models for HTTR Core Configurations

For the HTTR core simulations, detailed full core models were developed, based on IRPhE benchmark [6,7,8,9] descriptions, for both the continuous energy case and the multigroup case. Material composition data used for all HTTR simulations in this report are as provided in Ref. 6.The main difference between the multigroup and continuous energy models consists in the way that materials assigned to different regions are defined. In particular, for the multigroup model a homogeneous mixture is assigned as fuel, the cross sections for this homogeneous mixture being computed using the DOUBLEHET processing capability in SCALE (see Section 2.1.2). In the continuous energy model the fuel particles are represented in detail using a lattice representation for their distributions inside the fuel pins. Both multigroup and continuous energy cross-section sets that were used with SCALE for HTTR simulations are based on ENDF/B-VII data.

The SCALE/KENO-VI input files for the continuous energy model and the multigroup model of the full core HTTR (30 fuel columns) are included in Appendices A and B. The continuous energy model has about 1,600 lines of input, while the multigroup model contains approximately 1,700 lines. These include several lines of descriptive comments for better readability of the input.

The fresh core HTTR critical configurations differ by the number of fuel columns or the positions of the four banks of control rods. The positions of the tips of the control rod banks in the six critical core configurations considered, as measured from the bottom of the fuel, are listed in Table 3.14. Configuration 1 (19 fuel columns) uses mainly the central pair of control rods, whereas configuration 4

(24 fuel columns) uses the control rods in rings 2 and 3 (F23 pattern). The other four configurations use an FS (flat standard) pattern, in which the control rods in ring 3 are fully withdrawn.

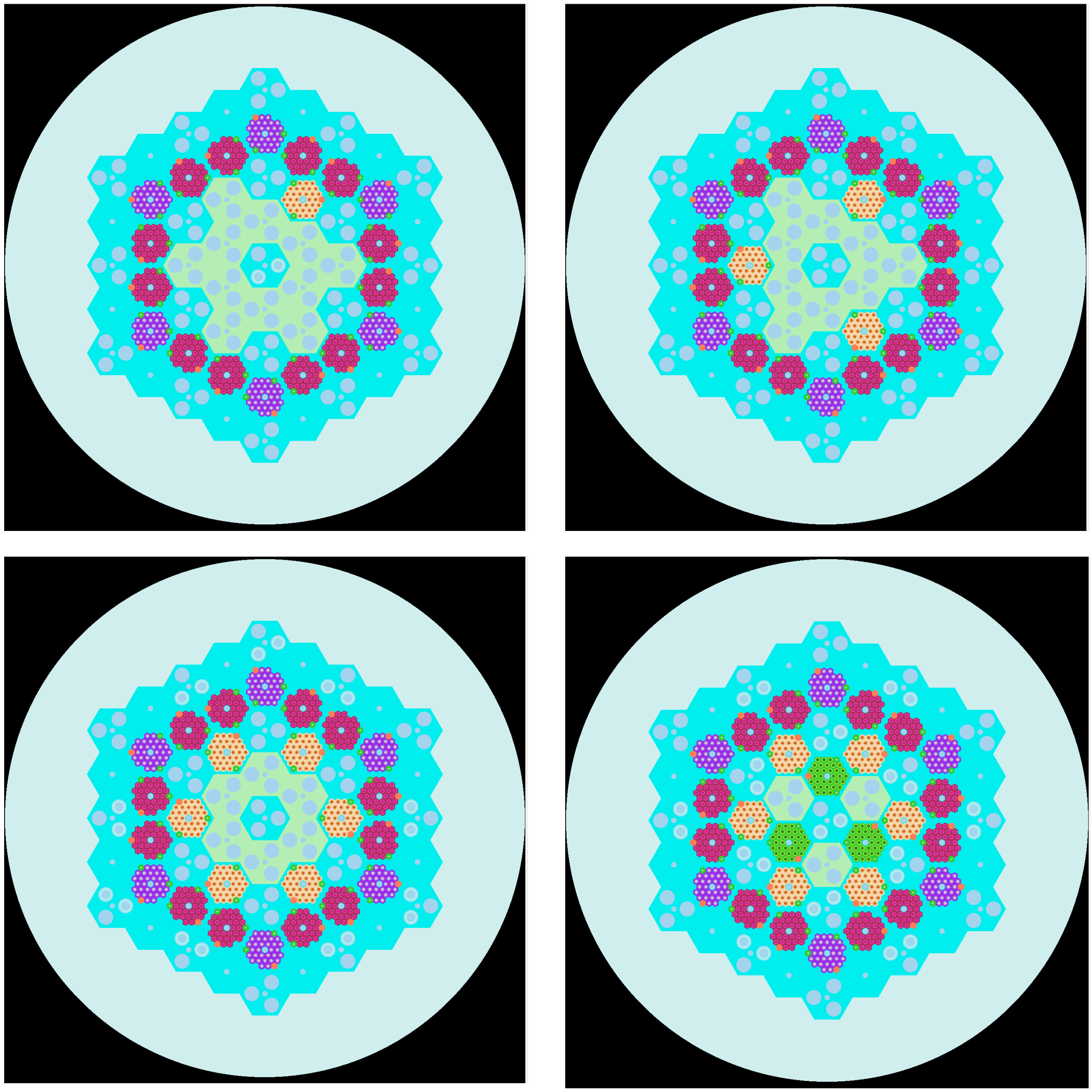
The SCALE/KENO-VI model for the fully loaded (30 column) HTTR core is illustrated in Fig 3.13. The models for partially loaded cores are presented in Fig. 3.14.

**Table 3.14. Control rod positions for the six HTTR critical core configurations**

| **Configuration**[a] | **Control Rod Bank**[b] **Position, Measured from the Bottom of the Fuel (mm)** | | | |
|---|---|---|---|---|
| | **C** | **R1** | A.1 **R2** | A.2 **R3** |
| 1 (19 columns) | 1739 | 4050 | 3325 | 4050 |
| 2 (21 columns, FS) | 2646 | 2646 | 2646 | 4049 |
| 3 (24 columns, FS) | 2215 | 2215 | 2215 | 4049 |
| 4 (24 columns, F23) | 4050 | 4050 | 1592 | 1592 |
| 5 (27 columns, FS) | 1900 | 1900 | 1900 | 4050 |
| 6 (30 columns, FS) | 1775 | 1775 | 1775 | 4049 |

[a] FS = Flat standard—control rods in ring 2 are fully withdrawn; F23 = pattern identification—uses control rods in rings 2 and 3.
[b] C = Central control rod bank; R1, R2, and R3 are control rod banks in rings 1, 2, and 3 respectively.

Development of the HTTR core models included a series of investigations to assess the effect of various modeling assumptions on the results of the simulations. Some of these investigations are summarized further.



From left to right and top to bottom: 19 fuel columns, 21 fuel columns, 24 fuel columns (F23 pattern shown; the FS pattern differs through the control rod positions), and 27 fuel columns. The dummy graphite blocks (light green) are visible.

**Fig. 3.14. Partially loaded HTTR core configurations.**

#### 3.3.3.2 Overcoat material simulation

The overcoat is the outermost layer of a TRISO particle. It is made of graphite with the same number density as the compact graphite matrix but with a 1.5 wt ppm of boron impurity, thus making it more absorbing than the compact graphite matrix, which has an EBC of 0.82 ppm. In a CE model, the fuel particles are modeled by means of a particle lattice in which the particles are represented using various arrangements. Given that the outer radius of a fuel particle including the overcoat material is 0.066 cm, issues arise when trying to fit the particles into the fuel compact using a simple cubic (SC) cell lattice arrangement. In the MCNP model of Ref. 6, the overcoat was simulated as an incomplete sphere of radius equal to the real radius (0.066 cm) but cut by the cube's surfaces. This approach does not conserve the mass of overcoat material—it underestimates it, while overestimating the amount of compact matrix material.

A sensitivity analysis was conducted to assess the effect of different modeling approximations for the overcoat material in a detailed continuous energy model. The simple cubic lattice used in the simulations has a packing fraction of ~0.52. Four different approximations have been considered, as follows:

a) Using overcoat material everywhere outside the outer pyrolitic carbon layer (no compact matrix material)
b) Using compact matrix material everywhere outside the outer pyrolitic carbon layer (no overcoat material)
c) Using volume-homogenized overcoat and matrix material everywhere outside the outer pyrolitic carbon layer
d) Using a segregated representation of the overcoat and the compact, with the overcoat modeled as a cubical region (to fit within the cubical lattice cell)

The results of these simulations, all performed with the continuous energy HTTR core model, show a minimal impact on the eigenvalue result for the core, within 1σ from the MCNP reference value for cases a, c, and d, and within 2σ for case b. For all results reported in Section 3.3.4 of this report, assumption c as listed above was used in the models.

#### 3.3.3.3 Fuel particle modeling in the continuous energy model

For a continuous energy model, the fuel particles are explicitly modeled by using a cubical lattice arrangement. When this lattice is positioned in a cylindrical or annular fuel pin, clipping might occur at the intersection of the fuel particle outer surface with the pin surfaces that might lead to fuel mass nonconservation.

To assess the maximum expected error resulting from this clipping in the lateral direction, calculations were performed to evaluate the variation of the multiplication constant with different modes of positioning the fuel particle lattice within the fuel pin. Because of the symmetry of the problem with respect to the $x$ and $y$ axes in a rectangular geometry, it is sufficient to assess the effect of the lattice shifting along one axis (say, $x$) that is perpendicular on the axial symmetry axis ($z$) of the cylindrical fuel pin. The reference case is considered the case when one grain of the lattice is centered at the geometrical center of the fuel pin. If this lattice is shifted with $\delta x$ with respect to the reference, the multiplication constant will differ slightly from the corresponding reference value. All the calculations were performed using the full core CE model, and the shift of the particles was applied uniformly in all the pins of all the fuel blocks in the core model. The variation of the multiplication constant with respect to its reference value as a function of the shift ($\delta x$) is presented in Fig. 3.15. As noted from this figure, the maximum expected error caused by the positioning of the fuel particle lattice within the annular cylindrical fuel pin is ~150 pcm. The fitting curve in the figure shows a sinusoid-like shape. The period of this sinusoid (theoretically equal to the particle lattice pitch, ~0.11 cm) is confirmed through the fitting in Fig. 3.15.

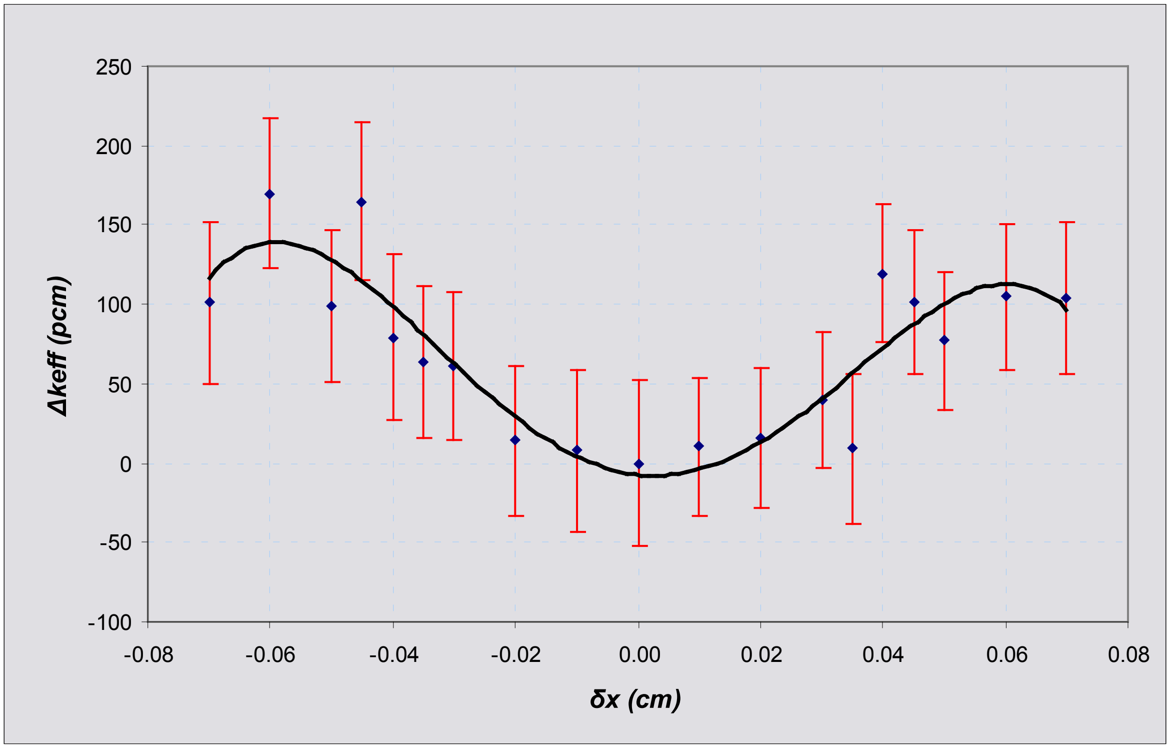



**Fig. 3.15. Variation of the multiplication constant with the fuel particle lattice positioning.**

An alternative that avoids clipping would be to move those particles that intersect the pins' surfaces inside the fuel volume, therefore carefully conserving the mass of the fuel. This procedure would require making the lattice pitch smaller, therefore having more cells within the same volume, to fit those particles that would have been clipped inside the pin's volume. It would require additional work for the manual placement of the particles within the lattice or to automate this placement. However, as it was determined, the effect of using this approach is the same magnitude (~150 pcm) as the use of a regular cubical lattice arrangement discussed above.

#### 3.3.3.4 Fuel mass conservation in the continuous energy model

The sensitivity of the multiplication constant to fuel mass nonconservation is estimated by using the multigroup model of the HTTR core. The results of this estimation will indicate the effect of fuel mass nonconservation in a CE model, in which mass nonconservation may occur from the geometry representation of the fuel particle lattices. It can also indicate the effect on $k_{eff}$ due to uncertainty in fuel mass specification in both CE and MG core models. For example, the precision (uncertainty) in the experimental determination of the mass of fuel per fuel pin is approximately ±3%. If a normal distribution is assumed for the distribution of mass of fuel in all fuel pins in the core, the resulting uncertainty in the mass of fuel in the core will be ~0.04%.

Because of the specifics of the multigroup model representation of fuel, the mass is always conserved exactly in this case compared to a CE model. Therefore, any applied change to this mass is exactly characterized. The fuel mass in the reference MG core model was perturbed slightly with respect to the reference mass value, and criticality calculations were carried out to determine the corresponding $k_{eff}$ values. The results are illustrated in Fig. 3.16, which presents the difference in $k_{eff}$ as a function of percent fuel mass change. The fit of the calculated points in Fig. 3.16 to a straight line indicates that a 1% change in the mass of core fuel leads to a change of ~150 pcm in the core multiplication constant.

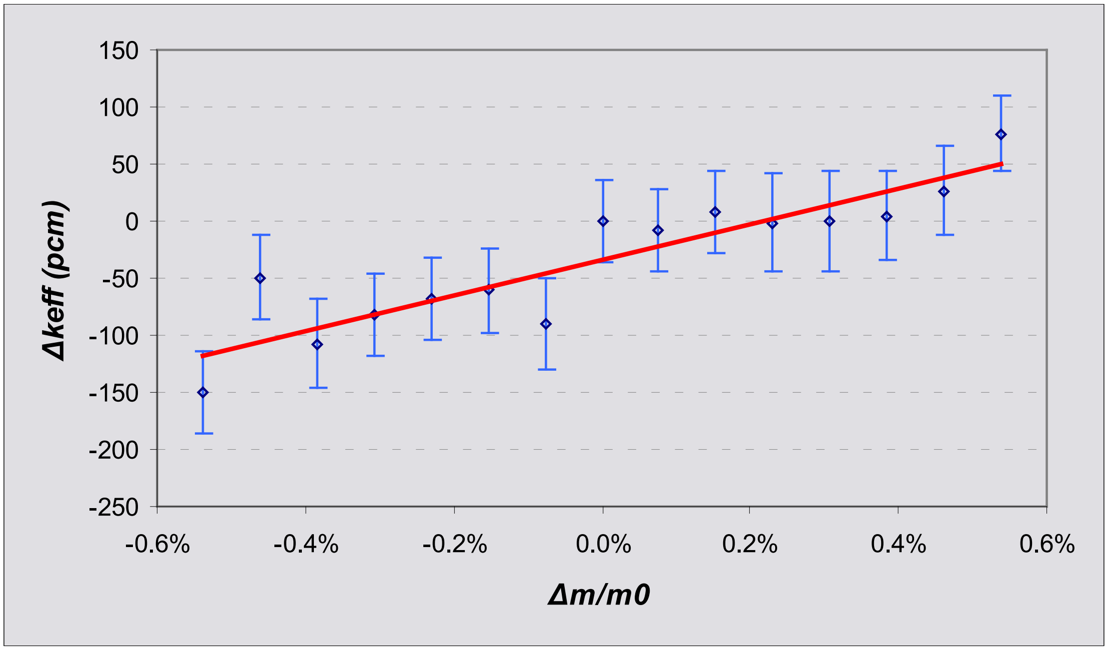



**Fig. 3.16. Variation of the multiplication constant with the core fuel mass.**

#### 3.3.3.5 Typical runtime

All SCALE calculations summarized in Section 3.3.3 were performed on a 2.26 GHz Linux workstation with no code parallelization used. The typical runtime for different sensitivity studies for the full core continuous energy model was slightly under 19 hours when 11 million particles were simulated (for 10 million active histories) to achieve typical statistical standard deviations in $k_{eff}$ of ~30 pcm. Approximately 16 of these 19 hours were spent in particle tracking itself, while the rest of the time was the overhead needed for different tasks performed by the code. For the multigroup model with the same number of histories as for the continuous energy case, the runtime is ~4 times smaller, with ~4 hours needed for particle tracking.

For the other studies summarized in Section 3.3.4 of this report, however, the number of histories was increased tenfold to achieve better accuracy, below 10 pcm in the eigenvalue. There was a corresponding increase in the runtime (~5 days for continuous energy models).

### 3.3.4 Results

#### 3.3.4.1 Multiplication constant for HTTR critical configurations

A comparison of the experimental and calculated $k_{eff}$ values for the HTTR critical core benchmarks is presented in Table 3.15. As discussed in Section 3.3.3 of this report, there were six fresh core critical configurations (see Figs. 3.13 and 3.14). These configurations differ through the number of fuel columns or the positions of the four banks of control rods (see Table 3.14).

Table 3.15 includes data calculated with MCNP, as reported in Ref. 7, and data calculated with SCALE in this report with both CE and MG models. As seen, both MCNP and SCALE results show a positive bias compared to the experiment. Part of this bias may be due to uncertainty in material data used in the computational models. As evaluated in the IRPhE, the uncertainties in $k_{eff}$ for the fully loaded core [7] and for the annular cores [8] are in the range ~±1000 pcm. The most significant contributors to the evaluated uncertainties for the full-core $k_{eff}$ are [7]: the IG-110 (core) graphite impurity, the PGX (reflector) graphite impurity, the $^{10}B$ concentration (abundance) in BP rods, and the uncertainty in the fuel enrichment. Each of these have contributions to the uncertainty in $k_{eff}$ in the range 145-442 pcm.

**Table 3.15. Calculated and experimental $k_{eff}$ for HTTR critical core configurations**

| Critical Configuration | Experimental[a] | MCNP[a] (benchmark) | SCALE6.1 CE | SCALE6.1 MG |
|---|---|---|---|---|
| 1. 19 columns | 1.0048 | 1.0276 (1) | 1.01931 (10) | 1.01753 (8) |
| 2. 21 columns | 1.0040 | 1.0297 (1) | 1.02539 (9) | 1.02323 (9) |
| 3. 24 columns, FS | 1.0035 | 1.0249 (1) | 1.02120 (9) | 1.01868 (8) |
| 4. 24 columns, F23 | 1.0032 | 1.0287 (1) | 1.02066 (9) | 1.01827 (9) |
| 5. 27 columns | 1.0029 | 1.0218 (1) | 1.01711 (10) | 1.01445 (9) |
| 6. 30 columns (fully loaded) | 1.0025 | 1.0229 (1) | 1.01847 (9) | 1.01510 (8) |

[a] As provided in Refs. 7 and 8 for calculations performed with ENDF/B-VII cross sections.
[b] The numbers in parentheses are statistical standard deviations affecting the last digit(s) of the result. For example, 1.01931 (10) should be read as 1.01931 ± 0.00010.

The relative differences in $k_{eff}$ for the six critical configurations are illustrated in Fig. 3.17, which shows these differences as a function of the number of fuel columns in the critical core. The average biases for the three simulations are 1473, 1735, and 2238 pcm for SCALE MG, SCALE CE, and MCNP, respectively. The standard deviation of these biases is approximately 300 pcm in each of these three cases. The causes of these biases can range from insufficiently detailed benchmark specifications (geometry, materials, etc.) of the critical states to the quality of the nuclear data used in simulations. The similarity of the curves in Fig. 3.17 indicates a possible cause of the deviation due to systematic issues.

The difference between the SCALE continuous energy and multigroup models is synthesized in Fig. 3.18 for the six critical configurations. The plot shows the difference (in pcm) between the eigenvalue predicted by the continuous energy model and the eigenvalue predicted by the multigroup model and includes the statistical standard deviation for this difference. It is observed that this difference increases with the number of fuel columns used for the critical configuration. The maximum difference, for the full core (30 fuel columns), is slightly below 350 pcm.

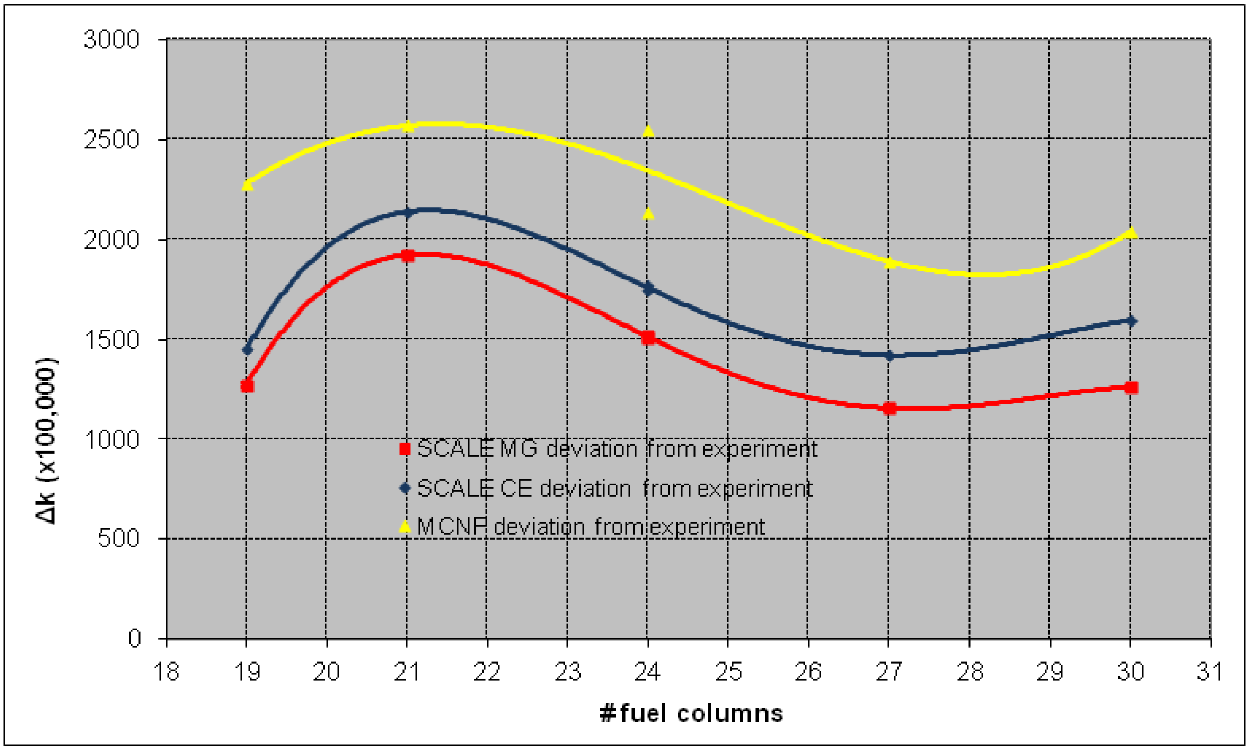



**Fig. 3.17. Variation of $k_{eff}$ bias vs. number of fuel columns (critical core).**

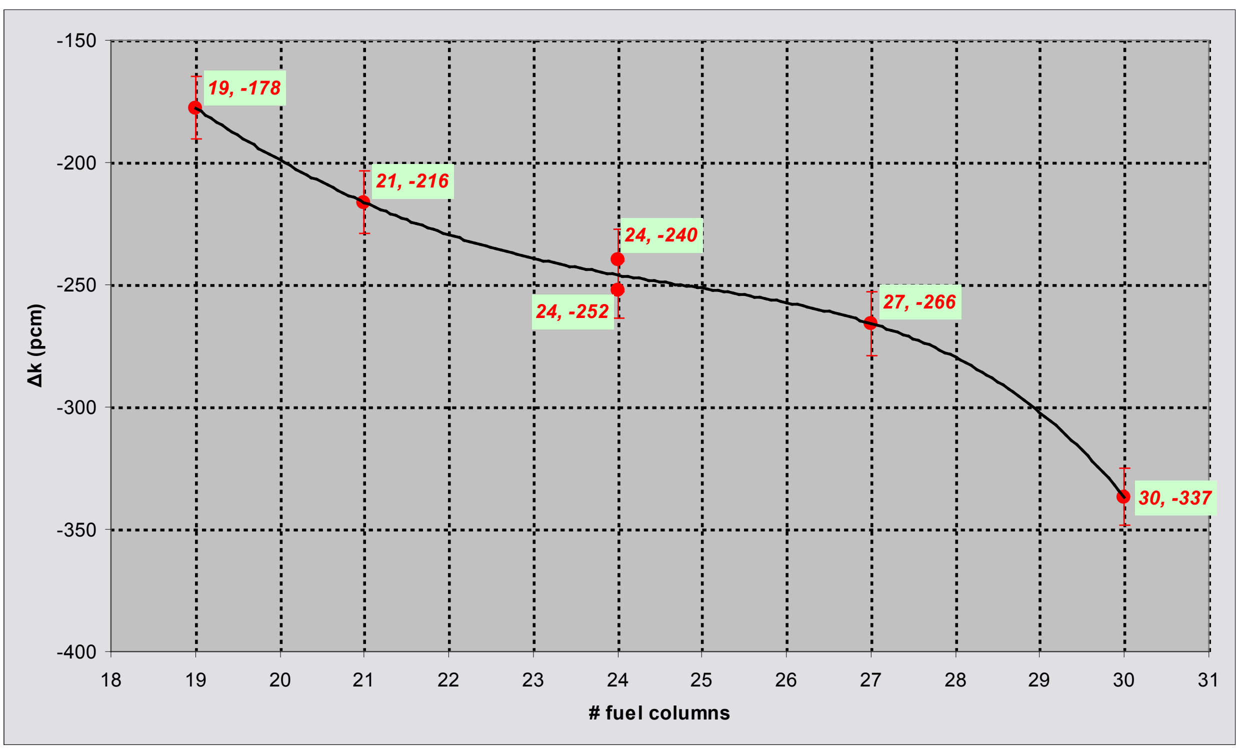



**Fig. 3.18. Difference in $k_{eff}$ calculated with the SCALE MG and CE models.**

#### 3.3.4.2 Multiplication constant for HTTR subcritical configurations

Subcritical configurations were obtained while approaching criticality during the initial fuel loading. Measurements are reported [7] for these configurations, as listed in Table 3.16, but the description of these configurations lacks the position of the control rods. As mentioned in Ref. 7, the control rods were most likely fully withdrawn for all these measurements. These configurations were not simulated with SCALE.

**Table 3.16. Multiplication constants for subcritical configurations during the approach to criticality**

| # | Subcritical Configuration | Experimental $k_{eff}$ |
|---|---|---|
| 1 | 9 columns | 0.9282 |
| 2 | 12 columns | 0.9481 |
| 3 | 15 columns | 0.9652 |
| 4 | 16 columns | 0.9701 |
| 5 | 17 columns | 0.9785 |
| 6 | 18 columns | 0.9913 |

For the full core (30 fuel columns) subcritical configuration, the information in the HTTR benchmark report [7] is somehow contradictory: in the description of experiments (Chapter 1), the control rods are inserted to the bottom of the fuel; in later chapters (Chapters 3, 4), this subcritical configuration is said to have been obtained with the control rods fully inserted (55 mm below the bottom of the fuel). The value for the multiplication constant is given as 0.685 ± 0.010, and 0.6876 ± 0.0104 to account for bias in control instrumentation. The full core subcritical configuration simulated with SCALE for the current study is the same as the full core critical configuration, but with the control rods fully inserted (55 mm below the bottom of the fuel). This configuration was modeled with both continuous energy and multigroup models. The results obtained are showed in Table 3.17.

**Table 3.17. Multiplication constants for full core subcritical configuration**

| Subcritical Configuration | Experimental $k_{eff}$ [a] | MCNP[b] | SCALE CE[c] | SCALE MG[d] |
|---|---|---|---|---|
| 30 columns, all CR fully inserted | 0.6876 (1004) | 0.6999 (1) | 0.69760 (9) | 0.69541 (8) |

[a] For the experimental result, the number in parenthesis represents the uncertainty as evaluated in Ref.7. All other numbers in parentheses are statistical standard deviations.
[b] As provided in Ref. 7, from calculations performed with ENDF/B-VII.0 cross sections.

As shown in Table 3.17, the SCALE results are marginally within the evaluated experimental uncertainty. As noted also for the critical configurations, both MCNP and SCALE calculations (CE and MG models) show a positive bias when compared with the experimental result, but SCALE results are slightly closer to the experiment than MCNP.

#### 3.3.4.3 Excess reactivity

The excess reactivity of a reactor core is defined as the amount of reactivity of the reactor with no control devices inserted. It is a quantity that cannot be measured directly when defined as such, because the reactor cannot be brought to such a state (which typically would be prompt critical). Computationally, however, such a reactor state can be simulated. The excess reactivity $\rho$ can be calculated as

$$\rho = 100 \times \left( \frac{1}{k_{crit}} - \frac{1}{k_{CRup}} \right)$$

where $k_{crit}$ is the multiplication constant corresponding to the critical configuration and $k_{CRup}$ is the multiplication constant corresponding to the reactor state with all the control rods fully withdrawn. The excess reactivity was calculated for each HTTR critical configuration by considering reactor states with the control rods fully withdrawn and with the control rods inserted so that a critical configuration is achieved. The "critical configuration" of the core was considered the core configuration with the control rods inserted as in the corresponding experimental critical configuration, although the multiplication constant produced by the calculation for such a configuration is not exactly unity. The results of these simulations are listed in Table 3.18. The statistical uncertainties for these calculations were negligible and were not included in the table. For the SCALE calculations, they were typically below 0.01% Δk/k, while for MCNP they were below 0.02% Δk/k. The experimental uncertainties, as provided in Ref. 7, are much larger, typically 25–30%. Details on the methods used to infer the so-called experimental excess reactivity shown in Table 3.18 are provided later in this section.

**Table 3.18. Excess reactivity for different fuel loadings**

| Core loading | Experimental[a] (%Δk/k) | SCALE MG | | SCALE CE | | MCNP | |
|---|---|---|---|---|---|---|---|
| | | (%Δk/k) | C/E[b]-1 (%) | (%Δk/k) | C/E-1 (%) | (%Δk/k) | C/E-1 (%) |
| 18 columns | -0.9 ± 0.6 | 0.40 | - | 0.39 | - | - | - |
| 19 columns | 1.5 ± 0.24 | 2.16 | 43.74 | 2.14 | 42.74 | 1.98 | 32.00 |
| 21 columns | 4.0 ± 1.1 | 4.36 | 9.03 | 4.32 | 8.04 | 4.28 | 7.05 |
| 24 columns | 7.7 ± 2.1 | 8.11 | 5.30 | 8.04 | 4.46 | 8.29 | 7.63 |
| 27 columns | 10.7 ± 3.0 | 10.90 | 1.91 | 10.86 | 1.48 | 11.52 | 7.67 |
| 30 columns | 12.0 ± 3.3 | 11.54 | -3.87 | 11.44 | -4.67 | 11.38 | -11.79 |

[a] As provided in Ref. 7, from calculations performed with ENDF/B-VII.0 cross sections.
[b] C = calculated value; E = experimental value.

From a literature search, there seems to be some ambiguity about the excess reactivity corresponding to the "19 columns" configuration. This excess reactivity is listed as 1.5% Δk/k in [33], but as 2.4% Δk/k in [7]. The reason given in [7] for this value is that this reactivity represents "the cumulative worth of fuel addition from the subcritical 18-fuel-column core and the 19-fuel-column core." This definition, however, would contradict the definition of excess reactivity given above. Therefore, the value 1.5% Δk/k as defined in [33] was included in Table 3.18. As observed in this table, the corresponding uncertainty of 0.24% Δk/k for the 19 column core, as taken from [7], is significantly different (~16%) than the other uncertainty values in the table, and is possibly underestimated.

Further ambiguities exist for the value listed for the (subcritical) 18 column configuration excess reactivity. Reference [33] gives a value of -0.3% Δk/k, whereas reference [7] gives a value of -0.9% Δk/k, which is listed in Table 3.18. This later value is believed to be closer to the true value, given its agreement with the multiplication constant listed in Table 3.16.

Because the "excess reactivity" for the 18-column core is, in fact, a "reactivity deficit," the configuration being subcritical, a particular approach was assumed to calculate the reactivity with SCALE in this case, as further described. First, the multiplication constant for the configuration with all the control rods fully withdrawn was calculated, as one would calculate for the excess reactivity. Then, this multiplication constant was corrected with the bias inferred from the 19 column critical core result in Table 3.15 (the multiplication constants listed in Table 3.15 correspond to critical configurations, hence the true *k* should be exactly 1). Therefore, the reactivity was calculated as

$$\rho = 100 \times \left(1 - \frac{1}{k_{CRup}^{18,corrected}}\right) = 100 \times \left(1 - \frac{1}{k_{CRup}^{18} - (k_{crit}^{19} - 1)}\right)$$

where $k_{CRup}^{18}$ is the uncorrected value for the multiplication constant for the 18 column core configuration (all control rods fully withdrawn), and $k_{crit}^{19}$ is the multiplication constant for the 19 column critical core as listed in Table 3.15. The quantity $k_{crit}^{19} - 1$ represents the code bias for the 19 column configuration, whose applicability was extended for correcting the 18 column core multiplication constant.

The positive value (~0.4% Δk/k) predicted for the 18 column core reactivity using the procedure summarized above would lead to the conclusion that the core can reach criticality with only 18 fuel columns, which does not correspond to the reality. Note, in this context, that the correction underlined above is an *a posteriori* correction (it makes use of the knowledge of the criticality achieved with 19 fuel columns) and therefore has no merit in predicting the first criticality of the HTTR core.

As inferred from Table 3.18, the departure from the experiment of the calculated values (C/E-1) shows a decreasing trend with the increase in the number of fuel columns and becomes negative (the computation underestimates the experiment) for the full core. As also observed in this table, there is excellent agreement between the MG and the CE predicted values for this later case.

The experimental procedure for measuring the excess reactivity assumed that a summation method from one critical state to the next was holding [7,33]. Experimentally, after each fuel addition (e.g., from 21 fuel columns to 24 fuel columns), the control rods were inserted deeper into the core to maintain criticality. The additional depth to which the control rods were inserted gave the additional reactivity excess that was added by the increase in the amount of fuel. According to Refs. 7 and 33, the reactivity was measured after each fuel addition using the inverse kinetics method. Neither of the above references describes this method. According to Ref. 33, the excess reactivity $\rho_{ex}$ was calculated as

$$\rho_{ex} = \sum_i \Delta\rho_i^m R_i$$

where $\Delta\rho_i^m$ is the increment in reactivity measured with the inverse kinetics method and $R_i$ is a correction factor inferred through calculations using the following:

$$R_i = \frac{\Delta\rho_i^v}{\Delta\rho_i^a}$$

In the above expression for $R_i$, $\Delta\rho_i^v$ is the increment in reactivity calculated with all the control rods fully withdrawn, and $\Delta\rho_i^a$ is the increment in reactivity for the actual control rod pattern for configuration *i*.

The evaluation procedure for the excess reactivity presented above indicates that the numbers presented as "experimental" are not based purely on experimental measurements but also use corrections based on calculations. These corrections are necessary to account for the shadowing effect of the control rods. Based on the described procedure, the incremental change in reactivity was evaluated in this report (i.e., the quantity $\Delta\rho_i^m R_i$ for *i* = 24, 27, and 30) by considering the reactivity added through fuel addition (i.e., fuel addition to cores identified by i = 21, 24, and 27). The results are presented in Table 3.19.

**Table 3.19. Incremental excess reactivity for different fuel loadings**

| Core fuel loading | Experimental[a] (% Δk/k) | SCALE MG | | SCALE CE | | MCNP | |
|---|---|---|---|---|---|---|---|
| | | (% Δk/k) | C/E[b]-1 (%) | (% Δk/k) | C/E[a]-1 (%) | (% Δk/k) | C/E[a]-1 (%) |
| 24 columns (FS) | 3.7 ± 1.0 | 3.67 | -0.0 | 3.67 | -0.0 | 4.01 | 8.3 |
| 27 columns | 3.0 ± 0.9 | 3.00 | 0.0 | 3.01 | 0.0 | 3.23 | 7.7 |
| 30 columns | 1.3 ± 0.3 | 1.48 | 13.8 | 1.53 | 17.7 | 1.30 | 0.1 |

[a] As provided in Ref. 7, from calculations performed with ENDF/B-VII.0 cross sections.
[b] C = calculated value; E = experimental value.

As observed in Table 3.19, the agreement between SCALE calculations and experiment is excellent for 24 and 27 fuel columns configurations, but the difference is larger for the fully loaded (30 fuel columns) core. The opposite is true for the MCNP estimations [7]. All the SCALE calculations, however, are within the reported experimental uncertainties.

### 3.3.4.4 Shutdown margin

For the purpose of this analysis, the "shutdown margin" does not coincide with NRC's definition of the shutdown margin. In NRC's glossary of terms at http://www.nrc.gov, the shutdown margin is defined as "The instantaneous amount of reactivity by which the reactor is subcritical or would be subcritical from its present condition assuming all full-length rod cluster assemblies (shutdown and control) are fully inserted except for the single rod cluster assembly of highest reactivity worth that is assumed to be fully withdrawn."

The shutdown margin, as used in this section and as measured experimentally, was evaluated for two shutdown cases on the fully loaded core configuration:

1. *Reflector CR in.* It is assumed that the central and first ring of control rods (C and R1 rods in Fig 3.13) maintain their position at a critical configuration, that is, 1775 mm above the bottom of the fuel blocks (Table 3.14), while the reflector rods (R2 and R3 in Fig 3.13) are fully inserted at 55 mm below the bottom of the fuel blocks.
2. *All control rods fully inserted.* At 55 mm below the bottom of the fuel blocks.

The reactivity insertion was calculated using the following relationship:

$$\rho = 100 \times \left( \frac{1}{k_{CRin}} - \frac{1}{k_{crit}} \right)$$

where $k_{crit}$ is the multiplication constant corresponding to the critical configuration and $k_{CRin}$ is the multiplication constant corresponding to any of the two shutdown configurations with the control rods inserted as mentioned above. Note that for a critical system, $k_{crit}$ should be unity. However, because of code biases and approximations in the computational models, the computed value of this quantity can be different from unity.

The results of the simulations are listed in Table 3.20 for both the CE and MG SCALE models, along with the experimental results and the MCNP simulation results as provided in Ref. 7. As seen, the agreement calculation–experiment is within the estimated experimental uncertainty for the case with all the control rods inserted. A larger difference in calculation–experiment is observed for the case where only the radial reflector control rods are inserted for all computational models. In both cases, the SCALE calculated data are in very good agreement with MCNP. Also, there is excellent agreement between the predictions of the MG and CE SCALE models.

Because the computational results for both SCALE models as well as for the MCNP model are in very good agreement, and because all three are quite far from the published experimental value for case 1 (Reflector CR in), it is believed that the large difference calculation–experiment in this case is due to an inconsistency in the specification for control rod positions.

**Table 3.20. Shutdown reactivities for full core configuration**

| # | Configuration | Experimental (% Δk/k) | SCALE MG (% Δk/k) | SCALE CE (% Δk/k) | MCNP CE (% Δk/k) |
|---|---|---|---|---|---|
| 1 | Reflector CR in | -12.1 ± 0.6 | -9.13 | -9.06 | -9.27 |
| 2 | All CR in | -46.3 ± 1.2 | -45.29 | -45.16 | -46.59 |

The above discrepancy for the shutdown margin with reflector CR inserted is even larger for calculations performed by the Japanese [33] using a diffusion code: -8.6% Δk/k. The same code predicts a -42.9% Δk/k shutdown margin for the case with all CR fully inserted, also significantly different from the reported experimental value.

### 3.3.4.5 Control rod worths

The worth of each control rod is an important parameter in reactor operation. Knowing the differential worth (calibration curve) of each control rod and/or bank of control rods allows for correct gauging of different reactivity effects. During normal operation, the core is assumed to be critical at all times. The reactivity inserted by different mechanisms such as fuel addition, temperature increase, xenon buildup, fuel depletion, etc. is compensated for by the movement of the control rods in such a way that the reactor is maintained critical. Therefore, measuring the insertion depth of the control rods allows for the estimation of the reactivity effects produced by different events, if the worth of the control rods is known as a function of their axial location.

The recent literature on HTTR experiments [7,8,33] mentions two types of control rod worth measurements. The first measurement is for the worth of a control rod at the center of the core. The description of this measurement, however, lacks important elements, and an attempt [6] to reproduce the experimental data was not successful. The set of data for the second experiment is described in [7] in the context of its use for the estimation of the reactivity coefficients and is presented as a calibration curve (reactivity as a function of the control rod position) for an FS pattern in the fully loaded core. The specification of the FS pattern is sufficient to fully characterize the core configuration.

Given the above considerations, it was only the second measurement that was modeled using the SCALE code system. The reference results were obtained by digitizing the experimental calibration curve in Figure 2.7 of [7]. The total reactivity worth of the control rods was evaluated by varying the position of the control rods in the fully loaded core. All control rods, except for those in ring R3 (Fig. 3.13) that were fully withdrawn, were moved synchronously, in an FS pattern. For each height of the control rods, the multiplication constant was calculated with SCALE. As used in Figure 2.7 of [7], the reference position was considered for a control rod insertion height of ~186 cm. The quantity calculated was

$$\%\frac{\Delta k}{k} \equiv 100 \times \left( \frac{1}{k_{ref}} - \frac{1}{k_h} \right)$$

where $k_{ref}$ is the multiplication constant corresponding to the reference insertion (~186 cm) of the control rods and $k_h$ is the multiplication constant corresponding to the insertion height $h$.

The digitized experimental curve [7] and the corresponding data calculated with both MG and CE SCALE models are presented in Figure 3.19. The agreement between experiment and calculation is very good over the whole range of the measurements. A slight overprediction of the control rod worth can be seen in the mid range of the curve (corresponding to the control rod tip near the top of the fuel) and an underprediction in the high range (corresponding to the control rod tip in the top axial graphite, i.e., the control rod fully extracted). The agreement between the MG and CE models is very good.

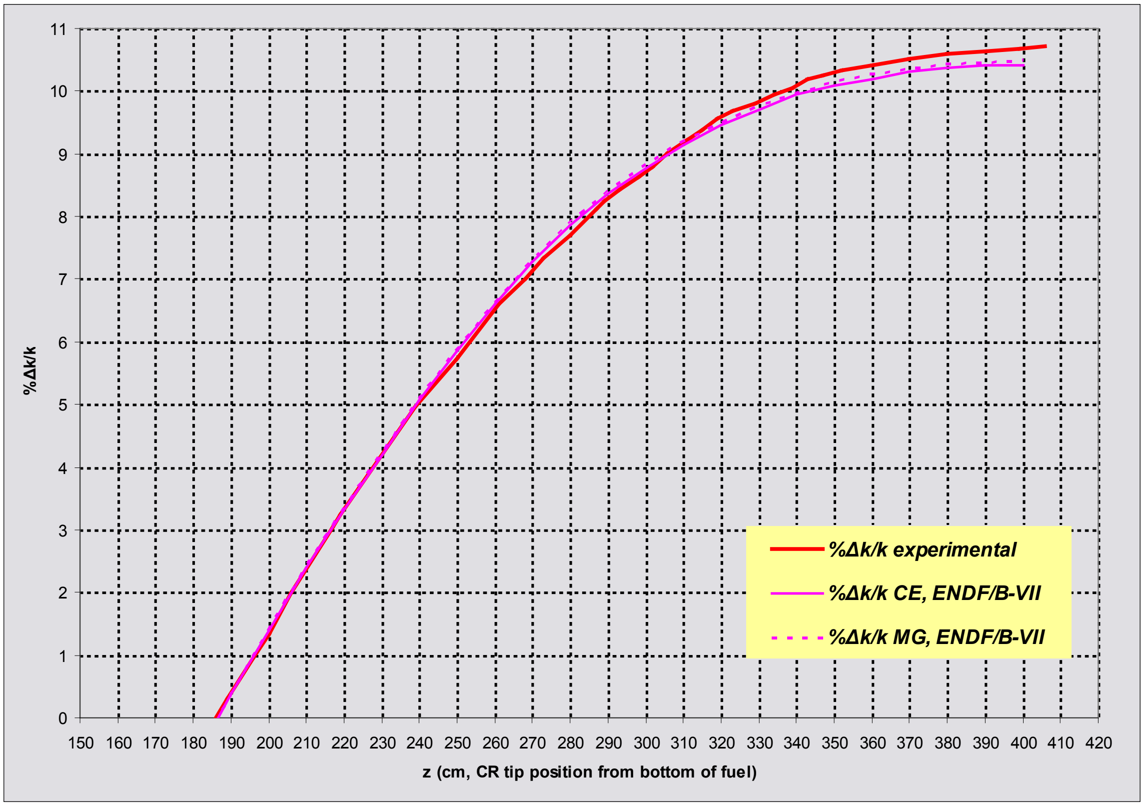



**Fig. 3.19. Control rod worth for the FS pattern.**

The calculations illustrated in Fig. 3.19 were extended for the whole height of the reactor core, starting at -5.5 cm below the fuel bottom, although no experimental data were available for the full range. The results are illustrated in Fig. 3.20 for the CE models. The results for the MG models are similar to those for the corresponding CE models. The curves shown in Fig. 3.20 for 300 K can be used to assess the sensitivity of the CR reactivity insertion, $\left(\frac{\partial \rho}{dz}\right)$, as a function of the CR position. As observed from the slope of the curve, this sensitivity reaches a maximum at ~65 cm and decreases towards zero as the control rods are either extracted or inserted. It was calculated that for an insertion depth of ~65 cm, the sensitivity is very high, ~500 pcm/cm.

The calculated reactivity curves corresponding to an isothermal core temperature of 600 K is also represented in Fig. 3.20. Comparison of the 300 K and 600 K curves shows that the sensitivity of the CR reactivity insertion increases with the core temperature—that is, the CR becomes more effective at higher temperatures. No experimental data with which to validate the calculated results were available for the 600 K temperature.

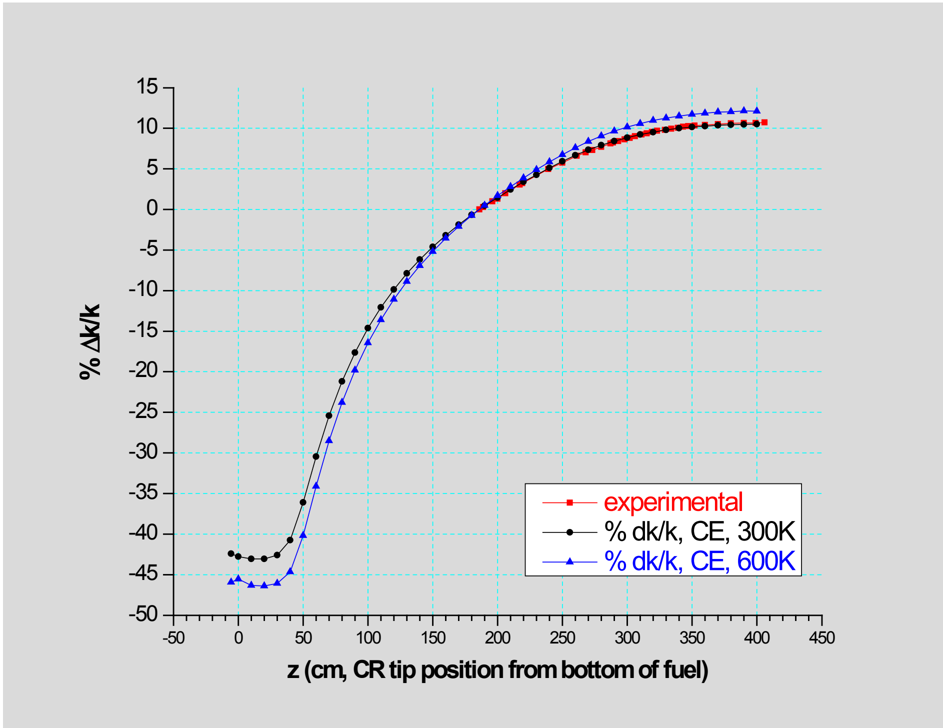



**Fig. 3.20. Control rod worth for the FS pattern at 300 K and 600 K.**

### 3.3.4.6 Isothermal reactivity coefficients

The isothermal temperature coefficient of reactivity was calculated using the reference SCALE full core MG model, for a temperature range from 0 to 500 °C. The results are presented in Table 3.21 and illustrated in Fig. 3.21. These SCALE results are compared to the experimental data and to the MCNP-calculated data as reported in Ref. 9. The SCALE results illustrated in Fig. 3.21 were obtained for a fixed insertion depth of the control rods; the corresponding points in the plot were fitted with a linear function.

The SCALE results agree reasonably well with the experimental values and the MCNP-calculated values, even though the computational model did not account for the thermal dilation. As noted in Fig. 3.21, the computed values are generally within 1σ experimental uncertainty.

**Table 3.21. Isothermal reactivity coefficients**

| T(°C) | ∂ρ/∂T (pcm/°C) Experimental | ∂ρ/∂T (pcm/°C) MCNP | ∂ρ/∂T (pcm/°C) SCALE MG |
|---|---|---|---|
| 72.85 | -12.3 (3.2)[a] | -11.6 (0.2)[b] | -15.0 |
| 133.85 | -13.2 (3.3) | -12.8 (0.2) | -14.7 |
| 147.85 | -21.7 (13) | -12.8 (0.2) | -14.7 |
| 259.85 | -16.5 (2.9) | -12.9 (0.2) | -14.1 |
| 368.85 | -10.3 (2.8) | -12.6 (0.2) | -13.5 |
| 462.85 | -8.6 (2.7) | -12.1 (0.2) | -13.1 |

[a] Data in parentheses correspond to 1σ experimental uncertainty.
[b] Data in parentheses correspond to 1σ statistical uncertainty.

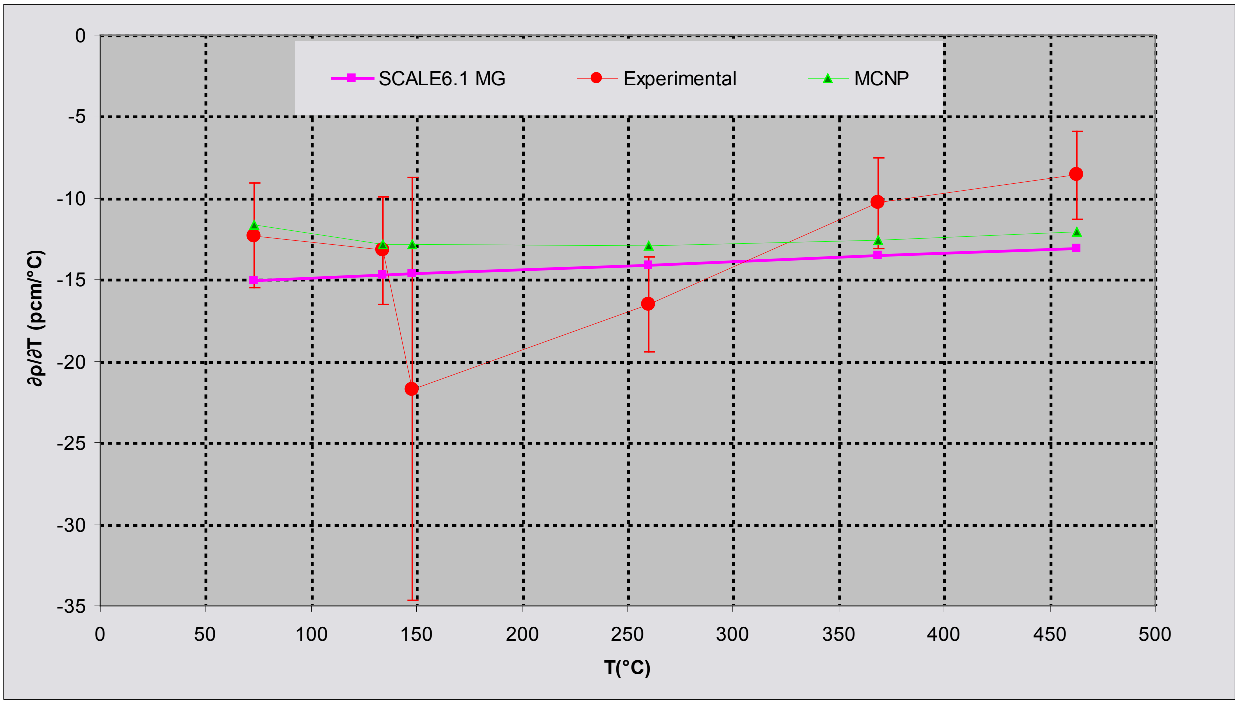



**Fig. 3.21. Isothermal reactivity coefficients.**

### 3.3.4.7 Flux and reaction rates distributions

*Fully Loaded Core*

Experimental fission rates for $^{235}$U were reported for the HTTR full core from measurements performed using a fission chamber located at selected heights along the irradiation column [7]. However, no information was provided on the configuration of the fission chamber to facilitate an accurate representation of this chamber in the computational model.

To facilitate a comparison of calculation and experiment to some extent, two types of data were extracted using the computational model: scalar flux distribution and reaction rate distribution, using some assumptions. Both the computational results and the measurement data were normalized to their largest value. In a first approximation, the relative scalar flux distribution (normalized to its maximum value) is similar to the relative reaction rate distribution, calculated as

$$R_{norm} = \frac{\int_0^\infty \Sigma(\vec{r},E)\Phi(\vec{r},E)dE}{\int_0^\infty \Sigma(\vec{r}_0,E)\Phi(\vec{r}_0,E)dE}$$

where $\Sigma$ and $\Phi$ identify the macroscopic cross section and scalar flux, and $\vec{r}$ and E stand for neutron spatial location and energy. The quantity in the denominator represents the maximum reaction rate used for normalization. In the assumption that the macroscopic cross section is independent of position, the above ratio is identically equal with the normalized flux (expression shown below) if the flux is a separable function of position and energy.

$$\Phi_{norm} = \frac{\int_0^\infty \Phi(\vec{r}, E)dE}{\int_0^\infty \Phi(\vec{r}_0, E)dE}$$

The above assumption is equivalent to assuming that the spectrum of the neutrons reaching the fission chamber is virtually independent of the position of the chamber in the irradiation column.

Calculations were performed for all three positions reported [7] for the fission chamber location along the irradiation column, with both the continuous energy and the multigroup SCALE models. The comparison between the SCALE computed normalized scalar fluxes and the normalized experimental fission rates are shown in Fig. 3.22. Three series of values for the flux are shown in the figure, corresponding to the three measurement locations. The agreement of calculation–experiment is consistent with the agreement observed between MCNP computations and experiment [7]. A possible cause of the observed difference between calculation and experiment may be that the experimental values were reported at shifted height values. This hypothesis is sustained by the fact that a shift of 10 cm in the location would bring the computed values in very good agreement with the experimental values, as illustrated in Fig. 3.23. The agreement between the flux distributions computed with the MG model and the CE model is excellent, as seen in Figs. 3.22 and 3.23.

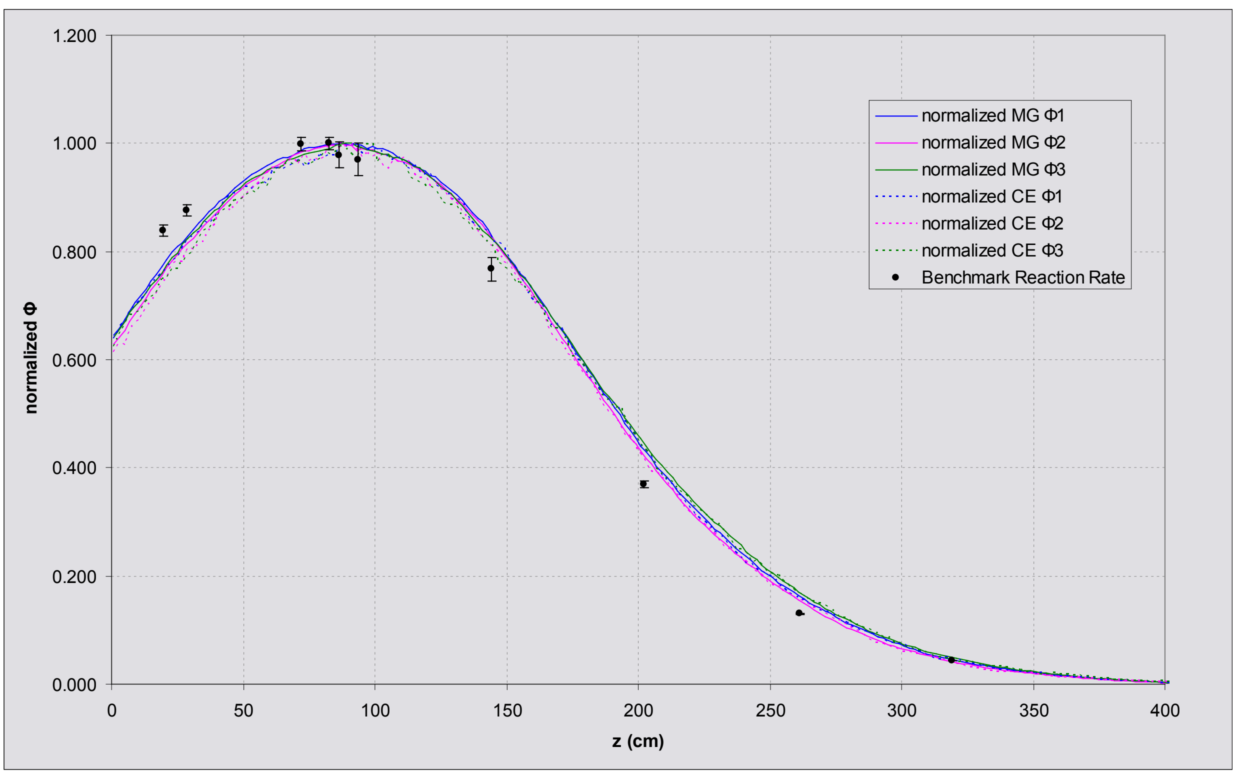



**Fig. 3.22. Multigroup and continuous energy flux distributions in the three channels and experimental points for $^{235}$U(n,f) reaction rate.**

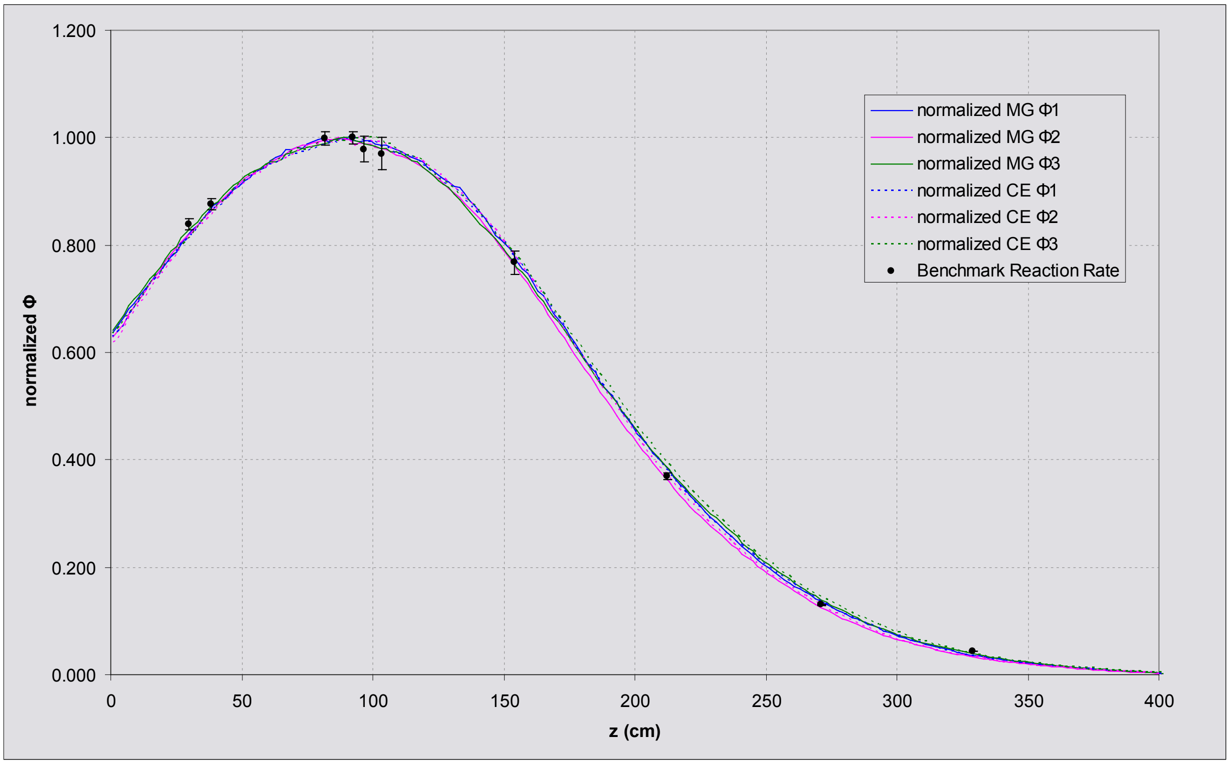



**Fig. 3.23. Multigroup and continuous energy flux distributions in the three channels and shifted experimental points for $^{235}$U(n,f) reaction rate.**

In a second approximation, fission rates for $^{235}U$ were estimated based on the computed values for the scalar fluxes and the $^{235}U(n,f)$ infinite dilution (without resonance self-shielding) reaction cross-section data from the ENDF/B-VII.0 library. The normalized fission reaction rate thus computed is compared to the corresponding normalized scalar flux and the measurement data for one of the experiment locations, as illustrated in Fig. 3.24. This computed fission rate is labeled "normalized MG RR1" in the figure. Although the reaction rate seems to be closer to the experimental points, the difference is still large and cannot be explained by the use of a reaction rate in lieu of the flux.

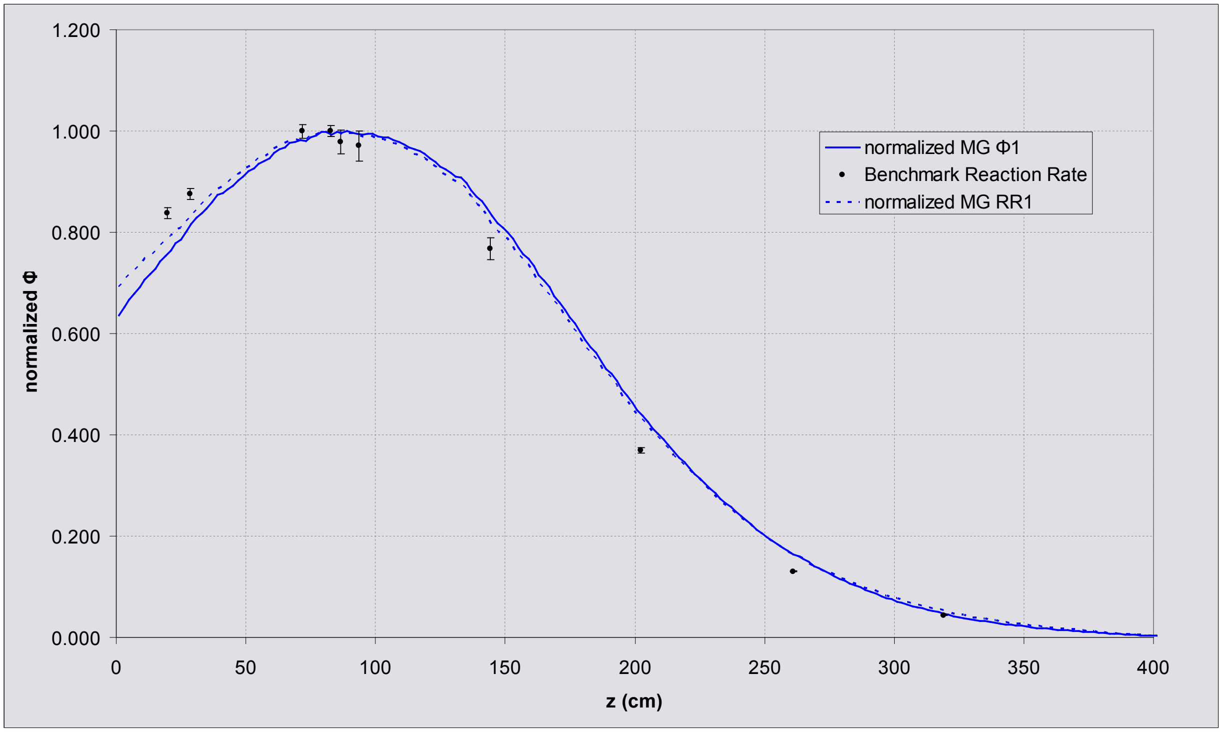



**Fig. 3.24. Multigroup flux and $^{235}U(n,f)$ reaction rate computed distributions in channel 1 and the experimental point for $^{235}U(n,f)$ reaction rate.**

*Critical Configuration 3*

The flux and reaction rate computations were also obtained for annular critical core 3 (24 fuel columns, with control rods in FS pattern). The agreement of calculation–experiment in this case, illustrated in Fig. 3.25, is similar to that seen for the full core. Again, the calculated reaction rates agree well with the experiment, and the agreement improves when a 10 cm shift is applied to the experiment location. As with the full core, there is practically no difference in results from SCALE MG and the CE simulations.

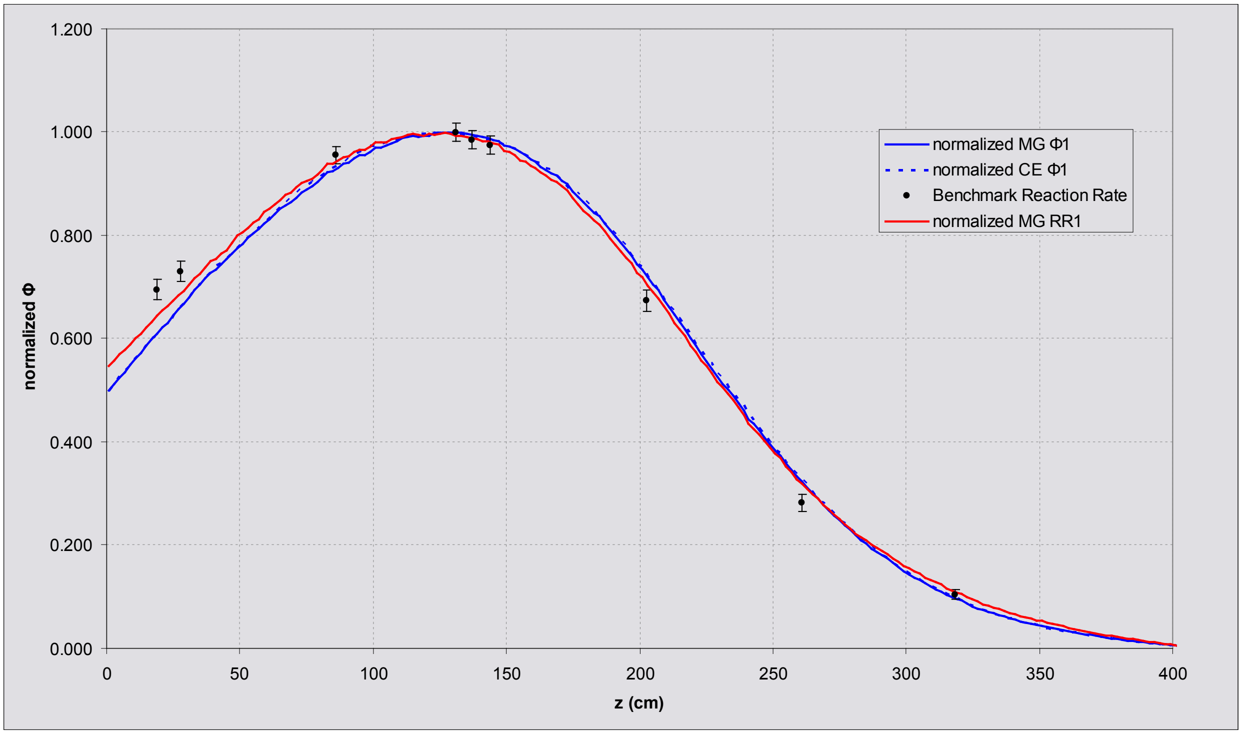



**Fig. 3.25. Flux and $^{235}U(n,f)$ reaction rate computed distributions in channel 1 and the experimental points for $^{235}U(n,f)$ reaction rate for critical configuration 3.**

*Critical Configuration 4*

Flux and reaction rates were calculated for the annular critical core 4 (24 fuel columns, with control rods in F23 pattern) and are compared to experimental data in Fig. 3.26. The agreement is excellent between the SCALE MG and the CE calculations. The calculated reaction rate, however, departs more from the flux distribution, meaning that the spectrum changes with the height on the irradiation column. The calculated reaction rate agrees better with the experiment than the scalar flux, as seen in Fig. 3.26.

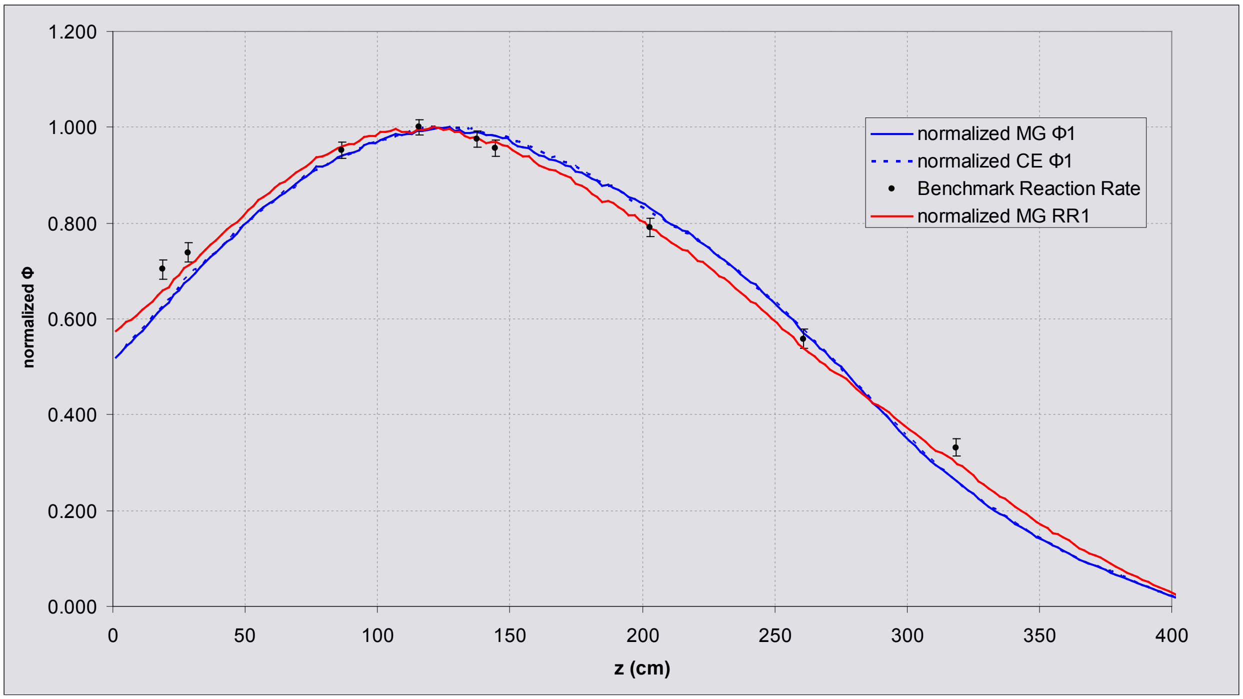



**Fig. 3.26. Flux and $^{235}U(n,f)$ reaction rate computed distributions in channel 1 and the experimental points for $^{235}U(n,f)$ reaction rate for critical configuration 4.**

# 4. SUMMARY

This report documents verification and validation studies to assess the performance of the SCALE code system for analysis of HTGR configurations. The experimental data used for validation were available from the *International Handbook of Evaluated Reactor Physics Benchmark Experiments* for two different HTGR designs: prismatic and pebble bed. SCALE 3-D models have been developed for HTTR, a prismatic fuel design reactor operated in Japan; HTR-10, a pebble bed reactor operated in China; and HTR-PROTEUS, a pebble bed configuration at the PROTEUS critical facility in Switzerland. The development of these models has involved a series of investigations to identify the particular issues associated with modeling the physics of the HTGRs and to understand and quantify the effect of particular modeling assumptions on calculation-to-experiment comparisons.

The 3-D simulations performed at the core level for the HTR-10 and HTTR cores were supplemented with investigations at the fuel pebble and fuel block level for better understanding of the underlying physics and for estimating the effects of the modeling assumptions and the cross-section data employed. In addition, four quasi 2-D configurations containing HTTR fuel blocks were studied to assess the effect on $k_{eff}$ of gradual changes in the arrangement and orientation of fuel and moderator blocks, from simple to more complex cores.

The SCALE calculations were performed using both continuous energy and multigroup (238-group) models, both based on ENDF/B-VII.0 nuclear data. The continuous energy model used an explicit representation of the fuel particles inside the fuel compacts. The multigroup model used the double-heterogeneity feature incorporated in SCALE.

Comparisons of experiment data with calculations were performed for criticality measurements available for all three reactor configurations considered. In addition, subcritical HTTR experiments were analyzed with SCALE, as well as HTTR experiments for determining important safety parameters such as control rod worth, excess reactivity, shutdown margin, isothermal reactivity coefficients, and reaction rates. The SCALE results were also compared with the corresponding MCNP-calculated results reported in the literature. The results of the simulations showed a relatively good agreement between SCALE and MCNP calculations. Both MCNP and SCALE consistently overestimated the experimental values of $k_{eff}$ for all three cores and all criticality measurements considered. The calculation–experiment agreement is generally good for differential quantities such as control rod worth, shutdown margin, and excess reactivity.

All experimental data used for validation in this report were obtained for cold cores at zero power and with fresh fuel. Conclusions on SCALE performance for these types of cores cannot be extended to analyses of higher temperature full-power cores without further confirmatory simulations. However, the models already developed and the lessons learned from the investigations performed would greatly facilitate such an additional benchmark effort when new measurement data become available.

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# APPENDIX A.
# SCALE CONTINUOUS ENERGY MODEL FOR HTTR

# APPENDIX A. SCALE CONTINUOUS ENERGY MODEL FOR HTTR

```
=csas26
Dan Ilas, 2009, 2010: HTTR core based on HTTR-GCR-RESR-001
ce_v7
' ------------------------------------------------------------------------------
' --- References:
' [1] John D. Bess, Nozomu Fujimoto: Evaluation of the Start-up Core Physics
' Tests at Japan's High Temperature Engineering Test Reactor
' (Fully-Loaded Core), Revision 0, March, 2009

' ------------------------------------------------------------------------------
' --- Materials ----------------------------------------------------------------
read comp
' Material References:
' --------------------
' m=1 to 12   CFP fuel atom densities from Table 3.1, pag. 195 of [1]
' m=13        Buffer atom densities from Table 3.2, pag. 196 of [1]
' m=14        IPyC atom densities from Table 3.2, pag. 196 of [1]
' m=15        SiC atom densities from Table 3.2, pag. 196 of [1]
' m=16        OPyC atom densities from Table 3.2, pag. 196 of [1]
' m=17        Overcoat atom densities from Table 3.2, pag. 196 of [1]
' m=18        Compact atom densities from Table 3.3, pag. 196 of [1]
' m=19        Sleeve atom densities from Table 3.4, pag. 196 of [1]
' m=20        IG-110 atom densities from Table 3.6, pag. 197 of [1]
'             by multiplying with 1.005
' m=21        Helium coolant from 3.1.3.10, page 199 of [1]
' m=22        Disks atom densities in BP pins from Table 3.5, pag. 197 of [1]
' m=23        BP atom densities (2.0%) from Table 3.5, pag. 197 of [1]
' m=24        BP atom densities (2.5%) from Table 3.5, pag. 197 of [1]
' m=25        PGX Graphite from Table 3.9, pag. 199 of [1]
' m=26        Absorber Compacts in CR from Table 3.7, pag. 198 of [1]
' m=27        Alloy 800H Clad in CR from Table 3.8, pag. 198 of [1]
'
'
===============================================================================
' --- Fuel Kernel, 3.4% enrichment:
  U-234          1  0   6.0946E-06   293.65  end
  U-235          1  0   7.9784E-04   293.65  end
  U-238          1  0   2.2376E-02   293.65  end
  O-16           1  0   4.6343E-02   293.65  end
  B-10           1  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 3.9% enrichment:
  U-234          2  0   6.9909E-06   293.65  end
  U-235          2  0   9.1517E-04   293.65  end
  U-238          2  0   2.2259E-02   293.65  end
  O-16           2  0   4.6343E-02   293.65  end
  B-10           2  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 4.3% enrichment:
  U-234          3  0   7.7079E-06   293.65  end
  U-235          3  0   1.0090E-03   293.65  end
  U-238          3  0   2.2166E-02   293.65  end
  O-16           3  0   4.6343E-02   293.65  end
  B-10           3  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 4.8% enrichment:
```

```
  U-234           4  0   8.6041E-06   293.65  end
  U-235           4  0   1.1264E-03   293.65  end
  U-238           4  0   2.2049E-02   293.65  end
  O-16            4  0   4.6343E-02   293.65  end
  B-10            4  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 5.2% enrichment:
  U-234           5  0   9.3211E-06   293.65  end
  U-235           5  0   1.2202E-03   293.65  end
  U-238           5  0   2.1955E-02   293.65  end
  O-16            5  0   4.6343E-02   293.65  end
  B-10            5  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 5.9% enrichment:
  U-234           6  0   1.0576E-05   293.65  end
  U-235           6  0   1.3845E-03   293.65  end
  U-238           6  0   2.1792E-02   293.65  end
  O-16            6  0   4.6343E-02   293.65  end
  B-10            6  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 6.3% enrichment:
  U-234           7  0   1.1293E-05   293.65  end
  U-235           7  0   1.4783E-03   293.65  end
  U-238           7  0   2.1699E-02   293.65  end
  O-16            7  0   4.6343E-02   293.65  end
  B-10            7  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 6.7% enrichment:
  U-234           8  0   1.2010E-05   293.65  end
  U-235           8  0   1.5722E-03   293.65  end
  U-238           8  0   2.1605E-02   293.65  end
  O-16            8  0   4.6343E-02   293.65  end
  B-10            8  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 7.2% enrichment:
  U-234           9  0   1.2906E-05   293.65  end
  U-235           9  0   1.6895E-03   293.65  end
  U-238           9  0   2.1489E-02   293.65  end
  O-16            9  0   4.6343E-02   293.65  end
  B-10            9  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 7.9% enrichment:
  U-234          10  0   1.4161E-05   293.65  end
  U-235          10  0   1.8538E-03   293.65  end
  U-238          10  0   2.1325E-02   293.65  end
  O-16           10  0   4.6343E-02   293.65  end
  B-10           10  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 9.4% enrichment:
  U-234          11  0   1.6850E-05   293.65  end
  U-235          11  0   2.2058E-03   293.65  end
  U-238          11  0   2.0975E-02   293.65  end
  O-16           11  0   4.6343E-02   293.65  end
  B-10           11  0   1.7276E-07   293.65  end
' --- Fuel Kernel, 9.9% enrichment:
  U-234          12  0   1.7746E-05   293.65  end
  U-235          12  0   2.3231E-03   293.65  end
  U-238          12  0   2.0858E-02   293.65  end
  O-16           12  0   4.6343E-02   293.65  end
  B-10           12  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     13  0   5.5153E-02   293.65  end
  B-10           13  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     14  0   9.2758E-02   293.65  end
```

```
  B-10           14  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     15  0   4.8061E-02   293.65  end
  Si             15  0   4.8061E-02   293.65  end
  B-10           15  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     16  0   9.2758E-02   293.65  end
  B-10           16  0   3.0761E-08   293.65  end
' --- Graphite overcoat:
  C-graphite     17  0   8.5237E-02   293.65  end
  B-10           17  0   2.8267E-08   293.65  end
' --- Graphite compact:
  C-graphite     18  0   8.5237E-02   293.65  end
  B-10           18  0   1.5452E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     19  0   8.8747E-02   293.65  end
  B-10           19  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     20  0   8.8243E-02   293.65  end
  B-10           20  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             21  0   2.4616E-05   293.65  end
' --- Graphite disks:
  C-graphite     22  0   8.8747E-02   293.65  end
  B-10           22  0   7.2596E-09   293.65  end
' --- Burnable poison (2.0wt%):
  C-graphite     23  0   8.8446E-02   293.65  end
  B-10           23  0   3.9906E-04   293.65  end
  B-11           23  0   1.6063E-03   293.65  end
' --- Burnable poison (2.5wt%):
  C-graphite     24  0   8.7995E-02   293.65  end
  B-10           24  0   4.9882E-04   293.65  end
  B-11           24  0   2.0078E-03   293.65  end
' --- PGX Graphite:
  C-graphite     25  0   8.6134E-02   293.65  end
  B-10           25  0   3.6372E-08   293.65  end
' --- Absorber Compacts in CR:
  C-graphite     26  0   6.6685E-02   293.65  end
  B-10           26  0   6.8220E-03   293.65  end
  B-11           26  0   2.4974E-02   293.65  end
' --- Alloy 800H Clad in CR:
  C-graphite     27  0   3.2210E-04   293.65  end
  Al             27  0   6.7209E-04   293.65  end
  Si             27  0   6.0263E-04   293.65  end
  P              27  0   3.1225E-05   293.65  end
  S              27  0   1.5081E-05   293.65  end
  Ti             27  0   3.7884E-04   293.65  end
  Cr             27  0   1.9530E-02   293.65  end
  Mn             27  0   8.8022E-04   293.65  end
  Fe             27  0   3.8092E-02   293.65  end
  Ni             27  0   2.6777E-02   293.65  end
  Cu             27  0   2.2830E-04   293.65  end
' --- Helium coolant used in CR to mark the CR placement:
  He             28  0   2.4616E-05   293.65  end
end comp

' ---------------------------------------------------------------------------
' --- Parameters ------------------------------------------------------------
```

```
read parm
       gen=1100
       npg=100000
       nsk=100
       tba=100
       htm=no
       flx=yes
       fdn=yes
end parm

' ----------------------------------------------------------------------------
' --- Geometry ---------------------------------------------------------------
read geom
' Dimensions for block and pin details based on Figure 1.52 page 68 of [1]
' Counting of pins starts at the lower left corner, going horizontally and
' then vertically
' Dimensions for grain cells based on Figure 3.1 page 176 of [1]
'
' Numbering scheme for cells that make up fuel block units:
'  zlb1   fuel grain
'  zlb2   BP pin
'  zlb3   fuel pin
'  zlb4   central hole
'  zlb5   empty pin
'  zlb6   graphite
'  zlb    block
'
' Block numbering (Fig. 3.15, page 190 of [1]):
' Each block is numbered according to the scheme 100*z+10*l+b, where:
'   z=1,...,8       zone number
'                      **Fuel: z=1,2 for zones 1 and 2, respectively
'                              z=3,5 alternatively as one goes
counterclockwise
'                              for zone 3, z=4 for zone 4
'                      **Replaceable Reflectors in fuel columns follow the
same
'                        pattern as fuel blocks, but with different l:
l=1,2,8,9
'                      **CR:   z=6 for "C" (b=1) and "R1" (b=2,...,7)
'                              z=7 for "R2" and "R3" (b=1,...,9, going
'                              counterclockwise)
'                      **Instrumentation Blocks have z=8 (b=1,2,3)
'   l=1,...,9       layer number from top to bottom
'                   (fuel blocks in layers 3 to 7 from top)
'   b=1,...,bmax(z) block number (starting from positive x, counterclockwise)
'                      bmax(1)=...=bmax(5)=6
'                      bmax(6)=7, bmax(7)=9
'                      bmax(8)=3
' Replaceable Reflector (RR) blocks that are not in fuel columns are assigned
' block# 900
' Graphite blocks to make up the Permanent Reflector are assigned block# 100
'
'================ Graphite Block =================
unit 100
  rhexprism     1  18.     29.    -29.
  media      25     1       1
  boundary      1
unit 10
```

```
  rhexprism      1  18.    261.   -261.
  array   10  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'================ Fuel Column: Zone 1 Block 1 =================
'================ Block 111 =================
unit 1113
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21      1       5
  media      20      1       6      -5
  boundary      6
unit 1114
  cone          1   2.5    29.      1.5    20.
  cylinder      2   1.5    20.     14.
  cylinder      3   2.25   14.      4.
  cylinder      4   2.505  29.    -29.
  hexprism      5   2.575  29.    -29.
  media      21      1       1
  media      21      1       2
  media      21      1       3
  media      20      1       4      -1       -2       -3
  media      20      1       5      -4
  boundary      5
unit 1116
  hexprism      1   2.575  29.    -29.
  media      20      1       1
  boundary      1
unit 111
  rhexprism     1  18.     29.    -29.
  array  111  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 131 =================
unit 1311
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       8      1       1
  media      13      1       2      -1
  media      14      1       3      -2
  media      15      1       4      -3
  media      16      1       5      -4
  media      17      1       6      -5
  boundary      6
unit 1312
  cylinder      1   0.7     5.2    -4.8
  cylinder      2   0.7    25.2   -24.8
  cylinder      3   0.75   25.2   -24.8
  cylinder      4   0.75   29.    -29.
  hexprism      5   2.575  29.    -29.
  media      22      1       1
  media      23      1       2      -1
  media      21      1       3      -2
  media      20      1       4      -3
  media      20      1       5      -4
  boundary      5
```

```
unit 1313
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   1311  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 1315
  cylinder      1   0.75   25.2   -24.8
  cylinder      2   0.75   29.    -29.
  hexprism      3   2.575  29.    -29.
  media      21     1       1
  media      20     1       2      -1
  media      20     1       3      -2
  boundary      3
unit 131
  rhexprism     1  18.     29.    -29.
  array  131  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 141 =================
unit 1411
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       5     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 1412
  cylinder      1   0.7     5.2    -4.8
  cylinder      2   0.7    25.2   -24.8
  cylinder      3   0.75   25.2   -24.8
  cylinder      4   0.75   29.    -29.
  hexprism      5   2.575  29.    -29.
  media      22     1       1
  media      24     1       2      -1
  media      21     1       3      -2
  media      20     1       4      -3
  media      20     1       5      -4
  boundary      5
unit 1413
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   1411  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
```

```
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 141
  rhexprism     1  18.     29.    -29.
  array  141  1  place  5  5  1   0.0      0.0      0.0
  boundary     1
'================ Block 151 =================
unit 1511
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       3     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 1513
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   1511  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 151
  rhexprism     1  18.     29.    -29.
  array  151  1  place  5  5  1   0.0      0.0      0.0
  boundary     1
'================ Block 161 =================
unit 1611
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       1     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
```

```
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 1613
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   1611  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 161
  rhexprism     1  18.     29.    -29.
  array  161  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Generic fuel column for ring 1 =================
unit 110
  rhexprism     1  17.    261.   -261.
  array   11  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'================ Ring 1: place the above-defined fuel column in six places
====
unit 11
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=0
  media      20     1       1
  boundary      1
unit 12
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=60
  media      20     1       1
  boundary      1
unit 13
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=120
  media      20     1       1
  boundary      1
unit 14
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=180
  media      20     1       1
  boundary      1
unit 15
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=240
  media      20     1       1
  boundary      1
unit 16
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=300
  media      20     1       1
  boundary      1
```

```
'================ Fuel Column: Zone 2 Block 1 =================
'================ Block 211 =================
unit 211
  rhexprism     1  18.     29.    -29.
  array  211  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 231 =================
unit 2311
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media      10     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 2313
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   2311  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 231
  rhexprism     1  18.     29.    -29.
  array  231  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 241 =================
unit 2411
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       7     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 2413
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   2411  2 -1  place  13  13  248   0.0      0.0      0.0
```

```
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 241
  rhexprism     1  18.     29.    -29.
  array  241  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 251 =================
unit 2511
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       5     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 2513
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   2511  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 251
  rhexprism     1  18.     29.    -29.
  array  251  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 261 =================
unit 2611
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       2     1       1
  media      13     1       2      -1
  media      14     1       3      -2
```

```
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 2613
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   2611  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 261
  rhexprism     1  18.     29.    -29.
  array  261  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Generic fuel column for ring 2 =================
unit 210
  rhexprism     1  17.    261.   -261.
  array   21  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'============= Ring 2: place the above-defined fuel column in six places ====
unit 21
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=0
  media      20     1       1
  boundary      1
unit 22
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=60
  media      20     1       1
  boundary      1
unit 23
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=120
  media      20     1       1
  boundary      1
unit 24
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=180
  media      20     1       1
  boundary      1
unit 25
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=240
  media      20     1       1
  boundary      1
unit 26
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=300
  media      20     1       1
  boundary      1
```

```
'================ Fuel Column: Zone 3 Block 1.1 =================
'================ Block 311 =================
unit 311
  rhexprism     1  18.     29.    -29.
  array  311  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 331 =================
unit 3311
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media      11     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 3313
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   3311  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 331
  rhexprism     1  18.     29.    -29.
  array  331  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 341 =================
unit 3411
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       9     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 3413
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   3411  2 -1  place  13  13  248   0.0      0.0      0.0
```

```
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 341
  rhexprism     1  18.     29.    -29.
  array  341  1  place  5  5  1   0.0       0.0       0.0
  boundary      1
'================ Block 351 =================
unit 3511
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       6     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 3513
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   3511  2 -1  place  13  13  248   0.0       0.0       0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 351
  rhexprism     1  18.     29.    -29.
  array  351  1  place  5  5  1   0.0       0.0       0.0
  boundary      1
'================ Block 361 =================
unit 3611
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       3     1       1
  media      13     1       2      -1
  media      14     1       3      -2
```

```
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 3613
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   3611  2 -1  place  13  13  248   0.0       0.0       0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 361
  rhexprism     1  18.     29.    -29.
  array  361  1  place  5  5  1   0.0       0.0       0.0
  boundary      1
'================ Generic fuel column for ring 3 =================
unit 310
  rhexprism     1  17.    261.   -261.
  array   31  1  place  1  1  5   0.0       0.0       0.0
  boundary      1
'============= Ring 3: place the above-defined fuel column in twelve places =
unit 31
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=0
  media      20     1       1
  boundary      1
unit 51
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=120
  media      20     1       1
  boundary      1
unit 32
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=60
  media      20     1       1
  boundary      1
unit 52
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=180
  media      20     1       1
  boundary      1
unit 33
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=120
  media      20     1       1
  boundary      1
unit 53
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=240
  media      20     1       1
  boundary      1
```

```
unit 34
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=180
  media      20     1       1
  boundary      1
unit 54
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=300
  media      20     1       1
  boundary      1
unit 35
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=240
  media      20     1       1
  boundary      1
unit 55
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=0
  media      20     1       1
  boundary      1
unit 36
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=300
  media      20     1       1
  boundary      1
unit 56
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=60
  media      20     1       1
  boundary      1
'================ Fuel Column: Zone 4 Block 1 =================
'================ Block 411 =================
unit 411
  rhexprism     1  18.     29.    -29.
  array  411  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 431 =================
unit 4311
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media      12     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 4313
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   4311  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
```

```
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 431
  rhexprism     1  18.     29.    -29.
  array  431  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'=============== Block 441 ================
unit 4411
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media      10     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 4413
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   4411  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 441
  rhexprism     1  18.     29.    -29.
  array  441  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'=============== Block 451 ================
unit 4511
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       7     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
```

```
  boundary      6
unit 4513
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   4511  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 451
  rhexprism     1  18.     29.    -29.
  array  451  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 461 =================
unit 4611
  sphere        1   0.03
  sphere        2   0.036
  sphere        3   0.039
  sphere        4   0.0415
  sphere        5   0.046
  cuboid        6 6p0.055377
  media       4     1       1
  media      13     1       2      -1
  media      14     1       3      -2
  media      15     1       4      -3
  media      16     1       5      -4
  media      17     1       6      -5
  boundary      6
unit 4613
  cylinder      1   0.5    27.3   -27.3
  cylinder      2   1.3    27.3   -27.3
  array   4611  2 -1  place  13  13  248   0.0      0.0      0.0
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      21     1       1
  media      21     1       3      -2
  media      19     1       4      -3
  media      21     1       5      -4
  media      20     1       6      -5
  boundary      6
unit 461
  rhexprism     1  18.     29.    -29.
  array  461  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Generic fuel column for ring 4 =================
unit 410
  rhexprism     1  17.    261.   -261.
  array   41  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'============= Ring 4: place the above-defined fuel column in six places ====
```

```
unit 41
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=0
  media      20     1       1
  boundary      1
unit 42
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=60
  media      20     1       1
  boundary      1
unit 43
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=120
  media      20     1       1
  boundary      1
unit 44
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=180
  media      20     1       1
  boundary      1
unit 45
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=240
  media      20     1       1
  boundary      1
unit 46
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=300
  media      20     1       1
  boundary      1
'
'================ Control rods (Fig. 3.8, pag. 183 of [1]) =============
'
'============== Control rod section (Fig. 3.7, pag. 182 of [1]) =============
unit 9101
  cylinder      1   0.5    30.      1.
  cylinder      2   3.25   30.      1.
  cylinder      3   3.75   30.      1.
  cylinder      4   5.25   30.      1.
  cylinder      5   5.65   31.      0.
  cylinder      6   6.15   31.      0.
  hexprism      7   7.     31.      0.
  media      27     1       1
  media      21     1       2      -1
  media      27     1       3      -2
  media      26     1       4      -3
  media      27     1       5      -4
  media      21     1       6      -5
  media      20     1       7      -6
  boundary      7
'================ Control rod empty region =============
unit 9102
  cylinder      1   6.15  522.      0.
  hexprism      2   7.    522.      0.
  media      21     1       1
  media      20     1       2      -1
  boundary      2
'================ Central region in CR =============
```

```
unit 6001
  cone          1   2.5    29.      1.     15.5
  cylinder      2   1.5    20.     14.
  cylinder      3   2.25   14.      4.
  hexprism      4   2.5    29.    -29.
  media      21     1       1      -2
  media      21     1       2
  media      21     1       3
  media      20     1       4      -1      -2      -3
  boundary      4
'================ CR Column 61: Central =================
unit 610
  cylinder      1   6.15  261.   -155.   origin x=-5.4       y=-9.353074
  cylinder      2   6.15  261.   -155.   origin x=10.8       y=0.
  cylinder      3   6.15  261.   -155.   origin x=-5.4       y=9.353074
  cylinder      4   2.3   261.   -261.
  array 9101  1  place  1  1  2    -5.4     -9.353074     32.5
  array 9101  2  place  1  1  2    10.8      0.           32.5
  array 600   4  place  1  1  5     0.0      0.0           0.0
  rhexprism     5     17.    261.   -261.
  media      21     1       3
  media      20     1       5      -1      -2      -3      -4
  boundary      5
'================ Central CR: place CR in central column =================
unit 61
  rhexprism     1  18.    261.   -261.
  hole  610  rotate a1=0
  media      20     1       1
  boundary      1
'================ CR Column 62: R1, Column 1 =================
unit 620
  cylinder      1   6.15  261.   -155.   origin x=-10.8      y=0.
  cylinder      2   6.15  261.   -155.   origin x=5.4        y=-9.353074
  cylinder      3   6.15  261.   -155.   origin x=5.4        y=9.353074
  cylinder      4   2.3   261.   -261.
  array 9101  1  place  1  1  2   -10.8      0.           32.5
  array 9101  2  place  1  1  2     5.4     -9.353074     32.5
  array 600   4  place  1  1  5     0.0      0.0           0.0
  rhexprism     5  17.    261.   -261.
  media      21     1       3
  media      20     1       5      -1      -2      -3      -4
  boundary      5
'================ Ring 1 CR: place CR in six columns =================
unit 62
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=0
  media      20     1       1
  boundary      1
unit 63
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=60
  media      20     1       1
  boundary      1
unit 64
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=120
  media      20     1       1
  boundary      1
```

```
unit 65
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=180
  media      20     1       1
  boundary      1
unit 66
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=240
  media      20     1       1
  boundary      1
unit 67
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=300
  media      20     1       1
  boundary      1
'================ CR Column 71: R2, Column 1 =================
unit 710
  cylinder      1   6.15  261.   -155.   origin x=-5.4       y=9.353074
  cylinder      2   6.15  261.   -155.   origin x=-5.4       y=-9.353074
  cylinder      3   6.15  261.   -155.   origin x=10.8       y=0.
  cylinder      4   2.3   261.   -261.
  array 9101  1  place  1  1  2    -5.4      9.353074      32.5
  array 9101  2  place  1  1  2    -5.4     -9.353074      32.5
  array 600   4  place  1  1  5     0.0      0.0            0.0
  rhexprism     5  17.    261.   -261.
  media      21     1       3
  media      20     1       5      -1      -2      -3      -4
  boundary      5
'================ Ring 2 CR: place CR in six columns =================
unit 71
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=0
  media      20     1       1
  boundary      1
unit 72
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=60
  media      20     1       1
  boundary      1
unit 74
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=120
  media      20     1       1
  boundary      1
unit 75
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=180
  media      20     1       1
  boundary      1
unit 77
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=240
  media      20     1       1
  boundary      1
unit 78
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=300
  media      20     1       1
```

```
  boundary      1
'================ CR Column 73: R3, Column 1 =================
unit 730
  cylinder      1   6.15  261.   -155.   origin x=-5.4       y=-9.353074
  cylinder      2   6.15  261.   -155.   origin x=10.8       y=0.
  cylinder      3   6.15  261.   -155.   origin x=-5.4       y=9.353074
  cylinder      4   2.3   261.   -261.
  array 9101  1  place  1  1  2    -5.4     -9.353074     259.9
  array 9101  2  place  1  1  2    10.8      0.0          259.9
  array 600   4  place  1  1  5     0.0      0.0            0.0
  rhexprism     5  17.    261.   -261.
  media      21     1       3
  media      20     1       5      -1      -2      -3      -4
  boundary      5
'================ Ring 3 CR: place CR in three columns =================
unit 73
  rhexprism     1  18.    261.   -261.
  hole  730  rotate a1=0
  media      20     1       1
  boundary      1
unit 76
  rhexprism     1  18.    261.   -261.
  hole  730  rotate a1=120
  media      20     1       1
  boundary      1
unit 79
  rhexprism     1  18.    261.   -261.
  hole  730  rotate a1=240
  media      20     1       1
  boundary      1
'================ Instrumentation Block =================
unit 801
  cylinder      1   6.15   29.    -29.   origin x=-10.8      y=0.
  cylinder      2   6.15   29.    -29.   origin x=5.4        y=9.353074
  cylinder      3   6.15   29.    -29.   origin x=5.4        y=-9.353074
  cone          4   2.5    29.      1.5    20.
  cylinder      5   1.5    20.     14.
  cylinder      6   2.25   14.      4.
  cylinder      7   2.505  29.    -29.
  rhexprism     8  18.     29.    -29.
  media      21     1       1
  media      21     1       2
  media      21     1       3
  media      21     1       4
  media      21     1       5
  media      21     1       6
  media      20     1       7      -4      -5      -6
  media      20     1       8      -1      -2      -3      -7
  boundary      8
unit 802
  cone          4   2.5    29.      1.5    20.
  cylinder      5   1.5    20.     14.
  cylinder      6   2.25   14.      4.
  cylinder      7   2.505  29.    -29.
  rhexprism     8  18.     29.    -29.
  media      21     1       4
  media      21     1       5
  media      21     1       6
```

```
  media      20     1       7      -4      -5      -6
  media      20     1       8      -7
  boundary      8
unit 80
  rhexprism     1  18.    261.   -261.
  array   80  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'=============== RR Block not in fuel column ================
unit 900
  cone          1   2.5    29.      1.5    20.
  cylinder      2   1.5    20.     14.
  cylinder      3   2.25   14.      4.
  cylinder      4   2.505  29.    -29.
  rhexprism     5  18.     29.    -29.
  media      21     1       1
  media      21     1       2
  media      21     1       3
  media      20     1       4      -1      -2      -3
  media      20     1       5      -4
  boundary      5
unit 90
  rhexprism     1  18.    261.   -261.
  array   90  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'=============== Global Geometry ================
global unit 1
  cylinder      1 212.5    261.   -261.
  array    1  1  place  10  10  1   0.0      0.0      0.0
  boundary      1
end geom

' ----------------------------------------------------------------------
' --- Boundary conditions ----------------------------------------------
read boun all=vacuum end boun

' ----------------------------------------------------------------------
read array
  ara=1 nux=19 nuy=19 nuz=1 typ=rhexagonal
  fill
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 80 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 77 90 45 90 78 10 10 10 10 10 10 10
       10 10 10 10 10 76 90 54 35 66 55 36 90 79 10 10 10 10 10
       10 10 10 10 10 90 44 65 25 15 26 67 46 90 10 10 10 10 10
       10 10 10 10 10 75 34 24 14 61 16 21 56 71 10 10 10 10 10
       10 10 10 10 10 90 53 64 13 12 11 62 31 90 10 10 10 10 10
       10 10 10 10 10 80 43 33 23 63 22 51 41 80 10 10 10 10 10
       10 10 10 10 10 10 90 74 52 42 32 72 90 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 90 73 90 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
```

```
  end fill
' --- Columns arrays ----------------------------------------------------------
  ara=10 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 100 100 100 100 100 100 100 100 100 end fill
  ara=11 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 111 111 161 161 151 141 131 111 111 end fill
  ara=21 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 211 211 261 261 251 241 231 211 211 end fill
  ara=31 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 311 311 361 361 351 341 331 311 311 end fill
  ara=41 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 411 411 461 461 451 441 431 411 411 end fill
  ara=80 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 802 801 801 801 801 801 801 801 801 end fill
  ara=90 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 900 900 900 900 900 900 900 900 900 end fill
' --- Fuel block arrays -------------------------------------------------------
  ara=111  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
      1116  1116  1116  1116  1116  1116  1116  1116  1116
        1116  1116  1116  1116  1116  1113  1113  1113  1116
          1116  1116  1116  1113  1113  1113  1113  1113  1116
            1116  1116  1113  1113  1113  1113  1113  1113  1116
              1116  1113  1113  1113  1114  1113  1113  1116  1116
                1116  1113  1113  1113  1113  1113  1113  1116  1116
                  1116  1113  1113  1113  1113  1113  1116  1116  1116
                    1116  1116  1113  1113  1113  1116  1116  1116  1116
                      1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill
  ara=131  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
      1116  1116  1116  1116  1116  1116  1116  1116  1116
        1116  1116  1116  1116  1312  1313  1313  1313  1116
          1116  1116  1116  1313  1313  1313  1313  1313  1116
            1116  1116  1313  1313  1313  1313  1313  1313  1116
              1116  1313  1313  1313  1114  1313  1313  1312  1116
                1116  1313  1313  1313  1313  1313  1313  1116  1116
                  1116  1313  1313  1313  1313  1313  1116  1116  1116
                    1116  1315  1313  1313  1313  1116  1116  1116  1116
                      1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill
  ara=141  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
      1116  1116  1116  1116  1116  1116  1116  1116  1116
        1116  1116  1116  1116  1412  1413  1413  1413  1116
          1116  1116  1116  1413  1413  1413  1413  1413  1116
            1116  1116  1413  1413  1413  1413  1413  1413  1116
              1116  1413  1413  1413  1114  1413  1413  1412  1116
                1116  1413  1413  1413  1413  1413  1413  1116  1116
                  1116  1413  1413  1413  1413  1413  1116  1116  1116
                    1116  1315  1413  1413  1413  1116  1116  1116  1116
                      1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill
  ara=151  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
      1116  1116  1116  1116  1116  1116  1116  1116  1116
        1116  1116  1116  1116  1412  1513  1513  1513  1116
          1116  1116  1116  1513  1513  1513  1513  1513  1116
```

```
          1116  1116  1513  1513  1513  1513  1513  1513  1116
            1116  1513  1513  1513  1114  1513  1513  1412  1116
              1116  1513  1513  1513  1513  1513  1513  1116  1116
                1116  1513  1513  1513  1513  1513  1116  1116  1116
                  1116  1315  1513  1513  1513  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=161  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1312  1613  1613  1613  1116
        1116  1116  1116  1613  1613  1613  1613  1613  1116
          1116  1116  1613  1613  1613  1613  1613  1613  1116
            1116  1613  1613  1613  1114  1613  1613  1312  1116
              1116  1613  1613  1613  1613  1613  1613  1116  1116
                1116  1613  1613  1613  1613  1613  1116  1116  1116
                  1116  1315  1613  1613  1613  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=211  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1113  1113  1113  1116  1116
        1116  1116  1116  1113  1113  1113  1113  1113  1116
          1116  1116  1113  1113  1113  1113  1113  1113  1116
            1116  1116  1113  1113  1114  1113  1113  1113  1116
              1116  1113  1113  1113  1113  1113  1113  1116  1116
                1116  1113  1113  1113  1113  1113  1116  1116  1116
                  1116  1113  1113  1113  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=231  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  2313  2313  2313  1315  1116
        1116  1116  1116  2313  2313  2313  2313  2313  1116
          1116  1116  2313  2313  2313  2313  2313  2313  1116
            1116  1312  2313  2313  1114  2313  2313  2313  1116
              1116  2313  2313  2313  2313  2313  2313  1116  1116
                1116  2313  2313  2313  2313  2313  1116  1116  1116
                  1116  2313  2313  2313  1312  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=241  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  2413  2413  2413  1315  1116
        1116  1116  1116  2413  2413  2413  2413  2413  1116
          1116  1116  2413  2413  2413  2413  2413  2413  1116
            1116  1412  2413  2413  1114  2413  2413  2413  1116
              1116  2413  2413  2413  2413  2413  2413  1116  1116
                1116  2413  2413  2413  2413  2413  1116  1116  1116
                  1116  2413  2413  2413  1412  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=251  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
```

```
      1116  1116  1116  1116  2513  2513  2513  1315  1116
        1116  1116  1116  2513  2513  2513  2513  2513  1116
          1116  1116  2513  2513  2513  2513  2513  2513  1116
            1116  1412  2513  2513  1114  2513  2513  2513  1116
              1116  2513  2513  2513  2513  2513  2513  1116  1116
                1116  2513  2513  2513  2513  2513  1116  1116  1116
                  1116  2513  2513  2513  1412  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=261  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  2613  2613  2613  1315  1116
        1116  1116  1116  2613  2613  2613  2613  2613  1116
          1116  1116  2613  2613  2613  2613  2613  2613  1116
            1116  1312  2613  2613  1114  2613  2613  2613  1116
              1116  2613  2613  2613  2613  2613  2613  1116  1116
                1116  2613  2613  2613  2613  2613  1116  1116  1116
                  1116  2613  2613  2613  1312  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=311  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1116  1113  1113  1116  1116
        1116  1116  1116  1113  1113  1113  1113  1113  1116
          1116  1116  1113  1113  1113  1113  1113  1113  1116
            1116  1113  1113  1113  1114  1113  1113  1116  1116
              1116  1113  1113  1113  1113  1113  1113  1116  1116
                1116  1113  1113  1113  1113  1113  1116  1116  1116
                  1116  1116  1113  1113  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=331  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1312  3313  3313  1116  1116
        1116  1116  1116  3313  3313  3313  3313  3313  1116
          1116  1116  3313  3313  3313  3313  3313  3313  1116
            1116  3313  3313  3313  1114  3313  3313  1315  1116
              1116  3313  3313  3313  3313  3313  3313  1116  1116
                1116  3313  3313  3313  3313  3313  1116  1116  1116
                  1116  1312  3313  3313  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=341  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1412  3413  3413  1116  1116
        1116  1116  1116  3413  3413  3413  3413  3413  1116
          1116  1116  3413  3413  3413  3413  3413  3413  1116
            1116  3413  3413  3413  1114  3413  3413  1315  1116
              1116  3413  3413  3413  3413  3413  3413  1116  1116
                1116  3413  3413  3413  3413  3413  1116  1116  1116
                  1116  1412  3413  3413  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=351  nux=9  nuy=9  nuz=1  typ=hexagonal
```

```
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1412  3513  3513  1116  1116
        1116  1116  1116  3513  3513  3513  3513  3513  1116
          1116  1116  3513  3513  3513  3513  3513  3513  1116
            1116  3513  3513  3513  1114  3513  3513  1315  1116
              1116  3513  3513  3513  3513  3513  3513  1116  1116
                1116  3513  3513  3513  3513  3513  1116  1116  1116
                  1116  1412  3513  3513  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=361  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1312  3613  3613  1116  1116
        1116  1116  1116  3613  3613  3613  3613  3613  1116
          1116  1116  3613  3613  3613  3613  3613  3613  1116
            1116  3613  3613  3613  1114  3613  3613  1315  1116
              1116  3613  3613  3613  3613  3613  3613  1116  1116
                1116  3613  3613  3613  3613  3613  1116  1116  1116
                  1116  1312  3613  3613  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=411  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1113  1113  1113  1116  1116
        1116  1116  1116  1113  1113  1113  1113  1113  1116
          1116  1116  1113  1113  1113  1113  1113  1113  1116
            1116  1116  1113  1113  1114  1113  1113  1116  1116
              1116  1113  1113  1113  1113  1113  1113  1116  1116
                1116  1113  1113  1113  1113  1113  1116  1116  1116
                  1116  1116  1113  1113  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=431  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  4313  4313  4313  1312  1116
        1116  1116  1116  4313  4313  4313  4313  4313  1116
          1116  1116  4313  4313  4313  4313  4313  4313  1116
            1116  1312  4313  4313  1114  4313  4313  1116  1116
              1116  4313  4313  4313  4313  4313  4313  1116  1116
                1116  4313  4313  4313  4313  4313  1116  1116  1116
                  1116  1116  4313  4313  1315  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=441  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  4413  4413  4413  1412  1116
        1116  1116  1116  4413  4413  4413  4413  4413  1116
          1116  1116  4413  4413  4413  4413  4413  4413  1116
            1116  1412  4413  4413  1114  4413  4413  1116  1116
              1116  4413  4413  4413  4413  4413  4413  1116  1116
                1116  4413  4413  4413  4413  4413  1116  1116  1116
                  1116  1116  4413  4413  1315  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
```

```
  end fill
  ara=451  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
     1116  1116  1116  1116  1116  1116  1116  1116  1116
       1116  1116  1116  1116  4513  4513  4513  1412  1116
         1116  1116  1116  4513  4513  4513  4513  4513  1116
           1116  1116  4513  4513  4513  4513  4513  4513  1116
             1116  1412  4513  4513  1114  4513  4513  1116  1116
               1116  4513  4513  4513  4513  4513  4513  1116  1116
                 1116  4513  4513  4513  4513  4513  1116  1116  1116
                   1116  1116  4513  4513  1315  1116  1116  1116  1116
                     1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill
  ara=461  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
     1116  1116  1116  1116  1116  1116  1116  1116  1116
       1116  1116  1116  1116  4613  4613  4613  1312  1116
         1116  1116  1116  4613  4613  4613  4613  4613  1116
           1116  1116  4613  4613  4613  4613  4613  4613  1116
             1116  1312  4613  4613  1114  4613  4613  1116  1116
               1116  4613  4613  4613  4613  4613  4613  1116  1116
                 1116  4613  4613  4613  4613  4613  1116  1116  1116
                   1116  1116  4613  4613  1315  1116  1116  1116  1116
                     1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill

  ara=600     nux=1  nuy=1  nuz=9  typ=hexagonal fill 9*6001 end fill
' --- Grains arrays ---------------------------------------------------------
  ara=1311    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*1311 end fill
  ara=1411    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*1411 end fill
  ara=1511    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*1511 end fill
  ara=1611    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*1611 end fill

  ara=2311    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*2311 end fill
  ara=2411    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*2411 end fill
  ara=2511    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*2511 end fill
  ara=2611    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*2611 end fill

  ara=3311    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*3311 end fill
  ara=3411    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*3411 end fill
  ara=3511    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*3511 end fill
  ara=3611    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*3611 end fill

  ara=4311    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*4311 end fill
  ara=4411    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*4411 end fill
  ara=4511    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*4511 end fill
  ara=4611    nux=25 nuy=25 nuz=495 typ=cuboidal fill 309375*4611 end fill

  ara=9101    nux=1  nuy=1  nuz=12  typ=hexagonal
      fill 9102 10*9101 9102 end fill
end array

' -------------------------------------------------------------------------
' --- Energy splitting ----------------------------------------------------
read energy
  2e7 1.01e6 0.625 1e-5
end energy
```

```
' ---------------------------------------------------------------------------
' --- Plot cros-section -----------------------------------------------------
read plot
ttl='z=242 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=242.
  XLR=213.0  YLR=-213.0 ZLR=242.
  NAX=1280 end
ttl='z=184 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=184.
  XLR=213.0  YLR=-213.0 ZLR=184.
  NAX=1280 end
ttl='z=126 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=126.
  XLR=213.0  YLR=-213.0 ZLR=126.
  NAX=1280 end
ttl='z=68 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=68.
  XLR=213.0  YLR=-213.0 ZLR=68.
  NAX=1280 end
ttl='z=10 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=10.
  XLR=213.0  YLR=-213.0 ZLR=10.
  NAX=1280 end
ttl='z=-48 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=-48.
  XLR=213.0  YLR=-213.0 ZLR=-48.
  NAX=1280 end
ttl='z=-106 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=-106.
  XLR=213.0  YLR=-213.0 ZLR=-106.
  NAX=1280 end
ttl='z=-164 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=-164.
  XLR=213.0  YLR=-213.0 ZLR=-164.
  NAX=1280 end
ttl='z=-222 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=-222.
  XLR=213.0  YLR=-213.0 ZLR=-222.
  NAX=1280 end
ttl='Vertical View of the HTTR Core'
  TYP=XZ
  XUL=-213. YUL=0.  ZUL=265.
  XLR=213.  YLR=0. ZLR=-265.
  UAX=1.0 WDN=-1.0 NAX=1280 end
end plot

end data
```

```
end
' ----------------------------------------------------------------------------
' --- End input deck ---------------------------------------------------------
```

# APPENDIX B. SCALE MULTIGROUP MODEL FOR HTTR

# APPENDIX B. SCALE MULTIGROUP MODEL FOR HTTR

```
=csas26 parm=centrm
Dan Ilas, 2009, 2010: HTTR core based on HTTR-GCR-RESR-001
v7-238
' ---------------------------------------------------------------------------
--
' --- References:
' [1] John D. Bess, Nozomu Fujimoto: Evaluation of the Start-up Core Physics
' Tests at Japan's High Temperature Engineering Test Reactor
' (Fully-Loaded Core), Revision 0, March, 2009

' ---------------------------------------------------------------------------
' --- Materials -------------------------------------------------------------
read comp
' Material References (n is the enrichment or block type number):
' --------------------
' m=(n-1)*10+1  CFP fuel atom densities from Table 3.1, pag. 195 of [1]
' m=(n-1)*10+2  Buffer atom densities from Table 3.2, pag. 196 of [1]
' m=(n-1)*10+3  IPyC atom densities from Table 3.2, pag. 196 of [1]
' m=(n-1)*10+4  SiC atom densities from Table 3.2, pag. 196 of [1]
' m=(n-1)*10+5  OPyC atom densities from Table 3.2, pag. 196 of [1]
' m=(n-1)*10+6  Homogenized compact
'               Obtained by volumetric homogenization of materials 121 and
130
' m=(n-1)*10+7  Sleeve atom densities from Table 3.4, pag. 196 of [1]
' m=(n-1)*10+8  IG-110 atom densities from Table 3.6, pag. 197 of [1]
'               by multiplying with 1.005
' m=(n-1)*10+9  Helium coolant from 3.1.3.10, page 199 of [1]
' m=(n-1)*10+10 Pin homogenized fuel
' m=121         Generic helium coolant from 3.1.3.10, page 199 of [1]
' m=122         Disks atom densities in BP pins from Table 3.5, pag. 197 of
[1]
' m=123         BP atom densities (2.0%) from Table 3.5, pag. 197 of [1]
' m=124         BP atom densities (2.5%) from Table 3.5, pag. 197 of [1]
' m=125         PGX Graphite from Table 3.9, pag. 199 of [1]
' m=126         Absorber Compacts in CR from Table 3.7, pag. 198 of [1]
' m=127         Alloy 800H Clad in CR from Table 3.8, pag. 198 of [1]
' m=128         Generic IG-110 atom densities from Table 3.6, pag. 197 of [1]
' m=129         Overcoat atom densities from Table 3.2, pag. 196 of [1]
' m=130         Compact atom densities from Table 3.3, pag. 196 of [1]
'
'
===========================================================================
' --- Fuel Kernel, 3.4% enrichment:
  U-234          1  0   6.0946E-06   293.65  end
  U-235          1  0   7.9784E-04   293.65  end
  U-238          1  0   2.2376E-02   293.65  end
  O-16           1  0   4.6343E-02   293.65  end
  B-10           1  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     2  0   5.5153E-02   293.65  end
  B-10           2  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     3  0   9.2758E-02   293.65  end
  B-10           3  0   3.0761E-08   293.65  end
' --- SiC:
```

```
  C-graphite      4  0   4.8061E-02   293.65  end
  Si              4  0   4.8061E-02   293.65  end
  B-10            4  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite      5  0   9.2758E-02   293.65  end
  B-10            5  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He              6  0   5.8706E-06   293.65  end
  C-graphite      6  0   6.4909E-02   293.65  end
  B-10            6  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite      7  0   8.8747E-02   293.65  end
  B-10            7  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite      8  0   8.8243E-02   293.65  end
  B-10            8  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He              9  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 3.9% enrichment:
  U-234          11  0   6.9909E-06   293.65  end
  U-235          11  0   9.1517E-04   293.65  end
  U-238          11  0   2.2259E-02   293.65  end
  O-16           11  0   4.6343E-02   293.65  end
  B-10           11  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     12  0   5.5153E-02   293.65  end
  B-10           12  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     13  0   9.2758E-02   293.65  end
  B-10           13  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     14  0   4.8061E-02   293.65  end
  Si             14  0   4.8061E-02   293.65  end
  B-10           14  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     15  0   9.2758E-02   293.65  end
  B-10           15  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             16  0   5.8706E-06   293.65  end
  C-graphite     16  0   6.4909E-02   293.65  end
  B-10           16  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     17  0   8.8747E-02   293.65  end
  B-10           17  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     18  0   8.8243E-02   293.65  end
  B-10           18  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             19  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 4.3% enrichment:
  U-234          21  0   7.7079E-06   293.65  end
  U-235          21  0   1.0090E-03   293.65  end
  U-238          21  0   2.2166E-02   293.65  end
  O-16           21  0   4.6343E-02   293.65  end
  B-10           21  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     22  0   5.5153E-02   293.65  end
  B-10           22  0   1.8290E-08   293.65  end
' --- IPyC
```

```
  C-graphite     23  0   9.2758E-02   293.65  end
  B-10           23  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     24  0   4.8061E-02   293.65  end
  Si             24  0   4.8061E-02   293.65  end
  B-10           24  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     25  0   9.2758E-02   293.65  end
  B-10           25  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             26  0   5.8706E-06   293.65  end
  C-graphite     26  0   6.4909E-02   293.65  end
  B-10           26  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     27  0   8.8747E-02   293.65  end
  B-10           27  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     28  0   8.8243E-02   293.65  end
  B-10           28  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             29  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 4.8% enrichment:
  U-234          31  0   8.6041E-06   293.65  end
  U-235          31  0   1.1264E-03   293.65  end
  U-238          31  0   2.2049E-02   293.65  end
  O-16           31  0   4.6343E-02   293.65  end
  B-10           31  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     32  0   5.5153E-02   293.65  end
  B-10           32  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     33  0   9.2758E-02   293.65  end
  B-10           33  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     34  0   4.8061E-02   293.65  end
  Si             34  0   4.8061E-02   293.65  end
  B-10           34  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     35  0   9.2758E-02   293.65  end
  B-10           35  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             36  0   5.8706E-06   293.65  end
  C-graphite     36  0   6.4909E-02   293.65  end
  B-10           36  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     37  0   8.8747E-02   293.65  end
  B-10           37  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     38  0   8.8243E-02   293.65  end
  B-10           38  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             39  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 5.2% enrichment:
  U-234          41  0   9.3211E-06   293.65  end
  U-235          41  0   1.2202E-03   293.65  end
  U-238          41  0   2.1955E-02   293.65  end
  O-16           41  0   4.6343E-02   293.65  end
  B-10           41  0   1.7276E-07   293.65  end
' --- Buffer:
```

```
  C-graphite     42  0   5.5153E-02   293.65  end
  B-10           42  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     43  0   9.2758E-02   293.65  end
  B-10           43  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     44  0   4.8061E-02   293.65  end
  Si             44  0   4.8061E-02   293.65  end
  B-10           44  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     45  0   9.2758E-02   293.65  end
  B-10           45  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             46  0   5.8706E-06   293.65  end
  C-graphite     46  0   6.4909E-02   293.65  end
  B-10           46  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     47  0   8.8747E-02   293.65  end
  B-10           47  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     48  0   8.8243E-02   293.65  end
  B-10           48  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             49  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 5.9% enrichment:
  U-234          51  0   1.0576E-05   293.65  end
  U-235          51  0   1.3845E-03   293.65  end
  U-238          51  0   2.1792E-02   293.65  end
  O-16           51  0   4.6343E-02   293.65  end
  B-10           51  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     52  0   5.5153E-02   293.65  end
  B-10           52  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     53  0   9.2758E-02   293.65  end
  B-10           53  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     54  0   4.8061E-02   293.65  end
  Si             54  0   4.8061E-02   293.65  end
  B-10           54  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     55  0   9.2758E-02   293.65  end
  B-10           55  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             56  0   5.8706E-06   293.65  end
  C-graphite     56  0   6.4909E-02   293.65  end
  B-10           56  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     57  0   8.8747E-02   293.65  end
  B-10           57  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     58  0   8.8243E-02   293.65  end
  B-10           58  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             59  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 6.3% enrichment:
  U-234          61  0   1.1293E-05   293.65  end
  U-235          61  0   1.4783E-03   293.65  end
  U-238          61  0   2.1699E-02   293.65  end
```

```
  O-16           61  0   4.6343E-02   293.65  end
  B-10           61  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     62  0   5.5153E-02   293.65  end
  B-10           62  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     63  0   9.2758E-02   293.65  end
  B-10           63  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     64  0   4.8061E-02   293.65  end
  Si             64  0   4.8061E-02   293.65  end
  B-10           64  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     65  0   9.2758E-02   293.65  end
  B-10           65  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             66  0   5.8706E-06   293.65  end
  C-graphite     66  0   6.4909E-02   293.65  end
  B-10           66  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     67  0   8.8747E-02   293.65  end
  B-10           67  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     68  0   8.8243E-02   293.65  end
  B-10           68  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             69  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 6.7% enrichment:
  U-234          71  0   1.2010E-05   293.65  end
  U-235          71  0   1.5722E-03   293.65  end
  U-238          71  0   2.1605E-02   293.65  end
  O-16           71  0   4.6343E-02   293.65  end
  B-10           71  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     72  0   5.5153E-02   293.65  end
  B-10           72  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     73  0   9.2758E-02   293.65  end
  B-10           73  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     74  0   4.8061E-02   293.65  end
  Si             74  0   4.8061E-02   293.65  end
  B-10           74  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     75  0   9.2758E-02   293.65  end
  B-10           75  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             76  0   5.8706E-06   293.65  end
  C-graphite     76  0   6.4909E-02   293.65  end
  B-10           76  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     77  0   8.8747E-02   293.65  end
  B-10           77  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     78  0   8.8243E-02   293.65  end
  B-10           78  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             79  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 7.2% enrichment:
```

```
  U-234          81  0   1.2906E-05   293.65  end
  U-235          81  0   1.6895E-03   293.65  end
  U-238          81  0   2.1489E-02   293.65  end
  O-16           81  0   4.6343E-02   293.65  end
  B-10           81  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     82  0   5.5153E-02   293.65  end
  B-10           82  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     83  0   9.2758E-02   293.65  end
  B-10           83  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     84  0   4.8061E-02   293.65  end
  Si             84  0   4.8061E-02   293.65  end
  B-10           84  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     85  0   9.2758E-02   293.65  end
  B-10           85  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             86  0   5.8706E-06   293.65  end
  C-graphite     86  0   6.4909E-02   293.65  end
  B-10           86  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     87  0   8.8747E-02   293.65  end
  B-10           87  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     88  0   8.8243E-02   293.65  end
  B-10           88  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             89  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 7.9% enrichment:
  U-234          91  0   1.4161E-05   293.65  end
  U-235          91  0   1.8538E-03   293.65  end
  U-238          91  0   2.1325E-02   293.65  end
  O-16           91  0   4.6343E-02   293.65  end
  B-10           91  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     92  0   5.5153E-02   293.65  end
  B-10           92  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     93  0   9.2758E-02   293.65  end
  B-10           93  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     94  0   4.8061E-02   293.65  end
  Si             94  0   4.8061E-02   293.65  end
  B-10           94  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     95  0   9.2758E-02   293.65  end
  B-10           95  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             96  0   5.8706E-06   293.65  end
  C-graphite     96  0   6.4909E-02   293.65  end
  B-10           96  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     97  0   8.8747E-02   293.65  end
  B-10           97  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     98  0   8.8243E-02   293.65  end
  B-10           98  0   7.8036E-09   293.65  end
```

```
' --- Helium coolant:
  He              99  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 9.4% enrichment:
  U-234          101  0   1.6850E-05   293.65  end
  U-235          101  0   2.2058E-03   293.65  end
  U-238          101  0   2.0975E-02   293.65  end
  O-16           101  0   4.6343E-02   293.65  end
  B-10           101  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     102  0   5.5153E-02   293.65  end
  B-10           102  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     103  0   9.2758E-02   293.65  end
  B-10           103  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     104  0   4.8061E-02   293.65  end
  Si             104  0   4.8061E-02   293.65  end
  B-10           104  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     105  0   9.2758E-02   293.65  end
  B-10           105  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             106  0   5.8706E-06   293.65  end
  C-graphite     106  0   6.4909E-02   293.65  end
  B-10           106  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     107  0   8.8747E-02   293.65  end
  B-10           107  0   7.2596E-09   293.65  end
' --- IG-110 Graphite:
  C-graphite     108  0   8.8243E-02   293.65  end
  B-10           108  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He             109  0   2.4616E-05   293.65  end
' --- Fuel Kernel, 9.9% enrichment:
  U-234          111  0   1.7746E-05   293.65  end
  U-235          111  0   2.3231E-03   293.65  end
  U-238          111  0   2.0858E-02   293.65  end
  O-16           111  0   4.6343E-02   293.65  end
  B-10           111  0   1.7276E-07   293.65  end
' --- Buffer:
  C-graphite     112  0   5.5153E-02   293.65  end
  B-10           112  0   1.8290E-08   293.65  end
' --- IPyC:
  C-graphite     113  0   9.2758E-02   293.65  end
  B-10           113  0   3.0761E-08   293.65  end
' --- SiC:
  C-graphite     114  0   4.8061E-02   293.65  end
  Si             114  0   4.8061E-02   293.65  end
  B-10           114  0   5.3208E-08   293.65  end
' --- OPyC:
  C-graphite     115  0   9.2758E-02   293.65  end
  B-10           115  0   3.0761E-08   293.65  end
' --- Homogenized graphite compact (inner and outer helium embedded):
  He             116  0   5.8706E-06   293.65  end
  C-graphite     116  0   6.4909E-02   293.65  end
  B-10           116  0   1.1767E-08   293.65  end
' --- Graphite sleeve:
  C-graphite     117  0   8.8747E-02   293.65  end
  B-10           117  0   7.2596E-09   293.65  end
```

```
' --- IG-110 Graphite:
  C-graphite    118  0   8.8243E-02   293.65  end
  B-10          118  0   7.8036E-09   293.65  end
' --- Helium coolant:
  He            119  0   2.4616E-05   293.65  end
' --- Helium coolant used in CR to mark the CR placement:
  He            121  0   2.4616E-05   293.65  end
' --- Graphite disks:
  C-graphite    122  0   8.8747E-02   293.65  end
  B-10          122  0   7.2596E-09   293.65  end
' --- Burnable poison (2.0wt%):
  C-graphite    123  0   8.8446E-02   293.65  end
  B-10          123  0   3.9906E-04   293.65  end
  B-11          123  0   1.6063E-03   293.65  end
' --- Burnable poison (2.5wt%):
  C-graphite    124  0   8.7995E-02   293.65  end
  B-10          124  0   4.9882E-04   293.65  end
  B-11          124  0   2.0078E-03   293.65  end
' --- PGX Graphite:
  C-graphite    125  0   8.6134E-02   293.65  end
  B-10          125  0   3.6372E-08   293.65  end
' --- Absorber Compacts in CR:
  C-graphite    126  0   6.6685E-02   293.65  end
  B-10          126  0   6.8220E-03   293.65  end
  B-11          126  0   2.4974E-02   293.65  end
' --- Alloy 800H Clad in CR:
  C-graphite    127  0   3.2210E-04   293.65  end
  Al            127  0   6.7209E-04   293.65  end
  Si            127  0   6.0263E-04   293.65  end
  P             127  0   3.1225E-05   293.65  end
  S             127  0   1.5081E-05   293.65  end
  Ti            127  0   3.7884E-04   293.65  end
  Cr            127  0   1.9530E-02   293.65  end
  Mn            127  0   8.8022E-04   293.65  end
  Fe            127  0   3.8092E-02   293.65  end
  Ni            127  0   2.6777E-02   293.65  end
  Cu            127  0   2.2830E-04   293.65  end
' --- IG-110 Graphite:
  C-graphite    128  0   8.8243E-02   293.65  end
  B-10          128  0   7.8036E-09   293.65  end
' --- Graphite overcoat:
  C-graphite    129  0   8.5237E-02   293.65  end
  B-10          129  0   2.8267E-08   293.65  end
' --- Graphite compact:
  C-graphite    130  0   8.5237E-02   293.65  end
  B-10          130  0   1.5452E-08   293.65  end
end comp

' ----------------------------------------------------------------------------
' --- Cell data --------------------------------------------------------------
read celldata
 doublehet fuelmix=10 end
    gfd=0.06       1
  coatr=0.036      2
  coatr=0.039      3
  coatr=0.0415     4
  coatr=0.046      5
 matrix=6
 numpar=12987 end grain
```

```
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 8 fuelr=1.325 fuelh=3.9 gapd=3.4 7 cladd=4.1 9 end

doublehet fuelmix=20 end
   gfd=0.06      11
 coatr=0.036     12
 coatr=0.039     13
 coatr=0.0415    14
 coatr=0.046     15
matrix=16
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 18 fuelr=1.325 fuelh=3.9 gapd=3.4 17 cladd=4.1 19 end

doublehet fuelmix=30 end
   gfd=0.06      21
 coatr=0.036     22
 coatr=0.039     23
 coatr=0.0415    24
 coatr=0.046     25
matrix=26
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 28 fuelr=1.325 fuelh=3.9 gapd=3.4 27 cladd=4.1 29 end

doublehet fuelmix=40 end
   gfd=0.06      31
 coatr=0.036     32
 coatr=0.039     33
 coatr=0.0415    34
 coatr=0.046     35
matrix=36
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 38 fuelr=1.325 fuelh=3.9 gapd=3.4 37 cladd=4.1 39 end

doublehet fuelmix=50 end
   gfd=0.06      41
 coatr=0.036     42
 coatr=0.039     43
 coatr=0.0415    44
 coatr=0.046     45
matrix=46
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 48 fuelr=1.325 fuelh=3.9 gapd=3.4 47 cladd=4.1 49 end

doublehet fuelmix=60 end
   gfd=0.06      51
 coatr=0.036     52
 coatr=0.039     53
 coatr=0.0415    54
 coatr=0.046     55
matrix=56
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 58 fuelr=1.325 fuelh=3.9 gapd=3.4 57 cladd=4.1 59 end

doublehet fuelmix=70 end
```

```
   gfd=0.06      61
 coatr=0.036     62
 coatr=0.039     63
 coatr=0.0415    64
 coatr=0.046     65
matrix=66
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 68 fuelr=1.325 fuelh=3.9 gapd=3.4 67 cladd=4.1 69 end

doublehet fuelmix=80 end
   gfd=0.06      71
 coatr=0.036     72
 coatr=0.039     73
 coatr=0.0415    74
 coatr=0.046     75
matrix=76
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 78 fuelr=1.325 fuelh=3.9 gapd=3.4 77 cladd=4.1 79 end

doublehet fuelmix=90 end
   gfd=0.06      81
 coatr=0.036     82
 coatr=0.039     83
 coatr=0.0415    84
 coatr=0.046     85
matrix=86
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 88 fuelr=1.325 fuelh=3.9 gapd=3.4 87 cladd=4.1 89 end

doublehet fuelmix=100 end
   gfd=0.06      91
 coatr=0.036     92
 coatr=0.039     93
 coatr=0.0415    94
 coatr=0.046     95
matrix=96
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 98 fuelr=1.325 fuelh=3.9 gapd=3.4 97 cladd=4.1 99 end

doublehet fuelmix=110 end
   gfd=0.06     101
 coatr=0.036    102
 coatr=0.039    103
 coatr=0.0415   104
 coatr=0.046    105
matrix=106
numpar=12987 end grain
rod triangpitch right_bdy=white left_bdy=reflected
pitch=5.15 108 fuelr=1.325 fuelh=3.9 gapd=3.4 107 cladd=4.1 109 end

doublehet fuelmix=120 end
   gfd=0.06     111
 coatr=0.036    112
 coatr=0.039    113
 coatr=0.0415   114
```

```
  coatr=0.046    115
 matrix=116
 numpar=12987 end grain
 rod triangpitch right_bdy=white left_bdy=reflected
 pitch=5.15 118 fuelr=1.325 fuelh=3.9 gapd=3.4 117 cladd=4.1 119 end
end celldata

' -----------------------------------------------------------------------------
' --- Parameters ---------------------------------------------------------------
read parm
       gen=1100
       npg=100000
       nsk=100
       tba=100
       htm=no
       flx=yes
       fdn=yes
       res=1100
       wrs=35
end parm

' -----------------------------------------------------------------------------
' --- Geometry -----------------------------------------------------------------
read geom
' Dimensions for block and pin details based on Figure 1.52 page 68 of [1]
' Counting of pins starts at the lower left corner, going horizontally and
' then vertically
' Dimensions for grain cells based on Figure 3.1 page 176 of [1]
'
' Numbering scheme for cells that make up fuel block units:
'  zlb1   fuel grain
'  zlb2   BP pin
'  zlb3   fuel pin
'  zlb4   central hole
'  zlb5   empty pin
'  zlb6   graphite
'  zlb    block
'
' Block numbering (Fig. 3.15, page 190 of [1]):
' Each block is numbered according to the scheme 100*z+10*l+b, where:
'   z=1,...,8       zone number
'                      **Fuel: z=1,2 for zones 1 and 2, respectively
'                              z=3,5 alternatively as one goes
counterclockwise
'                              for zone 3, z=4 for zone 4
'                      **Replaceable Reflectors in fuel columns follow the
same
'                        pattern as fuel blocks, but with different l:
l=1,2,8,9
'                      **CR:   z=6 for "C" (b=1) and "R1" (b=2,...,7)
'                              z=7 for "R2" and "R3" (b=1,...,9, going
'                              counterclockwise)
'                      **Instrumentation Blocks have z=8 (b=1,2,3)
'   l=1,...,9       layer number from top to bottom
'                   (fuel blocks in layers 3 to 7 from top)
'   b=1,...,bmax(z) block number (starting from positive x, counterclockwise)
'                      bmax(1)=...=bmax(5)=6
'                      bmax(6)=7, bmax(7)=9
'                      bmax(8)=3
```

```
' Replaceable Reflector (RR) blocks that are not in fuel columns are assigned
' block# 900
' Graphite blocks to make up the Permanent Reflector are assigned block# 100
'
'================ Graphite Block =================
unit 100
  rhexprism     1  18.     29.    -29.
  media     125     1       1
  boundary      1
unit 10
  rhexprism     1  18.    261.   -261.
  array   10  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'================ Fuel Column: Zone 1 Block 1 =================
'================ Block 111 =================
unit 1113
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media     121     1       5
  media     128     1       6      -5
  boundary      6
unit 1114
  cone          1   2.5    29.      1.5    20.
  cylinder      2   1.5    20.     14.
  cylinder      3   2.25   14.      4.
  cylinder      4   2.505  29.    -29.
  hexprism      5   2.575  29.    -29.
  media     121     1       1
  media     121     1       2
  media     121     1       3
  media     128     1       4      -1      -2      -3
  media     128     1       5      -4
  boundary      5
unit 1116
  hexprism      1   2.575  29.    -29.
  media     128     1       1
  boundary      1
unit 111
  rhexprism     1  18.     29.    -29.
  array  111  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 131 =================
unit 1312
  cylinder      1   0.7     5.2    -4.8
  cylinder      2   0.7    25.2   -24.8
  cylinder      3   0.75   25.2   -24.8
  cylinder      4   0.75   29.    -29.
  hexprism      5   2.575  29.    -29.
  media     122     1       1
  media     123     1       2      -1
  media      79     1       3      -2
  media      78     1       4      -3
  media      78     1       5      -4
  boundary      5
unit 1313
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
```

```
  hexprism      6   2.575  29.    -29.
  media      80     1       2
  media      79     1       3      -2
  media      77     1       4      -3
  media      79     1       5      -4
  media      78     1       6      -5
  boundary      6
unit 1315
  cylinder      1   0.75   25.2   -24.8
  cylinder      2   0.75   29.    -29.
  hexprism      3   2.575  29.    -29.
  media      79     1       1
  media      78     1       2      -1
  media      78     1       3      -2
  boundary      3
unit 131
  rhexprism     1  18.     29.    -29.
  array  131  1  place  5  5  1   0.0       0.0       0.0
  boundary      1
'================ Block 141 =================
unit 1412
  cylinder      1   0.7     5.2    -4.8
  cylinder      2   0.7    25.2   -24.8
  cylinder      3   0.75   25.2   -24.8
  cylinder      4   0.75   29.    -29.
  hexprism      5   2.575  29.    -29.
  media     122     1       1
  media     124     1       2      -1
  media      49     1       3      -2
  media      48     1       4      -3
  media      48     1       5      -4
  boundary      5
unit 1413
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      50     1       2
  media      49     1       3      -2
  media      47     1       4      -3
  media      49     1       5      -4
  media      48     1       6      -5
  boundary      6
unit 141
  rhexprism     1  18.     29.    -29.
  array  141  1  place  5  5  1   0.0       0.0       0.0
  boundary      1
'================ Block 151 =================
unit 1513
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      30     1       2
  media      29     1       3      -2
  media      27     1       4      -3
  media      29     1       5      -4
```

```
  media      28     1       6      -5
  boundary      6
unit 151
  rhexprism     1  18.     29.    -29.
  array  151  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 161 =================
unit 1613
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      10     1       2
  media       9     1       3      -2
  media       7     1       4      -3
  media       9     1       5      -4
  media       8     1       6      -5
  boundary      6
unit 161
  rhexprism     1  18.     29.    -29.
  array  161  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Generic fuel column for ring 1 =================
unit 110
  rhexprism     1  17.    261.   -261.
  array   11  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'============= Ring 1: place the above-defined fuel column in six places ====
unit 11
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=0
  media     128     1       1
  boundary      1
unit 12
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=60
  media     128     1       1
  boundary      1
unit 13
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=120
  media     128     1       1
  boundary      1
unit 14
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=180
  media     128     1       1
  boundary      1
unit 15
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=240
  media     128     1       1
  boundary      1
unit 16
  rhexprism     1  18.    261.   -261.
  hole  110  rotate a1=300
  media     128     1       1
  boundary      1
```

```
'================ Fuel Column: Zone 2 Block 1 =================
'================ Block 211 =================
unit 211
  rhexprism     1  18.     29.    -29.
  array  211  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 231 =================
unit 2313
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media     100     1       2
  media      99     1       3      -2
  media      97     1       4      -3
  media      99     1       5      -4
  media      98     1       6      -5
  boundary      6
unit 231
  rhexprism     1  18.     29.    -29.
  array  231  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 241 =================
unit 2413
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      70     1       2
  media      69     1       3      -2
  media      67     1       4      -3
  media      69     1       5      -4
  media      68     1       6      -5
  boundary      6
unit 241
  rhexprism     1  18.     29.    -29.
  array  241  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 251 =================
unit 2513
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      50     1       2
  media      49     1       3      -2
  media      47     1       4      -3
  media      49     1       5      -4
  media      48     1       6      -5
  boundary      6
unit 251
  rhexprism     1  18.     29.    -29.
  array  251  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 261 =================
unit 2613
```

```
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      20     1       2
  media      19     1       3      -2
  media      17     1       4      -3
  media      19     1       5      -4
  media      18     1       6      -5
  boundary      6
unit 261
  rhexprism     1  18.     29.    -29.
  array  261  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Generic fuel column for ring 2 =================
unit 210
  rhexprism     1  17.    261.   -261.
  array   21  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'============= Ring 2: place the above-defined fuel column in six places ====
unit 21
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=0
  media     128     1       1
  boundary      1
unit 22
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=60
  media     128     1       1
  boundary      1
unit 23
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=120
  media     128     1       1
  boundary      1
unit 24
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=180
  media     128     1       1
  boundary      1
unit 25
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=240
  media     128     1       1
  boundary      1
unit 26
  rhexprism     1  18.    261.   -261.
  hole  210  rotate a1=300
  media     128     1       1
  boundary      1
'================ Fuel Column: Zone 3 Block 1.1 =================
'================ Block 311 =================
unit 311
  rhexprism     1  18.     29.    -29.
  array  311  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 331 =================
unit 3313
```

```
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media     110     1       2
  media     109     1       3      -2
  media     107     1       4      -3
  media     109     1       5      -4
  media     108     1       6      -5
  boundary      6
unit 331
  rhexprism     1  18.     29.    -29.
  array  331  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 341 =================
unit 3413
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      90     1       2
  media      89     1       3      -2
  media      87     1       4      -3
  media      89     1       5      -4
  media      88     1       6      -5
  boundary      6
unit 341
  rhexprism     1  18.     29.    -29.
  array  341  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 351 =================
unit 3513
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      60     1       2
  media      59     1       3      -2
  media      57     1       4      -3
  media      59     1       5      -4
  media      58     1       6      -5
  boundary      6
unit 351
  rhexprism     1  18.     29.    -29.
  array  351  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 361 =================
unit 3613
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      30     1       2
  media      29     1       3      -2
  media      27     1       4      -3
```

```
  media      29     1       5      -4
  media      28     1       6      -5
  boundary      6
unit 361
  rhexprism     1  18.     29.    -29.
  array  361  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Generic fuel column for ring 3 =================
unit 310
  rhexprism     1  17.    261.   -261.
  array   31  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'============= Ring 3: place the above-defined fuel column in twelve places =
unit 31
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=0
  media     128     1       1
  boundary      1
unit 51
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=120
  media     128     1       1
  boundary      1
unit 32
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=60
  media     128     1       1
  boundary      1
unit 52
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=180
  media     128     1       1
  boundary      1
unit 33
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=120
  media     128     1       1
  boundary      1
unit 53
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=240
  media     128     1       1
  boundary      1
unit 34
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=180
  media     128     1       1
  boundary      1
unit 54
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=300
  media     128     1       1
  boundary      1
unit 35
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=240
  media     128     1       1
  boundary      1
unit 55
```

```
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=0
  media     128     1       1
  boundary      1
unit 36
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=300
  media     128     1       1
  boundary      1
unit 56
  rhexprism     1  18.    261.   -261.
  hole  310  rotate a1=60
  media     128     1       1
  boundary      1
'================ Fuel Column: Zone 4 Block 1 =================
'================ Block 411 =================
unit 411
  rhexprism     1  18.     29.    -29.
  array  411  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 431 =================
unit 4313
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media     120     1       2
  media     119     1       3      -2
  media     117     1       4      -3
  media     119     1       5      -4
  media     118     1       6      -5
  boundary      6
unit 431
  rhexprism     1  18.     29.    -29.
  array  431  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 441 =================
unit 4413
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media     100     1       2
  media      99     1       3      -2
  media      97     1       4      -3
  media      99     1       5      -4
  media      98     1       6      -5
  boundary      6
unit 441
  rhexprism     1  18.     29.    -29.
  array  441  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 451 =================
unit 4513
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
```

```
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      70     1       2
  media      69     1       3      -2
  media      67     1       4      -3
  media      69     1       5      -4
  media      68     1       6      -5
  boundary      6
unit 451
  rhexprism     1  18.     29.    -29.
  array  451  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Block 461 =================
unit 4613
  cylinder      2   1.325  27.3   -27.3
  cylinder      3   1.325  27.45  -27.45
  cylinder      4   1.7    28.85  -28.85
  cylinder      5   2.05   29.    -29.
  hexprism      6   2.575  29.    -29.
  media      40     1       2
  media      39     1       3      -2
  media      37     1       4      -3
  media      39     1       5      -4
  media      38     1       6      -5
  boundary      6
unit 461
  rhexprism     1  18.     29.    -29.
  array  461  1  place  5  5  1   0.0      0.0      0.0
  boundary      1
'================ Generic fuel column for ring 4 =================
unit 410
  rhexprism     1  17.    261.   -261.
  array   41  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'============= Ring 4: place the above-defined fuel column in six places ====
unit 41
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=0
  media     128     1       1
  boundary      1
unit 42
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=60
  media     128     1       1
  boundary      1
unit 43
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=120
  media     128     1       1
  boundary      1
unit 44
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=180
  media     128     1       1
  boundary      1
unit 45
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=240
  media     128     1       1
```

```
  boundary      1
unit 46
  rhexprism     1  18.    261.   -261.
  hole  410  rotate a1=300
  media     128     1       1
  boundary      1
'
'================ Control rods (Fig. 3.8, pag. 183 of [1]) =============
'
'============== Control rod section (Fig. 3.7, pag. 182 of [1]) =============
unit 9101
  cylinder      1   0.5    30.      1.
  cylinder      2   3.25   30.      1.
  cylinder      3   3.75   30.      1.
  cylinder      4   5.25   30.      1.
  cylinder      5   5.65   31.      0.
  cylinder      6   6.15   31.      0.
  hexprism      7   7.     31.      0.
  media     127     1       1
  media     121     1       2      -1
  media     127     1       3      -2
  media     126     1       4      -3
  media     127     1       5      -4
  media     121     1       6      -5
  media     128     1       7      -6
  boundary      7
'================ Control rod empty region =============
unit 9102
  cylinder      1   6.15  522.      0.
  hexprism      2   7.    522.      0.
  media     121     1       1
  media     128     1       2      -1
  boundary      2
'================ Central region in CR =============
unit 6001
  cone          1   2.5    29.      1.     15.5
  cylinder      2   1.5    20.     14.
  cylinder      3   2.25   14.      4.
  hexprism      4   2.5    29.    -29.
  media     121     1       1      -2
  media     121     1       2
  media     121     1       3
  media     128     1       4      -1      -2      -3
  boundary      4
'================ CR Column 61: Central =================
unit 610
  cylinder      1   6.15  261.   -155.   origin x=-5.4       y=-9.353074
  cylinder      2   6.15  261.   -155.   origin x=10.8       y=0.
  cylinder      3   6.15  261.   -155.   origin x=-5.4       y=9.353074
  cylinder      4   2.3   261.   -261.
  array 9101  1  place  1  1  2    -5.4     -9.353074     32.5
  array 9101  2  place  1  1  2    10.8      0.           32.5
  array 600   4  place  1  1  5     0.0      0.0           0.0
  rhexprism     5     17.    261.   -261.
  media     121     1       3
  media     128     1       5      -1      -2      -3      -4
  boundary      5
'================ Central CR: place CR in central column =================
unit 61
```

```
  rhexprism     1  18.    261.   -261.
  hole  610  rotate a1=0
  media     128     1       1
  boundary      1
'================ CR Column 62: R1, Column 1 =================
unit 620
  cylinder      1   6.15  261.   -155.   origin x=-10.8      y=0.
  cylinder      2   6.15  261.   -155.   origin x=5.4        y=-9.353074
  cylinder      3   6.15  261.   -155.   origin x=5.4        y=9.353074
  cylinder      4   2.3   261.   -261.
  array 9101  1  place  1  1  2   -10.8      0.           32.5
  array 9101  2  place  1  1  2     5.4     -9.353074     32.5
  array 600   4  place  1  1  5     0.0      0.0           0.0
  rhexprism     5  17.    261.   -261.
  media     121     1       3
  media     128     1       5      -1      -2      -3      -4
  boundary      5
'================ Ring 1 CR: place CR in six columns =================
unit 62
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=0
  media     128     1       1
  boundary      1
unit 63
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=60
  media     128     1       1
  boundary      1
unit 64
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=120
  media     128     1       1
  boundary      1
unit 65
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=180
  media     128     1       1
  boundary      1
unit 66
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=240
  media     128     1       1
  boundary      1
unit 67
  rhexprism     1  18.    261.   -261.
  hole  620  rotate a1=300
  media     128     1       1
  boundary      1
'================ CR Column 71: R2, Column 1 =================
unit 710
  cylinder      1   6.15  261.   -155.   origin x=-5.4       y=9.353074
  cylinder      2   6.15  261.   -155.   origin x=-5.4       y=-9.353074
  cylinder      3   6.15  261.   -155.   origin x=10.8       y=0.
  cylinder      4   2.3   261.   -261.
  array 9101  1  place  1  1  2    -5.4      9.353074      32.5
  array 9101  2  place  1  1  2    -5.4     -9.353074      32.5
  array 600   4  place  1  1  5     0.0      0.0            0.0
  rhexprism     5  17.    261.   -261.
  media     121     1       3
```

```
  media     128     1       5      -1      -2      -3      -4
  boundary      5
'================ Ring 2 CR: place CR in six columns =================
unit 71
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=0
  media     128     1       1
  boundary      1
unit 72
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=60
  media     128     1       1
  boundary      1
unit 74
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=120
  media     128     1       1
  boundary      1
unit 75
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=180
  media     128     1       1
  boundary      1
unit 77
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=240
  media     128     1       1
  boundary      1
unit 78
  rhexprism     1  18.    261.   -261.
  hole  710  rotate a1=300
  media     128     1       1
  boundary      1
'================ CR Column 73: R3, Column 1 =================
unit 730
  cylinder      1   6.15  261.   -155.   origin x=-5.4       y=-9.353074
  cylinder      2   6.15  261.   -155.   origin x=10.8       y=0.
  cylinder      3   6.15  261.   -155.   origin x=-5.4       y=9.353074
  cylinder      4   2.3   261.   -261.
  array 9101  1  place  1  1  2    -5.4     -9.353074     259.9
  array 9101  2  place  1  1  2    10.8      0.0          259.9
  array 600   4  place  1  1  5     0.0      0.0            0.0
  rhexprism     5  17.    261.   -261.
  media     121     1       3
  media     128     1       5      -1      -2      -3      -4
  boundary      5
'================ Ring 3 CR: place CR in three columns =================
unit 73
  rhexprism     1  18.    261.   -261.
  hole  730  rotate a1=0
  media     128     1       1
  boundary      1
unit 76
  rhexprism     1  18.    261.   -261.
  hole  730  rotate a1=120
  media     128     1       1
  boundary      1
unit 79
  rhexprism     1  18.    261.   -261.
```

```
  hole  730  rotate a1=240
  media     128     1       1
  boundary      1
'================ Instrumentation Block =================
unit 801
  cylinder      1   6.15   29.    -29.   origin x=-10.8      y=0.
  cylinder      2   6.15   29.    -29.   origin x=5.4        y=9.353074
  cylinder      3   6.15   29.    -29.   origin x=5.4        y=-9.353074
  cone          4   2.5    29.      1.5    20.
  cylinder      5   1.5    20.     14.
  cylinder      6   2.25   14.      4.
  cylinder      7   2.505  29.    -29.
  rhexprism     8  18.     29.    -29.
  media     121     1       1
  media     121     1       2
  media     121     1       3
  media     121     1       4
  media     121     1       5
  media     121     1       6
  media     128     1       7      -4      -5      -6
  media     128     1       8      -1      -2      -3      -7
  boundary      8
unit 802
  cone          4   2.5    29.      1.5    20.
  cylinder      5   1.5    20.     14.
  cylinder      6   2.25   14.      4.
  cylinder      7   2.505  29.    -29.
  rhexprism     8  18.     29.    -29.
  media     121     1       4
  media     121     1       5
  media     121     1       6
  media     128     1       7      -4      -5      -6
  media     128     1       8      -7
  boundary      8
unit 80
  rhexprism     1  18.    261.   -261.
  array   80  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'================ RR Block not in fuel column =================
unit 900
  cone          1   2.5    29.      1.5    20.
  cylinder      2   1.5    20.     14.
  cylinder      3   2.25   14.      4.
  cylinder      4   2.505  29.    -29.
  rhexprism     5  18.     29.    -29.
  media     121     1       1
  media     121     1       2
  media     121     1       3
  media     128     1       4      -1      -2      -3
  media     128     1       5      -4
  boundary      5
unit 90
  rhexprism     1  18.    261.   -261.
  array   90  1  place  1  1  5   0.0      0.0      0.0
  boundary      1
'================ Global Geometry ================
global unit 1
  cylinder      1 212.5    261.   -261.
  array    1  1  place  10  10  1   0.0      0.0      0.0
```

```
  boundary      1
end geom

' -----------------------------------------------------------------------------
' --- Boundary conditions -----------------------------------------------------
read boun all=vacuum end boun

' -----------------------------------------------------------------------------
read array
  ara=1 nux=19 nuy=19 nuz=1 typ=rhexagonal
  fill
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 80 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 77 90 45 90 78 10 10 10 10 10 10 10
       10 10 10 10 10 76 90 54 35 66 55 36 90 79 10 10 10 10 10
       10 10 10 10 10 90 44 65 25 15 26 67 46 90 10 10 10 10 10
       10 10 10 10 10 75 34 24 14 61 16 21 56 71 10 10 10 10 10
       10 10 10 10 10 90 53 64 13 12 11 62 31 90 10 10 10 10 10
       10 10 10 10 10 80 43 33 23 63 22 51 41 80 10 10 10 10 10
       10 10 10 10 10 10 90 74 52 42 32 72 90 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 90 73 90 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
       10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
  end fill
' --- Columns arrays ----------------------------------------------------------
  ara=10 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 100 100 100 100 100 100 100 100 100 end fill
  ara=11 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 111 111 161 161 151 141 131 111 111 end fill
  ara=21 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 211 211 261 261 251 241 231 211 211 end fill
  ara=31 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 311 311 361 361 351 341 331 311 311 end fill
  ara=41 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 411 411 461 461 451 441 431 411 411 end fill
  ara=80 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 802 801 801 801 801 801 801 801 801 end fill
  ara=90 nux=1 nuy=1 nuz=9 typ=rhexagonal
         fill 900 900 900 900 900 900 900 900 900 end fill
' --- Fuel block arrays -------------------------------------------------------
  ara=111  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
      1116  1116  1116  1116  1116  1116  1116  1116  1116
        1116  1116  1116  1116  1116  1113  1113  1113  1116
          1116  1116  1116  1113  1113  1113  1113  1113  1116
            1116  1116  1113  1113  1113  1113  1113  1113  1116
              1116  1113  1113  1113  1114  1113  1113  1116  1116
                1116  1113  1113  1113  1113  1113  1113  1116  1116
                  1116  1113  1113  1113  1113  1113  1116  1116  1116
                    1116  1116  1113  1113  1113  1116  1116  1116  1116
                      1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill
```

```
ara=131  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1312  1313  1313  1313  1116
        1116  1116  1116  1313  1313  1313  1313  1313  1116
          1116  1116  1313  1313  1313  1313  1313  1313  1116
            1116  1313  1313  1313  1114  1313  1313  1312  1116
              1116  1313  1313  1313  1313  1313  1313  1116  1116
                1116  1313  1313  1313  1313  1313  1116  1116  1116
                  1116  1315  1313  1313  1313  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=141  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1412  1413  1413  1413  1116
        1116  1116  1116  1413  1413  1413  1413  1413  1116
          1116  1116  1413  1413  1413  1413  1413  1413  1116
            1116  1413  1413  1413  1114  1413  1413  1412  1116
              1116  1413  1413  1413  1413  1413  1413  1116  1116
                1116  1413  1413  1413  1413  1413  1116  1116  1116
                  1116  1315  1413  1413  1413  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=151  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1412  1513  1513  1513  1116
        1116  1116  1116  1513  1513  1513  1513  1513  1116
          1116  1116  1513  1513  1513  1513  1513  1513  1116
            1116  1513  1513  1513  1114  1513  1513  1412  1116
              1116  1513  1513  1513  1513  1513  1513  1116  1116
                1116  1513  1513  1513  1513  1513  1116  1116  1116
                  1116  1315  1513  1513  1513  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=161  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1312  1613  1613  1613  1116
        1116  1116  1116  1613  1613  1613  1613  1613  1116
          1116  1116  1613  1613  1613  1613  1613  1613  1116
            1116  1613  1613  1613  1114  1613  1613  1312  1116
              1116  1613  1613  1613  1613  1613  1613  1116  1116
                1116  1613  1613  1613  1613  1613  1116  1116  1116
                  1116  1315  1613  1613  1613  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=211  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1113  1113  1113  1116  1116
        1116  1116  1116  1113  1113  1113  1113  1113  1116
          1116  1116  1113  1113  1113  1113  1113  1113  1116
            1116  1116  1113  1113  1114  1113  1113  1113  1116
              1116  1113  1113  1113  1113  1113  1113  1116  1116
                1116  1113  1113  1113  1113  1113  1116  1116  1116
                  1116  1113  1113  1113  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
```

```
end fill
ara=231  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  2313  2313  2313  1315  1116
        1116  1116  1116  2313  2313  2313  2313  2313  1116
          1116  1116  2313  2313  2313  2313  2313  2313  1116
            1116  1312  2313  2313  1114  2313  2313  2313  1116
              1116  2313  2313  2313  2313  2313  2313  1116  1116
                1116  2313  2313  2313  2313  2313  1116  1116  1116
                  1116  2313  2313  2313  1312  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=241  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  2413  2413  2413  1315  1116
        1116  1116  1116  2413  2413  2413  2413  2413  1116
          1116  1116  2413  2413  2413  2413  2413  2413  1116
            1116  1412  2413  2413  1114  2413  2413  2413  1116
              1116  2413  2413  2413  2413  2413  2413  1116  1116
                1116  2413  2413  2413  2413  2413  1116  1116  1116
                  1116  2413  2413  2413  1412  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=251  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  2513  2513  2513  1315  1116
        1116  1116  1116  2513  2513  2513  2513  2513  1116
          1116  1116  2513  2513  2513  2513  2513  2513  1116
            1116  1412  2513  2513  1114  2513  2513  2513  1116
              1116  2513  2513  2513  2513  2513  2513  1116  1116
                1116  2513  2513  2513  2513  2513  1116  1116  1116
                  1116  2513  2513  2513  1412  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=261  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  2613  2613  2613  1315  1116
        1116  1116  1116  2613  2613  2613  2613  2613  1116
          1116  1116  2613  2613  2613  2613  2613  2613  1116
            1116  1312  2613  2613  1114  2613  2613  2613  1116
              1116  2613  2613  2613  2613  2613  2613  1116  1116
                1116  2613  2613  2613  2613  2613  1116  1116  1116
                  1116  2613  2613  2613  1312  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=311  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1116  1113  1113  1116  1116
        1116  1116  1116  1113  1113  1113  1113  1113  1116
          1116  1116  1113  1113  1113  1113  1113  1113  1116
            1116  1113  1113  1113  1114  1113  1113  1116  1116
              1116  1113  1113  1113  1113  1113  1113  1116  1116
                1116  1113  1113  1113  1113  1113  1116  1116  1116
                  1116  1116  1113  1113  1116  1116  1116  1116  1116
```

```
                   1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=331  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1312  3313  3313  1116  1116
        1116  1116  1116  3313  3313  3313  3313  3313  1116
          1116  1116  3313  3313  3313  3313  3313  3313  1116
            1116  3313  3313  3313  1114  3313  3313  1315  1116
              1116  3313  3313  3313  3313  3313  3313  1116  1116
                1116  3313  3313  3313  3313  3313  1116  1116  1116
                  1116  1312  3313  3313  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=341  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1412  3413  3413  1116  1116
        1116  1116  1116  3413  3413  3413  3413  3413  1116
          1116  1116  3413  3413  3413  3413  3413  3413  1116
            1116  3413  3413  3413  1114  3413  3413  1315  1116
              1116  3413  3413  3413  3413  3413  3413  1116  1116
                1116  3413  3413  3413  3413  3413  1116  1116  1116
                  1116  1412  3413  3413  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=351  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1412  3513  3513  1116  1116
        1116  1116  1116  3513  3513  3513  3513  3513  1116
          1116  1116  3513  3513  3513  3513  3513  3513  1116
            1116  3513  3513  3513  1114  3513  3513  1315  1116
              1116  3513  3513  3513  3513  3513  3513  1116  1116
                1116  3513  3513  3513  3513  3513  1116  1116  1116
                  1116  1412  3513  3513  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=361  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1312  3613  3613  1116  1116
        1116  1116  1116  3613  3613  3613  3613  3613  1116
          1116  1116  3613  3613  3613  3613  3613  3613  1116
            1116  3613  3613  3613  1114  3613  3613  1315  1116
              1116  3613  3613  3613  3613  3613  3613  1116  1116
                1116  3613  3613  3613  3613  3613  1116  1116  1116
                  1116  1312  3613  3613  1116  1116  1116  1116  1116
                    1116  1116  1116  1116  1116  1116  1116  1116  1116
end fill
ara=411  nux=9  nuy=9  nuz=1  typ=hexagonal
fill
    1116  1116  1116  1116  1116  1116  1116  1116  1116
      1116  1116  1116  1116  1113  1113  1113  1116  1116
        1116  1116  1116  1113  1113  1113  1113  1113  1116
          1116  1116  1113  1113  1113  1113  1113  1113  1116
            1116  1116  1113  1113  1114  1113  1113  1116  1116
              1116  1113  1113  1113  1113  1113  1113  1116  1116
                1116  1113  1113  1113  1113  1113  1116  1116  1116
```

```
                1116  1116  1113  1113  1116  1116  1116  1116  1116
                  1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill
  ara=431  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
      1116  1116  1116  1116  1116  1116  1116  1116  1116
        1116  1116  1116  1116  4313  4313  4313  1312  1116
          1116  1116  1116  4313  4313  4313  4313  4313  1116
            1116  1116  4313  4313  4313  4313  4313  4313  1116
              1116  1312  4313  4313  1114  4313  4313  1116  1116
                1116  4313  4313  4313  4313  4313  4313  1116  1116
                  1116  4313  4313  4313  4313  4313  1116  1116  1116
                    1116  1116  4313  4313  1315  1116  1116  1116  1116
                      1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill
  ara=441  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
      1116  1116  1116  1116  1116  1116  1116  1116  1116
        1116  1116  1116  1116  4413  4413  4413  1412  1116
          1116  1116  1116  4413  4413  4413  4413  4413  1116
            1116  1116  4413  4413  4413  4413  4413  4413  1116
              1116  1412  4413  4413  1114  4413  4413  1116  1116
                1116  4413  4413  4413  4413  4413  4413  1116  1116
                  1116  4413  4413  4413  4413  4413  1116  1116  1116
                    1116  1116  4413  4413  1315  1116  1116  1116  1116
                      1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill
  ara=451  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
      1116  1116  1116  1116  1116  1116  1116  1116  1116
        1116  1116  1116  1116  4513  4513  4513  1412  1116
          1116  1116  1116  4513  4513  4513  4513  4513  1116
            1116  1116  4513  4513  4513  4513  4513  4513  1116
              1116  1412  4513  4513  1114  4513  4513  1116  1116
                1116  4513  4513  4513  4513  4513  4513  1116  1116
                  1116  4513  4513  4513  4513  4513  1116  1116  1116
                    1116  1116  4513  4513  1315  1116  1116  1116  1116
                      1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill
  ara=461  nux=9  nuy=9  nuz=1  typ=hexagonal
  fill
      1116  1116  1116  1116  1116  1116  1116  1116  1116
        1116  1116  1116  1116  4613  4613  4613  1312  1116
          1116  1116  1116  4613  4613  4613  4613  4613  1116
            1116  1116  4613  4613  4613  4613  4613  4613  1116
              1116  1312  4613  4613  1114  4613  4613  1116  1116
                1116  4613  4613  4613  4613  4613  4613  1116  1116
                  1116  4613  4613  4613  4613  4613  1116  1116  1116
                    1116  1116  4613  4613  1315  1116  1116  1116  1116
                      1116  1116  1116  1116  1116  1116  1116  1116  1116
  end fill

  ara=600     nux=1  nuy=1  nuz=9  typ=hexagonal fill 9*6001 end fill

  ara=9101    nux=1  nuy=1  nuz=12  typ=hexagonal
      fill 9102 10*9101 9102 end fill
end array

' ---------------------------------------------------------------------------
```

```
' --- Energy splitting ------------------------------------------------------
read energy
  2e7 1.01e6 0.625 1e-5
end energy

' --------------------------------------------------------------------------
' --- Plot cros-section -----------------------------------------------------
read plot
ttl='z=242 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=242.
  XLR=213.0  YLR=-213.0 ZLR=242.
  NAX=1280 end
ttl='z=184 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=184.
  XLR=213.0  YLR=-213.0 ZLR=184.
  NAX=1280 end
ttl='z=126 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=126.
  XLR=213.0  YLR=-213.0 ZLR=126.
  NAX=1280 end
ttl='z=68 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=68.
  XLR=213.0  YLR=-213.0 ZLR=68.
  NAX=1280 end
ttl='z=10 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=10.
  XLR=213.0  YLR=-213.0 ZLR=10.
  NAX=1280 end
ttl='z=-48 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=-48.
  XLR=213.0  YLR=-213.0 ZLR=-48.
  NAX=1280 end
ttl='z=-106 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=-106.
  XLR=213.0  YLR=-213.0 ZLR=-106.
  NAX=1280 end
ttl='z=-164 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=-164.
  XLR=213.0  YLR=-213.0 ZLR=-164.
  NAX=1280 end
ttl='z=-222 cm'
  TYP=XY
  XUL=-213.0 YUL=213.0  ZUL=-222.
  XLR=213.0  YLR=-213.0 ZLR=-222.
  NAX=1280 end
ttl='Vertical View of the HTTR Core'
  TYP=XZ
  XUL=-213. YUL=0.  ZUL=265.
  XLR=213.  YLR=0. ZLR=-265.
  UAX=1.0 WDN=-1.0 NAX=1280 end
end plot
```

```
end data
end
' -----------------------------------------------------------------------------
' --- End input deck -----------------------------------------------------------
```

# APPENDIX C. SCALE MULTIGROUP MODEL FOR HTR-10

# APPENDIX C. SCALE MULTIGROUP MODEL FOR HTR-10

```
'=============================================================================
' HTR-10 model for first critical core
' based on IRPhE 2009 high-fidelity benchmark specifications
' Authors: Eva Sunny and Germina Ilas
' Date: January 2010
'=============================================================================
=csas6
HTR-10
'=============================================================================
v7-238
'=============================================================================
' Material composition data based on Tables 3.5.a, 3.5.b, 3.6, 3.7, and 3.8
'=============================================================================
read composition
'-----------------------------------------------------------------------------
' boronated carbon bricks
'-----------------------------------------------------------------------------
 c-graphite  1 0 7.29410e-02 300   end
 b-10        1 0 6.53026e-02 300   end
 b-11        1 0 2.64508e-03 300   end
 n-14        1 0 1.86679e-06 300   end
 o-16        1 0 5.00805e-07 300   end
 ar-40       1 0 1.11653e-08 300   end
 h-1         1 0 4.09691e-08 300   end
 o-16        1 0 2.04846e-08 300   end
'-----------------------------------------------------------------------------
' top graphite reflector
'-----------------------------------------------------------------------------
 c-graphite  2 0 8.51462e-02 300   end
 b-10        2 0 9.05153e-08 300   end
 b-11        2 0 3.66633e-07 300   end
 n-14        2 0 1.37155e-06 300   end
 o-16        2 0 3.67947e-07 300   end
 ar-40       2 0 8.20327e-09 300   end
 h-1         2 0 3.01005e-08 300   end
 o-16        2 0 1.50502e-08 300   end
'-----------------------------------------------------------------------------
' cold coolant chamber
'-----------------------------------------------------------------------------
 c-graphite  3 0 1.45350e-02 300   end
 b-10        3 0 1.54516e-08 300   end
 b-11        3 0 6.25868e-08 300   end
 n-14        3 0 3.26568e-05 300   end
 o-16        3 0 8.76083e-06 300   end
 ar-40       3 0 1.95320e-07 300   end
 h-1         3 0 7.16694e-07 300   end
 o-16        3 0 3.58347e-07 300   end
'-----------------------------------------------------------------------------
' top reflector
'-----------------------------------------------------------------------------
 c-graphite  4 0 8.02916e-02 300   end
 b-10        4 0 8.53546e-08 300   end

 b-11        4 0 3.45729e-07 300   end
```

```
 n-14         4 0 3.52247e-06 300   end
 o-16         4 0 9.44972e-07 300   end
 ar-40        4 0 2.10679e-08 300   end
 h-1          4 0 7.73049e-08 300   end
 o-16         4 0 3.86524e-08 300   end
'-----------------------------------------------------------------------------
' top core cavity
'-----------------------------------------------------------------------------
 n-14         5 0 3.90968e-05 300   end
 o-16         5 0 1.04885e-05 300   end
 ar-40        5 0 2.33838e-07 300   end
 h-1          5 0 8.58028e-07 300   end
 o-16         5 0 4.29014e-07 300   end
'-----------------------------------------------------------------------------
' dummy pebbles
'-----------------------------------------------------------------------------
 c-graphite  6 0 5.72501e-02 300   end
 b-10         6 0 5.50210e-10 300   end
 b-11         6 0 2.22863e-09 300   end
 n-14         6 0 1.52478e-05 300   end
 o-16         6 0 4.09052e-06 300   end
 ar-40        6 0 9.11968e-08 300   end
 h-1          6 0 3.34631e-07 300   end
 o-16         6 0 1.67315e-07 300   end
'-----------------------------------------------------------------------------
 c-graphite  7 0 5.72501e-02 300   end
 b-10         7 0 5.50210e-10 300   end
 b-11         7 0 2.22863e-09 300   end
 n-14         7 0 1.52478e-05 300   end
 o-16         7 0 4.09052e-06 300   end
 ar-40        7 0 9.11968e-08 300   end
 h-1          7 0 3.34631e-07 300   end
 o-16         7 0 1.67315e-07 300   end
'-----------------------------------------------------------------------------
' bottom reflector structures
'-----------------------------------------------------------------------------
 c-graphite  8 0 7.81408e-02 300   end
 b-10         8 0 8.30683e-08 300   end
 b-11         8 0 3.36469e-07 300   end
 n-14         8 0 4.47541e-06 300   end
 o-16         8 0 1.20062e-06 300   end
 ar-40        8 0 2.67674e-08 300   end
 h-1          8 0 9.82185e-08 300   end
 o-16         8 0 4.91092e-08 300   end
'-----------------------------------------------------------------------------
 c-graphite  9 0 8.23751e-02 300   end
 b-10         9 0 8.75697e-08 300   end
 b-11         9 0 3.54701e-07 300   end
 n-14         9 0 2.59931e-06 300   end
 o-16         9 0 6.97317e-07 300   end
 ar-40        9 0 1.55465e-08 300   end
 h-1          9 0 5.70451e-08 300   end
 o-16         9 0 2.85226e-08 300   end
'-----------------------------------------------------------------------------
 c-graphite  10 0 8.43647e-02 300   end
 b-10         10 0 5.91038e-05 300   end
 b-11         10 0 2.39400e-04 300   end
```

```
n-14         10 0 1.58577e-06 300   end
o-16         10 0 4.25414e-07 300   end
ar-40        10 0 9.48447e-09 300   end
h-1          10 0 3.48016e-08 300   end
o-16         10 0 1.74008e-08 300   end
'---------------------------------------------------------------------------
c-graphite  11 0 8.17101e-02 300   end
b-10         11 0 3.09704e-05 300   end
b-11         11 0 1.25446e-04 300   end
n-14         11 0 2.82486e-06 300   end
o-16         11 0 7.57826e-07 300   end
ar-40        11 0 1.68955e-08 300   end
h-1          11 0 6.19951e-08 300   end
o-16         11 0 3.09975e-08 300   end
'---------------------------------------------------------------------------
c-graphite  12 0 8.50790e-02 300   end
b-10         12 0 4.14002e-05 300   end
b-11         12 0 1.67692e-04 300   end
n-14         12 0 1.30888e-06 300   end
o-16         12 0 3.51134e-07 300   end
ar-40        12 0 7.82843e-09 300   end
h-1          12 0 2.87251e-08 300   end
o-16         12 0 1.43625e-08 300   end
'---------------------------------------------------------------------------
c-graphite  13 0 8.19167e-02 300   end
b-10         13 0 7.09887e-06 300   end
b-11         13 0 2.87540e-05 300   end
n-14         13 0 2.78674e-06 300   end
o-16         13 0 7.47599e-07 300   end
ar-40        13 0 1.66675e-08 300   end
h-1          13 0 6.11585e-08 300   end
o-16         13 0 3.05793e-08 300   end
'---------------------------------------------------------------------------
c-graphite  14 0 5.41118e-02 300   end
b-10         14 0 1.14336e-05 300   end
b-11         14 0 4.63120e-05 300   end
n-14         14 0 1.50964e-05 300   end
o-16         14 0 4.04992e-06 300   end
ar-40        14 0 9.02919e-08 300   end
h-1          14 0 3.31310e-07 300   end
o-16         14 0 1.65655e-07 300   end
'---------------------------------------------------------------------------
c-graphite  15 0 3.32110e-02 300   end
b-10         15 0 3.53052e-08 300   end
b-11         15 0 1.43004e-07 300   end
n-14         15 0 2.43823e-05 300   end
o-16         15 0 6.54105e-06 300   end
ar-40        15 0 1.45831e-07 300   end
h-1          15 0 5.35101e-07 300   end
o-16         15 0 2.67550e-07 300   end
'---------------------------------------------------------------------------
c-graphite  16 0 8.81811e-02 300   end
b-10         16 0 7.10555e-06 300   end
b-11         16 0 2.87811e-05 300   end
n-14         16 0 1.12208e-08 300   end
o-16         16 0 3.01020e-09 300   end
ar-40        16 0 6.71115e-11 300   end
```

```
h-1         16 0 2.46254e-10 300   end
o-16        16 0 1.23127e-10 300   end
'----------------------------------------------------------------------------
' boronated carbon bricks
'----------------------------------------------------------------------------
c-graphite  17 0 7.65984e-02 300   end
b-10        17 0 6.85771e-04 300   end
b-11        17 0 2.77772e-03 300   end
'----------------------------------------------------------------------------
' carbon bricks
'----------------------------------------------------------------------------
c-graphite  18 0 7.97184e-02 300   end
'----------------------------------------------------------------------------
' boronated carbon bricks
'----------------------------------------------------------------------------
c-graphite  19 0 7.61157e-02 300   end
b-10        19 0 6.81449e-04 300   end
b-11        19 0 2.76021e-03 300   end
n-14        19 0 2.46380e-07 300   end
o-16        19 0 6.60950e-08 300   end
ar-40       19 0 1.47360e-09 300   end
h-1         19 0 5.40704e-09 300   end
o-16        19 0 2.70352e-09 300   end
'----------------------------------------------------------------------------
' graphite reflector structures
'----------------------------------------------------------------------------
c-graphite  20 0 8.78374e-02 300   end
b-10        20 0 9.33762e-08 300   end
b-11        20 0 3.78221e-07 300   end
n-14        20 0 1.79180e-07 300   end
o-16        20 0 4.80680e-08 300   end
ar-40       20 0 1.07170e-09 300   end
h-1         20 0 3.93226e-09 300   end
o-16        20 0 1.96613e-09 300   end
'----------------------------------------------------------------------------
c-graphite  21 0 5.79696e-02 300   end
b-10        21 0 6.16251e-08 300   end
b-11        21 0 2.49613e-07 300   end
n-14        21 0 1.34130e-05 300   end
o-16        21 0 3.59820e-06 300   end
ar-40       21 0 8.02200e-08 300   end
h-1         21 0 2.94355e-07 300   end
o-16        21 0 1.47178e-07 300   end
'----------------------------------------------------------------------------
c-graphite  22 0 8.82418e-02 300   end
b-10        22 0 9.38063e-08 300   end
b-11        22 0 3.79963e-07 300   end
c-graphite  23 0 8.82418e-02 300   end
b-10        23 0 9.38063e-08 300   end
b-11        23 0 3.79963e-07 300   end
'----------------------------------------------------------------------------
c-graphite  24 0 8.79541e-02 300   end
b-10        24 0 3.33371e-05 300   end
b-11        24 0 1.35032e-04 300   end
n-14        24 0 5.30930e-08 300   end
o-16        24 0 1.42430e-08 300   end
ar-40       24 0 3.17550e-10 300   end
```

```
h-1          24 0 1.16520e-09 300   end
o-16         24 0 5.82601e-10 300   end
'----------------------------------------------------------------------------
c-graphite  25 0 8.82418e-04 300   end
b-10         25 0 9.38063e-08 300   end
b-11         25 0 3.79963e-07 300   end
'----------------------------------------------------------------------------
c-graphite  26 0 8.82418e-04 300   end
b-10         26 0 9.38063e-08 300   end
b-11         26 0 3.79963e-07 300   end
'----------------------------------------------------------------------------
' boronated carbon bricks
'----------------------------------------------------------------------------
c-graphite  27 0 7.65984e-02 300   end
b-10         27 0 6.85771e-04 300   end
b-11         27 0 2.77772e-03 300   end
'----------------------------------------------------------------------------
' graphite reflector structures
'----------------------------------------------------------------------------
c-graphite  28 0 8.82418e-02 300   end
b-10         28 0 9.38063e-08 300   end
b-11         28 0 3.79963e-07 300   end
'----------------------------------------------------------------------------
c-graphite  29 0 5.24843e-02 300   end
b-10         29 0 3.60299e-06 300   end
b-11         29 0 1.45939e-05 300   end
n-14         29 0 9.01730e-06 300   end
o-16         29 0 2.41910e-06 300   end
ar-40        29 0 5.39320e-08 300   end
h-1          29 0 1.97896e-07 300   end
o-16         29 0 9.89478e-08 300   end
'----------------------------------------------------------------------------
c-graphite  30 0 8.82418e-02 300   end
b-10         30 0 9.38063e-08 300   end
b-11         30 0 3.79963e-07 300   end
'----------------------------------------------------------------------------
' graphite reflector, control rods borin regions
'----------------------------------------------------------------------------
c-graphite  31 0 8.82418e-02 300   end
b-10         31 0 9.38063e-08 300   end
b-11         31 0 3.79963e-07 300   end
'----------------------------------------------------------------------------
' graphite reflector structures
'----------------------------------------------------------------------------
c-graphite  42 0 8.79637e-02 300   end
b-10         42 0 3.22548e-05 300   end
b-11         42 0 1.30648e-04 300   end
n-14         42 0 1.58430e-05 300   end
o-16         42 0 4.25010e-06 300   end
ar-40        42 0 9.47560e-08 300   end
h-1          42 0 3.47690e-07 300   end
o-16         42 0 1.73845e-07 300   end
'----------------------------------------------------------------------------
c-graphite  43 0 8.82418e-02 300   end
b-10         43 0 9.38063e-08 300   end
b-11         43 0 3.79963e-07 300   end
'----------------------------------------------------------------------------
```

```
c-graphite  44 0 8.82418e-02 300   end
b-10        44 0 9.38063e-08 300   end
b-11        44 0 3.79963e-07 300   end
'-----------------------------------------------------------------------------
' boronated carbon bricks
'-----------------------------------------------------------------------------
c-graphite  46 0 7.65984e-02 300   end
b-10        46 0 6.85771e-04 300   end
b-11        46 0 2.77772e-03 300   end
'-----------------------------------------------------------------------------
' carbon bricks
'-----------------------------------------------------------------------------
c-graphite  47 0 7.97184e-02 300   end
'-----------------------------------------------------------------------------
' graphite reflector structures
'-----------------------------------------------------------------------------
c-graphite  53 0 8.82418e-02 300   end
b-10        53 0 9.38063e-08 300   end
b-11        53 0 3.79963e-07 300   end
'-----------------------------------------------------------------------------
c-graphite  57 0 7.28262e-02 300   end
b-10        57 0 7.74186e-08 300   end
b-11        57 0 3.13584e-07 300   end
n-14        57 0 1.32800e-05 300   end
o-16        57 0 3.56250e-06 300   end
ar-40       57 0 7.94250e-08 300   end
h-1         57 0 2.91438e-07 300   end
o-16        57 0 1.45719e-07 300   end
'-----------------------------------------------------------------------------
' graphite reflector, cold coolant flow region
'-----------------------------------------------------------------------------
c-graphite  58 0 8.82418e-02 300   end
b-10        58 0 9.38063e-08 300   end
b-11        58 0 3.79963e-07 300   end
'-----------------------------------------------------------------------------
c-graphite  60 0 8.79538e-02 300   end
b-10        60 0 3.33371e-05 300   end
b-11        60 0 1.35032e-04 300   end
n-14        60 0 6.83020e-06 300   end
o-16        60 0 1.83230e-06 300   end
ar-40       60 0 4.08510e-08 300   end
h-1         60 0 1.49897e-07 300   end
o-16        60 0 7.49487e-08 300   end
'-----------------------------------------------------------------------------
c-graphite  62 0 8.82418e-02 300   end
b-10        62 0 9.38063e-08 300   end
b-11        62 0 3.79963e-07 300   end
'-----------------------------------------------------------------------------
' boronated carbon bricks
'-----------------------------------------------------------------------------
c-graphite  64 0 7.65984e-02 300   end
b-10        64 0 6.85771e-04 300   end
b-11        64 0 2.77772e-03 300   end
'-----------------------------------------------------------------------------
' carbon bricks
'-----------------------------------------------------------------------------
c-graphite  65 0 7.97184e-02 300   end
```

```
'------------------------------------------------------------------------------
' graphite reflector structures
'------------------------------------------------------------------------------
 c-graphite  66 0 5.82699e-02 300   end
 b-10        66 0 6.19443e-08 300   end
 b-11        66 0 2.50906e-07 300   end
 n-14        66 0 1.23220e-07 300   end
 o-16        66 0 3.30560e-08 300   end
 ar-40       66 0 7.36960e-10 300   end
 h-1         66 0 2.70416e-09 300   end
 o-16        66 0 1.35208e-09 300   end
'------------------------------------------------------------------------------
 c-graphite  70 0 8.82418e-02 300   end
 b-10        70 0 9.38063e-08 300   end
 b-11        70 0 3.79963e-07 300   end
'------------------------------------------------------------------------------
' boronated carbon bricks
'------------------------------------------------------------------------------
 c-graphite  77 0 7.65984e-02 300   end
 b-10        77 0 6.85771e-04 300   end
 b-11        77 0 2.77772e-03 300   end
'------------------------------------------------------------------------------
' dummy pebbles
'------------------------------------------------------------------------------
 c-graphite  81 0 8.47872e-02 300   end
 n-14        81 0 1.52480e-05 300   end
 o-16        81 0 4.09050e-06 300   end
 ar-40       81 0 9.11970e-08 300   end
 h-1         81 0 3.34631e-07 300   end
 o-16        81 0 1.67315e-07 300   end
'------------------------------------------------------------------------------
' bottom reflector with hot coolant flow borings
'------------------------------------------------------------------------------
 c-graphite  83 0 8.51047e-02 300   end
 b-10        83 0 9.04713e-08 300   end
 b-11        83 0 3.66455e-07 300   end
 n-14        83 0 1.38993e-06 300   end
 o-16        83 0 3.72877e-07 300   end
 ar-40       83 0 8.31317e-09 300   end
 h-1         83 0 3.05038e-08 300   end
 o-16        83 0 1.52519e-08 300   end
'------------------------------------------------------------------------------
' dummy pebbles
'------------------------------------------------------------------------------
 c-graphite  91 0 5.72501e-02 300   end
 b-10        91 0 5.50210e-10 300   end
 b-11        91 0 2.22863e-09 300   end
 n-14        91 0 1.52478e-05 300   end
 o-16        91 0 4.09052e-06 300   end
 ar-40       91 0 9.11968e-08 300   end
 h-1         91 0 3.34631e-07 300   end
 o-16        91 0 1.67315e-07 300   end
'------------------------------------------------------------------------------
' coolant - saturated air at 15C
'------------------------------------------------------------------------------
 n-14        96 0 3.95901e-05 300   end
 o-16        96 0 1.06209e-05 300   end
```

```
 ar-40       96 0 2.36778e-07 300   end
 h-1         96 0 8.58028e-07 300   end
 o-16        96 0 4.29014e-07 300   end
'-----------------------------------------------------------------------------
' fuel kernel
'-----------------------------------------------------------------------------
 u-235       99 0 3.99198e-03 300   end
 u-238       99 0 1.92441e-02 300   end
 o-16        99 0 4.64720e-02 300   end
 b-10        99 0 4.06384e-07 300   end
 b-11        99 0 1.63575e-06 300   end
'-----------------------------------------------------------------------------
' 1st coating - buffer
'-----------------------------------------------------------------------------
 c-graphite  101 0 5.51511e-02 300   end
 b-10        101 0 1.58513e-08 300   end
 b-11        101 0 6.38035e-08 300   end
'-----------------------------------------------------------------------------
' 2nd coating - inner pyrolitic carbon
'-----------------------------------------------------------------------------
 c-graphite  102 0 9.52610e-02 300   end
 b-10        102 0 2.73795e-08 300   end
 b-11        102 0 1.10206e-07 300   end
'-----------------------------------------------------------------------------
' 3rd coating - SiC
'-----------------------------------------------------------------------------
 c           103 0 4.77597e-02 300   end
 si-28       103 0 4.77597e-02 300   end
'-----------------------------------------------------------------------------
' 4th coating - outer pyrolitic carbon
'-----------------------------------------------------------------------------
 c-graphite  104 0 8.67377e-02 300   end
 b-10        104 0 2.49298e-08 300   end
 b-11        104 0 1.00345e-07 300   end
'-----------------------------------------------------------------------------
' graphite matrix
'-----------------------------------------------------------------------------
 c-graphite  105 0 8.67377e-02 300   end
 b-10        105 0 2.49298e-08 300   end
 b-11        105 0 1.00345e-07 300   end
'-----------------------------------------------------------------------------
' pebble shell - graphite
'-----------------------------------------------------------------------------
 c-graphite  106 0 8.67377e-02 300   end
 b-10        106 0 2.49298e-08 300   end
 b-11        106 0 1.00345e-07 300   end
'-----------------------------------------------------------------------------
' dummy pebbles - graphite
'-----------------------------------------------------------------------------
 c-graphite  107 0 9.22528e-02 300   end
 b-10        107 0 2.54951e-09 300   end
 b-11        107 0 1.02621e-08 300   end
end composition
'=============================================================================
' Unit cell data - use DOUBLEHET option
'=============================================================================
read celldata
```

```
doublehet fuelmix=100  end
           gfr=0.025     99
           coatr=0.034  101
           coatr=0.038  102
           coatr=0.0415 103
           coatr=0.0455 104
           numpar=8335
           matrix=105   end grain
 pebble sphtriangp right_bdy=white
           hpitch=3.859776 96
           fuelr=2.5
           cladr=3.0    106 end
end celldata
'============================================================================
' Beginning of KENO model section
'============================================================================
'----------------------------------------------------------------------------
' parameter data
'----------------------------------------------------------------------------
read parameter
 gen=1100
 npg=10000
 nsk=100
 htm=no
 flx=no
end parameter
'----------------------------------------------------------------------------
' geometry data
'----------------------------------------------------------------------------
read geometry
'----------------------------------------------------------------------------
unit 13
com='unit 13'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
```

```
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 18
com='unit 18'
 hexprism 30   8.1962    9.798        0
 media 96 1 30
 boundary 30
unit 11
com='unit 11'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
```

```
 sphere 66    2.999   origin  x=5.196152  y=-3       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3       z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 16
com='unit 16'
 hexprism 30   8.1962    4.553        0
 media 96 1 30
 boundary 30
unit 12
com='unit 12'
 hexprism 30   8.1962    5.245        0
 sphere 41    2.999   origin  x=3.4641    y=0 z=0.346
 sphere 42    2.999   origin  x=-1.7321   y=3        z=0.346
 sphere 43    2.999   origin  x=-1.7321   y=-3       z=0.346
 sphere 44    2.999   origin  x=3.4641    y=6        z=0.346
 sphere 45    2.999   origin  x=3.4641    y=-6       z=0.346
 sphere 46    2.999   origin  x=-6.9283   y=0        z=0.346
 sphere 47    2.999   origin  x=9.4641    y=0        z=0.346
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962  z=0.346
 sphere 49    2.999   origin  x=-4.7321   y=8.1962   z=0.346
 sphere 61    2.999   origin  x=0         y=0        z=5.245
 sphere 62    2.999   origin  x=5.196152  y=3        z=5.245
 sphere 63    2.999   origin  x=-5.196152 y=3        z=5.245
 sphere 64    2.999   origin  x=0         y=-6       z=5.245
 sphere 65    2.999   origin  x=0         y=6        z=5.245
 sphere 66    2.999   origin  x=5.196152  y=-3       z=5.245
 sphere 67    2.999   origin  x=-5.196152 y=-3       z=5.245
 media 107 1 41
 media 107 1 42
 media 107 1 43
```

```
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -41 -42 -43 -44 -45 -46 -47 -48 -49 -61 -62 -63 -64 -65 -66 -
67
 boundary 30
'----------------------------------------------------------------------------
unit 17
com='unit 17'
 hexprism 30   8.1962    5.245        0
 media 96 1 30
 boundary 30
unit 14
com='unit 14'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3        z=0
 sphere 23    2.999   origin  x=-5.196152 y=3        z=0
 sphere 24    2.999   origin  x=0         y=-6       z=0
 sphere 25    2.999   origin  x=0         y=6        z=0
 sphere 26    2.999   origin  x=5.196152  y=-3       z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3       z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'----------------------------------------------------------------------------
unit 19
com='unit 19'
 hexprism 30   8.1962    9.798        0
 media 96 1 30
 boundary 30
unit 310
com='unit 310'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
```

```
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 315
com='unit 315'
 hexprism 30   8.1962    2.999        0
 media 96 1 30
 boundary 30
unit 320
com='unit 320'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0          y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 65    2.999   origin  x=0          y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 96  1 30 -61 -62 -64 -65 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 321
com='unit 321'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0          y=0  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 65    2.999   origin  x=0          y=6  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 67
 media 96  1 30 -61 -63 -64 -65 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 324
com='unit 324'
 hexprism 30   8.1962    2.999        0
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 107 1 62
 media 107 1 64
 media 107 1 66
 media 96  1 30 -62 -64 -66
```

```
 boundary 30
'-----------------------------------------------------------------------------
unit 325
com='unit 325'
 hexprism 30   8.1962    2.999        0
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 63
 media 107 1 64
 media 107 1 67
 media 96  1 30 -63 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 326
com='unit 326'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 64
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 327
com='unit 327'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 63
 media 107 1 64
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -63 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 328
com='unit 328'
 hexprism 30   8.1962    2.999        0
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 64
 media 107 1 66
 media 107 1 67
 media 96  1 30 -64 -66 -67
 boundary 30
```

```
'-----------------------------------------------------------------------------
unit 329
com='unit 329'
 hexprism 30   8.1962    2.999        0
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 63
 media 107 1 65
 media 107 1 67
 media 96  1 30 -63 -65 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 330
com='unit 330'
 hexprism 30   8.1962    2.999        0
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 107 1 62
 media 107 1 65
 media 107 1 66
 media 96  1 30 -62 -65 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 331
com='unit 331'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 65
 media 107 1 67
 media 96  1 30 -61 -62 -63 -65 -67
 boundary 30
'-----------------------------------------------------------------------------
-unit 332
com='unit 332'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 65
 media 107 1 66
 media 96  1 30 -61 -62 -63 -65 -66
 boundary 30
'-----------------------------------------------------------------------------
```

```
unit 333
com='unit 333'
 hexprism 30   8.1962    2.999        0
 sphere 62    2.999   origin  x=5.196152  y=3 z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 107 1 62
 media 107 1 63
 media 107 1 65
 media 96  1 30 -62 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 334
com='unit 334'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 335
com='unit 335'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 336
com='unit 336'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
```

```
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 337
com='unit 337'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 338
com='unit 338'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 339
com='unit 339'
```

```
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'------------------------------------------------------------------------
unit 340
com='unit 340'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'------------------------------------------------------------------------
unit 341
com='unit 341'
 hexprism 30   8.1962    2.999        0
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
```

```
'-----------------------------------------------------------------------------
unit 420
com='unit 420'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 47
 media 96  1 30 -21 -22 -24 -25 -26 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 421
com='unit 421'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 media 107 1 21
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 27
 media 107 1 46
 media 96  1 30 -21 -23 -24 -25 -27 -46
 boundary 30
'-----------------------------------------------------------------------------
unit 424
com='unit 424'
 hexprism 30   8.1962    9.798        0
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 media 107 1 22
 media 107 1 24
 media 107 1 26
 media 96  1 30 -22 -24 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 425
com='unit 425'
 hexprism 30   8.1962    9.798        0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 23
 media 107 1 24
```

```
 media 107 1 27
 media 96  1 30 -23 -24 -27
 boundary 30
'------------------------------------------------------------------------------
unit 426
com='unit 426'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 24
 media 107 1 26
 media 107 1 27
 media 107 1 45
 media 96  1 30 -21 -22 -24 -26 -27 -45
 boundary 30
'------------------------------------------------------------------------------
unit 427
com='unit 427'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 23
 media 107 1 24
 media 107 1 26
 media 107 1 27
 media 107 1 48
 media 96  1 30 -21 -23 -24 -26 -27 -48
 boundary 30
'------------------------------------------------------------------------------
unit 428
com='unit 428'
 hexprism 30   8.1962    9.798        0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 24
 media 107 1 26
 media 107 1 27
 media 96 1 30 -24 -26 -27
 boundary 30
'------------------------------------------------------------------------------
unit 429
com='unit 429'
 hexprism 30   8.1962    9.798        0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
```

```
 sphere 27    2.999   origin  x=-5.196152 y=-3       z=0
 media 107 1 23
 media 107 1 25
 media 107 1 27
 media 96  1 30 -23 -25 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 430
com='unit 430'
 hexprism 30   8.1962    9.798        0
 sphere 22    2.999   origin  x=5.196152  y=3        z=0
 sphere 25    2.999   origin  x=0         y=6        z=0
 sphere 26    2.999   origin  x=5.196152  y=-3       z=0
 media 107 1 22
 media 107 1 25
 media 107 1 26
 media 96  1 30 -22 -25 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 431
com='unit 431'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3        z=0
 sphere 23    2.999   origin  x=-5.196152 y=3        z=0
 sphere 25    2.999   origin  x=0         y=6        z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3       z=0
 sphere 42    2.999   origin  x=-1.7321   y=3        z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6        z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0        z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962   z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 25
 media 107 1 27
 media 107 1 42
 media 107 1 44
 media 107 1 46
 media 107 1 49
 media 96  1 30 -21 -22 -23 -25 -27 -42 -44 -46 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 432
com='unit 432'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3        z=0
 sphere 23    2.999   origin  x=-5.196152 y=3        z=0
 sphere 25    2.999   origin  x=0         y=6        z=0
 sphere 26    2.999   origin  x=5.196152  y=-3       z=0
 sphere 41    2.999   origin  x=3.4641    y=0        z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3        z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6        z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0        z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962   z=4.899
 media 107 1 21
```

```
 media 107 1 22
 media 107 1 23
 media 107 1 25
 media 107 1 26
 media 107 1 41
 media 107 1 42
 media 107 1 44
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -25 -26 -41 -42 -44 -47 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 433
com='unit 433'
 hexprism 30   8.1962    9.798        0
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 107 1 22
 media 107 1 23
 media 107 1 25
 media 96 1 30 -22 -23 -25
 boundary 30
'-----------------------------------------------------------------------------
unit 434
com='unit 434'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 44
 media 107 1 45
 media 107 1 47
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -44 -45 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 435
com='unit 435'
 hexprism 30   8.1962    9.798        0
```

```
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 42
 media 107 1 43
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -43 -46 -48 -49
 boundary 30
'----------------------------------------------------------------------------
unit 436
com='unit 436'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 47
```

```
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -45 -46 -47 -48
 boundary 30
'----------------------------------------------------------------------------
unit 437
com='unit 437'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 43
 media 107 1 45
 media 107 1 47
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -43 -45 -47 -48
 boundary 30
'----------------------------------------------------------------------------
unit 438
com='unit 438'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
```

```
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -45 -46 -48
 boundary 30
'----------------------------------------------------------------------------
unit 439
com='unit 439'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 42
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -43 -45 -46 -48
 boundary 30
'----------------------------------------------------------------------------
unit 440
com='unit 440'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
```

```
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -45 -46 -48 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 441
com='unit 441'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -45 -46 -48 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 442
com='unit 442'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
```

```
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 47
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -47 -48
 boundary 30'-------------------------------------------------------------
-------------
unit 443
com='unit 443'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 47
```

```
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -47 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 444
com='unit 444'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -47 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 445
com='unit 445'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
```

```
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -46 -48 -49
 boundary 30
'----------------------------------------------------------------------------
unit 446
com='unit 446'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -47 -49
 boundary 30
'----------------------------------------------------------------------------
unit 447
com='unit 447'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
```

```
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -46 -48 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 448
com='unit 448'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 47
```

```
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -47 -48 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 449
com='unit 449'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -46 -48 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 450
com='unit 450'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
```

```
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 44
 media 107 1 46
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -44 -46 -47 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 700
com='unit 700'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 46
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -46 -47 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 451
com='unit 451'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
```

```
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -49
 boundary 30
'----------------------------------------------------------------------------
unit 452
com='unit 452'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
```

```
 media 107 1 46
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 453
com='unit 453'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -45 -46 -47 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 454
com='unit 454'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
```

```
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 65
 media 107 1 66
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -65 -66
 boundary 30
'----------------------------------------------------------------------------
unit 455
com='unit 455'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
```

```
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 65
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -65 -67
 boundary 30
'----------------------------------------------------------------------------
unit 456
com='unit 456'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
```

```
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -64 -65 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 457
com='unit 457'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
```

```
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -63 -64 -65 -67
 boundary 30
'----------------------------------------------------------------------------
unit 458
com='unit 458'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 64
 media 107 1 66
 media 107 1 67
```

```
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 459
com='unit 459'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 63
 media 107 1 64
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -63 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 460
com='unit 460'
```

```
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 43
 media 107 1 45
 media 107 1 47
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -43 -45 -47 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 461
com='unit 461'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96 1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 462
com='unit 462'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
```

```
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 463
com='unit 463'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 47
 media 96  1 30 -21 -22 -24 -25 -26 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 464
com='unit 464'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 465
com='unit 465'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
```

```
 sphere 24    2.999   origin  x=0          y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 466
com='unit 466'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0          y=-6      z=0
 sphere 25    2.999   origin  x=0          y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 467
com='unit 467'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0          y=-6      z=0
 sphere 25    2.999   origin  x=0          y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
```

```
 media 107 1 43
 media 107 1 45
 media 107 1 47
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -43 -45 -47 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 468
com='unit 468'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -43 -45 -46 -47 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 469
com='unit 469'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
```

```
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -43 -45 -46 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 470
com='unit 470'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 43
 media 107 1 45
 media 107 1 47
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -43 -45 -47 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 471
com='unit 471'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
```

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 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 61
 media 107 1 62
 media 107 1 64
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
61
                -62 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 472
com='unit 472'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
```

```
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 473
com='unit 473'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
```

```
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 474
com='unit 474'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
```

```
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 63
 media 107 1 64
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -47 -46 -48 -
49
                -61 -63 -64 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 475
com='unit 475'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -43 -45 -46 -48
 boundary 30
'----------------------------------------------------------------------------
unit 476
com='unit 476'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
```

```
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 47
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -43 -44 -45 -47 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 477
com='unit 477'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
```

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 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 478
com='unit 478'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
```

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 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 479
com='unit 479'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 42
 media 107 1 43
 media 107 1 45
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -43 -45 -46 -48 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 480
com='unit 480'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
```

```
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 44
 media 107 1 45
 media 107 1 47
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -44 -45 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 483
com='unit 483'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 42
 media 107 1 43
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -43 -46 -48 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 484
com='unit 484'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
```

```
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -64 -65 -66
 boundary 30
'----------------------------------------------------------------------------
unit 485
com='unit 485'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
```

```
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -48 -49 -
61
                -63 -64 -65 -67
 boundary 30
'----------------------------------------------------------------------------
unit 486
com='unit 486'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 44
 media 107 1 45
 media 107 1 47
```

```
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -44 -45 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 487
com='unit 487'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
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 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
```

```
unit 488
com='unit 488'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 489
com='unit 489'
 hexprism 30   8.1962    9.798        0
```

```
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 42
 media 107 1 43
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -43 -46 -48 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 490
com='unit 490'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 44
 media 107 1 45
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -44 -45 -47 -49
```

```
 boundary 30
'-----------------------------------------------------------------------------
unit 491
com='unit 491'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -43 -44 -46 -48 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 492
com='unit 492'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 44
```

```
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -44 -47 -49
 boundary 30
'------------------------------------------------------------------------------
unit 493
com='unit 493'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 65
 media 107 1 66
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -49 -
61
                -62 -63 -65 -66
 boundary 30
'------------------------------------------------------------------------------
unit 494
com='unit 494'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
```

```
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
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 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 495
com='unit 495'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
```

```
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 496
com='unit 496'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
```

```
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
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 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 65
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -65 -67
 boundary 30
'----------------------------------------------------------------------------
unit 497
com='unit 497'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
```

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 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 42
 media 107 1 44
 media 107 1 46
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -44 -46 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 498
com='unit 498'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 44
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -44 -47 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 499
com='unit 499'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
```

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 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
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 media 107 1 26
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 media 107 1 46
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -44 -46 -47 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 500
com='unit 500'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
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 media 107 1 27
 media 107 1 42
 media 107 1 44
 media 107 1 46
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -44 -46 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 501
com='unit 501'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
```

```
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
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 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 502
com='unit 502'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
```

```
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
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 media 107 1 26
 media 107 1 27
 media 107 1 41
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 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 503
com='unit 503'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
```

```
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
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 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 504
com='unit 504'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
```

```
 sphere 64    2.999   origin  x=0         y=-6       z=9.798
 sphere 65    2.999   origin  x=0         y=6        z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3       z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
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 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 505
com='unit 505'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3        z=0
 sphere 23    2.999   origin  x=-5.196152 y=3        z=0
 sphere 24    2.999   origin  x=0         y=-6       z=0
 sphere 25    2.999   origin  x=0         y=6        z=0
 sphere 26    2.999   origin  x=5.196152  y=-3       z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3       z=0
 sphere 41    2.999   origin  x=3.4641    y=0        z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3        z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6        z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0        z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0        z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0        z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3        z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3        z=9.798
 sphere 64    2.999   origin  x=0         y=-6       z=9.798
 sphere 65    2.999   origin  x=0         y=6        z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3       z=9.798
```

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 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
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 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
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 media 107 1 47
 media 107 1 48
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 media 107 1 61
 media 107 1 62
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 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 506
com='unit 506'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
```

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 media 107 1 23
 media 107 1 24
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 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 507
com='unit 507'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
```

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 media 107 1 26
 media 107 1 27
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 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 508
com='unit 508'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
```

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 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
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 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 509
com='unit 509'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
```

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 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 510
com='unit 510'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
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 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
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 media 107 1 46
 media 107 1 47
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 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 511
com='unit 511'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
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 media 107 1 48
 media 107 1 49
 media 107 1 61
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 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 512
com='unit 512'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
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 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
```

```
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 513
com='unit 513'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
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 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
```

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 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 514
com='unit 514'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
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 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
```

```
 boundary 30
'-----------------------------------------------------------------------------
unit 515
com='unit 515'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
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 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 516
```

```
com='unit 516'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
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 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'------------------------------------------------------------------------
unit 517
com='unit 517'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
```

```
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
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 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'--------------------------------------------------------------------------------
unit 518
com='unit 518'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
```

```
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 520
com='unit 520'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 21
 media 107 1 22
```

```
 media 107 1 24
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -24 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 521
com='unit 521'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 43
 media 107 1 45
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -43 -45 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 522
com='unit 522'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 43
```

```
 media 107 1 45
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -43 -45 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 523
com='unit 523'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3        z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 21
 media 107 1 23
 media 107 1 24
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -23 -24 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 524
com='unit 524'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 sphere 41    2.999   origin  x=3.4641    y=0  z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6 z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 45
 media 107 1 47
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -45 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 525
com='unit 525'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
```

```
 sphere 42    2.999   origin  x=-1.7321   y=3        z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0        z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 42
 media 107 1 43
 media 107 1 46
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -43 -46 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 526
com='unit 526'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 47    2.999   origin  x=9.4641    y=0  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 47
 media 96  1 30 -21 -22 -24 -25 -26 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 527
com='unit 527'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 sphere 46    2.999   origin  x=-6.9283   y=0  z=4.899
 media 107 1 21
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 27
 media 107 1 46
 media 96  1 30 -21 -23 -24 -25 -27 -46
 boundary 30
'-----------------------------------------------------------------------------
unit 528
com='unit 528'
 hexprism 30   8.1962    9.798        0
```

```
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 sphere 41    2.999   origin  x=3.4641    y=0  z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3  z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6  z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 44
 media 107 1 47
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -44 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 529
com='unit 529'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 24    2.999   origin  x=0         y=-6     z=0
 sphere 25    2.999   origin  x=0         y=6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3     z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3     z=0
 sphere 42    2.999   origin  x=-1.7321   y=3      z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3     z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0      z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 42
 media 107 1 43
 media 107 1 46
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -42 -43 -46 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 530
com='unit 530'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
```

```
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 25
 media 107 1 26
 media 96  1 30 -21 -22 -23 -25 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 531
com='unit 531'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 24    2.999   origin  x=0         y=-6     z=0
 sphere 25    2.999   origin  x=0         y=6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3     z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3     z=0
 sphere 41    2.999   origin  x=3.4641    y=0      z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0      z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 44
 media 107 1 47
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -44 -47 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 532
com='unit 532'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 24    2.999   origin  x=0         y=-6     z=0
 sphere 25    2.999   origin  x=0         y=6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3     z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3     z=0
 sphere 41    2.999   origin  x=3.4641    y=0      z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0      z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=4.899
```

```
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 44
 media 107 1 46
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -44 -46 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 533
com='unit 533'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 25
 media 107 1 27
 media 96  1 30 -21 -22 -23 -25 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 534
com='unit 534'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 24    2.999   origin  x=0         y=-6     z=0
 sphere 25    2.999   origin  x=0         y=6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3     z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3     z=0
 sphere 41    2.999   origin  x=3.4641    y=0      z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3      z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3     z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6     z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0      z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=4.899
 sphere 61    2.999   origin  x=0         y=0      z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3      z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3      z=9.798
 sphere 65    2.999   origin  x=0         y=6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3     z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
```

```
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 65
 media 107 1 66
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -49 -
61
                -62 -63 -65 -66
 boundary 30
'----------------------------------------------------------------------------
unit 535
com='unit 535'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
```

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 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 536
com='unit 536'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
```

```
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 65
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -65 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 537
com='unit 537'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
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 media 107 1 48
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 media 107 1 61
 media 107 1 62
 media 107 1 63
```

```
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 538
com='unit 538'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
```

```
 media 107 1 67
 media 96 1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
               -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 539
com='unit 539'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 96 1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
               -61 -62 -64 -65 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 540
```

```
com='unit 540'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
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 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -63 -64 -65 -67
 boundary 30
'----------------------------------------------------------------------------
unit 541
com='unit 541'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
```

```
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
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 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
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 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96 1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
              -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 542
com='unit 542'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
```

```
 sphere 42    2.999   origin  x=-1.7321    y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321    y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641     y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641     y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283    y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641     y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321    y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321    y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0          y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152   y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152  y=3       z=9.798
 sphere 64    2.999   origin  x=0          y=-6      z=9.798
 sphere 65    2.999   origin  x=0          y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152   y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152  y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
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 media 107 1 47
 media 107 1 48
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 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
 unit 543
com='unit 543'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152   y=3       z=0
 sphere 23    2.999   origin  x=-5.196152  y=3       z=0
 sphere 24    2.999   origin  x=0          y=-6      z=0
 sphere 25    2.999   origin  x=0          y=6       z=0
 sphere 26    2.999   origin  x=5.196152   y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152  y=-3      z=0
 sphere 41    2.999   origin  x=3.4641     y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321    y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321    y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641     y=6       z=4.899
```

```
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 61
 media 107 1 62
 media 107 1 64
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
61
                -62 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 544
com='unit 544'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
```

```
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 545
com='unit 545'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
```

```
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 63
 media 107 1 64
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48
                -49 -61 -63 -64 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 546
com='unit 546'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 25
 media 107 1 26
 media 96  1 30 -21 -22 -23 -25 -26
 boundary 30
'----------------------------------------------------------------------------
unit 547
com='unit 547'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 24    2.999   origin  x=0         y=-6     z=0
 sphere 25    2.999   origin  x=0         y=6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3     z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3     z=0
 sphere 44    2.999   origin  x=3.4641    y=6      z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
```

```
 media 107 1 27
 media 107 1 44
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -44 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 548
com='unit 548'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 25
 media 107 1 27
 media 96  1 30 -21 -22 -23 -25 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 549
com='unit 549'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 sphere 44    2.999   origin  x=3.4641    y=6  z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 44
 media 107 1 47
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -44 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 550
com='unit 550'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 24    2.999   origin  x=0         y=-6     z=0
 sphere 25    2.999   origin  x=0         y=6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3     z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3     z=0
 sphere 46    2.999   origin  x=-6.9283   y=0      z=4.899
```

```
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 46
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -46 -49
 boundary 30
'-----------------------------------------------------------------------------
unit 551
com='unit 551'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 96  1 30 -21 -22 -24 -25 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 552
com='unit 552'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 21
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 27
 media 96  1 30 -21 -23 -24 -25 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 553
com='unit 553'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 sphere 45    2.999   origin  x=3.4641    y=-6 z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0  z=4.899
```

```
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 45
 media 107 1 47
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -45 -47
 boundary 30
'-----------------------------------------------------------------------------
unit 554
com='unit 554'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 46
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -46 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 555
com='unit 555'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 21
 media 107 1 22
 media 107 1 24
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -24 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 556
com='unit 556'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
```

```
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 45
 media 107 1 48
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -45 -48
 boundary 30
'-----------------------------------------------------------------------------
unit 557
com='unit 557'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 21
 media 107 1 23
 media 107 1 24
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -23 -24 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 558
com='unit 558'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
```

```
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
 boundary 30
'-----------------------------------------------------------------------------
unit 559
com='unit 559'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
 boundary 30
'-----------------------------------------------------------------------------
unit 560
```

```
com='unit 560'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
 boundary 30
'-----------------------------------------------------------------------------
unit 561
com='unit 561'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
```

```
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
 boundary 30
'---------------------------------------------------------------------------
unit 562
com='unit 562'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
```

```
 boundary 30
'-----------------------------------------------------------------------------
unit 563
com='unit 563'
 hexprism 30   8.1962    4.553        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
 boundary 30
'-----------------------------------------------------------------------------
unit 564
com='unit 564'
 hexprism 30   8.1962    5.245        0
 sphere 44    2.999   origin  x=3.4641  y=6      z=0.346
 sphere 49    2.999   origin  x=-4.7321 y=8.1962 z=0.346
 sphere 65    2.999   origin  x=0       y=6      z=5.245
 media 107 1 44
 media 107 1 49
 media 107 1 65
 media 96  1 30 -44 -49 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 565
com='unit 565'
 hexprism 30   8.1962    5.245        0
 sphere 44    2.999   origin  x=3.4641    y=6 z=0.346
```

```
 sphere 47    2.999   origin  x=9.4641   y=0 z=0.346
 sphere 62    2.999   origin  x=5.196152 y=3 z=5.245
 media 107 1 44
 media 107 1 47
 media 107 1 62
 media 96  1 30 -44 -47 -62
 boundary 30
'-----------------------------------------------------------------------------
unit 566
com='unit 566'
 hexprism 30   8.1962    5.245        0
 sphere 46    2.999   origin  x=-6.9283   y=0      z=0.346
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=0.346
 sphere 63    2.999   origin  x=-5.196152 y=3      z=5.245
 media 107 1 46
 media 107 1 49
 media 107 1 63
 media 96  1 30 -46 -49 -63
 boundary 30
'-----------------------------------------------------------------------------
unit 567
com='unit 567'
 hexprism 30   8.1962    5.245        0
 sphere 45    2.999   origin  x=3.4641   y=-6 z=0.346
 sphere 47    2.999   origin  x=9.4641   y=0  z=0.346
 sphere 66    2.999   origin  x=5.196152 y=-3 z=5.245
 media 107 1 45
 media 107 1 47
 media 107 1 66
 media 96  1 30 -45 -47 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 568
com='unit 568'
 hexprism 30   8.1962    5.245        0
 sphere 46    2.999   origin  x=-6.9283   y=0       z=0.346
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=0.346
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=5.245
 media 107 1 46
 media 107 1 48
 media 107 1 67
 media 96  1 30 -46 -48 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 569
com='unit 569'
 hexprism 30   8.1962    5.245        0
 sphere 45    2.999   origin  x=3.4641  y=-6      z=0.346
 sphere 48    2.999   origin  x=-4.7321 y=-8.1962 z=0.346
 sphere 64    2.999   origin  x=0       y=-6      z=5.245
 media 107 1 45
 media 107 1 48
 media 107 1 64
 media 96  1 30 -45 -48 -64
 boundary 30
'-----------------------------------------------------------------------------
unit 570
```

```
com='unit 570'
 hexprism 30   8.1962    5.245        0
 sphere 41    2.999   origin  x=3.4641    y=0       z=0.346
 sphere 42    2.999   origin  x=-1.7321   y=3       z=0.346
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=0.346
 sphere 44    2.999   origin  x=3.4641    y=6       z=0.346
 sphere 45    2.999   origin  x=3.4641    y=-6      z=0.346
 sphere 46    2.999   origin  x=-6.9283   y=0       z=0.346
 sphere 47    2.999   origin  x=9.4641    y=0       z=0.346
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=0.346
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=0.346
 sphere 61    2.999   origin  x=0         y=0       z=5.245
 sphere 62    2.999   origin  x=5.196152  y=3       z=5.245
 sphere 63    2.999   origin  x=-5.196152 y=3       z=5.245
 sphere 64    2.999   origin  x=0         y=-6      z=5.245
 sphere 65    2.999   origin  x=0         y=6       z=5.245
 sphere 66    2.999   origin  x=5.196152  y=-3      z=5.245
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=5.245
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -41 -42 -43 -44 -45 -46 -47 -48 -49 -61 -62 -63 -64 -65 -66 -
67
 boundary 30
'-----------------------------------------------------------------------------
unit 571
com='unit 571'
 hexprism 30   8.1962    5.245        0
 sphere 41    2.999   origin  x=3.4641    y=0       z=0.346
 sphere 42    2.999   origin  x=-1.7321   y=3       z=0.346
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=0.346
 sphere 44    2.999   origin  x=3.4641    y=6       z=0.346
 sphere 45    2.999   origin  x=3.4641    y=-6      z=0.346
 sphere 46    2.999   origin  x=-6.9283   y=0       z=0.346
 sphere 47    2.999   origin  x=9.4641    y=0       z=0.346
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=0.346
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=0.346
 sphere 61    2.999   origin  x=0         y=0       z=5.245
 sphere 62    2.999   origin  x=5.196152  y=3       z=5.245
 sphere 63    2.999   origin  x=-5.196152 y=3       z=5.245
 sphere 64    2.999   origin  x=0         y=-6      z=5.245
 sphere 65    2.999   origin  x=0         y=6       z=5.245
 sphere 66    2.999   origin  x=5.196152  y=-3      z=5.245
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=5.245
```

```
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -41 -42 -43 -44 -45 -46 -47 -48 -49 -61 -62 -63 -64 -65 -66 -
67
 boundary 30
'-----------------------------------------------------------------------------
unit 572
com='unit 572'
 hexprism 30   8.1962    5.245        0
 sphere 41    2.999   origin  x=3.4641    y=0       z=0.346
 sphere 42    2.999   origin  x=-1.7321   y=3       z=0.346
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=0.346
 sphere 44    2.999   origin  x=3.4641    y=6       z=0.346
 sphere 45    2.999   origin  x=3.4641    y=-6      z=0.346
 sphere 46    2.999   origin  x=-6.9283   y=0       z=0.346
 sphere 47    2.999   origin  x=9.4641    y=0       z=0.346
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=0.346
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=0.346
 sphere 61    2.999   origin  x=0         y=0       z=5.245
 sphere 62    2.999   origin  x=5.196152  y=3       z=5.245
 sphere 63    2.999   origin  x=-5.196152 y=3       z=5.245
 sphere 64    2.999   origin  x=0         y=-6      z=5.245
 sphere 65    2.999   origin  x=0         y=6       z=5.245
 sphere 66    2.999   origin  x=5.196152  y=-3      z=5.245
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=5.245
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -41 -42 -43 -44 -45 -46 -47 -48 -49 -61 -62 -63 -64 -65 -66 -
67
```

```
 boundary 30
'-----------------------------------------------------------------------------
unit 573
com='unit 573'
 hexprism 30   8.1962    5.245        0
 sphere 41    2.999   origin  x=3.4641    y=0       z=0.346
 sphere 42    2.999   origin  x=-1.7321   y=3       z=0.346
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=0.346
 sphere 44    2.999   origin  x=3.4641    y=6       z=0.346
 sphere 45    2.999   origin  x=3.4641    y=-6      z=0.346
 sphere 46    2.999   origin  x=-6.9283   y=0       z=0.346
 sphere 47    2.999   origin  x=9.4641    y=0       z=0.346
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=0.346
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=0.346
 sphere 61    2.999   origin  x=0         y=0       z=5.245
 sphere 62    2.999   origin  x=5.196152  y=3       z=5.245
 sphere 63    2.999   origin  x=-5.196152 y=3       z=5.245
 sphere 64    2.999   origin  x=0         y=-6      z=5.245
 sphere 65    2.999   origin  x=0         y=6       z=5.245
 sphere 66    2.999   origin  x=5.196152  y=-3      z=5.245
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=5.245
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -41 -42 -43 -44 -45 -46 -47 -48 -49 -61 -62 -63 -64 -65 -66 -
67
 boundary 30
'-----------------------------------------------------------------------------
unit 574
com='unit 574'
 hexprism 30   8.1962    5.245        0
 sphere 41    2.999   origin  x=3.4641    y=0       z=0.346
 sphere 42    2.999   origin  x=-1.7321   y=3       z=0.346
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=0.346
 sphere 44    2.999   origin  x=3.4641    y=6       z=0.346
 sphere 45    2.999   origin  x=3.4641    y=-6      z=0.346
 sphere 46    2.999   origin  x=-6.9283   y=0       z=0.346
 sphere 47    2.999   origin  x=9.4641    y=0       z=0.346
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=0.346
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=0.346
 sphere 61    2.999   origin  x=0         y=0       z=5.245
 sphere 62    2.999   origin  x=5.196152  y=3       z=5.245
 sphere 63    2.999   origin  x=-5.196152 y=3       z=5.245
 sphere 64    2.999   origin  x=0         y=-6      z=5.245
```

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 sphere 65    2.999   origin  x=0          y=6       z=5.245
 sphere 66    2.999   origin  x=5.196152  y=-3      z=5.245
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=5.245
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -41 -42 -43 -44 -45 -46 -47 -48 -49 -61 -62 -63 -64 -65 -66 -
67
 boundary 30
'----------------------------------------------------------------------------
unit 575
com='unit 575'
 hexprism 30   8.1962    5.245        0
 sphere 41    2.999   origin  x=3.4641    y=0       z=0.346
 sphere 42    2.999   origin  x=-1.7321   y=3       z=0.346
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=0.346
 sphere 44    2.999   origin  x=3.4641    y=6       z=0.346
 sphere 45    2.999   origin  x=3.4641    y=-6      z=0.346
 sphere 46    2.999   origin  x=-6.9283   y=0       z=0.346
 sphere 47    2.999   origin  x=9.4641    y=0       z=0.346
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=0.346
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=0.346
 sphere 61    2.999   origin  x=0          y=0       z=5.245
 sphere 62    2.999   origin  x=5.196152  y=3       z=5.245
 sphere 63    2.999   origin  x=-5.196152 y=3       z=5.245
 sphere 64    2.999   origin  x=0          y=-6      z=5.245
 sphere 65    2.999   origin  x=0          y=6       z=5.245
 sphere 66    2.999   origin  x=5.196152  y=-3      z=5.245
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=5.245
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
```

```
 media 107 1 67
 media 96  1 30 -41 -42 -43 -44 -45 -46 -47 -48 -49 -61 -62 -63 -64 -65 -66 -
67
 boundary 30
'------------------------------------------------------------------------------
unit 576
com='unit 576'
 hexprism 30   8.1962    9.798        0
 sphere 25    2.999   origin  x=0        y=6       z=0
 sphere 44    2.999   origin  x=3.4641  y=6       z=4.899
 sphere 49    2.999   origin  x=-4.7321 y=8.1962 z=4.899
 sphere 65    2.999   origin  x=0        y=6       z=9.798
 media 107 1 25
 media 107 1 44
 media 107 1 49
 media 107 1 65
 media 96  1 30 -25 -44 -49 -65
 boundary 30
'------------------------------------------------------------------------------
unit 577
com='unit 577'
 hexprism 30   8.1962    9.798        0
 sphere 22    2.999   origin  x=5.196152 y=3        z=0
 sphere 44    2.999   origin  x=3.4641   y=6        z=4.899
 sphere 47    2.999   origin  x=9.4641   y=0        z=4.899
 sphere 62    2.999   origin  x=5.196152 y=3        z=9.798
 media 107 1 22
 media 107 1 44
 media 107 1 47
 media 107 1 62
 media 96  1 30 -22 -44 -47 -62
 boundary 30
'-----------------------------------------------------------------------------
unit 578
com='unit 578'
 hexprism 30   8.1962    9.798        0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 46    2.999   origin  x=-6.9283   y=0      z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 63    2.999   origin  x=-5.196152 y=3      z=9.798
 media 107 1 23
 media 107 1 46
 media 107 1 49
 media 107 1 63
 media 96  1 30 -23 -46 -49 -63
 boundary 30
'-----------------------------------------------------------------------------
unit 579
com='unit 579'
 hexprism 30   8.1962    9.798        0
 sphere 26    2.999   origin  x=5.196152 y=-3      z=0
 sphere 45    2.999   origin  x=3.4641   y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641   y=0        z=4.899
 sphere 66    2.999   origin  x=5.196152 y=-3      z=9.798
 media 107 1 26
 media 107 1 45
 media 107 1 47
```

```
 media 107 1 66
 media 96  1 30 -26 -45 -47 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 580
com='unit 580'
 hexprism 30   8.1962    9.798        0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 27
 media 107 1 46
 media 107 1 48
 media 107 1 49
 media 107 1 67
 media 96  1 30 -27 -46 -48 -49 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 581
com='unit 581'
 hexprism 30   8.1962    9.798        0
 sphere 24    2.999   origin  x=0       y=-6      z=0
 sphere 45    2.999   origin  x=3.4641  y=-6      z=4.899
 sphere 48    2.999   origin  x=-4.7321 y=-8.1962 z=4.899
 sphere 64    2.999   origin  x=0       y=-6      z=9.798
 media 107 1 24
 media 107 1 45
 media 107 1 48
 media 107 1 64
 media 96  1 30 -24 -45 -48 -64
 boundary 30
'-----------------------------------------------------------------------------
unit 582
com='unit 582'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
```

```
 sphere 65    2.999   origin  x=0          y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48
               -49 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 583
com='unit 583'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
```

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 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48
                -49 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 584
com='unit 584'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
```

```
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48
               -49 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 585
com='unit 585'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
```

```
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48
                -49 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 586
com='unit 586'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
```

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 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48
                -49 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 587
com='unit 587'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 107 1 44
 media 107 1 45
 media 107 1 46
 media 107 1 47
 media 107 1 48
 media 107 1 49
 media 107 1 61
```

```
 media 107 1 62
 media 107 1 63
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48
                -49 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 588
com='unit 588'
 hexprism 30   8.1962    9.798        0
 sphere 25    2.999   origin  x=0 y=6 z=0
 media 107 1 25
 media 96  1 30 -25
 boundary 30
'-----------------------------------------------------------------------------
unit 589
com='unit 589'
 hexprism 30   8.1962    9.798        0
 sphere 22    2.999   origin  x=5.196152 y=3 z=0
 media 107 1 22
 media 96  1 30 -22
 boundary 30
'-----------------------------------------------------------------------------
unit 590
com='unit 590'
 hexprism 30   8.1962    9.798        0
 sphere 23    2.999   origin  x=-5.196152 y=3 z=0
 media 107 1 23
 media 96  1 30 -23
 boundary 30
'-----------------------------------------------------------------------------
unit 591
com='unit 591'
 hexprism 30   8.1962    9.798        0
 sphere 26    2.999   origin  x=5.196152 y=-3 z=0
 media 107 1 26
 media 96  1 30 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 592
com='unit 592'
 hexprism 30   8.1962    9.798        0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 27
 media 96  1 30 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 593
com='unit 593'
 hexprism 30   8.1962    9.798        0
 sphere 24    2.999   origin  x=0 y=-6 z=0
 media 107 1 24
 media 96  1 30 -24
 boundary 30
```

```
'-----------------------------------------------------------------------------
unit 594
com='unit 594'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 595
com='unit 595'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 596
com='unit 596'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
```

```
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'------------------------------------------------------------------------------
unit 597
com='unit 597'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'------------------------------------------------------------------------------
unit 598
com='unit 598'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'------------------------------------------------------------------------------
unit 599
com='unit 599'
 hexprism 30   8.1962    9.798        0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 21
 media 107 1 22
 media 107 1 23
```

```
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 601
com='unit 601'
 hexprism 30   8.1962    2.999        0
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 107 1 64
 media 107 1 66
 media 96  1 30 -64 -66
 boundary 30
'-----------------------------------------------------------------------------
-unit 602
com='unit 602'
 hexprism 30   8.1962    9.798        0
 sphere 24    2.999   origin  x=0        y=-6      z=0
 sphere 26    2.999   origin  x=5.196152 y=-3      z=0
 media 107 1 24
 media 107 1 26
 media 96  1 30 -24 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 603
com='unit 603'
 hexprism 30   8.1962    2.999        0
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 64
 media 107 1 67
 media 96  1 30 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 604
com='unit 604'
 hexprism 30   8.1962    9.798        0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 107 1 24
 media 107 1 27
 media 96  1 30 -24 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 605
com='unit 605'
 hexprism 30   8.1962    2.999        0
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 64
 media 107 1 67
 media 96  1 30 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
```

```
unit 606
com='unit 606'
 hexprism 30   8.1962    9.798        0
 sphere 24    2.999   origin  x=0          y=-6       z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3       z=0
 media 107 1 24
 media 107 1 27
 media 96  1 30 -24 -27
 boundary 30
'----------------------------------------------------------------------------
unit 607
com='unit 607'
 hexprism 30   8.1962    2.999        0
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 63
 media 107 1 67
 media 96  1 30 -63 -67
 boundary 30
'----------------------------------------------------------------------------
unit 608
com='unit 608'
 hexprism 30   8.1962    9.798        0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 23
 media 107 1 27
 media 96  1 30 -23 -27
 boundary 30
'----------------------------------------------------------------------------
unit 609
com='unit 609'
 hexprism 30   8.1962    2.999        0
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 107 1 63
 media 107 1 67
 media 96  1 30 -63 -67
 boundary 30
'----------------------------------------------------------------------------
-unit 610
com='unit 610'
 hexprism 30   8.1962    9.798        0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 107 1 23
 media 107 1 27
 media 96  1 30 -23 -27
 boundary 30
'----------------------------------------------------------------------------
unit 611
com='unit 611'
 hexprism 30   8.1962    2.999        0
 sphere 63    2.999   origin  x=-5.196152 y=3 z=2.999
 sphere 65    2.999   origin  x=0          y=6 z=2.999
 media 107 1 63
 media 107 1 65
```

```
 media 96  1 30 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 612
com='unit 612'
 hexprism 30   8.1962    9.798        0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 107 1 23
 media 107 1 25
 media 96  1 30 -23 -25
 boundary 30
'-----------------------------------------------------------------------------
unit 613
com='unit 613'
 hexprism 30   8.1962    2.999        0
 sphere 63    2.999   origin  x=-5.196152 y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 107 1 63
 media 107 1 65
 media 96  1 30 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
-unit 614
com='unit 614'
 hexprism 30   8.1962    9.798        0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 107 1 23
 media 107 1 25
 media 96  1 30 -23 -25
 boundary 30
'-----------------------------------------------------------------------------
unit 615
com='unit 615'
 hexprism 30   8.1962    2.999        0
 sphere 62    2.999   origin  x=5.196152  y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 107 1 62
 media 107 1 65
 media 96  1 30 -62 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 616
com='unit 616'
 hexprism 30   8.1962    9.798        0
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 107 1 22
 media 107 1 25
 media 96  1 30 -22 -25
 boundary 30
'-----------------------------------------------------------------------------
unit 617
com='unit 617'
 hexprism 30   8.1962    2.999        0
 sphere 62    2.999   origin  x=5.196152  y=3 z=2.999
```

```
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 107 1 62
 media 107 1 65
 media 96  1 30 -62 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 618
com='unit 618'
 hexprism 30   8.1962    9.798        0
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 107 1 22
 media 107 1 25
 media 96  1 30 -22 -25
 boundary 30
'-----------------------------------------------------------------------------
unit 619
com='unit 619'
 hexprism 30   8.1962    2.999        0
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 107 1 62
 media 107 1 66
 media 96  1 30 -62 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 620
com='unit 620'
 hexprism 30   8.1962    9.798        0
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 107 1 22
 media 107 1 26
 media 96  1 30 -22 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 621
com='unit 621'
 hexprism 30   8.1962    2.999        0
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 107 1 62
 media 107 1 66
 media 96  1 30 -62 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 622
com='unit 622'
 hexprism 30   8.1962    9.798        0
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 media 107 1 22
 media 107 1 26
 media 96  1 30 -22 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 623
```

```
com='unit 623'
 hexprism 30   8.1962    2.999        0
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 107 1 64
 media 107 1 66
 media 96  1 30 -64 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 624
com='unit 624'
 hexprism 30   8.1962    9.798        0
 sphere 24    2.999   origin  x=0          y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 media 107 1 24
 media 107 1 26
 media 96  1 30 -24 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 210
com='unit 210'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0          y=0  z=2.999
 sphere 52      2.5   origin  x=5.196152  y=3  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 61    2.999   origin  x=0          y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 65    2.999   origin  x=0          y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
' empty hexagonal unit cell used to form array
'-----------------------------------------------------------------------------
unit 215
com='unit 215'
 hexprism 30   8.1962    2.999        0
 media 96 1 30
 boundary 30
'----------------------------------------------------------------------------
unit 220
com='unit 220'
```

```
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0          y=0  z=2.999
 sphere 52      2.5   origin  x=5.196152  y=3  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 61    2.999   origin  x=0          y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 65    2.999   origin  x=0          y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 221
com='unit 221'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0          y=0  z=2.999
 sphere 52      2.5   origin  x=5.196152  y=3  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 61    2.999   origin  x=0          y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 65    2.999   origin  x=0          y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 222
com='unit 222'
 hexprism 30   8.1962    2.999        0
```

```
 sphere 52      2.5   origin  x=5.196152  y=3  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 100 1 52
 media 106 1 62 -52
 media 107 1 66
 media 96  1 30 -62 -66
 boundary 30
'----------------------------------------------------------------------------
unit 223
com='unit 223'
 hexprism 30   8.1962    2.999        0
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 53
 media 106 1 63 -53
 media 107 1 67
 media 96  1 30 -63 -67
 boundary 30
'----------------------------------------------------------------------------
unit 224
com='unit 224'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0         y=0 z=2.999
 sphere 52      2.5   origin  x=5.196152  y=3 z=2.999
 sphere 54      2.5   origin  x=0         y=-6 z=2.999
 sphere 61    2.999   origin  x=0         y=0 z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3 z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 64 -54
 media 107 1 66
 media 96  1 30 -61 -62 -64 -66
 boundary 30
'----------------------------------------------------------------------------
unit 225
com='unit 225'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0         y=0  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 54      2.5   origin  x=0         y=-6 z=2.999
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 63 -53
 media 106 1 64 -54
```

```
 media 107 1 67
 media 96  1 30 -61 -63 -64 -67
 boundary 30
'------------------------------------------------------------------------------
unit 226
com='unit 226'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0         y=0  z=2.999
 sphere 52      2.5   origin  x=5.196152 y=3  z=2.999
 sphere 54      2.5   origin  x=0         y=-6 z=2.999
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 64 -54
 media 107 1 66
 media 96  1 30 -61 -62 -64 -66
 boundary 30
'------------------------------------------------------------------------------
unit 227
com='unit 227'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0          y=0  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 61    2.999   origin  x=0          y=0  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 67
 media 96  1 30 -61 -63 -64 -67
 boundary 30
'------------------------------------------------------------------------------
unit 228
com='unit 228'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0         y=0  z=2.999
 sphere 52      2.5   origin  x=5.196152 y=3  z=2.999
 sphere 54      2.5   origin  x=0         y=-6 z=2.999
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 54
```

```
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 64 -54
 media 107 1 66
 media 96  1 30 -61 -62 -64 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 229
com='unit 229'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0          y=0  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 61    2.999   origin  x=0          y=0  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 67
 media 96  1 30 -61 -63 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 230
com='unit 230'
 hexprism 30   8.1962    2.999        0
 sphere 54      2.5   origin  x=0         y=-6 z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152 y=-3 z=2.999
 media 100 1 54
 media 106 1 64 -54
 media 107 1 66
 media 96  1 30 -64 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 231
com='unit 231'
 hexprism 30   8.1962    2.999        0
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 54
 media 106 1 64 -54
 media 107 1 67
 media 96  1 30 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 232
com='unit 232'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0          y=0  z=2.999
 sphere 52      2.5   origin  x=5.196152  y=3  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
```

```
 sphere 54       2.5   origin  x=0          y=-6 z=2.999
 sphere 61     2.999   origin  x=0          y=0  z=2.999
 sphere 62     2.999   origin  x=5.196152   y=3  z=2.999
 sphere 63     2.999   origin  x=-5.196152  y=3  z=2.999
 sphere 64     2.999   origin  x=0          y=-6 z=2.999
 sphere 65     2.999   origin  x=0          y=6  z=2.999
 sphere 66     2.999   origin  x=5.196152   y=-3 z=2.999
 sphere 67     2.999   origin  x=-5.196152  y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 233
com='unit 233'
 hexprism 30   8.1962    2.999        0
 sphere 51       2.5   origin  x=0          y=0  z=2.999
 sphere 53       2.5   origin  x=-5.196152  y=3  z=2.999
 sphere 54       2.5   origin  x=0          y=-6 z=2.999
 sphere 61     2.999   origin  x=0          y=0  z=2.999
 sphere 62     2.999   origin  x=5.196152   y=3  z=2.999
 sphere 63     2.999   origin  x=-5.196152  y=3  z=2.999
 sphere 64     2.999   origin  x=0          y=-6 z=2.999
 sphere 65     2.999   origin  x=0          y=6  z=2.999
 sphere 66     2.999   origin  x=5.196152   y=-3 z=2.999
 sphere 67     2.999   origin  x=-5.196152  y=-3 z=2.999
 media 100 1 51
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 107 1 62
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 234
com='unit 234'
 hexprism 30   8.1962    2.999        0
 sphere 54       2.5   origin  x=0         y=-6 z=2.999
 sphere 64     2.999   origin  x=0         y=-6 z=2.999
 sphere 66     2.999   origin  x=5.196152  y=-3 z=2.999
 media 100 1 54
 media 106 1 64 -54
 media 107 1 66
```

```
 media 96  1 30 -64 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 235
com='unit 235'
 hexprism 30   8.1962    2.999        0
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 54
 media 106 1 64 -54
 media 107 1 67
 media 96  1 30 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 236
com='unit 236'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0          y=0  z=2.999
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 61    2.999   origin  x=0          y=0  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 54
 media 106 1 61 -51
 media 106 1 64 -54
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 237
com='unit 237'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0          y=0  z=2.999
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 61    2.999   origin  x=0          y=0  z=2.999
 sphere 64    2.999   origin  x=0          y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 54
 media 106 1 61 -51
 media 106 1 64 -54
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 238
com='unit 238'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0          y=0  z=2.999
 sphere 54      2.5   origin  x=0          y=-6 z=2.999
 sphere 61    2.999   origin  x=0          y=0  z=2.999
```

```
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 54
 media 106 1 61 -51
 media 106 1 64 -54
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 239
com='unit 239'
 hexprism 30   8.1962    2.999        0
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 53
 media 106 1 63 -53
 media 107 1 67
 media 96  1 30 -63 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 240
com='unit 240'
 hexprism 30   8.1962    2.999        0
 sphere 52      2.5   origin  x=5.196152  y=3  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 media 100 1 52
 media 106 1 62 -52
 media 107 1 66
 media 96  1 30 -62 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 241
com='unit 241'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0         y=0  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 53
 media 106 1 61 -51
 media 106 1 63 -53
 media 107 1 65
 media 107 1 67
 media 96  1 30 -61 -63 -65 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 242
com='unit 242'
 hexprism 30   8.1962    2.999        0
```

```
 sphere 51      2.5   origin  x=0        y=0  z=2.999
 sphere 52      2.5   origin  x=5.196152 y=3  z=2.999
 sphere 61    2.999   origin  x=0        y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152 y=3  z=2.999
 sphere 65    2.999   origin  x=0        y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 106 1 61 -51
 media 106 1 62 -52
 media 107 1 65
 media 107 1 66
 media 96  1 30 -61 -62 -65 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 243
com='unit 243'
 hexprism 30   8.1962    2.999       0
 sphere 51      2.5   origin  x=0         y=0  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 53
 media 106 1 61 -51
 media 106 1 63 -53
 media 107 1 65
 media 107 1 67
 media 96  1 30 -61 -63 -65 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 244
com='unit 244'
 hexprism 30   8.1962    2.999       0
 sphere 51      2.5   origin  x=0        y=0  z=2.999
 sphere 52      2.5   origin  x=5.196152 y=3  z=2.999
 sphere 61    2.999   origin  x=0        y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152 y=3  z=2.999
 sphere 65    2.999   origin  x=0        y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 106 1 61 -51
 media 106 1 62 -52
 media 107 1 65
 media 107 1 66
 media 96  1 30 -61 -62 -65 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 245
com='unit 245'
 hexprism 30   8.1962    2.999       0
 sphere 51      2.5   origin  x=0         y=0  z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 61    2.999   origin  x=0         y=0  z=2.999
```

```
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 53
 media 106 1 61 -51
 media 106 1 63 -53
 media 107 1 65
 media 107 1 67
 media 96  1 30 -61 -63 -65 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 246
com='unit 246'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0        y=0  z=2.999
 sphere 52      2.5   origin  x=5.196152 y=3  z=2.999
 sphere 61    2.999   origin  x=0        y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152 y=3  z=2.999
 sphere 65    2.999   origin  x=0        y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 106 1 61 -51
 media 106 1 62 -52
 media 107 1 65
 media 107 1 66
 media 96  1 30 -61 -62 -65 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 247
com='unit 247'
 hexprism 30   8.1962    2.999        0
 sphere 53      2.5   origin  x=-5.196152 y=3 z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 100 1 53
 media 106 1 63 -53
 media 107 1 65
 media 96  1 30 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 248
com='unit 248'
 hexprism 30   8.1962    2.999        0
 sphere 52      2.5   origin  x=5.196152  y=3 z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 100 1 52
 media 106 1 62 -52
 media 107 1 65
 media 96  1 30 -62 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 249
com='unit 249'
 hexprism 30   8.1962    2.999        0
```

```
 sphere 51       2.5   origin  x=0         y=0  z=2.999
 sphere 52       2.5   origin  x=5.196152  y=3  z=2.999
 sphere 53       2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 250
com='unit 250'
 hexprism 30   8.1962    2.999        0
 sphere 51       2.5   origin  x=0         y=0  z=2.999
 sphere 52       2.5   origin  x=5.196152  y=3  z=2.999
 sphere 53       2.5   origin  x=-5.196152 y=3  z=2.999
 sphere 61    2.999   origin  x=0         y=0  z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3  z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3  z=2.999
 sphere 64    2.999   origin  x=0         y=-6 z=2.999
 sphere 65    2.999   origin  x=0         y=6  z=2.999
 sphere 66    2.999   origin  x=5.196152  y=-3 z=2.999
 sphere 67    2.999   origin  x=-5.196152 y=-3 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -61 -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 251
com='unit 251'
 hexprism 30   8.1962    2.999        0
 sphere 53       2.5   origin  x=-5.196152 y=3 z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 100 1 53
 media 106 1 63 -53
```

```
 media 107 1 65
 media 96  1 30 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 252
com='unit 252'
 hexprism 30   8.1962    2.999        0
 sphere 52      2.5   origin  x=5.196152  y=3 z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 100 1 52
 media 106 1 62 -52
 media 107 1 65
 media 96  1 30 -62 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 253
com='unit 253'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0         y=0 z=2.999
 sphere 52      2.5   origin  x=5.196152  y=3 z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3 z=2.999
 sphere 61    2.999   origin  x=0         y=0 z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3 z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 65
 media 96  1 30 -61 -62 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 254
com='unit 254'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0         y=0 z=2.999
 sphere 52      2.5   origin  x=5.196152  y=3 z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3 z=2.999
 sphere 61    2.999   origin  x=0         y=0 z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3 z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 65
 media 96  1 30 -61 -62 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 255
```

```
com='unit 255'
 hexprism 30   8.1962    2.999        0
 sphere 51      2.5   origin  x=0         y=0 z=2.999
 sphere 52      2.5   origin  x=5.196152  y=3 z=2.999
 sphere 53      2.5   origin  x=-5.196152 y=3 z=2.999
 sphere 61    2.999   origin  x=0         y=0 z=2.999
 sphere 62    2.999   origin  x=5.196152  y=3 z=2.999
 sphere 63    2.999   origin  x=-5.196152 y=3 z=2.999
 sphere 65    2.999   origin  x=0         y=6 z=2.999
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 65
 media 96  1 30 -61 -62 -63 -65
 boundary 30
'---------------------------------------------------------------------------
unit 110
com='unit 110'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 14      2.5   origin  x=0         y=-6 z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'----------------------------------------------------------------------------
' empty hexagonal unit cell used to form array
'----------------------------------------------------------------------------
unit 115
com='unit 115'
 hexprism 30   8.1962    2.999        0
 media 96 1 30
 boundary 30
'----------------------------------------------------------------------------
unit 120
com='unit 120'
```

```
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 14      2.5   origin  x=0         y=-6 z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 121
com='unit 121'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 14      2.5   origin  x=0         y=-6 z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 122
com='unit 122'
 hexprism 30   8.1962    2.999        0
```

```
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 100 1 12
 media 106 1 22 -12
 media 107 1 26
 media 96  1 30 -22 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 123
com='unit 123'
 hexprism 30   8.1962    2.999        0
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 13
 media 106 1 23 -13
 media 107 1 27
 media 96  1 30 -23 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 124
com='unit 124'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152 y=3  z=0
 sphere 14      2.5   origin  x=0        y=-6 z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0        y=-6 z=0
 sphere 26    2.999   origin  x=5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 24 -14
 media 107 1 26
 media 96  1 30 -21 -22 -24 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 125
com='unit 125'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 14      2.5   origin  x=0         y=-6 z=0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 23 -13
 media 106 1 24 -14
```

```
 media 107 1 27
 media 96  1 30 -21 -23 -24 -27
 boundary 30
'------------------------------------------------------------------------------
unit 126
com='unit 126'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 14      2.5   origin  x=0         y=-6 z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 24 -14
 media 107 1 26
 media 96  1 30 -21 -22 -24 -26
 boundary 30
'------------------------------------------------------------------------------
unit 127
com='unit 127'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 14      2.5   origin  x=0         y=-6 z=0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 27
 media 96  1 30 -21 -23 -24 -27
 boundary 30
'------------------------------------------------------------------------------
unit 128
com='unit 128'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 14      2.5   origin  x=0         y=-6 z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 100 1 14
```

```
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 24 -14
 media 107 1 26
 media 96  1 30 -21 -22 -24 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 129
com='unit 129'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 14      2.5   origin  x=0         y=-6 z=0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 27
 media 96  1 30 -21 -23 -24 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 130
com='unit 130'
 hexprism 30   8.1962    2.999        0
 sphere 14      2.5   origin  x=0        y=-6      z=0
 sphere 24    2.999   origin  x=0        y=-6      z=0
 sphere 26    2.999   origin  x=5.196152 y=-3      z=0
 media 100 1 14
 media 106 1 24 -14
 media 107 1 26
 media 96  1 30 -24 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 131
com='unit 131'
 hexprism 30   8.1962    2.999        0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 100 1 14
 media 106 1 24 -14
 media 107 1 27
 media 96  1 30 -24 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 132
com='unit 132'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
```

```
 sphere 14      2.5   origin  x=0          y=-6 z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0          y=-6 z=0
 sphere 25    2.999   origin  x=0          y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'----------------------------------------------------------------------------
unit 133
com='unit 133'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 14      2.5   origin  x=0          y=-6 z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0          y=-6 z=0
 sphere 25    2.999   origin  x=0          y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 107 1 22
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'----------------------------------------------------------------------------
unit 134
com='unit 134'
 hexprism 30   8.1962    2.999        0
 sphere 14      2.5   origin  x=0        y=-6      z=0
 sphere 24    2.999   origin  x=0        y=-6      z=0
 sphere 26    2.999   origin  x=5.196152 y=-3      z=0
 media 100 1 14
 media 106 1 24 -14
 media 107 1 26
```

```
 media 96  1 30 -24 -26
 boundary 30
'---------------------------------------------------------------------------
unit 135
com='unit 135'
 hexprism 30   8.1962    2.999        0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 100 1 14
 media 106 1 24 -14
 media 107 1 27
 media 96  1 30 -24 -27
 boundary 30
'---------------------------------------------------------------------------
unit 136
com='unit 136'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 100 1 11
 media 100 1 14
 media 106 1 21 -11
 media 106 1 24 -14
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -24 -26 -27
 boundary 30
'---------------------------------------------------------------------------
-unit 137
com='unit 137'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 100 1 11
 media 100 1 14
 media 106 1 21 -11
 media 106 1 24 -14
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -24 -26 -27
 boundary 30
'---------------------------------------------------------------------------
unit 138
com='unit 138'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
```

```
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 media 100 1 11
 media 100 1 14
 media 106 1 21 -11
 media 106 1 24 -14
 media 107 1 26
 media 107 1 27
 media 96  1 30 -21 -24 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 139
com='unit 139'
 hexprism 30   8.1962    2.999        0
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 13
 media 106 1 23 -13
 media 107 1 27
 media 96  1 30 -23 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 140
com='unit 140'
 hexprism 30   8.1962    2.999        0
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 100 1 12
 media 106 1 22 -12
 media 107 1 26
 media 96  1 30 -22 -26
 boundary 30
'-----------------------------------------------------------------------------
unit 141
com='unit 141'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 13
 media 106 1 21 -11
 media 106 1 23 -13
 media 107 1 25
 media 107 1 27
 media 96  1 30 -21 -23 -25 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 142
com='unit 142'
 hexprism 30   8.1962    2.999        0
```

```
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 106 1 21 -11
 media 106 1 22 -12
 media 107 1 25
 media 107 1 26
 media 96  1 30 -21 -22 -25 -26
 boundary 30
'----------------------------------------------------------------------------
unit 143
com='unit 143'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 13
 media 106 1 21 -11
 media 106 1 23 -13
 media 107 1 25
 media 107 1 27
 media 96  1 30 -21 -23 -25 -27
 boundary 30
'----------------------------------------------------------------------------
unit 144
com='unit 144'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 106 1 21 -11
 media 106 1 22 -12
 media 107 1 25
 media 107 1 26
 media 96  1 30 -21 -22 -25 -26
 boundary 30
'----------------------------------------------------------------------------
unit 145
com='unit 145'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 21    2.999
```

```
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 13
 media 106 1 21 -11
 media 106 1 23 -13
 media 107 1 25
 media 107 1 27
 media 96  1 30 -21 -23 -25 -27
 boundary 30
'---------------------------------------------------------------------------
unit 146
com='unit 146'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 106 1 21 -11
 media 106 1 22 -12
 media 107 1 25
 media 107 1 26
 media 96  1 30 -21 -22 -25 -26
 boundary 30
'---------------------------------------------------------------------------
unit 147
com='unit 147'
 hexprism 30   8.1962    2.999        0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 100 1 13
 media 106 1 23 -13
 media 107 1 25
 media 96  1 30 -23 -25
 boundary 30
'---------------------------------------------------------------------------
unit 148
com='unit 148'
 hexprism 30   8.1962    2.999        0
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 100 1 12
 media 106 1 22 -12
 media 107 1 25
 media 96  1 30 -22 -25
 boundary 30
'---------------------------------------------------------------------------
unit 149
com='unit 149'
 hexprism 30   8.1962    2.999        0
```

```
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96 1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 150
com='unit 150'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 13      2.5   origin  x=-5.196152 y=3  z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 23    2.999   origin  x=-5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0         y=-6 z=0
 sphere 25    2.999   origin  x=0         y=6  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3 z=0
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 96 1 30 -21 -22 -23 -24 -25 -26 -27
 boundary 30
'-----------------------------------------------------------------------------
unit 151
com='unit 151'
 hexprism 30   8.1962    2.999        0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 100 1 13
 media 106 1 23 -13
```

```
 media 107 1 25
 media 96  1 30 -23 -25
 boundary 30
'------------------------------------------------------------------------------
unit 152
com='unit 152'
 hexprism 30   8.1962    2.999        0
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 100 1 12
 media 106 1 22 -12
 media 107 1 25
 media 96  1 30 -22 -25
 boundary 30
'------------------------------------------------------------------------------
unit 153
com='unit 153'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 107 1 25
 media 96 1 30 -21 -22 -23 -25
 boundary 30
'------------------------------------------------------------------------------
unit 154
com='unit 154'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 107 1 25
 media 96  1 30 -21 -22 -23 -25
 boundary 30
'------------------------------------------------------------------------------
unit 155
```

```
com='unit 155'
 hexprism 30   8.1962    2.999        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 107 1 25
 media 96  1 30 -21 -22 -23 -25
 boundary 30
'-----------------------------------------------------------------------------
' full hexagonal fuel unit cell containing all the pebbles
'-----------------------------------------------------------------------------
unit 10
com='unit 10'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 52      2.5   origin  x=5.196152  y=3       z=9.798
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
```

```
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 100 1 34
 media 100 1 35
 media 100 1 36
 media 100 1 37
 media 100 1 38
 media 100 1 39
 media 106 1 44 -34
 media 106 1 45 -35
 media 106 1 46 -36
 media 106 1 47 -37
 media 106 1 48 -38
 media 106 1 49 -39
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96 1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
49
               -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
' empty hexagonal unit cell used to form array
'----------------------------------------------------------------------------
unit 15
com='unit 15'
 hexprism 30   8.1962    9.798        0
 media 96 1 30
 boundary 30
'----------------------------------------------------------------------------
' units 20 to 55 are hexagonal unit cells to form edge of layer
'----------------------------------------------------------------------------
unit 20
```

```
com='unit 20'
 hexprism 30   8.1962    9.798        0
 sphere 11       2.5
 sphere 12       2.5   origin  x=5.196152  y=3        z=0
 sphere 13       2.5   origin  x=-5.196152 y=3        z=0
 sphere 14       2.5   origin  x=0         y=-6       z=0
 sphere 21     2.999
 sphere 22     2.999   origin  x=5.196152  y=3        z=0
 sphere 23     2.999   origin  x=-5.196152 y=3        z=0
 sphere 24     2.999   origin  x=0         y=-6       z=0
 sphere 25     2.999   origin  x=0         y=6        z=0
 sphere 26     2.999   origin  x=5.196152  y=-3       z=0
 sphere 27     2.999   origin  x=-5.196152 y=-3       z=0
 sphere 34       2.5   origin  x=3.4641    y=6        z=4.899
 sphere 35       2.5   origin  x=3.4641    y=-6       z=4.899
 sphere 37       2.5   origin  x=9.4641    y=0        z=4.899
 sphere 38       2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 39       2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 41     2.999   origin  x=3.4641    y=0        z=4.899
 sphere 42     2.999   origin  x=-1.7321   y=3        z=4.899
 sphere 43     2.999   origin  x=-1.7321   y=-3       z=4.899
 sphere 44     2.999   origin  x=3.4641    y=6        z=4.899
 sphere 45     2.999   origin  x=3.4641    y=-6       z=4.899
 sphere 47     2.999   origin  x=9.4641    y=0        z=4.899
 sphere 48     2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49     2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51       2.5   origin  x=0         y=0        z=9.798
 sphere 52       2.5   origin  x=5.196152  y=3        z=9.798
 sphere 53       2.5   origin  x=-5.196152 y=3        z=9.798
 sphere 54       2.5   origin  x=0         y=-6       z=9.798
 sphere 61     2.999   origin  x=0         y=0        z=9.798
 sphere 62     2.999   origin  x=5.196152  y=3        z=9.798
 sphere 63     2.999   origin  x=-5.196152 y=3        z=9.798
 sphere 64     2.999   origin  x=0         y=-6       z=9.798
 sphere 65     2.999   origin  x=0         y=6        z=9.798
 sphere 66     2.999   origin  x=5.196152  y=-3       z=9.798
 sphere 67     2.999   origin  x=-5.196152 y=-3       z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 100 1 34
 media 100 1 35
 media 100 1 37
 media 100 1 38
 media 100 1 39
 media 106 1 44 -34
```

```
 media 106 1 45 -35
 media 106 1 47 -37
 media 106 1 48 -38
 media 106 1 49 -39
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96 1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -47 -48 -49 -
61
              -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 21
com='unit 21'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 31      2.5   origin  x=3.4641    y=0       z=4.899
 sphere 32      2.5   origin  x=-1.7321   y=3       z=4.899
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 52      2.5   origin  x=5.196152  y=3       z=9.798
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
```

```
 sphere 64    2.999   origin  x=0         y=-6       z=9.798
 sphere 65    2.999   origin  x=0         y=6        z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3       z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 100 1 31
 media 100 1 32
 media 100 1 33
 media 100 1 34
 media 100 1 35
 media 100 1 36
 media 100 1 38
 media 100 1 39
 media 106 1 41 -31
 media 106 1 42 -32
 media 106 1 43 -33
 media 106 1 44 -34
 media 106 1 45 -35
 media 106 1 46 -36
 media 106 1 48 -38
 media 106 1 49 -39
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -48 -49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 22
com='unit 22'
 hexprism 30   8.1962    9.798        0
 sphere 12      2.5   origin  x=5.196152  y=3  z=0
 sphere 22    2.999   origin  x=5.196152  y=3  z=0
 sphere 26    2.999   origin  x=5.196152  y=-3 z=0
 sphere 35      2.5   origin  x=3.4641    y=-6 z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0  z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6 z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0  z=4.899
 sphere 52      2.5   origin  x=5.196152  y=3  z=9.798
```

```
 sphere 62    2.999   origin  x=5.196152  y=3  z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3 z=9.798
 media 100 1 12
 media 106 1 22 -12
 media 107 1 26
 media 100 1 35
 media 100 1 37
 media 106 1 45 -35
 media 106 1 47 -37
 media 100 1 52
 media 106 1 62 -52
 media 107 1 66
 media 96 1 30 -22 -26 -45 -47 -62 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 23
com='unit 23'
 hexprism 30   8.1962    9.798        0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 13
 media 106 1 23 -13
 media 107 1 27
 media 100 1 36
 media 100 1 38
 media 106 1 46 -36
 media 106 1 48 -38
 media 100 1 53
 media 106 1 63 -53
 media 107 1 67
 media 96 1 30 -23 -27 -46 -48 -63 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 24
com='unit 24'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152 y=3  z=0
 sphere 14      2.5   origin  x=0        y=-6 z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152 y=3  z=0
 sphere 24    2.999   origin  x=0        y=-6 z=0
 sphere 26    2.999   origin  x=5.196152 y=-3 z=0
 sphere 31      2.5   origin  x=3.4641   y=0  z=4.899
 sphere 34      2.5   origin  x=3.4641   y=6  z=4.899
 sphere 35      2.5   origin  x=3.4641   y=-6 z=4.899
 sphere 37      2.5   origin  x=9.4641   y=0  z=4.899
 sphere 41    2.999   origin  x=3.4641   y=0  z=4.899
 sphere 44    2.999   origin  x=3.4641   y=6  z=4.899
```

```
 sphere 45    2.999   origin  x=3.4641   y=-6 z=4.899
 sphere 47    2.999   origin  x=9.4641   y=0  z=4.899
 sphere 51      2.5   origin  x=0        y=0  z=9.798
 sphere 52      2.5   origin  x=5.196152 y=3  z=9.798
 sphere 54      2.5   origin  x=0        y=-6 z=9.798
 sphere 61    2.999   origin  x=0        y=0  z=9.798
 sphere 62    2.999   origin  x=5.196152 y=3  z=9.798
 sphere 64    2.999   origin  x=0        y=-6 z=9.798
 sphere 66    2.999   origin  x=5.196152 y=-3 z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 24 -14
 media 107 1 26
 media 100 1 31
 media 100 1 34
 media 100 1 35
 media 100 1 37
 media 106 1 41 -31
 media 106 1 44 -34
 media 106 1 45 -35
 media 106 1 47 -37
 media 100 1 51
 media 100 1 52
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 64 -54
 media 107 1 66
 media 96 1 30 -21 -22 -24 -26 -41 -44 -45 -47 -61 -62 -64 -66
 boundary 30
'----------------------------------------------------------------------------
unit 25
com='unit 25'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 32      2.5   origin  x=-1.7321   y=3       z=4.899
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
```

```
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 27
 media 100 1 32
 media 100 1 33
 media 100 1 36
 media 100 1 38
 media 100 1 39
 media 106 1 42 -32
 media 106 1 43 -33
 media 106 1 46 -36
 media 106 1 48 -38
 media 106 1 49 -39
 media 100 1 51
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 67
 media 96  1 30 -21 -23 -24 -27 -42 -43 -46 -48 -49 -61 -63 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 26
com='unit 26'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 31      2.5   origin  x=3.4641    y=0       z=4.899
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 52      2.5   origin  x=5.196152  y=3       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
```

```
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 24 -14
 media 107 1 26
 media 100 1 31
 media 100 1 33
 media 100 1 34
 media 100 1 35
 media 100 1 37
 media 100 1 38
 media 106 1 41 -31
 media 106 1 43 -33
 media 106 1 44 -34
 media 106 1 45 -35
 media 106 1 47 -37
 media 106 1 48 -38
 media 100 1 51
 media 100 1 52
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 64 -54
 media 107 1 66
 media 96 1 30 -21 -22 -24 -26 -41 -43 -44 -45 -47 -48 -61 -62 -64 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 27
com='unit 27'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 32      2.5   origin  x=-1.7321   y=3       z=4.899
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
```

```
 sphere 61    2.999   origin  x=0          y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0          y=-6      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 27
 media 100 1 32
 media 100 1 33
 media 100 1 35
 media 100 1 36
 media 100 1 38
 media 100 1 39
 media 106 1 42 -32
 media 106 1 43 -33
 media 106 1 45 -35
 media 106 1 46 -36
 media 106 1 48 -38
 media 106 1 49 -39
 media 100 1 51
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 67
 media 96 1 30 -21 -23 -24 -27 -42 -43 -45 -46 -48 -49 -61 -63 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 28
com='unit 28'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 31      2.5   origin  x=3.4641    y=0       z=4.899
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 52      2.5   origin  x=5.196152  y=3       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
```

```
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 24 -14
 media 107 1 26
 media 100 1 31
 media 100 1 33
 media 100 1 35
 media 100 1 37
 media 100 1 38
 media 106 1 41 -31
 media 106 1 43 -33
 media 106 1 45 -35
 media 106 1 47 -37
 media 106 1 48 -38
 media 100 1 51
 media 100 1 52
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 64 -54
 media 107 1 66
 media 96 1 30 -21 -22 -24 -26 -41 -43 -45 -47 -48 -61 -62 -64 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 29
com='unit 29'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 13
```

```
 media 100 1 14
 media 106 1 21 -11
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 27
 media 100 1 33
 media 100 1 35
 media 100 1 36
 media 100 1 38
 media 106 1 43 -33
 media 106 1 45 -35
 media 106 1 46 -36
 media 106 1 48 -38
 media 100 1 51
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 67
 media 96 1 30 -21 -23 -24 -27 -43 -45 -46 -48 -61 -63 -64 -67
 boundary 30
'----------------------------------------------------------------------------
unit 30
com='unit 30'
 hexprism 30   8.1962    9.798        0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 100 1 14
 media 106 1 24 -14
 media 107 1 26
 media 100 1 34
 media 100 1 35
 media 100 1 37
 media 106 1 44 -34
 media 106 1 45 -35
 media 106 1 47 -37
 media 100 1 54
 media 106 1 64 -54
 media 107 1 66
 media 96 1 30 -24 -26 -44 -45 -47 -64 -66
 boundary 30
'----------------------------------------------------------------------------
unit 31
com='unit 31'
 hexprism 30   8.1962    9.798        0
 sphere 14      2.5   origin  x=0         y=-6      z=0
```

```
 sphere 24    2.999   origin  x=0          y=-6      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 54      2.5   origin  x=0          y=-6      z=9.798
 sphere 64    2.999   origin  x=0          y=-6      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 14
 media 106 1 24 -14
 media 107 1 27
 media 100 1 38
 media 106 1 48 -38
 media 100 1 54
 media 106 1 64 -54
 media 107 1 67
 media 96 1 30 -24 -27 -48 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 32
com='unit 32'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 14      2.5   origin  x=0          y=-6      z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0          y=-6      z=0
 sphere 25    2.999   origin  x=0          y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 31      2.5   origin  x=3.4641    y=0       z=4.899
 sphere 32      2.5   origin  x=-1.7321   y=3       z=4.899
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 51      2.5   origin  x=0          y=0       z=9.798
 sphere 52      2.5   origin  x=5.196152  y=3       z=9.798
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 54      2.5   origin  x=0          y=-6      z=9.798
 sphere 61    2.999   origin  x=0          y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0          y=-6      z=9.798
 sphere 65    2.999   origin  x=0          y=6       z=9.798
```

```
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 100 1 31
 media 100 1 32
 media 100 1 33
 media 100 1 34
 media 100 1 35
 media 100 1 36
 media 100 1 37
 media 100 1 38
 media 106 1 41 -31
 media 106 1 42 -32
 media 106 1 43 -33
 media 106 1 44 -34
 media 106 1 45 -35
 media 106 1 46 -36
 media 106 1 47 -37
 media 106 1 48 -38
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -48 -
61
                -62 -63 -64 -65 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 33
com='unit 33'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
```

```
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 13
 media 100 1 14
 media 106 1 21 -11
 media 107 1 22
 media 106 1 23 -13
 media 106 1 24 -14
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 100 1 35
 media 100 1 36
 media 100 1 38
 media 100 1 39
 media 106 1 45 -35
 media 106 1 46 -36
 media 106 1 48 -38
 media 106 1 49 -39
 media 100 1 51
 media 100 1 53
 media 100 1 54
 media 106 1 61 -51
 media 107 1 62
 media 106 1 63 -53
 media 106 1 64 -54
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -45 -46 -48 -49 -61 -
62
                -63 -64 -65 -66 -67
 boundary 30
```

```
'-----------------------------------------------------------------------------
unit 34
com='unit 34'
 hexprism 30   8.1962    9.798        0
 sphere 14      2.5   origin  x=0          y=-6      z=0
 sphere 24    2.999   origin  x=0          y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 54      2.5   origin  x=0          y=-6      z=9.798
 sphere 64    2.999   origin  x=0          y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 100 1 14
 media 106 1 24 -14
 media 107 1 26
 media 100 1 35
 media 100 1 38
 media 106 1 45 -35
 media 106 1 48 -38
 media 100 1 54
 media 106 1 64 -54
 media 107 1 66
 media 96  1 30 -24 -26 -45 -48 -64 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 35
com='unit 35'
 hexprism 30   8.1962    9.798        0
 sphere 14      2.5   origin  x=0          y=-6      z=0
 sphere 24    2.999   origin  x=0          y=-6      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 54      2.5   origin  x=0          y=-6      z=9.798
 sphere 64    2.999   origin  x=0          y=-6      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 14
 media 106 1 24 -14
 media 107 1 27
 media 100 1 35
 media 100 1 38
 media 106 1 45 -35
 media 106 1 48 -38
 media 100 1 54
 media 106 1 64 -54
 media 107 1 67
 media 96  1 30 -24 -27 -45 -48 -64 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 36
com='unit 36'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
```

```
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 31      2.5   origin  x=3.4641    y=0       z=4.899
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 14
 media 106 1 21 -11
 media 106 1 24 -14
 media 107 1 26
 media 107 1 27
 media 100 1 31
 media 100 1 33
 media 100 1 35
 media 100 1 37
 media 100 1 38
 media 106 1 41 -31
 media 106 1 43 -33
 media 106 1 45 -35
 media 106 1 47 -37
 media 106 1 48 -38
 media 100 1 51
 media 100 1 54
 media 106 1 61 -51
 media 106 1 64 -54
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -24 -26 -27 -41 -43 -45 -47 -48 -61 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 37
com='unit 37'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
```

```
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 14
 media 106 1 21 -11
 media 106 1 24 -14
 media 107 1 26
 media 107 1 27
 media 100 1 33
 media 100 1 35
 media 100 1 36
 media 100 1 38
 media 106 1 43 -33
 media 106 1 45 -35
 media 106 1 46 -36
 media 106 1 48 -38
 media 100 1 51
 media 100 1 54
 media 106 1 61 -51
 media 106 1 64 -54
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -24 -26 -27 -43 -45 -46 -48 -61 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 38
com='unit 38'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 14      2.5   origin  x=0         y=-6      z=0
 sphere 21    2.999
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 31      2.5   origin  x=3.4641    y=0       z=4.899
 sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
```

```
 sphere 54      2.5   origin  x=0         y=-6      z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 64    2.999   origin  x=0         y=-6      z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 14
 media 106 1 21 -11
 media 106 1 24 -14
 media 107 1 26
 media 107 1 27
 media 100 1 31
 media 100 1 33
 media 100 1 35
 media 100 1 36
 media 100 1 37
 media 100 1 38
 media 106 1 41 -31
 media 106 1 43 -33
 media 106 1 45 -35
 media 106 1 46 -36
 media 106 1 47 -37
 media 106 1 48 -38
 media 100 1 51
 media 100 1 54
 media 106 1 61 -51
 media 106 1 64 -54
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -24 -26 -27 -41 -43 -45 -46 -47 -48 -61 -64 -66 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 39
com='unit 39'
 hexprism 30   8.1962    9.798        0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 13
 media 106 1 23 -13
 media 107 1 27
 media 100 1 36
 media 100 1 39
 media 106 1 46 -36
 media 106 1 49 -39
 media 100 1 53
 media 106 1 63 -53
 media 107 1 67
 media 96  1 30 -23 -27 -46 -49 -63 -67
 boundary 30
```

```
'-----------------------------------------------------------------------------
unit 40
com='unit 40'
 hexprism 30   8.1962    9.798        0
 sphere 12       2.5   origin  x=5.196152  y=3       z=0
 sphere 22     2.999   origin  x=5.196152  y=3       z=0
 sphere 26     2.999   origin  x=5.196152  y=-3      z=0
 sphere 34       2.5   origin  x=3.4641    y=6       z=4.899
 sphere 37       2.5   origin  x=9.4641    y=0       z=4.899
 sphere 44     2.999   origin  x=3.4641    y=6       z=4.899
 sphere 47     2.999   origin  x=9.4641    y=0       z=4.899
 sphere 52       2.5   origin  x=5.196152  y=3       z=9.798
 sphere 62     2.999   origin  x=5.196152  y=3       z=9.798
 sphere 66     2.999   origin  x=5.196152  y=-3      z=9.798
 media 100 1 12
 media 106 1 22 -12
 media 107 1 26
 media 100 1 34
 media 100 1 37
 media 106 1 44 -34
 media 106 1 47 -37
 media 100 1 52
 media 106 1 62 -52
 media 107 1 66
 media 96  1 30 -22 -26 -44 -47 -62 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 41
com='unit 41'
 hexprism 30   8.1962    9.798        0
 sphere 11       2.5
 sphere 13       2.5   origin  x=-5.196152 y=3       z=0
 sphere 21     2.999
 sphere 23     2.999   origin  x=-5.196152 y=3       z=0
 sphere 25     2.999   origin  x=0         y=6       z=0
 sphere 27     2.999   origin  x=-5.196152 y=-3      z=0
 sphere 32       2.5   origin  x=-1.7321   y=3       z=4.899
 sphere 33       2.5   origin  x=-1.7321   y=-3      z=4.899
 sphere 36       2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 38       2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 39       2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 42     2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43     2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 46     2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48     2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49     2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51       2.5   origin  x=0         y=0       z=9.798
 sphere 53       2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 61     2.999   origin  x=0         y=0       z=9.798
 sphere 63     2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 65     2.999   origin  x=0         y=6       z=9.798
 sphere 67     2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 13
 media 106 1 21 -11
 media 106 1 23 -13
 media 107 1 25
```

```
 media 107 1 27
 media 100 1 32
 media 100 1 33
 media 100 1 36
 media 100 1 38
 media 100 1 39
 media 106 1 42 -32
 media 106 1 43 -33
 media 106 1 46 -36
 media 106 1 48 -38
 media 106 1 49 -39
 media 100 1 51
 media 100 1 53
 media 106 1 61 -51
 media 106 1 63 -53
 media 107 1 65
 media 107 1 67
 media 96  1 30 -21 -23 -25 -27 -42 -43 -46 -48 -49 -61 -63 -65 -67
 boundary 30
'----------------------------------------------------------------------------
unit 42
com='unit 42'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 31      2.5   origin  x=3.4641    y=0       z=4.899
 sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
 sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 52      2.5   origin  x=5.196152  y=3       z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 100 1 11
 media 100 1 12
 media 106 1 21 -11
 media 106 1 22 -12
 media 107 1 25
 media 107 1 26
 media 100 1 31
 media 100 1 34
 media 100 1 35
 media 100 1 37
 media 106 1 41 -31
 media 106 1 44 -34
 media 106 1 45 -35
 media 106 1 47 -37
```

```
 media 100 1 51
 media 100 1 52
 media 106 1 61 -51
 media 106 1 62 -52
 media 107 1 65
 media 107 1 66
 media 96  1 30 -21 -22 -25 -26 -41 -44 -45 -47 -61 -62 -65 -66
 boundary 30
'----------------------------------------------------------------------------
unit 43
com='unit 43'
 hexprism 30   8.1962    9.798        0
 sphere 11       2.5
 sphere 13       2.5   origin  x=-5.196152 y=3        z=0
 sphere 21     2.999
 sphere 23     2.999   origin  x=-5.196152 y=3        z=0
 sphere 25     2.999   origin  x=0         y=6        z=0
 sphere 27     2.999   origin  x=-5.196152 y=-3       z=0
 sphere 32       2.5   origin  x=-1.7321   y=3        z=4.899
 sphere 33       2.5   origin  x=-1.7321   y=-3       z=4.899
 sphere 34       2.5   origin  x=3.4641    y=6        z=4.899
 sphere 36       2.5   origin  x=-6.9283   y=0        z=4.899
 sphere 38       2.5   origin  x=-4.7321   y=-8.1962  z=4.899
 sphere 39       2.5   origin  x=-4.7321   y=8.1962   z=4.899
 sphere 42     2.999   origin  x=-1.7321   y=3        z=4.899
 sphere 43     2.999   origin  x=-1.7321   y=-3       z=4.899
 sphere 44     2.999   origin  x=3.4641    y=6        z=4.899
 sphere 46     2.999   origin  x=-6.9283   y=0        z=4.899
 sphere 48     2.999   origin  x=-4.7321   y=-8.1962  z=4.899
 sphere 49     2.999   origin  x=-4.7321   y=8.1962   z=4.899
 sphere 51       2.5   origin  x=0         y=0        z=9.798
 sphere 53       2.5   origin  x=-5.196152 y=3        z=9.798
 sphere 61     2.999   origin  x=0         y=0        z=9.798
 sphere 63     2.999   origin  x=-5.196152 y=3        z=9.798
 sphere 65     2.999   origin  x=0         y=6        z=9.798
 sphere 67     2.999   origin  x=-5.196152 y=-3       z=9.798
 media 100 1 11
 media 100 1 13
 media 106 1 21 -11
 media 106 1 23 -13
 media 107 1 25
 media 107 1 27
 media 100 1 32
 media 100 1 33
 media 100 1 34
 media 100 1 36
 media 100 1 38
 media 100 1 39
 media 106 1 42 -32
 media 106 1 43 -33
 media 106 1 44 -34
 media 106 1 46 -36
 media 106 1 48 -38
 media 106 1 49 -39
 media 100 1 51
 media 100 1 53
 media 106 1 61 -51
```

```
 media 106 1 63 -53
 media 107 1 65
 media 107 1 67
 media 96  1 30 -21 -23 -25 -27 -42 -43 -44 -46 -48 -49 -61 -63 -65 -67
 boundary 30
'------------------------------------------------------------------------------
unit 44
com='unit 44'
 hexprism 30   8.1962    9.798        0
 sphere 11       2.5
 sphere 12       2.5   origin  x=5.196152  y=3       z=0
 sphere 21     2.999
 sphere 22     2.999   origin  x=5.196152  y=3       z=0
 sphere 25     2.999   origin  x=0         y=6       z=0
 sphere 26     2.999   origin  x=5.196152  y=-3      z=0
 sphere 31       2.5   origin  x=3.4641    y=0       z=4.899
 sphere 32       2.5   origin  x=-1.7321   y=3       z=4.899
 sphere 34       2.5   origin  x=3.4641    y=6       z=4.899
 sphere 35       2.5   origin  x=3.4641    y=-6      z=4.899
 sphere 37       2.5   origin  x=9.4641    y=0       z=4.899
 sphere 39       2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 41     2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42     2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44     2.999   origin  x=3.4641    y=6       z=4.899
 sphere 45     2.999   origin  x=3.4641    y=-6      z=4.899
 sphere 47     2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49     2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51       2.5   origin  x=0         y=0       z=9.798
 sphere 52       2.5   origin  x=5.196152  y=3       z=9.798
 sphere 61     2.999   origin  x=0         y=0       z=9.798
 sphere 62     2.999   origin  x=5.196152  y=3       z=9.798
 sphere 65     2.999   origin  x=0         y=6       z=9.798
 sphere 66     2.999   origin  x=5.196152  y=-3      z=9.798
 media 100 1 11
 media 100 1 12
 media 106 1 21 -11
 media 106 1 22 -12
 media 107 1 25
 media 107 1 26
 media 100 1 31
 media 100 1 32
 media 100 1 34
 media 100 1 35
 media 100 1 37
 media 100 1 39
 media 106 1 41 -31
 media 106 1 42 -32
 media 106 1 44 -34
 media 106 1 45 -35
 media 106 1 47 -37
 media 106 1 49 -39
 media 100 1 51
 media 100 1 52
 media 106 1 61 -51
 media 106 1 62 -52
 media 107 1 65
 media 107 1 66
```

```
 media 96  1 30 -21 -22 -25 -26 -41 -42 -44 -45 -47 -49 -61 -62 -65 -66
 boundary 30
'-----------------------------------------------------------------------------
unit 45
com='unit 45'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 21    2.999
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 32      2.5   origin  x=-1.7321   y=3       z=4.899
 sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
 media 100 1 11
 media 100 1 13
 media 106 1 21 -11
 media 106 1 23 -13
 media 107 1 25
 media 107 1 27
 media 100 1 32
 media 100 1 34
 media 100 1 36
 media 100 1 39
 media 106 1 42 -32
 media 106 1 44 -34
 media 106 1 46 -36
 media 106 1 49 -39
 media 100 1 51
 media 100 1 53
 media 106 1 61 -51
 media 106 1 63 -53
 media 107 1 65
 media 107 1 67
 media 96  1 30 -21 -23 -25 -27 -42 -44 -46 -49 -61 -63 -65 -67
 boundary 30
'-----------------------------------------------------------------------------
unit 46
com='unit 46'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
```

```
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 31      2.5   origin  x=3.4641    y=0       z=4.899
 sphere 32      2.5   origin  x=-1.7321   y=3       z=4.899
 sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 51      2.5   origin  x=0         y=0       z=9.798
 sphere 52      2.5   origin  x=5.196152  y=3       z=9.798
 sphere 61    2.999   origin  x=0         y=0       z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
 media 100 1 11
 media 100 1 12
 media 106 1 21 -11
 media 106 1 22 -12
 media 107 1 25
 media 107 1 26
 media 100 1 31
 media 100 1 32
 media 100 1 34
 media 100 1 37
 media 100 1 39
 media 106 1 41 -31
 media 106 1 42 -32
 media 106 1 44 -34
 media 106 1 47 -37
 media 106 1 49 -39
 media 100 1 51
 media 100 1 52
 media 106 1 61 -51
 media 106 1 62 -52
 media 107 1 65
 media 107 1 66
 media 96  1 30 -21 -22 -25 -26 -41 -42 -44 -47 -49 -61 -62 -65 -66
 boundary 30
'--------------------------------------------------------------------------------
unit 47
com='unit 47'
 hexprism 30   8.1962    9.798        0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
 sphere 65    2.999   origin  x=0         y=6       z=9.798
 media 100 1 13
 media 106 1 23 -13
 media 107 1 25
 media 100 1 39
```

```
 media 106 1 49 -39
 media 100 1 53
 media 106 1 63 -53
 media 107 1 65
 media 96  1 30 -23 -25 -49 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 48
com='unit 48'
 hexprism 30   8.1962    9.798        0
 sphere 12      2.5   origin  x=5.196152 y=3       z=0
 sphere 22    2.999   origin  x=5.196152 y=3       z=0
 sphere 25    2.999   origin  x=0        y=6       z=0
 sphere 34      2.5   origin  x=3.4641   y=6       z=4.899
 sphere 37      2.5   origin  x=9.4641   y=0       z=4.899
 sphere 44    2.999   origin  x=3.4641   y=6       z=4.899
 sphere 47    2.999   origin  x=9.4641   y=0       z=4.899
 sphere 52      2.5   origin  x=5.196152 y=3       z=9.798
 sphere 62    2.999   origin  x=5.196152 y=3       z=9.798
 sphere 65    2.999   origin  x=0        y=6       z=9.798
 media 100 1 12
 media 106 1 22 -12
 media 107 1 25
 media 100 1 34
 media 100 1 37
 media 106 1 44 -34
 media 106 1 47 -37
 media 100 1 52
 media 106 1 62 -52
 media 107 1 65
 media 96 1 30 -22 -25 -44 -47 -62 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 49
com='unit 49'
 hexprism 30   8.1962    9.798        0
 sphere 11      2.5
 sphere 12      2.5   origin  x=5.196152  y=3       z=0
 sphere 13      2.5   origin  x=-5.196152 y=3       z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3       z=0
 sphere 23    2.999   origin  x=-5.196152 y=3       z=0
 sphere 24    2.999   origin  x=0         y=-6      z=0
 sphere 25    2.999   origin  x=0         y=6       z=0
 sphere 26    2.999   origin  x=5.196152  y=-3      z=0
 sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
 sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
 sphere 38      2.5   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3       z=4.899
 sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
 sphere 48    2.999   origin  x=-4.7321   y=-8.1962 z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
```

```
 sphere 51       2.5   origin  x=0          y=0        z=9.798
 sphere 52       2.5   origin  x=5.196152  y=3        z=9.798
 sphere 53       2.5   origin  x=-5.196152 y=3        z=9.798
 sphere 61    2.999   origin  x=0          y=0        z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3        z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3        z=9.798
 sphere 64    2.999   origin  x=0          y=-6       z=9.798
 sphere 65    2.999   origin  x=0          y=6        z=9.798
 sphere 66    2.999   origin  x=5.196152  y=-3       z=9.798
 sphere 67    2.999   origin  x=-5.196152 y=-3       z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 107 1 24
 media 107 1 25
 media 107 1 26
 media 107 1 27
 media 107 1 41
 media 107 1 42
 media 107 1 43
 media 100 1 34
 media 100 1 36
 media 100 1 38
 media 100 1 39
 media 106 1 44 -34
 media 106 1 46 -36
 media 106 1 48 -38
 media 106 1 49 -39
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -46 -48 -49 -61
               -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 50
com='unit 50'
 hexprism 30   8.1962    9.798        0
 sphere 11       2.5
 sphere 12       2.5   origin  x=5.196152  y=3      z=0
 sphere 13       2.5   origin  x=-5.196152 y=3      z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 24    2.999   origin  x=0          y=-6     z=0
 sphere 25    2.999   origin  x=0          y=6      z=0
 sphere 26    2.999   origin  x=5.196152  y=-3     z=0
```

```
sphere 27    2.999   origin  x=-5.196152 y=-3      z=0
sphere 31      2.5   origin  x=3.4641    y=0       z=4.899
sphere 32      2.5   origin  x=-1.7321   y=3       z=4.899
sphere 33      2.5   origin  x=-1.7321   y=-3      z=4.899
sphere 34      2.5   origin  x=3.4641    y=6       z=4.899
sphere 35      2.5   origin  x=3.4641    y=-6      z=4.899
sphere 36      2.5   origin  x=-6.9283   y=0       z=4.899
sphere 37      2.5   origin  x=9.4641    y=0       z=4.899
sphere 39      2.5   origin  x=-4.7321   y=8.1962  z=4.899
sphere 41    2.999   origin  x=3.4641    y=0       z=4.899
sphere 42    2.999   origin  x=-1.732    y=3       z=4.899
sphere 43    2.999   origin  x=-1.7321   y=-3      z=4.899
sphere 44    2.999   origin  x=3.4641    y=6       z=4.899
sphere 45    2.999   origin  x=3.4641    y=-6      z=4.899
sphere 46    2.999   origin  x=-6.9283   y=0       z=4.899
sphere 47    2.999   origin  x=9.4641    y=0       z=4.899
sphere 49    2.999   origin  x=-4.7321   y=8.1962  z=4.899
sphere 51      2.5   origin  x=0         y=0       z=9.798
sphere 52      2.5   origin  x=5.196152  y=3       z=9.798
sphere 53      2.5   origin  x=-5.196152 y=3       z=9.798
sphere 61    2.999   origin  x=0         y=0       z=9.798
sphere 62    2.999   origin  x=5.196152  y=3       z=9.798
sphere 63    2.999   origin  x=-5.196152 y=3       z=9.798
sphere 64    2.999   origin  x=0         y=-6      z=9.798
sphere 65    2.999   origin  x=0         y=6       z=9.798
sphere 66    2.999   origin  x=5.196152  y=-3      z=9.798
sphere 67    2.999   origin  x=-5.196152 y=-3      z=9.798
media 100 1 11
media 100 1 12
media 100 1 13
media 106 1 21 -11
media 106 1 22 -12
media 106 1 23 -13
media 107 1 24
media 107 1 25
media 107 1 26
media 107 1 27
media 100 1 31
media 100 1 32
media 100 1 33
media 100 1 34
media 100 1 35
media 100 1 36
media 100 1 37
media 100 1 39
media 106 1 41 -31
media 106 1 42 -32
media 106 1 43 -33
media 106 1 44 -34
media 106 1 45 -35
media 106 1 46 -36
media 106 1 47 -37
media 106 1 49 -39
media 100 1 51
media 100 1 52
media 100 1 53
media 106 1 61 -51
```

```
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 64
 media 107 1 65
 media 107 1 66
 media 107 1 67
 media 96  1 30 -21 -22 -23 -24 -25 -26 -27 -41 -42 -43 -44 -45 -46 -47 -49
                -61 -62 -63 -64 -65 -66 -67
 boundary 30
'----------------------------------------------------------------------------
unit 51
com='unit 51'
 hexprism 30   8.1962    9.798        0
 sphere 13      2.5   origin  x=-5.196152 y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 25    2.999   origin  x=0         y=6      z=0
 sphere 34      2.5   origin  x=3.4641    y=6      z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962 z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6      z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=4.899
 sphere 53      2.5   origin  x=-5.196152 y=3      z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3      z=9.798
 sphere 65    2.999   origin  x=0         y=6      z=9.798
 media 100 1 13
 media 106 1 23 -13
 media 107 1 25
 media 100 1 34
 media 100 1 39
 media 106 1 44 -34
 media 106 1 49 -39
 media 100 1 53
 media 106 1 63 -53
 media 107 1 65
 media 96  1 30 -23 -25 -44 -49 -63 -65
 boundary 30
'----------------------------------------------------------------------------
unit 52
com='unit 52'
 hexprism 30   8.1962    9.798        0
 sphere 12      2.5   origin  x=5.196152 y=3      z=0
 sphere 22    2.999   origin  x=5.196152 y=3      z=0
 sphere 25    2.999   origin  x=0        y=6      z=0
 sphere 34      2.5   origin  x=3.4641   y=6      z=4.899
 sphere 39      2.5   origin  x=-4.7321  y=8.1962 z=4.899
 sphere 44    2.999   origin  x=3.4641   y=6      z=4.899
 sphere 49    2.999   origin  x=-4.7321  y=8.1962 z=4.899
 sphere 52      2.5   origin  x=5.196152 y=3      z=9.798
 sphere 62    2.999   origin  x=5.196152 y=3      z=9.798
 sphere 65    2.999   origin  x=0        y=6      z=9.798
 media 100 1 12
 media 106 1 22 -12
 media 107 1 25
 media 100 1 34
 media 100 1 39
 media 106 1 44 -34
 media 106 1 49 -39
 media 100 1 52
```

```
 media 106 1 62 -52
 media 107 1 65
 media 96  1 30 -22 -25 -44 -49 -62 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 53
com='unit 53'
 hexprism 30   8.1962    9.798        0
 sphere 11       2.5
 sphere 12       2.5   origin  x=5.196152  y=3      z=0
 sphere 13       2.5   origin  x=-5.196152 y=3      z=0
 sphere 21     2.999
 sphere 22     2.999   origin  x=5.196152  y=3      z=0
 sphere 23     2.999   origin  x=-5.196152 y=3      z=0
 sphere 25     2.999   origin  x=0         y=6      z=0
 sphere 32       2.5   origin  x=-1.7321   y=3      z=4.899
 sphere 34       2.5   origin  x=3.4641    y=6      z=4.899
 sphere 36       2.5   origin  x=-6.9283   y=0      z=4.899
 sphere 39       2.5   origin  x=-4.7321   y=8.1962 z=4.899
 sphere 42     2.999   origin  x=-1.7321   y=3      z=4.899
 sphere 44     2.999   origin  x=3.4641    y=6      z=4.899
 sphere 46     2.999   origin  x=-6.9283   y=0      z=4.899
 sphere 49     2.999   origin  x=-4.7321   y=8.1962 z=4.899
 sphere 51       2.5   origin  x=0         y=0      z=9.798
 sphere 52       2.5   origin  x=5.196152  y=3      z=9.798
 sphere 53       2.5   origin  x=-5.196152 y=3      z=9.798
 sphere 61     2.999   origin  x=0         y=0      z=9.798
 sphere 62     2.999   origin  x=5.196152  y=3      z=9.798
 sphere 63     2.999   origin  x=-5.196152 y=3      z=9.798
 sphere 65     2.999   origin  x=0         y=6      z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 107 1 25
 media 100 1 32
 media 100 1 34
 media 100 1 36
 media 100 1 39
 media 106 1 42 -32
 media 106 1 44 -34
 media 106 1 46 -36
 media 106 1 49 -39
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 65
 media 96  1 30 -21 -22 -23 -25 -42 -44 -46 -49 -61 -62 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 54
com='unit 54'
```

```
 hexprism 30   8.1962    9.798        0
 sphere 11       2.5
 sphere 12       2.5   origin  x=5.196152  y=3      z=0
 sphere 13       2.5   origin  x=-5.196152 y=3      z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 25    2.999   origin  x=0         y=6      z=0
 sphere 31       2.5   origin  x=3.4641    y=0      z=4.899
 sphere 32       2.5   origin  x=-1.7321   y=3      z=4.899
 sphere 34       2.5   origin  x=3.4641    y=6      z=4.899
 sphere 37       2.5   origin  x=9.4641    y=0      z=4.899
 sphere 39       2.5   origin  x=-4.7321   y=8.1962 z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0      z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0      z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=4.899
 sphere 51       2.5   origin  x=0         y=0      z=9.798
 sphere 52       2.5   origin  x=5.196152  y=3      z=9.798
 sphere 53       2.5   origin  x=-5.196152 y=3      z=9.798
 sphere 61    2.999   origin  x=0         y=0      z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3      z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3      z=9.798
 sphere 65    2.999   origin  x=0         y=6      z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 107 1 25
 media 100 1 31
 media 100 1 32
 media 100 1 34
 media 100 1 37
 media 100 1 39
 media 106 1 41 -31
 media 106 1 42 -32
 media 106 1 44 -34
 media 106 1 47 -37
 media 106 1 49 -39
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 65
 media 96  1 30 -21 -22 -23 -25 -41 -42 -44 -47 -49 -61 -62 -63 -65
 boundary 30
'-----------------------------------------------------------------------------
unit 55
com='unit 55'
 hexprism 30   8.1962    9.798        0
 sphere 11       2.5
 sphere 12       2.5   origin  x=5.196152  y=3      z=0
```

```
 sphere 13      2.5   origin  x=-5.196152 y=3      z=0
 sphere 21    2.999
 sphere 22    2.999   origin  x=5.196152  y=3      z=0
 sphere 23    2.999   origin  x=-5.196152 y=3      z=0
 sphere 25    2.999   origin  x=0         y=6      z=0
 sphere 31      2.5   origin  x=3.4641    y=0      z=4.899
 sphere 32      2.5   origin  x=-1.7321   y=3      z=4.899
 sphere 34      2.5   origin  x=3.4641    y=6      z=4.899
 sphere 36      2.5   origin  x=-6.9283   y=0      z=4.899
 sphere 37      2.5   origin  x=9.4641    y=0      z=4.899
 sphere 39      2.5   origin  x=-4.7321   y=8.1962 z=4.899
 sphere 41    2.999   origin  x=3.4641    y=0      z=4.899
 sphere 42    2.999   origin  x=-1.7321   y=3      z=4.899
 sphere 44    2.999   origin  x=3.4641    y=6      z=4.899
 sphere 46    2.999   origin  x=-6.9283   y=0      z=4.899
 sphere 47    2.999   origin  x=9.4641    y=0      z=4.899
 sphere 49    2.999   origin  x=-4.7321   y=8.1962 z=4.899
 sphere 51      2.5   origin  x=0         y=0      z=9.798
 sphere 52      2.5   origin  x=5.196152  y=3      z=9.798
 sphere 53      2.5   origin  x=-5.196152 y=3      z=9.798
 sphere 61    2.999   origin  x=0         y=0      z=9.798
 sphere 62    2.999   origin  x=5.196152  y=3      z=9.798
 sphere 63    2.999   origin  x=-5.196152 y=3      z=9.798
 sphere 65    2.999   origin  x=0         y=6      z=9.798
 media 100 1 11
 media 100 1 12
 media 100 1 13
 media 106 1 21 -11
 media 106 1 22 -12
 media 106 1 23 -13
 media 107 1 25
 media 100 1 31
 media 100 1 32
 media 100 1 34
 media 100 1 36
 media 100 1 37
 media 100 1 39
 media 106 1 41 -31
 media 106 1 42 -32
 media 106 1 44 -34
 media 106 1 46 -36
 media 106 1 47 -37
 media 106 1 49 -39
 media 100 1 51
 media 100 1 52
 media 100 1 53
 media 106 1 61 -51
 media 106 1 62 -52
 media 106 1 63 -53
 media 107 1 65
 media 96  1 30 -21 -22 -23 -25 -41 -42 -44 -46 -47 -49 -61 -62 -63 -65
 boundary 30
'-----------------------------------------------------------------------
' control channels units
'-----------------------------------------------------------------------
unit 3
com='hot gas duct'
```

```
 xcylinder 117       15      190       90   origin  x=0         y=0 z=480
 media 96 1 117
 boundary 117
unit 4
com='elliptical klak'
 cuboid 113        5   -5      3  -3  258.764  0
 cylinder 114      3  258.764  0  origin  x=-5 y=0 z=0
 cylinder 115      3  258.764  0  origin  x=5  y=0 z=0
 cuboid 116        8   -8      3  -3  258.764  0
 media 96 1 113
 media 96 1 114 -113
 media 96 1 115 -113
 media 31 1 116 -113 -114 -115
 boundary 116
unit 5
com='upper circular klak channel'
 cylinder 112      3  221.236 0
 media 96 1 112
 boundary 112
unit 6
com='upper circular klak channel'
 cylinder 112      3  130     0
 media 96 1 112
 boundary 112
unit 7
com='control rod channel'
 cylinder 111     6.5 450     0
 media 96 1 111
 boundary 111
unit 8
com='irradiation channels'
 cylinder 111     6.5 450     0
 media 96 1 111
 boundary 111
unit 9
com='coolant channel'
 cylinder 110     4   505     0
 media 96 1 110
 boundary 110
'-----------------------------------------------------------------------------
' central 90cm radius column
'-----------------------------------------------------------------------------
unit 2
com='central 90cm column'
 cylinder 10       90       40        0
 cylinder 20       90       95        0
 cylinder 30       90      105        0
 cylinder 40       90      130        0
 cylinder 50       90      228.244    0
 cylinder 60       90      351.818    0
 cylinder 61       90      351.818  228.244
 cylinder 70       90      388.764    0
 cone 71           25      388.764   90      351.818
 cylinder 72       25      388.764    0
 cylinder 73       25      494.988  388.764
 cylinder 80       90      402        0
 cylinder 90       90      430        0
```

```
 cylinder 91       41.75   430        0
 cylinder 100      90      450        0
 cylinder 101      41.75   450        0
 cylinder 110      90      465        0
 cylinder 111      70.75   465        0
 cylinder 120      90      495        0
 cylinder 121      70.75   495        0
 cylinder 122      41.75   495        0
 cylinder 123      25      494.988    0
 cylinder 130      90      510        0
 cylinder 131      41.75   510        0
 cylinder 140      90      540        0
 cylinder 141      25      540        0
 cylinder 150      90      610        0
 cylinder 151      25      610        0
 array 1 61  place 7 7 1 0 0 228.244
 array 2 71  place 7 7 1 0 0 351.818
 array 3 73  place 7 7 1 0 0 388.764
 media 1  1  10
 media 2  1  20 -10
 media 3  1  30 -20
 media 4  1  40 -30
 media 5  1  50 -40  -61
 media 83 1  70 -71  -60
 media 7  1 141 -123
 media 81 1 151 -141
 media 8  1  80 -70  -123
 media 9  1  90 -80  -123
 media 10 1 101 -91  -123
 media 11 1 100 -90  -131
 media 12 1 131 -101 -141
 media 13 1 110 -100 -131
 media 14 1 121 -111 -131
 media 15 1 120 -110 -121
 media 16 1 130 -120 -131
 media 17 1 140 -130 -141
 media 18 1 150 -140 -151
 boundary 150
'-----------------------------------------------------------------------------
' global unit
'-----------------------------------------------------------------------------
global unit 1
com='annular regions between radii 90 and 95.6 cm'
 cylinder 10     95.6      610        0
 cylinder 11     95.6       40        0
 cylinder 12     95.6       95        0
 cylinder 13     95.6      105        0
 cylinder 14     95.6      388.74     0
 cylinder 15     95.6      430        0
 cylinder 16     95.6      450        0
 cylinder 17     95.6      465        0
 cylinder 18     95.6      495        0
 cylinder 19     95.6      510        0
 cylinder 20     95.6      540        0
 cylinder 30    108.6      610        0
 cylinder 31    108.6       40        0
 cylinder 32    108.6       95        0
```

```
cylinder 33    108.6      105        0
cylinder 34    108.6      114.7      0
cylinder 35    108.6      130        0
cylinder 36    108.6      388.74     0
cylinder 37    108.6      430        0
cylinder 38    108.6      450        0
cylinder 39    108.6      465        0
cylinder 40    108.6      495        0
cylinder 41    108.6      510        0
cylinder 42    108.6      540        0
cylinder 50    140.6      610        0
cylinder 51    140.6       40        0
cylinder 52    140.6       95        0
cylinder 53    140.6      105        0
cylinder 54    140.6      388.74     0
cylinder 55    140.6      430        0
cylinder 56    140.6      450        0
cylinder 57    140.6      465        0
cylinder 58    140.6      495        0
cylinder 59    140.6      510        0
cylinder 60    140.6      540        0
cylinder 70    148.6      610        0
cylinder 71    148.6       40        0
cylinder 72    148.6       95        0
cylinder 73    148.6      105        0
cylinder 74    148.6      388.74     0
cylinder 75    148.6      430        0
cylinder 76    148.6      450        0
cylinder 77    148.6      465        0
cylinder 78    148.6      495        0
cylinder 79    148.6      510        0
cylinder 80    148.6      540        0
cylinder 90    167.793    610        0
cylinder 91    167.793     40        0
cylinder 92    167.793    388.74     0
cylinder 93    167.793    430        0
cylinder 94    167.793    450        0
cylinder 95    167.793    465        0
cylinder 96    167.793    495        0
cylinder 97    167.793    510        0
cylinder 98    167.793    540        0
cylinder 100   190        610        0
cylinder 101   190         40        0
cylinder 102   190        465        0
cylinder 103   190        495        0
cylinder 104   190        540        0
cuboid 105     191       -191       191      -191       611         0
hole 9   origin  x=22.62042  y=142.8197  z=105
hole 9   origin  x=65.64703  y=128.8395  z=105
hole 9   origin  x=102.2476  y=102.2476  z=105
hole 9   origin  x=128.8395  y=65.64703  z=105
hole 9   origin  x=142.8197  y=22.62042  z=105
hole 9   origin  x=142.8197  y=-22.62042 z=105
hole 9   origin  x=128.8395  y=-65.64703 z=105
hole 9   origin  x=102.2476  y=-102.2476 z=105
hole 9   origin  x=65.64703  y=-128.8395 z=105
hole 9   origin  x=22.62042  y=-142.8197 z=105
```

```
hole 9   origin  x=-22.62042 y=-142.8197 z=105
hole 9   origin  x=-65.64703 y=-128.8395 z=105
hole 9   origin  x=-102.2476 y=-102.2476 z=105
hole 9   origin  x=-128.8395 y=-65.64703 z=105
hole 9   origin  x=-142.8197 y=-22.62042 z=105
hole 9   origin  x=-142.8197 y=22.62042  z=105
hole 9   origin  x=-128.8395 y=65.64703  z=105
hole 9   origin  x=-102.2476 y=102.2476  z=105
hole 9   origin  x=-65.64703 y=128.8395  z=105
hole 9   origin  x=-22.62042 y=142.8197  z=105
hole 8   origin  x=100.843   y=15.97196  z=0
hole 8   origin  x=-15.97196 y=-100.843  z=0
hole 8   origin  x=-100.843  y=-15.97196 z=0
hole 7   origin  x=46.35243  y=90.97177  z=0
hole 7   origin  x=90.97177  y=46.35243  z=0
hole 7   origin  x=100.843   y=-15.97196 z=0
hole 7   origin  x=72.1956   y=-72.1956  z=0
hole 7   origin  x=15.97196  y=-100.843  z=0
hole 7   origin  x=-46.35243 y=-90.97177 z=0
hole 7   origin  x=-90.97177 y=-46.35243 z=0
hole 7   origin  x=-100.843  y=15.97196  z=0
hole 7   origin  x=-72.1956  y=72.1956   z=0
hole 7   origin  x=-15.97196 y=100.843   z=0
hole 6   origin  x=15.42444  y=97.38607  z=0
hole 6   origin  x=69.72073  y=69.72073  z=0
hole 6   origin  x=87.85324  y=-44.76346 z=0
hole 6   origin  x=44.76346  y=-87.85324 z=0
hole 6   origin  x=-69.72073 y=-69.72073 z=0
hole 6   origin  x=-87.85324 y=44.76346  z=0
hole 6   origin  x=-44.76346 y=87.85324  z=0
hole 5   origin  x=15.42444  y=97.38607  z=388.764
hole 5   origin  x=69.72073  y=69.72073  z=388.764
hole 5   origin  x=87.85324  y=-44.76346 z=388.764
hole 5   origin  x=44.76346  y=-87.85324 z=388.764
hole 5   origin  x=-69.72073 y=-69.72073 z=388.764
hole 5   origin  x=-87.85324 y=44.76346  z=388.764
hole 5   origin  x=-44.76346 y=87.85324  z=388.764
hole 4   origin  x=15.42444  y=97.38607  z=130 rotate  a1=351 a2=0 a3=0
hole 4   origin  x=69.72073  y=69.72073  z=130 rotate  a1=315 a2=0 a3=0
hole 4   origin  x=87.85324  y=-44.76346 z=130 rotate  a1=243 a2=0 a3=0
hole 4   origin  x=44.76346  y=-87.85324 z=130 rotate  a1=207 a2=0 a3=0
hole 4   origin x=-69.72073  y=-69.72073 z=130 rotate  a1=135 a2=0 a3=0
hole 4   origin  x=-87.85324 y=44.76346  z=130 rotate  a1=63  a2=0 a3=0
hole 4   origin  x=-44.76346 y=87.85324  z=130 rotate  a1=27  a2=0 a3=0
hole 3
hole 2
media 19 1 11
media 20 1 12 -11
media 21 1 13 -12
media 22 1 14 -13
media 22 1 15 -14
media 24 1 16 -15
media 22 1 17 -16
media 26 1 18 -17
media 22 1 19 -18
media 17 1 20 -19
media 18 1 10 -20
```

```
 media 27 1 31 -10
 media 28 1 32 -31 -10
 media 29 1 33 -32 -10
 media 28 1 34 -33 -10
 media 30 1 35 -34 -10
 media 31 1 36 -35 -10
 media 30 1 37 -36 -10
 media 42 1 38 -37 -10
 media 43 1 39 -38 -10
 media 44 1 40 -39 -10
 media 43 1 41 -40 -10
 media 46 1 42 -41 -10
 media 47 1 30 -42 -10
 media 17 1 51 -30
 media 22 1 52 -51 -30
 media 66 1 53 -52 -30
 media 22 1 54 -53 -30
 media 22 1 55 -54 -30
 media 24 1 56 -55 -30
 media 22 1 57 -56 -30
 media 53 1 58 -57 -30
 media 22 1 59 -58 -30
 media 17 1 60 -59 -30
 media 18 1 50 -60 -30
 media 17 1 71 -50
 media 22 1 72 -71 -50
 media 57 1 73 -72 -50
 media 58 1 74 -73 -50
 media 58 1 75 -74 -50
 media 60 1 76 -75 -50
 media 58 1 77 -76 -50
 media 62 1 78 -77 -50
 media 58 1 79 -78 -50
 media 64 1 80 -79 -50
 media 65 1 70 -80 -50
 media 17 1 91 -70
 media 22 1 92 -91 -70
 media 22 1 93 -92 -70
 media 24 1 94 -93 -70
 media 22 1 95 -94 -70
 media 70 1 96 -95 -70
 media 22 1 97 -96 -70
 media 17 1 98 -97 -70
 media 18 1 90 -98 -70
 media 17 1 101 -90
 media 17 1 102 -101 -90
 media 77 1 103 -102 -90
 media 17 1 104 -103 -90
 media 17 1 100 -104 -90
 media 0  1 105 -100
 boundary 105
end geometry
'-----------------------------------------------------------------------------
' array data
'-----------------------------------------------------------------------------
read array
'-----------------------------------------------------------------------------
```

```
' active core region array
'------------------------------------------------------------------------------
ara=1 nux=13 nuy=13 nuz=14 typ=shexagonal
 fill
  215  215  215  215  252  254  255  253  251  215  215  215  215
  215  215  248  250  210  210  210  210  249  247  215  215  215
  215  215  246  210  210  210  210  210  210  210  245  215  215
  215  244  210  210  210  210  210  210  210  210  243  215  215
  215  242  210  210  210  210  210  210  210  210  210  241  215
  240  210  210  210  210  210  210  210  210  210  210  239  215
  215  220  210  210  210  210  210  210  210  210  210  221  215
  222  210  210  210  210  210  210  210  210  210  210  223  215
  215  224  210  210  210  210  210  210  210  210  210  225  215
  215  226  210  210  210  210  210  210  210  210  227  215  215
  215  215  228  210  210  210  210  210  210  210  229  215  215
  215  215  230  232  210  210  210  210  233  231  215  215  215
  215  215  215  215  234  236  238  237  235  215  215  215  215
   15   15   15   15   52   54   55   53   51   15   15   15   15
   15   15   48   50   10   10   10   10   49   47   15   15   15
   15   15   46   10   10   10   10   10   10   10   45   15   15
   15   44   10   10   10   10   10   10   10   10   43   15   15
   15   42   10   10   10   10   10   10   10   10   10   41   15
   40   10   10   10   10   10   10   10   10   10   10   39   15
   15   20   10   10   10   10   10   10   10   10   10   21   15
   22   10   10   10   10   10   10   10   10   10   10   23   15
   15   24   10   10   10   10   10   10   10   10   10   25   15
   15   26   10   10   10   10   10   10   10   10   27   15   15
   15   15   28   10   10   10   10   10   10   10   29   15   15
   15   15   30   32   10   10   10   10   33   31   15   15   15
   15   15   15   15   34   36   38   37   35   15   15   15   15
   15   15   15   15   52   54   55   53   51   15   15   15   15
   15   15   48   50   10   10   10   10   49   47   15   15   15
   15   15   46   10   10   10   10   10   10   10   45   15   15
   15   44   10   10   10   10   10   10   10   10   43   15   15
   15   42   10   10   10   10   10   10   10   10   10   41   15
   40   10   10   10   10   10   10   10   10   10   10   39   15
   15   20   10   10   10   10   10   10   10   10   10   21   15
   22   10   10   10   10   10   10   10   10   10   10   23   15
   15   24   10   10   10   10   10   10   10   10   10   25   15
   15   26   10   10   10   10   10   10   10   10   27   15   15
   15   15   28   10   10   10   10   10   10   10   29   15   15
   15   15   30   32   10   10   10   10   33   31   15   15   15
   15   15   15   15   34   36   38   37   35   15   15   15   15
   15   15   15   15   52   54   55   53   51   15   15   15   15
   15   15   48   50   10   10   10   10   49   47   15   15   15
   15   15   46   10   10   10   10   10   10   10   45   15   15
   15   44   10   10   10   10   10   10   10   10   43   15   15
   15   42   10   10   10   10   10   10   10   10   10   41   15
   40   10   10   10   10   10   10   10   10   10   10   39   15
   15   20   10   10   10   10   10   10   10   10   10   21   15
   22   10   10   10   10   10   10   10   10   10   10   23   15
   15   24   10   10   10   10   10   10   10   10   10   25   15
   15   26   10   10   10   10   10   10   10   10   27   15   15
   15   15   28   10   10   10   10   10   10   10   29   15   15
   15   15   30   32   10   10   10   10   33   31   15   15   15
   15   15   15   15   34   36   38   37   35   15   15   15   15
   15   15   15   15   52   54   55   53   51   15   15   15   15
```

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 15 | 48 | 50 | 10 | 10 | 10 | 10 | 49 | 47 | 15 | 15 | 15 |
| 15 | 15 | 46 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 45 | 15 | 15 |
| 15 | 44 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 43 | 15 | 15 |
| 15 | 42 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 41 | 15 |
| 40 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 39 | 15 |
| 15 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 21 | 15 |
| 22 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 23 | 15 |
| 15 | 24 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 15 |
| 15 | 26 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 27 | 15 | 15 |
| 15 | 15 | 28 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 29 | 15 | 15 |
| 15 | 15 | 30 | 32 | 10 | 10 | 10 | 10 | 33 | 31 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 34 | 36 | 38 | 37 | 35 | 15 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 52 | 54 | 55 | 53 | 51 | 15 | 15 | 15 | 15 |
| 15 | 15 | 48 | 50 | 10 | 10 | 10 | 10 | 49 | 47 | 15 | 15 | 15 |
| 15 | 15 | 46 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 45 | 15 | 15 |
| 15 | 44 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 43 | 15 | 15 |
| 15 | 42 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 41 | 15 |
| 40 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 39 | 15 |
| 15 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 21 | 15 |
| 22 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 23 | 15 |
| 15 | 24 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 15 |
| 15 | 26 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 27 | 15 | 15 |
| 15 | 15 | 28 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 29 | 15 | 15 |
| 15 | 15 | 30 | 32 | 10 | 10 | 10 | 10 | 33 | 31 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 34 | 36 | 38 | 37 | 35 | 15 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 52 | 54 | 55 | 53 | 51 | 15 | 15 | 15 | 15 |
| 15 | 15 | 48 | 50 | 10 | 10 | 10 | 10 | 49 | 47 | 15 | 15 | 15 |
| 15 | 15 | 46 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 45 | 15 | 15 |
| 15 | 44 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 43 | 15 | 15 |
| 15 | 42 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 41 | 15 |
| 40 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 39 | 15 |
| 15 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 21 | 15 |
| 22 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 23 | 15 |
| 15 | 24 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 15 |
| 15 | 26 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 27 | 15 | 15 |
| 15 | 15 | 28 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 29 | 15 | 15 |
| 15 | 15 | 30 | 32 | 10 | 10 | 10 | 10 | 33 | 31 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 34 | 36 | 38 | 37 | 35 | 15 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 52 | 54 | 55 | 53 | 51 | 15 | 15 | 15 | 15 |
| 15 | 15 | 48 | 50 | 10 | 10 | 10 | 10 | 49 | 47 | 15 | 15 | 15 |
| 15 | 15 | 46 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 45 | 15 | 15 |
| 15 | 44 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 43 | 15 | 15 |
| 15 | 42 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 41 | 15 |
| 40 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 39 | 15 |
| 15 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 21 | 15 |
| 22 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 23 | 15 |
| 15 | 24 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 15 |
| 15 | 26 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 27 | 15 | 15 |
| 15 | 15 | 28 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 29 | 15 | 15 |
| 15 | 15 | 30 | 32 | 10 | 10 | 10 | 10 | 33 | 31 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 34 | 36 | 38 | 37 | 35 | 15 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 52 | 54 | 55 | 53 | 51 | 15 | 15 | 15 | 15 |
| 15 | 15 | 48 | 50 | 10 | 10 | 10 | 10 | 49 | 47 | 15 | 15 | 15 |
| 15 | 15 | 46 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 45 | 15 | 15 |
| 15 | 44 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 43 | 15 | 15 |
| 15 | 42 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 41 | 15 |
| 40 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 39 | 15 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 21 | 15 |
| 22 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 23 | 15 |
| 15 | 24 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 15 |
| 15 | 26 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 27 | 15 | 15 |
| 15 | 15 | 28 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 29 | 15 | 15 |
| 15 | 15 | 30 | 32 | 10 | 10 | 10 | 10 | 33 | 31 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 34 | 36 | 38 | 37 | 35 | 15 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 52 | 54 | 55 | 53 | 51 | 15 | 15 | 15 | 15 |
| 15 | 15 | 48 | 50 | 10 | 10 | 10 | 10 | 49 | 47 | 15 | 15 | 15 |
| 15 | 15 | 46 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 45 | 15 | 15 |
| 15 | 44 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 43 | 15 | 15 |
| 15 | 42 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 41 | 15 |
| 40 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 39 | 15 |
| 15 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 21 | 15 |
| 22 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 23 | 15 |
| 15 | 24 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 15 |
| 15 | 26 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 27 | 15 | 15 |
| 15 | 15 | 28 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 29 | 15 | 15 |
| 15 | 15 | 30 | 32 | 10 | 10 | 10 | 10 | 33 | 31 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 34 | 36 | 38 | 37 | 35 | 15 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 52 | 54 | 55 | 53 | 51 | 15 | 15 | 15 | 15 |
| 15 | 15 | 48 | 50 | 10 | 10 | 10 | 10 | 49 | 47 | 15 | 15 | 15 |
| 15 | 15 | 46 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 45 | 15 | 15 |
| 15 | 44 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 43 | 15 | 15 |
| 15 | 42 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 41 | 15 |
| 40 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 39 | 15 |
| 15 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 21 | 15 |
| 22 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 23 | 15 |
| 15 | 24 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 15 |
| 15 | 26 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 27 | 15 | 15 |
| 15 | 15 | 28 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 29 | 15 | 15 |
| 15 | 15 | 30 | 32 | 10 | 10 | 10 | 10 | 33 | 31 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 34 | 36 | 38 | 37 | 35 | 15 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 52 | 54 | 55 | 53 | 51 | 15 | 15 | 15 | 15 |
| 15 | 15 | 48 | 50 | 10 | 10 | 10 | 10 | 49 | 47 | 15 | 15 | 15 |
| 15 | 15 | 46 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 45 | 15 | 15 |
| 15 | 44 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 43 | 15 | 15 |
| 15 | 42 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 41 | 15 |
| 40 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 39 | 15 |
| 15 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 21 | 15 |
| 22 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 23 | 15 |
| 15 | 24 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 15 |
| 15 | 26 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 27 | 15 | 15 |
| 15 | 15 | 28 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 29 | 15 | 15 |
| 15 | 15 | 30 | 32 | 10 | 10 | 10 | 10 | 33 | 31 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 34 | 36 | 38 | 37 | 35 | 15 | 15 | 15 | 15 |
| 15 | 15 | 15 | 15 | 52 | 54 | 55 | 53 | 51 | 15 | 15 | 15 | 15 |
| 15 | 15 | 48 | 50 | 10 | 10 | 10 | 10 | 49 | 47 | 15 | 15 | 15 |
| 15 | 15 | 46 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 45 | 15 | 15 |
| 15 | 44 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 43 | 15 | 15 |
| 15 | 42 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 41 | 15 |
| 40 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 39 | 15 |
| 15 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 21 | 15 |
| 22 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 23 | 15 |
| 15 | 24 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 15 |
| 15 | 26 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 27 | 15 | 15 |
| 15 | 15 | 28 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 29 | 15 | 15 |

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   15   15   30   32   10   10   10   10   33   31   15   15   15
   15   15   15   15   34   36   38   37   35   15   15   15   15
  115  115  115  115  152  154  155  153  151  115  115  115  115
  115  115  148  150  110  110  110  110  149  147  115  115  115
  115  115  146  110  110  110  110  110  110  110  145  115  115
  115  144  110  110  110  110  110  110  110  110  143  115  115
  115  142  110  110  110  110  110  110  110  110  110  141  115
  140  110  110  110  110  110  110  110  110  110  110  139  115
  115  120  110  110  110  110  110  110  110  110  110  121  115
  122  110  110  110  110  110  110  110  110  110  110  123  115
  115  124  110  110  110  110  110  110  110  110  110  125  115
  115  126  110  110  110  110  110  110  110  110  127  115  115
  115  115  128  110  110  110  110  110  110  110  129  115  115
  115  115  130  132  110  110  110  110  133  131  115  115  115
  115  115  115  115  134  136  138  137  135  115  115  115  115
 end fill
'-----------------------------------------------------------------------------
' conical section of the discharge tube (region 91 in Fig. 3.3)
'                                      351.818cm - 388.764cm
'-----------------------------------------------------------------------------
ara=2 nux=13 nuy=13 nuz=5 typ=shexagonal
 fill
  315  315  315  315  315  615  333  613  315  315  315  315  315
  315  315  315  332  341  310  310  341  331  315  315  315  315
  315  315  617  339  310  310  310  310  310  340  611  315  315
  315  330  310  310  310  310  310  310  310  310  329  315  315
  315  619  310  310  310  310  310  310  310  310  310  609  315
  315  334  310  310  310  310  310  310  310  310  335  315  315
  315  320  310  310  310  310  310  310  310  310  310  321  315
  315  334  310  310  310  310  310  310  310  310  335  315  315
  315  621  310  310  310  310  310  310  310  310  310  607  315
  315  324  310  310  310  310  310  310  310  310  325  315  315
  315  315  623  337  310  310  310  310  310  338  605  315  315
  315  315  315  326  336  310  310  336  327  315  315  315  315
  315  315  315  315  315  601  328  603  315  315  315  315  315
   18   18   18   18   18  616  433  614   18   18   18   18   18
   18   18   18  432  450  451  452  700  431   18   18   18   18
   18   18  618  448  454  516  517  518  455  449  612   18   18
   18  430  446  514   13   13   13   13  515  447  429   18   18
   18  620  444  512   13   13   13   13   13  513  445  610   18
   18  434  510   13   13   13   13   13   13  511  435   18   18
   18  420  456   13   13   13   13   13   13   13  457  421   18
   18  434  508   13   13   13   13   13   13  509  435   18   18
   18  622  443  506   13   13   13   13   13  507  441  608   18
   18  424  442  504   13   13   13   13  505  440  425   18   18
   18   18  624  437  458  501  502  503  459  439  606   18   18
   18   18   18  426  460  436  453  438  427   18   18   18   18
   18   18   18   18   18  602  428  604   18   18   18   18   18
   18   18   18   18   18   18   18   18   18   18   18   18   18
   18   18   18   18   18   18   18   18   18   18   18   18   18
   18   18   18   18  461  498  499  500  462   18   18   18   18
   18   18   18  492  493  494  495  496  497   18   18   18   18
   18   18   18  490  487   13   13   13  488  491   18   18   18
   18   18  486  487   13   13   13   13  488  489   18   18   18
   18   18  463  484   13   13   13   13   13  485  464   18   18
   18   18  480  477   13   13   13   13  478  483   18   18   18
   18   18   18  476  477   13   13   13  478  479   18   18   18
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   18   18   18  470  471  472  473  474  475   18   18   18   18
   18   18   18   18  465  467  468  469  466   18   18   18   18
   18   18   18   18   18   18   18   18   18   18   18   18   18
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   18   18   18   18  530  531  532  533   18   18   18   18   18
   18   18   18   18  528  534  535  536  529   18   18   18   18
   18   18   18  528  537   13   13  538  529   18   18   18   18
   18   18   18  526  539   13   13   13  540  527   18   18   18
   18   18   18  524  541   13   13  542  525   18   18   18   18
   18   18   18   18  524  543  544  545  525   18   18   18   18
   18   18   18   18  520  521  522  523   18   18   18   18   18
   18   18   18   18   18   18   18   18   18   18   18   18   18
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   18   18   18   18   18   18   18   18   18   18   18   18   18
   16   16   16   16   16   16   16   16   16   16   16   16   16
   16   16   16   16   16   16   16   16   16   16   16   16   16
   16   16   16   16   16   16   16   16   16   16   16   16   16
   16   16   16   16   16   16   16   16   16   16   16   16   16
   16   16   16   16   16  546  547  548   16   16   16   16   16
   16   16   16   16  549  558  559  550   16   16   16   16   16
   16   16   16   16  551  560   11  561  552   16   16   16   16
   16   16   16   16  553  562  563  554   16   16   16   16   16
   16   16   16   16   16  555  556  557   16   16   16   16   16
   16   16   16   16   16   16   16   16   16   16   16   16   16
   16   16   16   16   16   16   16   16   16   16   16   16   16
   16   16   16   16   16   16   16   16   16   16   16   16   16
   16   16   16   16   16   16   16   16   16   16   16   16   16
 end fill
'-----------------------------------------------------------------------------
' cylindrical section of the discharge tube (region 6 in Fig. 3.3)
'                                              388.764cm -  495.0cm
'-----------------------------------------------------------------------------
ara=3 nux=13 nuy=13 nuz=12 typ=shexagonal
 fill
   17   17   17   17   17   17   17   17   17   17   17   17   17
   17   17   17   17   17   17   17   17   17   17   17   17   17
   17   17   17   17   17   17   17   17   17   17   17   17   17
   17   17   17   17   17   17   17   17   17   17   17   17   17
   17   17   17   17   17   17  564   17   17   17   17   17   17
   17   17   17   17  565  570  571  566   17   17   17   17   17
   17   17   17   17   17  572   12  573   17   17   17   17   17
   17   17   17   17  567  574  575  568   17   17   17   17   17
   17   17   17   17   17   17  569   17   17   17   17   17   17
   17   17   17   17   17   17   17   17   17   17   17   17   17
   17   17   17   17   17   17   17   17   17   17   17   17   17
   17   17   17   17   17   17   17   17   17   17   17   17   17
   17   17   17   17   17   17   17   17   17   17   17   17   17
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   18   18   18   18   18   18  576   18   18   18   18   18   18
   18   18   18   18  577  582  583  578   18   18   18   18   18
   18   18   18   18   18  584   13  585   18   18   18   18   18
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| 18 | 18 | 18 | 18 | 579 | 586 | 587 | 580 | 18 | 18 | 18 | 18 | 18 |
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   18   18   18   18   18   18  576   18   18   18   18   18   18
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   19   19   19   19   19   19  588   19   19   19   19   19   19
   19   19   19   19  589  594  595  590   19   19   19   19   19
   19   19   19   19   19  596   14  597   19   19   19   19   19
   19   19   19   19  591  598  599  592   19   19   19   19   19
   19   19   19   19   19   19  593   19   19   19   19   19   19
   19   19   19   19   19   19   19   19   19   19   19   19   19
   19   19   19   19   19   19   19   19   19   19   19   19   19
   19   19   19   19   19   19   19   19   19   19   19   19   19
   19   19   19   19   19   19   19   19   19   19   19   19   19
 end fill
'-----------------------------------------------------------------------------
end array
'-----------------------------------------------------------------------------
' source (start) data
'-----------------------------------------------------------------------------
read start
 nst=0
 xsm=-90
 xsp=90
 ysm=-90
 ysp=90
 zsm=228.244
 zsp=388.764
end start
'-----------------------------------------------------------------------------
' volume data
'-----------------------------------------------------------------------------
read volume
  type=random
  batches=1000
  points=1000000
end volume
'-----------------------------------------------------------------------------
end data
end
'=============================================================================
'end of model
'=============================================================================
```

**NRC FORM 335** **U.S. NUCLEAR REGULATORY COMMISSION**
**(12-2010)**
**NRCMD 3.7**

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3. DATE REPORT PUBLISHED

| MONTH | YEAR |
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| July | 2012 |

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10. SUPPLEMENTARY NOTES

n/a

11. ABSTRACT *(200 words or less)*

This report documents verification and validation studies carried out to assess the performance of the SCALE code system methods and nuclear data for modeling and analysis of High Temperature Gas-Cooled Reactor (HTGR) configurations. Validation data were available form the International Handbook of Evaluated Reactor Physics Benchmark Experiments, IRPhE, prepared by the International Reactor Physics Experiment Evaluation Project, for two different HTGR designs: prismatic and pebble bed. SCALE models have been developed for HTTR, a prismatic fuel design reactor operated in Japan and HTR-10, a pebble bed reactor operated in China. The models were based on benchmark specifications included in the 2009, 2010 and 2011 releases of the IRPhE Handbook. SCALE models for the HTR-PROTEUS pebble bed configuration at the PROTEUS critical facility in Switzerland have also been developed, based on benchmark specifications included in a 2009 IRPhE draft benchmark. The development of the SCALE models has involved a series of investigations to identify particular issues associated with modeling the physics of HTGRs and to understand and quantify the effect of particular modeling assumptions on calculation-to-experiment comparisons.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

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14. SECURITY CLASSIFICATION

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unclassified

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15. NUMBER OF PAGES

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