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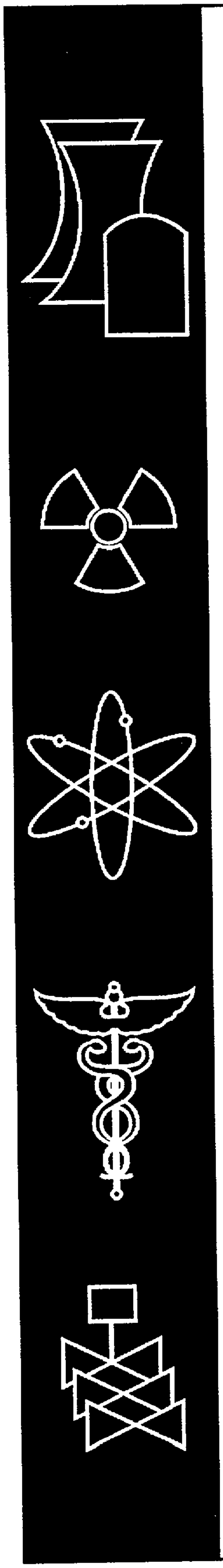

# Validation of SCALE Sequence CSAS26 for Criticality Safety Analysis of VVER and RBMK Fuel Designs

State Nuclear Regulatory Committee of Ukraine

U.S. Nuclear Regulatory Commission
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# Validation of SCALE Sequence CSAS26 for Criticality Safety Analysis of VVER and RBMK Fuel Designs

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# Abstract

This report describes the input data and results from numerical modeling of critical experiments with fuel assemblies typical of RBMK-1000 and VVER-1000 reactors. The primary purpose for performing these benchmark analyses was to check how the accuracy of calculation results for the multiplication factor and power distribution for these experimental assemblies varies with the different multi-group libraries included in the SCALE standard code package, as well as the extent to which that accuracy depends on different ways of preparing the working libraries. This benchmarking activity establishes the calculational bias that can be expected when using the SCALE code package to evaluate fuel assemblies for the VVER-1000 and RBMK-1000 reactors and the safety analysis of actions at the Chornobyl Shelter.

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# Acknowledgments

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# Acronyms and Abbreviations

| | |
|---|---|
| 3-D | three-dimensional |
| BWR | boiling water reactor |
| CE | calculation/experimental |
| CR | control rod |
| CSAS | criticality safety analysis sequence |
| EALF | energy of the average lethargy causing fission |
| FA | fuel assembly |
| IAEA | International Atomic Energy Agency |
| $k_{eff}$ | effective multiplication factor |
| LAW | Library to Analyze radioactive Waste |
| LWR | light-water-reactor |
| MCNP | Monte Carlo N-particle |
| NPP | nuclear power plant |
| ORNL | Oak Ridge National Laboratory |
| PHYBER | KAB GmbH, Germany |
| PWR | pressurized water reactor |
| RBMK | Reaktor Bolshoi Mochnosti Kanalynyi |
| SCALE | Standardized Computer Analyses for Licensing Evaluation |
| SSTC NRS | State Scientific and Technical Center for Nuclear and Radiation Safety |
| $UO_2$ | uranium dioxide |
| USL | upper safety limit |
| VVER | Vodo-Vodyanoi Energetichesky Reaktor |

# 1 Introduction

The SCALE computer code system (Ref. 1) from Oak Ridge National Laboratory (ORNL) is used frequently for licensing-related safety analyses of storage and transport systems for nuclear fuel from VVER and RBMK reactors. Until now, insufficient information was available concerning the applicability of the SCALE code package for criticality calculations of systems with the fuel of such reactors. Consequently, it was necessary to conduct benchmark testing using experimental results.

The Ukrainian Regulatory Authority is considering the use of SCALE for two specific licensing-related projects under way in Ukraine:

- the Chornobyl Shelter – Researchers have hypothesized that the Shelter contains mixtures composed of fragments of fuel and moderator (water and/or graphite) or even of single fragments of core. Experiments from the RBMK critical facility presented for such systems are representative of the neutron and physical characteristics of the processes progressing within the Shelter.

- Chornobyl nuclear power plant (NPP) - Under decommissioning of Chornobyl NPP, the SCALE code package could be used for expert assessment of the sequence for unloading the fuel assemblies from the core and changes in sub-criticality level during this work.

Both projects involve complex systems containing fuels of different enrichment and different kinds of neutron moderators (water, graphite). The SCALE user's manual strongly recommends validating the code package's applicability and accuracy for use with such systems.

Experiments performed previously at a facility in the Czech Republic measured the relative power density distribution between fuel elements under reactor critical conditions. With these experimental data, it is possible to evaluate the error of effective multiplication factor ($k_{eff}$) calculations for a research reactor containing fuel assemblies similar to those of a VVER-1000 reactor. On the other hand, the data also are useful for estimating the accuracy of the spatial distribution of power density determined under these core conditions. We are interested in the latter information for several reasons:

- This information may be used to establish a correlation between accuracy of the $k_{eff}$ determination and that of the spatial distribution of neutron flux densities. When accuracy of the $k_{eff}$ determination in the critical condition is known, then it is possible to correlate the accuracy of the calculation to that of the spatial distribution of neutron flux densities or power density.

- With this information, the SCALE code package may be used as a precise computer code to estimate the accuracy of spatial distribution of sources of fast neutrons used by the other programs for physical calculation of the reactor, including calculating the neutron fluence on the reactor pressure vessel.

- Accuracy of spatial distribution identification with respect to burnup enables estimation of the acceptability of SCALE multigroup neutron cross-section libraries for calculations related to VVER or RBMK reactors, with their differences in neutron spectra as compared to spectra of the Western-type reactors.

The Czech measurements of power density distributions between fuel elements in VVER-1000 fuel assemblies are not direct critical experiments that can be used for testing the calculational accuracy of the neutron multiplication factor. In terms of neutron multiplication factor, only one experiment was conducted to measure that factor. However, modeling of such differential characteristics as power density per fuel element enabled us to test more refined capabilities of the SCALE 4.3 program; that accurate modeling (accuracy of the $k_{eff}$ determination depends upon accuracy of the neutron flux density spatial distribution) can serve as indirect confirmation of accurately calculating such an integral characteristic as coefficient of neutron multiplication. In addition, the calculations performed revealed certain limitations of SCALE 4.3 for modeling complex systems with VVER-1000 fuel assemblies, indicating that SCALE 4.4a is preferable for such calculations. The results presented here represent a continuation and further development of the work carried out previously in a project conducted for the International Atomic Energy Agency (IAEA, Ref. 2).

Within the framework of this project, experimental data were compared with the results of calculations obtained through diffusion and Monte Carlo programs. For diffusion calculation of relative power distribution per fuel element, the calculating complex PHYBER (KAB GmbH, Germany) was used. Previously, PHYBER was widely applied by specialists at the State Scientific and Technical Center for Nuclear and Radiation Safety (SSTC NRS) as part of its efforts to license fuel loading for VVER-440 and VVER-1000 reactors at Ukrainian NPPs. For comparison, new results of diffusion calculations are presented together with the experimental data in Section 9 of this report.

Experimental data presented in this report were collected mainly from two sources. The experimental results for the RBMK-1000 fuel assemblies were obtained at the RBMK critical facility at the Russian Research Center Kurchatov Institute (Ref. 3).

Experimental data for the VVER-1000 were obtained at the LR-0 Mock-Up in the Nuclear Research Institute Řež, Czech Republic. These data were collected and processed during the previous IAEA project (Refs. 2, 4).

# 2 RBMK-1000 Fuel Elements

One of the principal distinguishing characteristics of an RBMK reactor is that each fuel assembly is housed in the core within an individual pressure tube. The RBMK core contains fueled channels separated from their nearest neighbors by the walls of the pressure tubes and graphite blocks. Each pressure tube has considerable autonomy. For example, the coolant flow rate to the tube is controlled online by an individual control valve, and additional valves make it possible to de-couple it from the primary cooling system while the reactor is in operation. This makes it possible to change fuel clusters online and also has a significant impact on the potential consequences of loss-of-coolant accidents (Refs. 5-7).

## 2.1 Fuel Assembly

The nuclear fuel used in an RBMK is slightly enriched uranium in the form of uranium dioxide ($UO_2$). This is a chemically stable and heat-resistant ceramic material. It is prepared in powdered form, pressed into small pellets 11.5 mm in diameter and 15 mm long, and sintered in the presence of a binder. The pellet shape is adapted to an intensive, high-temperature operating mode. For example, the pellets have hemispherical indentations to reduce the fuel column's thermal expansion and thermal mechanical interaction with the cladding (Figure 2.1).

The pellets are placed into a tube with an outside diameter of 13.6 mm, a wall thickness of 0.825 mm, and an active length of 3.4 m. Tube material is an alloy of zirconium with 1% niobium. This alloy has good anticorrosive properties and a low neutron absorption coefficient. The initial clearance between the $UO_2$ pellets and the wall of the tube varies from about 0.22 to 0.38 mm.

The tubes are pressurized with helium at 0.5 MPa and sealed. In the radial direction, retaining rings, which help to withstand the pressure of the fuel channel and improve the heat transfer from the pellet to the zirconium tube, augment the fuel clad. In the axial direction, the fuel pellets are held in place by a spring.

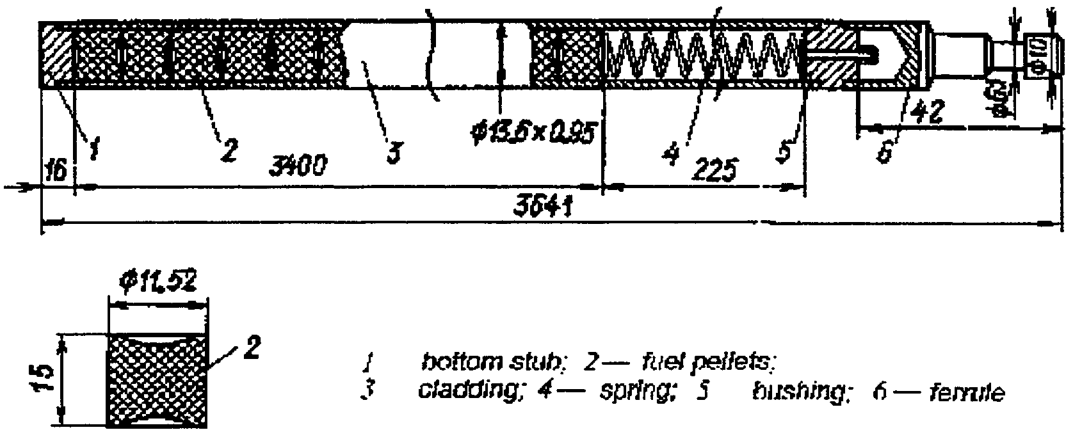


Figure 2.1 Fuel Pin

At this stage, the RBMK reactor fuel differs a little from the analogous fuel elements manufactured for the widely prevalent boiling water reactors (BWRs). For example, a typical BWR fuel tube in the United States also is manufactured of zirconium-niobium alloy and has a similar wall thickness and an outside diameter ranging from 12 to 13.5 mm. The uranium enrichment also is similar, namely, 2% to 2.4% for the RBMK and 2.2% to 3% in the case of the BWR. Greater differences arise only when the fuel elements are mounted into a structurally integral fuel assembly (or fuel cluster). The shape of the assembly is determined by the geometric characteristics of the core fuel channel. In the BWR, this results in a square (usually 8 x 8) fuel cluster that fits into the square core spaces between the control rod blades. For an RBMK reactor, the fuel assembly must fit into a circular channel having an inside diameter of 80 mm and an active core height of 7 m. To achieve the required height, two fuel elements must be joined end-to-end. The radial spatial restriction determines the arrangement and the number of the fuel rods that can fit into a fuel assembly.

The principal features of a fuel assembly are represented schematically in Figure 2.2. The assembly contains 18 fuel elements arranged within two concentric rings in a central carrier rod, which is a 15-mm-diameter tube with a 1.25-mm wall thickness; the central carrier rod is made of a zirconium (2.5% niobium) alloy. The complete fuel assembly consists of two segments joined by a sleeve (7) at the central plane. Thus, along the axis of the core, there is a region in which fission does not occur. This generates a flattening of the fast neutron flux and a dip of the thermal neutron flux at this location and influences the neutron kinetic characteristics of the core.

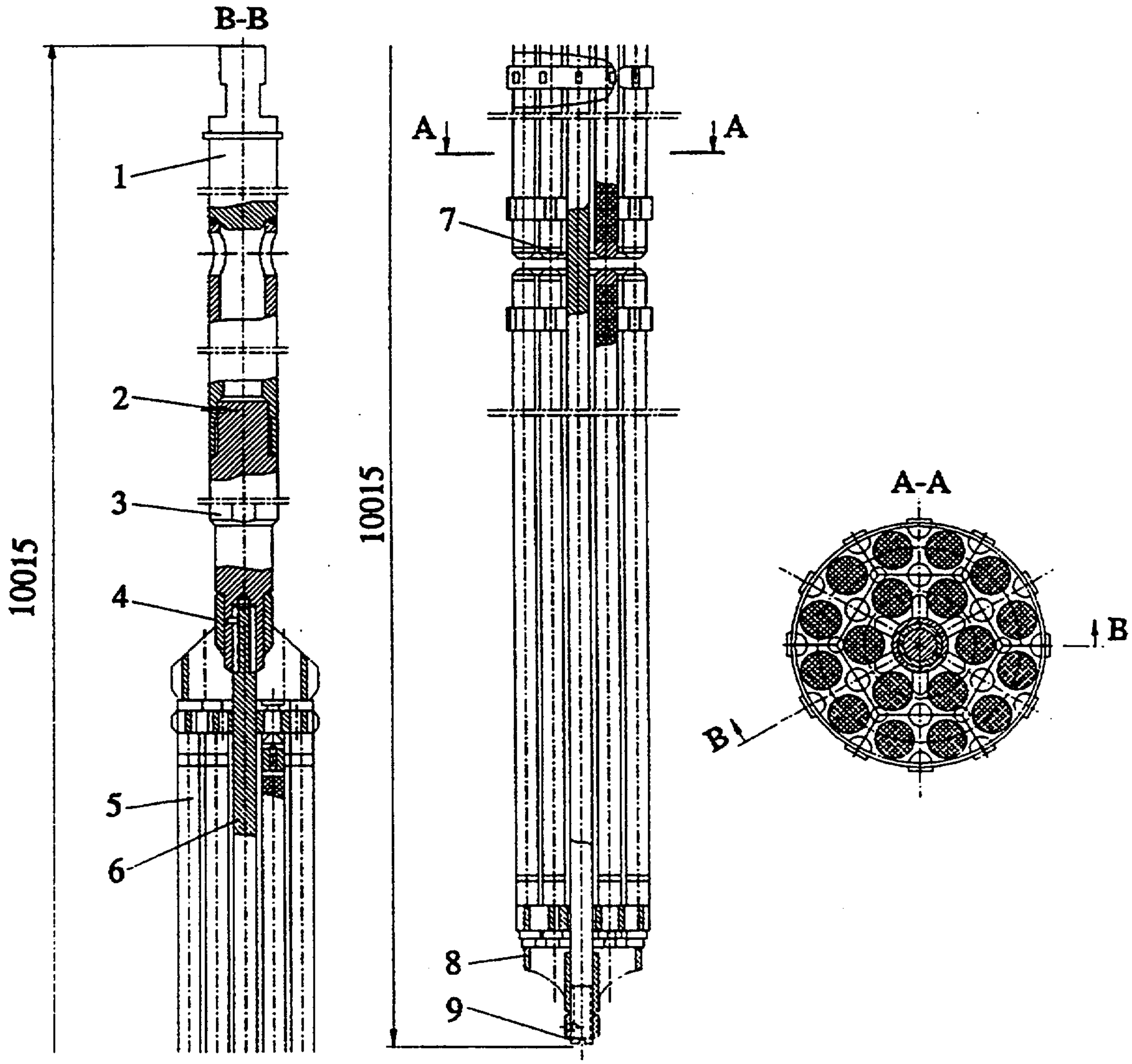
The lower segment of the fuel assembly is provided with an end grid and ten spacing grids. The central tube and the end spacer also are made of the zirconium alloy. The remaining spacers are made of stainless steel, rigidly fixed (welded) to the central tube and positioned 360 mm apart. The fuel tubes are mounted so that axial expansion of the upper or lower segments occurs toward the center of the core.

For ease of manipulation, the fuel assembly is provided with appropriate fittings at both ends. The principal technical parameters of the fuel assemblies are summarized in Table 2.1.

## 2.2 Fuel Channel

The top, center, and bottom segments of a typical reactor fuel channel are shown schematically in Figure 2.3. The main component of the channel is the coolant-carrying tube constructed from separate end and center segments. The center segment (10) is an 88-mm-outside-diameter (4-mm-thick wall) tube, made of a zirconium-niobium alloy (Zr+2.5%Nb). The top (3) and bottom (12) segments are made of a stainless steel tube. The choice of zirconium-niobium for the center part was based on the relatively low thermal neutron absorption cross section of the material and its adequate mechanical and anti-corrosive properties at high temperatures (up to 350°C). The center and end pieces are joined by special intermediate couplings made of a steel-zirconium alloy.

The fuel channel tubes are set into the circular passages, which consist of the aligned central openings of the graphite blocks and the stainless steel guide tubes of the top and bottom core plate structures. The channel tubes are welded to the top (2) and bottom (11) metal-structure plates to hermetically seal the core region. The tube is welded to a support ledge (4) at the top and, at the bottom, to the guide tube of



*1 - suspension bracket, 2 - top plug, 3 - adapter, 4 - connecting rod, 5 - fuel element, 6 - carrier rod, 7 - end sleeve, 8 - endcap, 9 - retaining nut*

**Figure 2.2 Fuel Assembly**

the metal structure (11). A bellows (13) is used to compensate for the differences in thermal expansion between the reactor metal core plates and the fuel channel. The design life of the channel tube is about 20 to 25 years. If necessary, the channel tube can be replaced by removing the top and bottom welds.

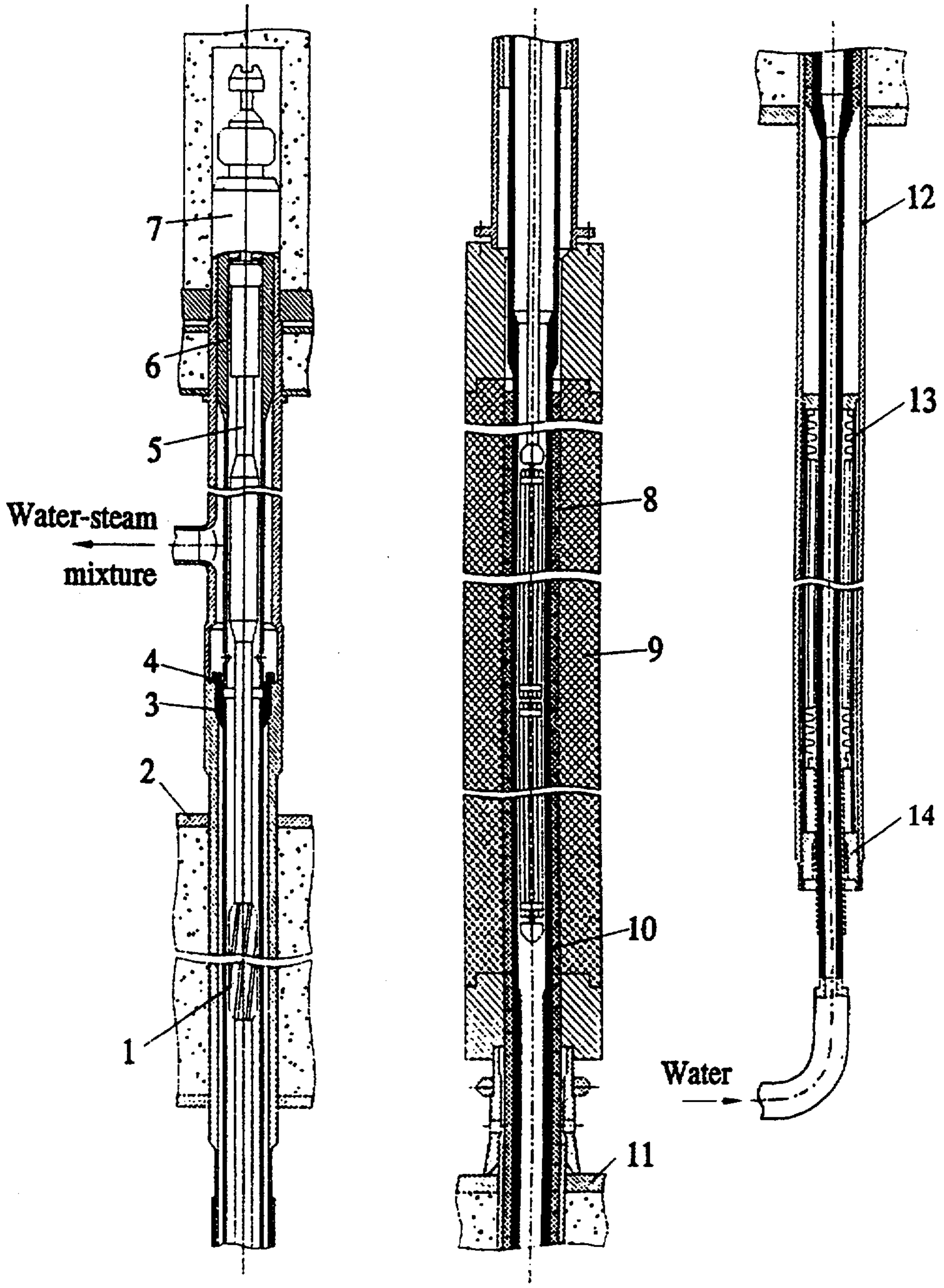
The fuel coolant tubes also provide cooling for the energy deposited in the graphite moderator of the core region. To improve heat transfer from the graphite stack, the central segment of the fuel channel is surrounded by the 20-mm-high split graphite rings (8). These rings are arranged next to one another in such a manner that one is in contact with the channel and the other with the graphite stack block. The

## Table 2.1 RBMK-1000 Core Elements

| | |
|---|---|
| **Fuel pin** | |
| Active length of fuel pin (height of fuel pellet column in cold state) | 3400 mm |
| Pellet | $UO_2$ |
| Outer radius | 0.575 cm |
| Length of fuel element | 3.64 m |
| Active length of fuel element | 3.4 m |
| Maximum fuel temperature | 2100°C |
| **Fuel pin cladding** | |
| Inner radius | 0.5975 cm |
| Outer radius | 0.68 cm |
| Density | 6.45157 g/cm$^3$ |
| Composition | Zr - 98.97, Nb - 1, Hf - 0.03 wt% |
| Central tube | |
| Inner radius | 0.625 cm |
| Outer radius | 0.75 cm |
| Density | 6.45157 g/cm$^3$ |
| Composition | Zr – 97.47, Nb - 2.5, Hf – 0.03 wt% |
| **Fuel assembly** | |
| Number of segments per fuel assembly | 2 |
| Number of fuel pins per segment | 18 |
| Total length of fuel assembly, m | 10.015 |
| Active length of fuel assembly, m | 6.862 |
| Mass of fuel assembly without bracket, kg | 185 |
| Total mass of fuel assembly with the bracket, kg | 280 |
| Total steel mass within fuel assembly, kg | 2.34 |
| Total mass of zirconium alloy within fuel assembly, kg | 40 |
| Mass of uranium per fuel assembly, kg | 114,7 |
| Enrichment | 2.0, 2.4 |
| Maximum burnup | 2800 MW day/FA (24.4 MW day/kgU) |
| **Spacer grid** | |
| Thickness | 2.0 cm |
| Composition | Steel |
| Weight | 0.7 kg |
| Core | |
| Type | Square-pitch (quadratic) lattice |
| Assembly pitch | 25 cm |
| Number of core channels (core graphite blocks) | 1884 |
| Moderator | Graphite |
| Average moderator temperature | 650°C |
| Coolant | $H_2O$ |
| Power | 3000 MW (thermal) |

minimum clearance between the fuel channel and the graphite ring is 1.3 mm; between the ring and the graphite stack, the clearance is 1.5 mm. These clearances prevent compression of the fuel channel tube due to radiation and/or thermal expansion of the graphite stack.

Fuel channels described in this section also may contain supplementary absorbers. In addition, they may be devoid of structural elements and be filled only with cooling water.



*1 - steel biological shield plug, 2,11 - top and bottom metal structures, respectively, 3 - top part of the fuel channel, 4 - welding-support ledge, 5 - fuel assembly support bracket, 6 - encasement cylinder, 7 - seal plug, 8 - graphite cylinder, 10- central part of the channel, 12 - bottom part of the channel, 13 - thermal expansion bellows compensator, 14 - stuffing box, 9 - graphite stack*

**Figure 2.3 Fuel Channel**

# 3 RBMK Critical Facility

During the period 1984 through 1986 at the RBMK critical facility in the Kurchatov Institute, several experiments were conducted on the criticality evaluation of neutron multiplying systems based on RBMK fuel elements (Ref. 3). An important feature common to all of these experimental configurations of the RBMK reactor is the presence of two moderating materials in the core: water and graphite. Differences among the experimental configurations included the absence of fuel and/or water in specific graphite channels as well as variations in fuel enrichment and the position and number of control rods.

## 3.1 Mock-Up Arrangement

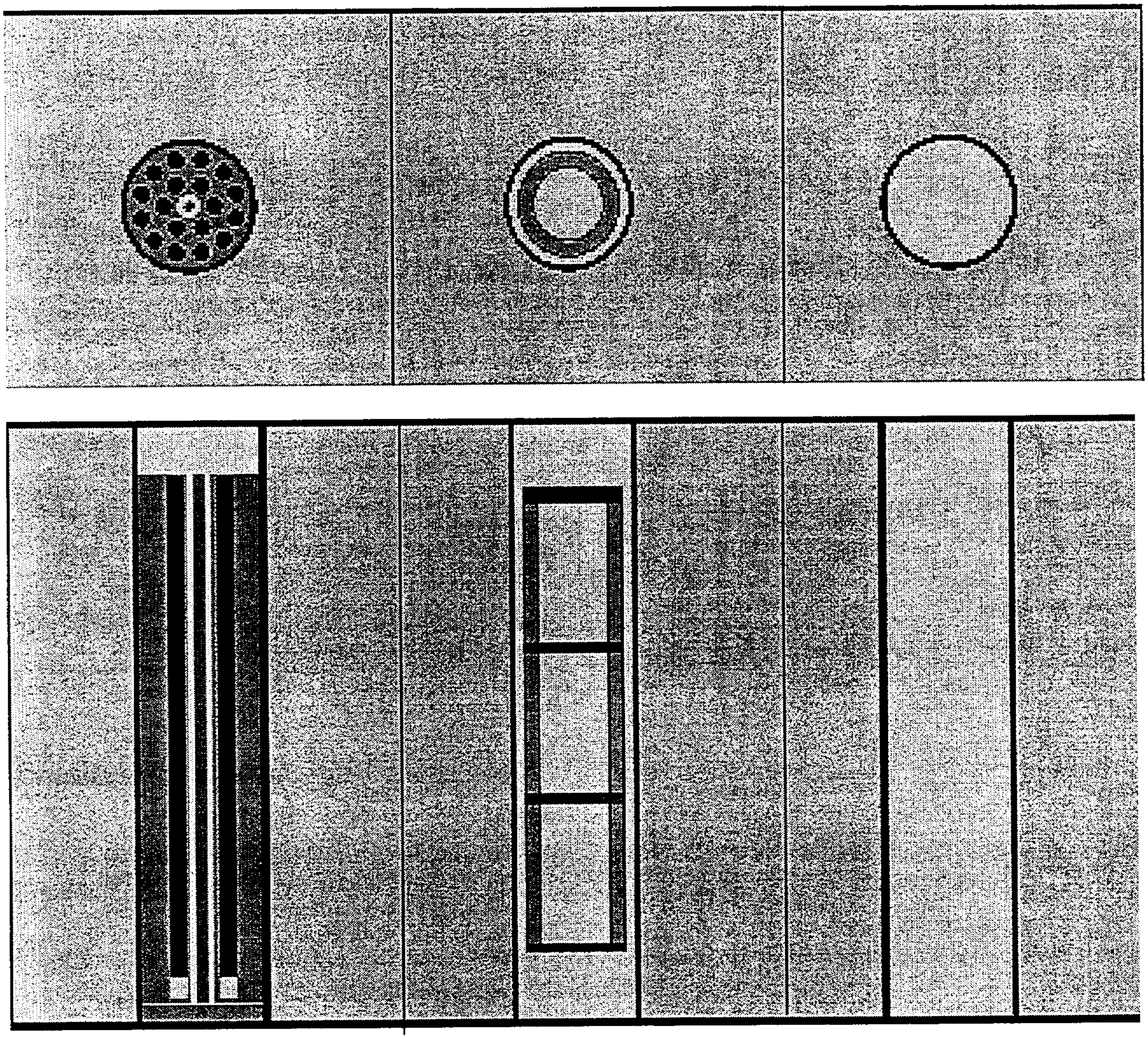
The graphite stack of the RBMK mock-up is assembled from rectangular parallelepiped blocks, with a base of 25 x 25 cm, height of 410 cm, and central vertical annular holes 8.9 cm in diameter. In the x-y plane, the graphite stack is represented by a rectangular lattice of 324 channels (18 x 18). The stack holes are used for the placing of channel tubes with an external diameter of 8.8 cm, an inner diameter of 8.0 cm, and a length of 410 cm. In experiments, some channel tubes are loaded with fuel assemblies or control rods similar to those of an RBMK reactor core. A schematic view of the main mock-up elements (channel with fuel assembly, channel with control rod, and unloaded channel) is shown in Figure 3.1. Dimensions and material composition of some parts of these elements are presented in Tables 3.1 and 3.2.

The height of the mock-up core is equal to the common height of fuel in the fuel pins (346 cm). Upper and lower graphite reflectors are 32.8 cm and 31.2 cm, respectively. The unloaded channel surrounding the channel with a fuel assembly serves as a radial reflector; its dimension depends on the arrangement of the mock-up core. Some channels may be filled with water; the water level is always the same and stands 1 to 2 cm above the core fuel level.

The mock-up fuel assembly contains 18 fuel pins arranged within two concentric rings in a central carried rod, which is a zirconium alloy tube. This tube and fuel pins, with the help of upper and bottom restriction elements as well as 10 distance grids (with a common mass of 510 g per assembly), are mounted into a structurally integral fuel assembly. The nuclear fuel used in the mock-up is slightly enriched uranium in the form of uranium dioxide powdered pellets, 1.152 cm in diameter, which are placed into a cladding tube between upper and bottom end elements (the same way as in an RBMK reactor).

Additional absorber can be loaded via a hermetically sealed carrying pipe (with end-fitting stubs) in which absorbing bushings are placed. When being loaded into the channel, additional absorber is placed symmetrically with respect to the center of the graphite stack.

The control rod consists of three equal sections, each of which has a central absorption part and end-fitting details (Figure 3.1). The absorption part consists of two coaxial pipes between which absorbing bushings are placed. At full insertion, the control rod lower edge is placed at 157.7 cm below the center of the graphite stack. A completely withdrawn control rod is placed at 12 cm (from upper edge of graphite). Channels with control rods are not filled with water.



**Fuel Assembly (FA)** **Control Rod (CR)** **Unloaded Channel**

**Figure 3.1 Calculation Model of Main Mock-Up Elements**

The control rod imitator also has a three-section structure with the same radial sizes as the control rod itself. However, there are several differences as to the length of sections and connecting details. The control rod imitator is fixed in the channel: its top level is at 162.8 cm with respect to the center of the graphite stack. Channels with control rod imitators can be filled with water, which passes into the internal cavity. Water does not fill the space between pipes where absorbing bushings are placed.

**Table 3.1 Dimensions of Main Mock-Up Elements**

| Element | Dimension, cm | Element | Dimension, cm |
|---|---|---|---|
| Central tube of fuel assembly: | | Control rod: | |
| Outside diameter | 1.5 | Length of absorber section | 96.2 |
| Inside diameter | 0.65 | Length of couple section | 07.5 |
| Length | 365.00 | Length of upper elements | 11.7 |
| | | Length of bottom elements | 06.0 |
| Fuel pins: | | | |
| Radius of centers for 6 inner pins | 1.6 | Control rod imitator: | |
| Radius of centers for 12 external pins | 3.1 | Length of absorber section | 98.4 |
| Length | 364.0 | Length of couple section | 04.8 |
| Length of upper elements | 0.8 | Length of upper elements | 09.8 |
| Length of bottom elements | 2.7 | Length of bottom elements | 05.0 |
| Fuel pins cladding: | | External cladding tube of control rod and control rod imitator: | |
| Outside diameter | 1.363 | Outside diameter | 07.0 |
| Inside diameter | 1.170 | Inside diameter | 06.6 |
| Length | 361.300 | | |
| | | Inner cladding tube of control rod and control rod imitator: | |
| Central tube of additional absorber: | | Outside diameter | 05.0 |
| Outside diameter | 5.0 | Inside diameter | 04.6 |
| Inside diameter | 4.4 | | |
| Length | 365.0 | Absorber tube of control rod and control rod imitator: | |
| | | Outside diameter | 6.565 |
| Absorb bushings of additional absorber: | | Inside diameter | 5.045 |
| Outside diameter | 5.9 | | |
| Inside diameter | 5.3 | | |
| Length | 350.0 | | |

## 3.2 Experiment Description

### 3.2.1 Critical Assembly 1

The assembly loading scheme is shown in Figure 3.2. It consists of 18 fuel assemblies (FAs) with 2% enriched fuel. All channels with a fuel assembly were filled with water. Average mass of $^{235}$U was 1149.9 g/FA. Average uranium mass was 57479 g/FA. Criticality was achieved when all control rods were inserted to the depth of 2.5 m from zero position.

Experiment 1-1. Reactivity measured after full withdrawal of control rods P6-13, P12-7, and P12-13. Control rod P6-7 was inserted 2.5 m. Measured reactivity was $\rho = 1.633E-3$.

## Table 3.2 Material Composition of Main Mock-Up Elements

| No. | Element | Density, g/cm$^3$ | Main elements of composition, Weight % |
|---|---|---|---|
| 1 | Graphite stack | 1.7 | C>99.99, H=0.0011, O=0.0018, N=0.0004, Si=0.0007, Cd<0.0003 |
| 2 | Channel tubes | 2.15 | Al>95.7, Mg<0.9, Si<1.2, Cu<1.0, Mn<0.35, Fe<0.5, Zn<0.2, Ti=0.15 |
| 3 | Absorber of control rods and control rod imitator | 1.65 | $B_4C$, with natural boric composition |
| 4 | Control rods and control rod imitator tubes and couple elements | 2.7 | Al>97.8, Mg=0.45–0.9, Si=0.6-1.2, Cu<1.0 |
| 5 | Fuel pin cladding | 6.55 | Hf<0.04, Nb=1.0, Fe=0.018, Ni=0.011, Al=0.0046, Zr>98.832 |
| 6 | Central tubes of fuel assembly | 6.55 | Hf<0.04, Nb=2.5, Fe=0.018, Ni=0.011, Al=0.0046, Zr>97.332 |
| 7 | Distance grid | 7.8 | Cr=18, Ni=10, Ti=1, C=0.06, Fe=70.994 |
| 8 | Additional absorber | 7.6 | Cr=18.7, Ni=34, Si=2.55, C=0.009, Al=2.25, B=2.0, Fe=40.491 |
| 9 | Central tube of additional absorber | 7.8 | Cr=18, Ni=10, Ti=1, C=0.12, Fe=70.88 |

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P18 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P17 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P16 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P15 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P14 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P13 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P12 |  |  |  |  |  |  | CR |  |  |  |  |  | CR |  |  |  |  |  |
| P11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P10 |  |  |  |  |  |  |  | F | F | F | F |  |  |  |  |  |  |  |
| P9 |  |  |  |  |  |  |  | F | F | F | F | F |  |  |  |  |  |  |
| P8 |  |  |  |  |  |  |  | F | F | F | F | F |  |  |  |  |  |  |
| P7 |  |  |  |  |  |  |  | F | F | F | F |  |  |  |  |  |  |  |
| P6 |  |  |  |  |  |  | CR |  |  |  |  |  | CR |  |  |  |  |  |
| P5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Assembly 1**

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P18 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P17 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P16 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P15 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P14 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P13 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P12 |  |  |  |  |  |  | CR |  |  |  |  |  | CR |  |  |  |  |  |
| P11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P10 |  |  |  |  |  |  |  | F | F | F | F |  |  |  |  |  |  |  |
| P9 |  |  |  |  |  |  |  | F | F | F | F |  |  |  |  |  |  |  |
| P8 |  |  |  |  |  |  |  | F | F | F | F | F |  |  |  |  |  |  |
| P7 |  |  |  |  |  |  |  | F | F | F | F | F |  |  |  |  |  |  |
| P6 |  |  |  |  |  |  | CR |  |  |  |  |  | CR |  |  |  |  |  |
| P5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Assembly 2**

CR - Control Rod, F - FA with the fuel of 2% enrichment.

**Figure 3.2 Assemblies 1 and 2**

Reactivity was measured after full withdrawal of control rod P6-7, and control rods P6-13, P12-7, and P12-13 inserted 2.5 m. Measured reactivity was $\rho = 1.278E\text{-}3$.

Estimation of the system reactivity without control rods was defined as the sum of the two effects: $\rho = 2.911E\text{-}3$.

Experiment 1-2. Reactivity effect measured after a change in the system configuration.

The fuel assembly from channel P9-12 was moved into channel P7-12. All channels with fuel assemblies were filled with water. All control rods were withdrawn from the core.

Measured reactivity was ρ = 1.42E-3.

### 3.2.2 Critical Assembly 2

The loading scheme is shown in Figure 3.2. It consists of 18 fuel assemblies (FAs) with fuel of 2% enrichment. All channels with fuel assemblies were filled with water. The average $^{235}$U mass was 1156 g/FA. Average uranium mass was 57636 g/FA. Critical state was unknown.

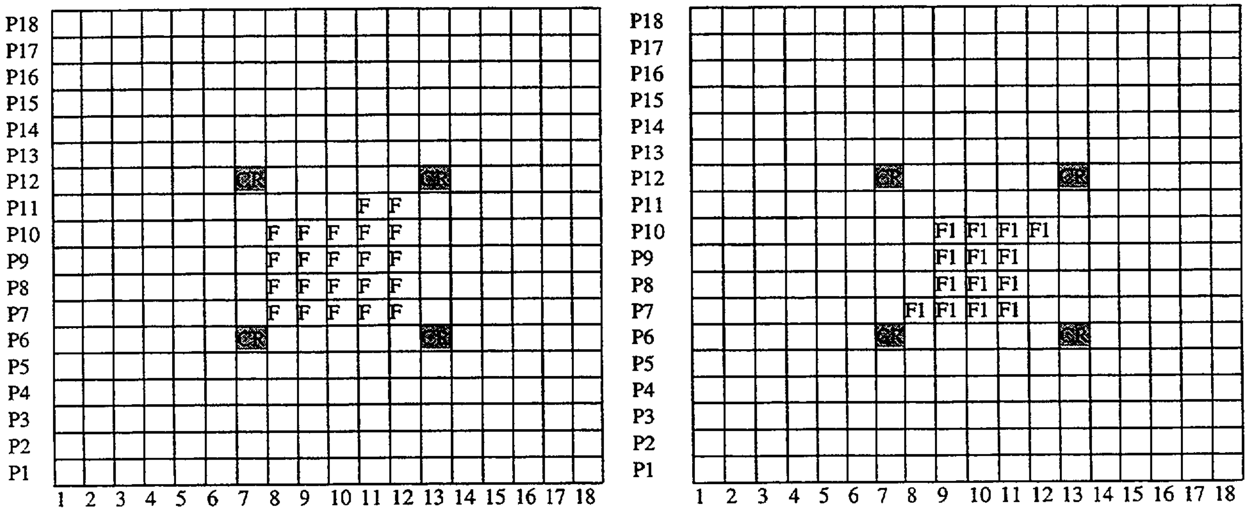
Experiment 2-1. Reactivity measured after full withdrawal of all control rods. Measured reactivity was ρ = 1.349E-3.

Experiment 2-2. Dry fuel assemblies, no control rods.

All fuel assemblies were without water. All control rods were withdrawn from the core. Measured reactivity was ρ = -3.266E-2.

### 3.2.3 Critical Assembly 3

The loading pattern is shown in Figure 3.3. It included 22 fuel assemblies with fuel of 2% enrichment. All assembly channels were without water. Average $^{235}$U mass was 1149.9 g/FA.



**Assembly 3** **Assembly 4**

CR - Control Rod, F - FA with the fuel of 2% enrichment, F1 - FA with the fuel of 2.4% enrichment

**Figure 3.3 Assemblies 3 and 4**

Average uranium mass was 57494 g/FA. In the critical system condition, the control rods in channels P12-7 and P6-13 were inserted to the depth of 2.2 m from the zero position.

Experiment 3-1. System reactivity with completely withdrawn control rods was measured. Experimental result was ρ = 1.633E-3.

### 3.2.4 Critical Assembly 4

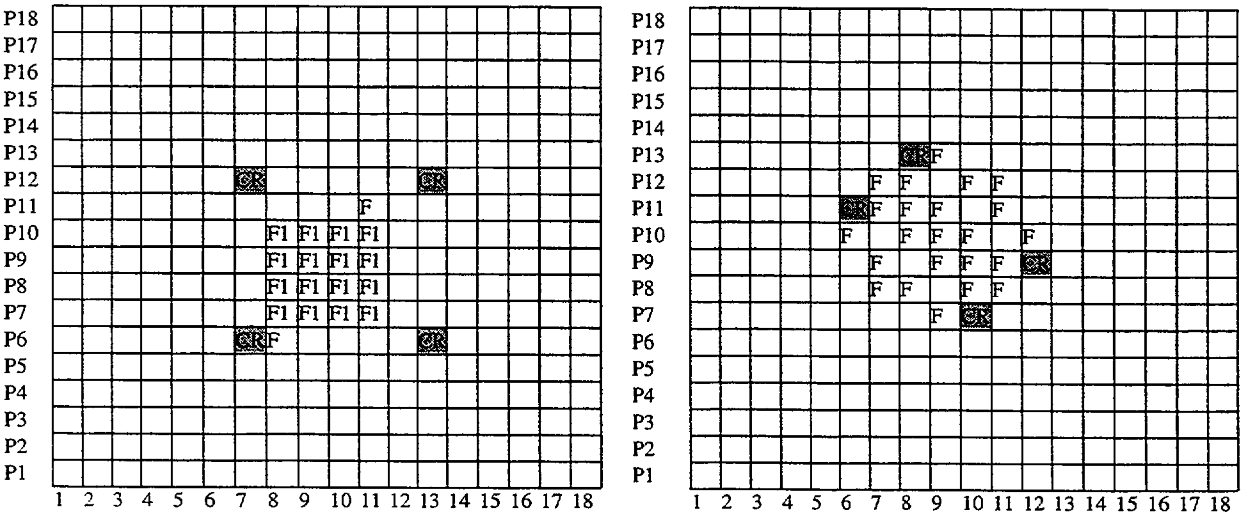
The loading pattern is shown in Figure 3.3. Assembly 4 consists of 14 fuel assemblies with fuel of 2.4% enrichment. All channels with fuel assemblies were filled with water. Average mass of $^{235}$U was 1360 g/FA. Average uranium mass was 56687 g/FA. In the critical system condition, all CRs were inserted to a depth of 2.2 m from the zero position.

Experiment 4-1. System reactivity with completely withdrawn control rods was measured. Experimental result was ρ = 1.633E-3.

Experiment 4-2. Measurement of channel efficiency with fuel assemblies. The fuel assembly from channel P10-12 was withdrawn, and the system reactivity with completely withdrawn control rods was measured at ρ = -8.946E-3.

### 3.2.5 Critical Assembly 5

Assembly 5, shown in Figure 3.4, consists of 16 fuel assemblies with fuel of 2.4% enrichment and 2 fuel assemblies with fuel of 2.0% enrichment (channels P11-11 and P6-8). All assembly channels were



**Assembly 5** **Assembly 6**

CR - Control Rod, F - FA with the fuel of 2% enrichment, F1 - FA with the fuel of 2.4% enrichment

**Figure 3.4 Assemblies 5 and 6**

dry. For fuel assemblies with 2.4% enrichment, the average $^{235}U$ mass was 1356 g/FA. Average uranium mass was 56695 g/FA. For fuel assemblies with 2.0% enrichment, the $^{235}U$ mass was 1160 g/FA (channel P11-11) and 1154 g/FA (channel P6-8). Average uranium mass was 57820 g/FA. In the critical system condition, all control rods were inserted to the depth of 2.2 m from the zero position.

Experiment 5-1. Fuel assembly efficiency with 2.0% enrichment in channel P6-8 was measured. After the fuel assembly in channel P6-8 was removed, system reactivity was measured at $\rho = -7.526E-3$.

Experiment 5-2. Measurements were conducted after all control rods and fuel assemblies were withdrawn from channel P6-8. Measured reactivity was $\rho = -2.698E-3$.

### 3.2.6 Critical Assembly 6

Assembly 6 (Figure 2.4) consists of 23 fuel assemblies with fuel of 2.0% enrichment. The average $^{235}U$ mass was 1156.4 g/FA. Average uranium mass was 57659 g/FA. Critical system conditions were as follows:

1. All channels of assembly were dry. All control rods were inserted 1.2 m deep from the zero position.
2. All channels with fuel assemblies were filled with water. Control rods P13-8 and P7-10 were inserted to 1.5 m deep from the zero position.

Experiment 6-1. All assembly channels were dry. System reactivity was measured with control rods withdrawn. For this purpose, system reactivity measurements were taken under the alternating removal of one of the CRs:

- withdrawn control rod P13-8, $\rho = 8.52E-4$
- withdrawn control rod P7-10, $\rho = 9.94E-4$
- withdrawn control rod P11-6, $\rho = 8.52E-4$
- withdrawn control rod P9-12, $\rho = 10.65E-4$.

Total effect was defined as the summation of the four measurements: $\rho = 3.763E-3$.

Experiment 6-2. All channels with FAs were filled with water. From critical conditions

- withdrawn control rod P7-10, $\rho = 14.2E-4$
- withdrawn control rod P13-8, $\rho = 13.49E-4$

the effect of the system filled with water and all control rods fully withdrawn was $\rho = 2.769E-3$.

### 3.2.7 Critical Assembly 7

Assembly 7, shown in Figure 3.5, consists of 45 fuel assemblies with fuel of 2.0% enrichment and four channels with additional absorber. The average mass of the $^{235}U$ was 1151.5 g/FA. Average uranium mass was 57562 g/FA. Critical state was unknown.

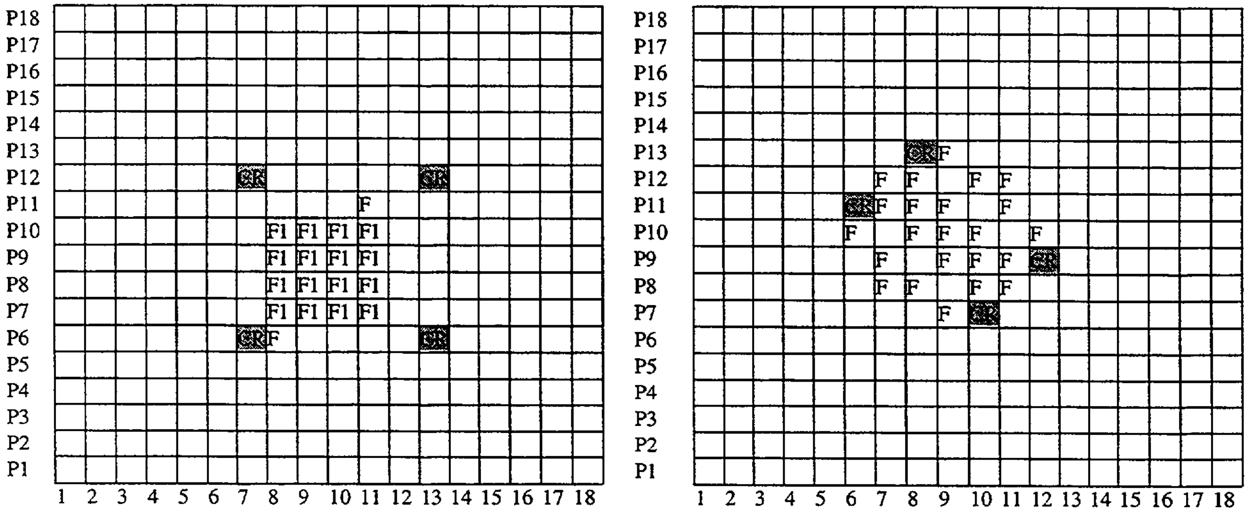
Experiment 7-1. System reactivity with control rods withdrawn was defined. For this purpose, system reactivity under the withdrawal of various control rods was measured:

- control rod P15-10 fully inserted, all the rest withdrawn: $\rho = 14.91E-4$
- control rods P15-10 and P5-8 fully inserted, all the rest withdrawn: $\rho = -2.84E-4$
- control rods P15-10, P5-8, and P11-14 fully inserted, all the rest withdrawn: $\rho = -19.88E-4$
- control rods P5-8 and P11-14 fully inserted, all the rest withdrawn: $\rho = -1.42E-4$.

The total effect of withdrawn control rods was defined as a combination of the four measurements, or $\rho = 3.337E-3$.

Experiment 7-2. The effect of removing water from the system was studied. In the initial state, control rod P7-10 was introduced on the full depth, the other control rods were withdrawn, and $\rho = -9.23E-3$. All 49 channels (45 with fuel assemblies and 4 with additional absorber) were dry; $\rho = -29.82E-3$.

Experiment 7-3. The effect of removing water from four channels with additional absorber was studied. In the initial state, control rod P7-10 was inserted and all the rest were withdrawn; $\rho = -21.3E-3$. The effect of removing water was $\rho = -8.52E-3$.



Assembly 5

Assembly 6

CR - Control Rod, F - FA with the fuel of 2% enrichment, F1 - FA with the fuel of 2.4% enrichment

**Figure 3.5 Assemblies 5 and 6**

### 3.2.8 Critical Assembly 8

Assembly 8 (Figure 3.5) consists of 71 fuel assemblies with 2.0% enriched fuel and 12 channels with additional absorber. Average mass of the $^{235}$U was 1152.4 g/FA. Average uranium mass was 57550 g/FA. All channels with fuel assemblies were filled with water; 12 channels with additional absorber were dry. Critical state was unknown.

Experiment 8-1. System reactivity with control rods withdrawn was defined: $\rho = 1.207E\text{-}3$.

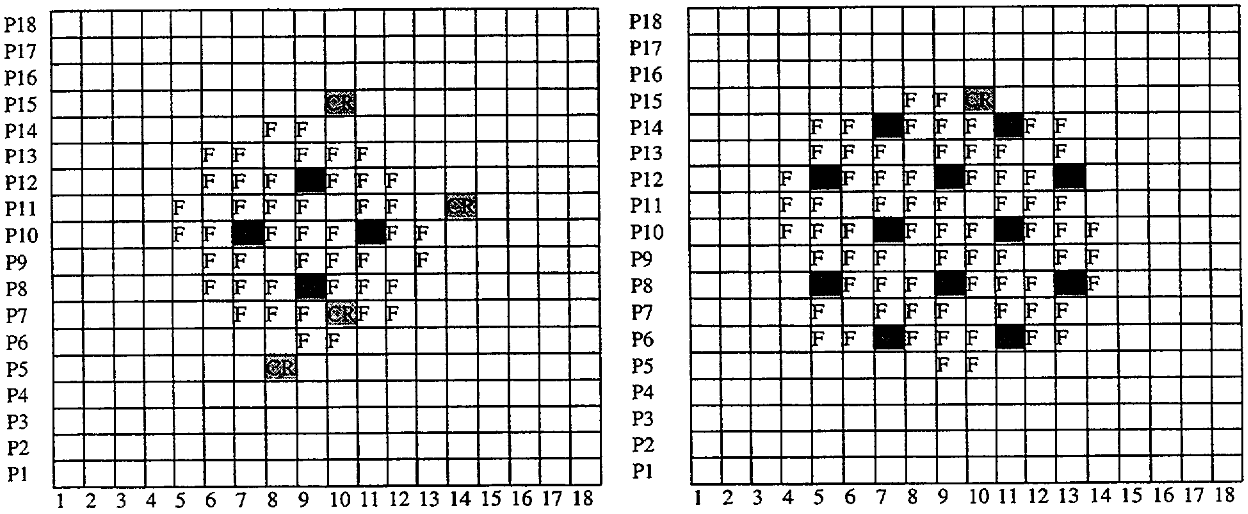
Experiment 8-2. The effect of removing water from the system was studied. In the initial state, control rod P15-10 was introduced on the full depth, the rest were withdrawn, and $\rho = -1.562E\text{-}3$. With all 71 channels with fuel assemblies dry, $\rho = -17.963E\text{-}3$.

### 3.2.9 Critical Assembly 9

Assembly 9, shown in Figure 3.6, consists of 23 fuel assemblies with fuel of 1.8% enrichment. The $^{235}$U average mass was 998 g/FA. Average uranium mass was 55716 g/FA. All channels with fuel assemblies were filled with water. An additional fuel assembly with 1.8% enrichment was inserted in dry channel P11-9. In the critical condition, control rods P6-7, P6-13, P12-7, and P12-13 were introduced on the depth 3.2 m from the zero position.

Experiment 9-1. After withdrawal, the reactivity of the additional fuel assembly system was $\rho = 8.378E\text{-}3$.

Experiment 9-2. Additional fuel assemblies and all control rods were withdrawn; $\rho = -0.994E\text{-}3$.



Assembly 7 Assembly 8

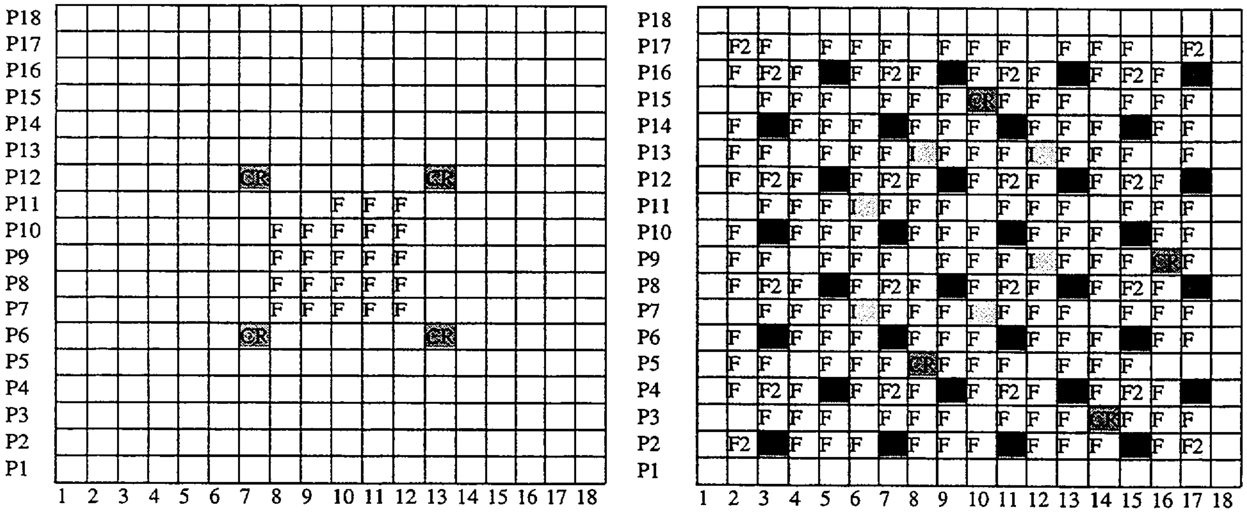
CR - Control Rod, A – Additional Absorber, F - FA with the fuel of 2% enrichment

Figure 3.6 Assemblies 7 and 8

### 3.2.10 Critical Assembly 10

Assembly 10 (Figure 3.7) consists of 192 fuel assemblies with fuel of 2.0% enrichment (20 fuel assemblies with 18 additional distance grids) and 6 channels with control rod imitator. The average $^{235}$U mass was 1157 g/FA. Average uranium mass was 57801 g/FA. All channels with fuel assemblies and additional absorber were filled with water.

Experiment 10-1. Control rods P15-10, P9-16, and P3-14 were introduced to the full depth, and control rod P5-8 was withdrawn; ρ = 2.13E-3.



**Assembly 9** **Assembly 10**

CR - Control Rod, I - Control Rod Imitator, A – Additional Absorber,
F - FA with the fuel of 2% enrichment, F2 - FA with the fuel of 2% enrichment with additional grids

**Figure 3.7 Assemblies 9 and 10**

### 3.2.11 Accuracy of Experimental Results

Estimating the uncertainty in the calculations and experiments is very important for analyzing the calculation results and their consistency with the experimental data. The calculation inaccuracies will be considered further in the appropriate section dealing with the description of calculation results.

The inaccuracy of experimental values of reactivity may have the following components (Ref. 3):

- Control rod system detectors installed into off-core graphite block channels were not modeled during calculation. Experimental estimation of the detectors' impact upon the value of $k_{eff}$ was equal to 0.0022 (Ref. 3). This error was taken as the systematic error of experimental results.

- Inaccuracy due to registration of critical conditions is evaluated by the value 0.35E-4.

- As to multiplication factor measurements, under conditions different from critical, inaccuracy of separate experiment forms a value of 0.0005.

General inaccuracy of experimental results will be defined by a sum of these components. Thus, for the experiments where critical condition was fixed, we will obtain

$$dk_{\text{eff exp critical}} = dk_{\text{eff methodical}} + dk_{\text{eff registration}} = 0.0022 + 0.000035 = 0.002235$$

For the experiments where $k_{\text{eff exp}}$ was other than 1, the inaccuracy of experimental results can be estimated as

$$dk_{\text{eff exp uncritical}} = dk_{\text{eff methodical}} + dk_{\text{eff registration}} = 0.0022 + 0.0005 = 0.0027$$

These values will be used in the comparison of calculation and experimental results.

# 4 VVER-1000 Fuel Elements

The fuel elements for VVER-1000 reactors use enriched pellets of $UO_2$ fuel. The pellets have a central hole, which makes them unique among the world's water reactors. The function of the central hole is to reduce center $UO_2$ temperature and stored thermal energy, as well as to increase the rod plenum volume to contain any released fission gases without causing the rod internal pressure to exceed that of the coolant. Currently, the hollow pellets in VVER-1000 fuel rods have a 2.4-mm–diameter hole, but this is expected to be reduced to between 1.4 and 1.6 mm.

Most VVER fuel pellets have a chamfer inclined at a low angle to the pellet end faces. The purpose of the chamfer is twofold. First, it minimizes the risk of breaking off fragments as the pellets are loaded into the cladding tubes during manufacturing. Second, it reduces the pellet-clad mechanical interaction during power changes later when the fuel and the cladding are in contact.

Since the earliest days, all fuel rods for VVER reactors have had cladding tubes made of the alloy Zr-1%Nb. The fuel rods for VVER-1000 reactors have Zr-1%Nb fuel cladding used in the fully recrystallized condition. At the wall thickness of 0.65 mm, the coolant pressure will produce a clad hoop stress of about 60 to 70 MPa, allowing for an internal helium pressure well below the yield stress at coolant temperature.

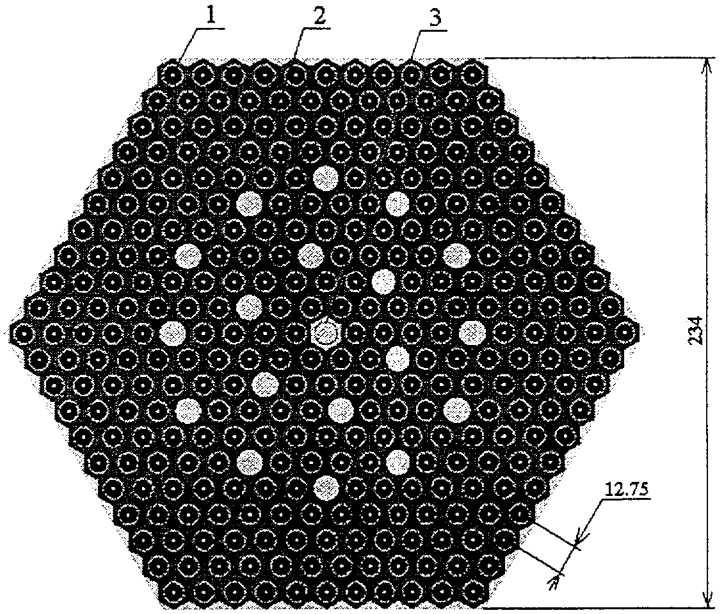
In the VVER-1000 design, the use of annular $UO_2$ pellets provides a large internal free volume, over 30 $cm^3$, not including fuel-clad gap, pellet chamfer, and $UO_2$ pellet open porosity. Such a large internal volume is necessary in case of large fission gas release and high temperature of the released gas stored in the hot center bore of the pellets.

The fuel assemblies for the VVER-1000 reactors (Figures 4.1 and 4.2) are composed of 312 fuel rods, which are 3.84 m long. The rods are 9.1 mm in diameter and are set into a triangular array, with a pitch of 12.75 mm. They are supported by 15 elastic spacer grids and one rigid grid. All spacer grids are of stainless steel. Spacer grids of Zr-1%Nb currently are being tested. The spacer grids are attached to a central support tube used for assembly power distribution measurements.

There is also a central support tube used for assembly power distribution measurements; the spacer grids are attached to it.

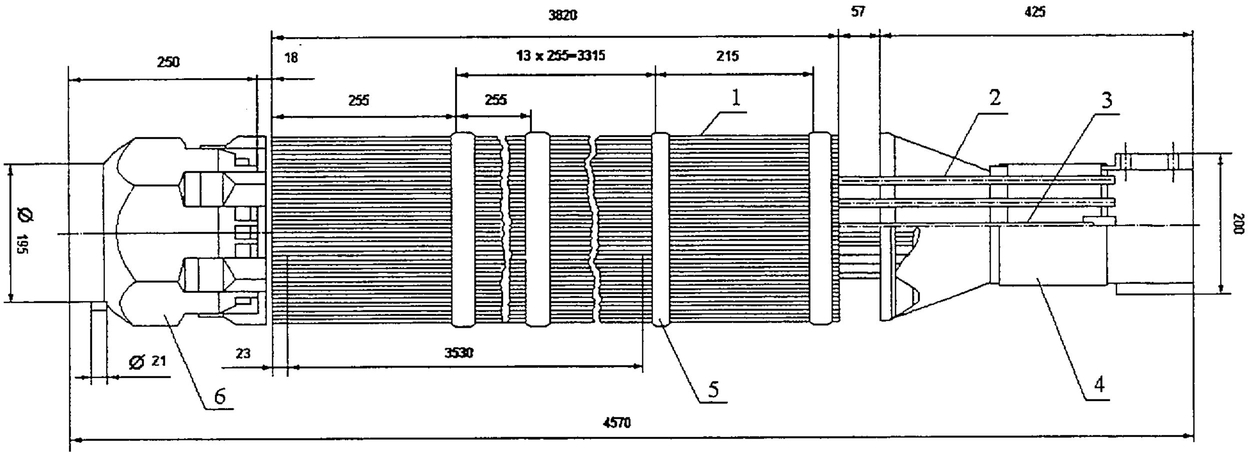
The VVER-1000 assemblies also have 18 stainless steel guide tubes (also expected to be replaced with zirconium-based alloy) placed as shown in Figure 4.1. The guide tubes, with an outside diameter of 12.6 mm and an 0.85-mm wall thickness, will accommodate either control rods or burnable poison rods. The burnable poison currently in use is chromium diborate within an aluminum matrix, although gadolinium ($Gd_2O_3$) at up to about 10% enrichment in $UO_2$ is under consideration as an alternative.

The control rods contain natural boron ($B_4C$) in steel cladding and are 8.2 mm in diameter (outer) with a 0.6-mm wall thickness. The density of $B_4C$ is 1.75-2.0 $g/cm^3$, and there is an upper plenum to accommodate the helium gas generated by the $(n, \alpha)$ reaction. The rods have welded end plugs; the lower ones are



**1** – fuel pin; **2** – guide tube for control rod or burnable absorber; **3** – central tube

**Figure 4.1 VVER-1000 Fuel Assembly Lattice**



**1** – fuel pin; **2** – guide tube for control rod or burnable absorber; **3** – central tube, **4** – FA head, **5** – distance grid; **6** - tailpiece

**Figure 4.2 VVER-1000 Fuel Assembly Layout**

pointed to ease insertion into the guide tubes. Because of swelling of $B_4C$ and liberation of helium, the life of these control rods is limited. The maximum lifetime in the automatic control regime recently has been increased up to two years, with five years permitted in the emergency protection regime. There has been no failure of any $B_4C$ control rod or associated components.

The principal technical parameters of the fuel assemblies are summarized in Table 4.1. The physical descriptions and specifications for the VVER-1000 fuel elements are based on information in References 7 through 11.

### Table 4.1 VVER-1000 Core Elements

| | |
|---|---|
| | **Fuel pin** |
| Height of fuel (hot) | 3550 mm |
| Pellet | $UO_2$ |
| Inner radius | 0.12 cm |
| Outer radius | 0.3765 cm |
| Fuel temperature | 1005 K |
| Note: central hole (diameter 2.2 mm) | |
| | **Fuel pin cladding** |
| Inner radius | 0.386 cm |
| Outer radius | 0.455 cm |
| Density | 6.45157 g/cm$^3$ |
| Composition | Zr (98.97%), Nb (1%), Hf (0.03%) wt% |
| | **Central tube** |
| Inner radius | 0.45 cm |
| Outer radius | 0.515 cm |
| Density | 6.45157 g/cm$^3$ |
| Composition | Zr (98.97%), Nb (1%), Hf (0.03%) wt% |
| | **Control element** |
| Pellet | $B_4C$ |
| Outer radius | 0.35 cm |
| Density | 1.8 g/cm$^3$ |
| Composition | $B_{10}$ (19.8%), $B_{11}$ (80.2%) wt% |
| | **Control element cladding** |
| Inner radius | 0.35 cm |
| Outer radius | 0.41 cm |
| Density | 7.8 g/cm$^3$ |
| Composition | Steel (Fe – 69.5, Cr – 18., Ni – 11., Mn – 1.5 wt%) |
| | **Burnable absorber** |
| Outer radius | 0.379 cm |
| Composition | Cr – 0.087, B – 0.036, Al – 2.5646, Zr – 0.0535, Fe – 0.0054, Ni – 0.0535 wt% |
| | **Burnable absorber cladding** |
| Inner radius | 0.386 cm |
| Outer radius | 0.455 cm |
| Density | 6.45157 g/cm$^3$ |
| Composition | Zr (98.97%), Nb (1%), Hf (0.03%) wt% |
| | **Control element/Burnable absorber tube** |
| Inner radius | 0.55 cm |
| Outer radius | 0.63 cm |
| Composition | Steel (Fe – 69.5, Cr – 18., Ni – 11., Mn – 1.5 wt%) |
| | **Spacer grid** |
| Thickness | 2.0 cm |
| Density | 1.205 g/cm$^3$ (homogenized) |
| Composition | Steel |

**Table 4.1. (Contd)**

| | |
|---|---|
| Weight | 0.7 kg |
| Dimension | 23.6 cm |
| | **Fuel assembly** |
| Type | Hexagonal lattice |
| Lattice pitch (mm) | 12.75 |
| Number of lattice elements | 331 |
| Number of fuel pins | 312 |
| Number of control elements/Burnable absorber tubes | 18 |
| Fuel ($UO_2$) mass (kg) | 455.52 |
| Enrichment | 1.6, 2.0, 3.0, 3.3, 3.6, 4.4 |
| Max. Average burnup | 49 MW day/kgU |
| | **Core** |
| Type | Hexagonal lattice |
| Assembly pitch | 23.6 cm |
| Number of fuel assembly | 163 |
| Moderator | $H_2O + H_3BO_3$ (water + boric acid) |
| Average moderator temperature | 578 K |
| Moderator pressure | 15.5 MPa |
| Moderator flow | 80000 $m^3/h$ |
| Power | 3000 MW (thermal) |

# 5 VVER Critical Facility

In 1997 and 1998, experiments with VVER-1000 fuel were performed on the LR-0 Mock-Up at the Nuclear Research Institute Řež, Czech Republic (Refs. 2, 4). These experiments focused particularly on the pin-by-pin power density distribution in fuel assemblies.

Suitable geometrical conditions and flexible technical capability of the LR-0 enable the arrangement of full-scale physical models of chosen sectors in the radial direction from the core to the reactor biological shielding of the VVER reactor. Simulators of the reactor internals (thermal core shielding, barrel) are located inside the LR-0 tank, and the reactor pressure vessel and biological shielding simulators are outside the tank but inside the LR-0 shielding room. Special attention was paid to the background due to albedo of the core leakage neutrons at the measuring points. The 25-cm-thick water axial reflector effectively suppresses the background at distant measuring points, far from the core. The critical height with this axial reflector usually is reached by adjusting the boron acid concentration in the water moderator during the start-up period. To simulate the water density decrease that takes place under VVER power reactor operational conditions, a steel displacing tank with appropriate air gap is positioned in the water layer between the barrel simulator and the LR-0 tank. The pressure vessel simulator consists of four 5-cm-thick steel layers that can be separately moved radially to form an additional air gap layer about 65 mm wide needed for the spectrometric measurements over the pressure vessel thickness.

The scheme of the mock-up benchmark core and its composition are presented in Figure 5.1 and Tables 5.1 and 5.2.

The core is composed of 32 fuel assemblies arranged as shown in Figure 5.1. Each fuel assembly contains 312 fuel elements in a triangular lattice with a pitch of 12.75 mm, 18 absorbing element channels (clusters), and a central tube. Detailed descriptions are shown in Figures 5.1 through 5.4. The cluster channels are made of stainless steel (the inner and outer radii are 5.5 and 6.3 mm), and the central tube is made of Zr-1%Ni alloy (with inner and outer radii of 4.5 and 5.15 mm, respectively). The absorbing element is made of boron carbide. In fuel assembly 27 (Figure 5.3), the central dry channel for neutron spectrum measurement is positioned (73 × 2.5 mm). Control clusters are installed in fuel assemblies 19 and 23 (three rods per assembly, at positions 55, 172, and 271 in fuel assembly 19, and positions 61, 160, and 277 in fuel assembly 23, respectively, as shown in Figure 5.5).

Thirty fuel assemblies have cluster tubes positioned in a triangular (regular) lattice (Figure 5.2); the other two are distributed in the standard arrangement for the cluster tubes of the VVER-1000 power assembly shown in Figure 4.1. Each fuel assembly contains five spacing grids. The triangular lattice of the hexagonal fuel assembly has a 236-mm pitch.

Delayed critical was reached when the moderator level reached 1500 mm from the lower edge of in-core fuel. The critical boric acid concentration in the moderator was 4.6 ± 0.1 g/l of water. At that time, control rods in fuel assemblies 19 and 23 were inserted down to the middle of core.

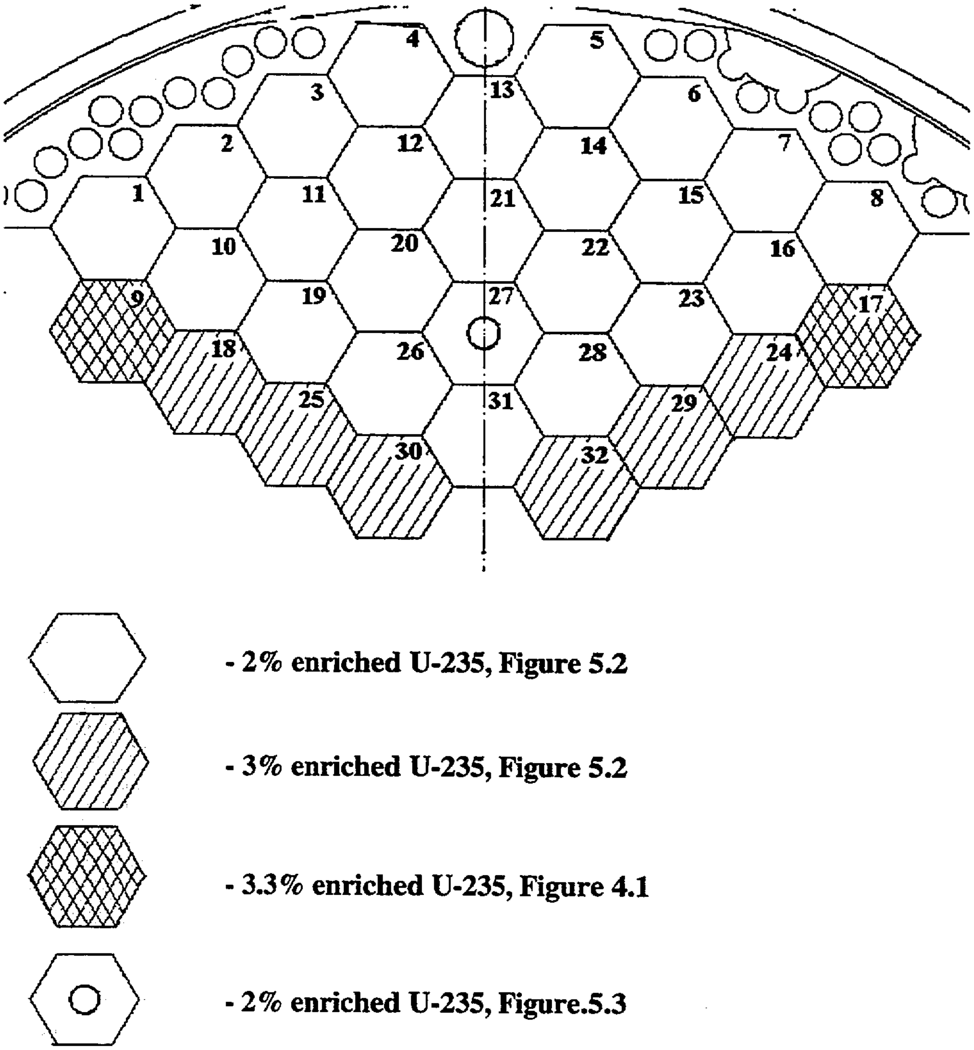


**Figure 5.1 Fuel Assembly Arrangement**

The core power distribution was measured by gamma scanning the irradiated fuel elements. The radial (at the center, 5-cm fuel part) distribution was measured in the symmetrical position (Figure 5.4) with two independent measuring devices. During measurement, the pins were rotating before a collimator. The four measured values were averaged (as of independent measurements), and measured uncertainties were evaluated (one sigma). The measured values were normalized to an average value equal to 1,000. These values, after a revision, were determined to be the final ones for use in subsequent evaluations.

## Table 5.1 LR-0 Fuel Element Description

| | |
|---|---|
| **Fuel element** | |
| Height | 125.0 cm |
| Pellet | $UO_2$ |
| Inner radius | 0.07 cm |
| Outer radius | 0.3765 cm |
| Density | 10.33 g/cm$^3$ |
| Note: central hole (diameter 1.4 mm), gap (0.09 mm) between pellet and cladding. | |
| **Cladding** | |
| Inner radius | 0.3855 cm |
| Outer radius | 0.4575 cm |
| Density | 6.44 g/cm$^3$ |
| Composition | Zr (98.97 wt%), Nb (1 wt%), Hf (0.03 wt%) |
| **Central tube** | |
| Inner radius | 0.45 cm |
| Outer radius | 0.515 cm |
| Density | 6.44 g/cm$^3$ |
| Composition | Zr (98.97 wt%), Nb (1 wt%), Hf (0.03 wt%) |
| **Control element** | |
| Height | 125.0 cm |
| Pellet | $B_4C$ |
| Radius | 0.35 cm |
| Density | 1.6 g/cm$^3$ |
| Composition | $B_{10}$ (19.8 wt%), $B_{11}$ (80.2 wt%) |
| **Control element cladding** | |
| Outer radius | 0.41 cm |
| Density | 7.646 g/cm$^3$ |
| Composition | Steel (see Table 5.2) |
| **Control element tube** | |
| Inner radius | 0.55 cm |
| Outer radius | 0.61 cm |
| Density | 7.646 g/cm$^3$ |
| Composition | Steel (see Table 5.2) |
| **Spacer grid** | |
| Thickness | 2.0 cm |
| Density | 1.205 g/cm$^3$ (homogenized) |
| Composition | Steel (see Table 5.2) |
| Weight | 0.7 kg |
| Dimension | 23.6 cm |
| Note: The number of grids per fuel assembly = 5. The center of gravity of the grids is positioned above the lower end of fuel pellets at 24.4 cm, 49.9 cm, 75.4 cm, 100.9 cm, and 126.4 cm. The rest of the fuel assembly is made of stainless steel of the same composition and density as the control element cladding and cluster tubes. | |
| **Core** | |
| Assembly pitch | 23.6 cm |
| Hexagonal lattice pitch | 1.275 cm |
| Moderator | $H_2O$ |
| Density | 1.0 g/cm$^3$ |

**Table 5.2 Steel Composition**

| | | | |
|---|---|---|---|
| C | max 0.12%+0.01% | Ni | (7.7-11.5)% |
| Mn | max 2.00%+0.15% | Ti | min 5×(C-0.03) |
| Si | max 1.0%+0.05% | P | max 0.045% |
| Cr | (16.7-20.5)% | S | max 0.030% |

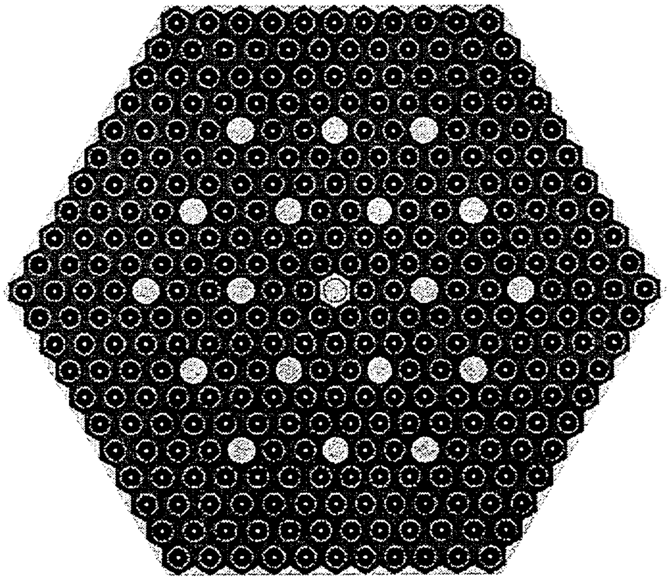


**Figure 5.2 Fuel Assembly with Regular Cluster Lattice Pitch**

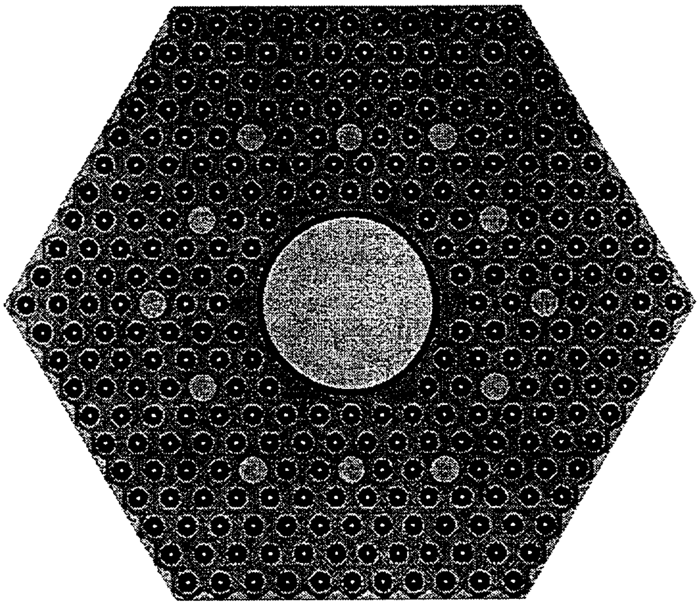


**Figure 5.3 Fuel Assembly 27**

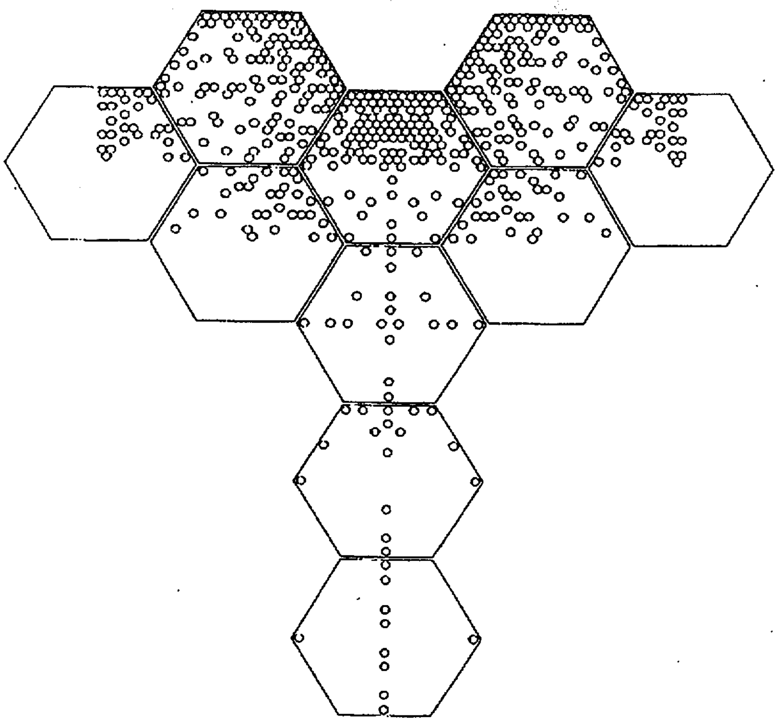


Figure 5.4 Measured Fuel Pin Arrangement

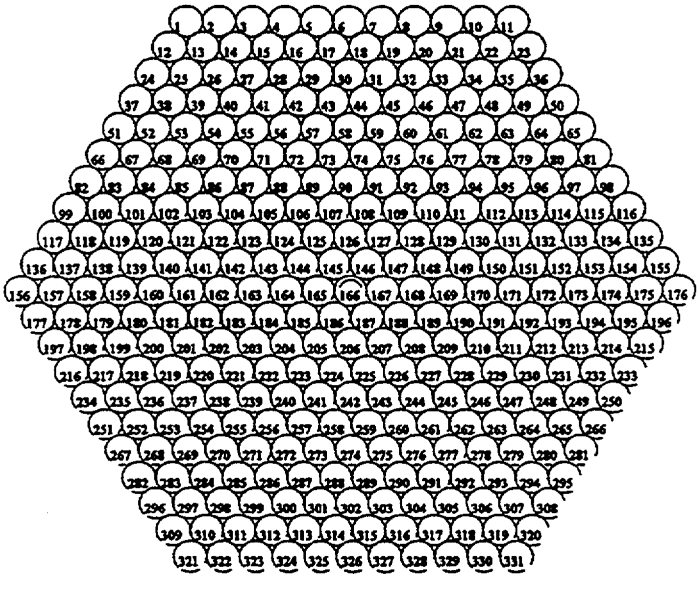


Figure 5.5 Fuel Pin Numbering

# 6 SCALE Code System Description

The descriptive information on the SCALE code package in this section was taken mainly from Reference 1.

SCALE is a computational system consisting of a set of well-established codes and data libraries suitable for analyses of nuclear fuel facility and package designs in the areas of criticality safety, radiation shielding, source term characterization, and heat transfer. The codes are compiled in a modular fashion and called by control modules that provide automated sequences for standard system analyses in each area.

## 6.1 Criticality Safety Analysis Sequences

The control modules for the criticality safety analysis sequences (CSAS and CSAS4) contain automated sequences that perform problem-dependent cross-section processing and three-dimensional (3-D) Monte Carlo calculations of neutron multiplication. Two control sequences--CSASN and CSAS26--were used to perform resonance processing and/or calculate effective neutron multiplication factors for the critical benchmark experiments supplied in this document. All neutronic control sequences use the SCALE Material Information Processor to calculate material number densities and prepare geometry data for resonance self-shielding and optional flux-weighting cell calculations and to create data input files for the cross-section processing codes. The BONAMI and NITAWL-II codes then are used to perform problem-specific (resonance- and temperature-corrected) cross-section processing. BONAMI applies the Bondarenko method of resonance self-shielding for nuclides that have Bondarenko data included in the cross-section library. NITAWL-II uses the Nordheim integral treatment to perform resonance self-shielding corrections for nuclides that have resonance parameters included with their cross-section data. The CSASN sequence terminates at this point; the cross-section library produced from this calculation can be used as is or combined with other cross-section libraries and used in a subsequent criticality calculation with KENO-VI stand-alone.

The CSAS26 sequence performs the cross-section processing as in CSASN and then invokes KENO-VI, a 3-D multigroup Monte Carlo criticality code, to determine the $k_{eff}$ from the problem-dependent cross-section data and the user-specified geometry data. Other calculated KENO-VI quantities include average neutron lifetime and generation time, energy-dependent leakages, energy- and region-dependent absorptions, fissions, fluxes, and fission densities.

## 6.2 SCALE Code System Libraries

In the SCALE system, nine cross-section libraries currently are available and distributed with SCALE, eight of which are automatically available in the SCALE system. Six of these libraries were designed primarily for criticality analysis. The group structure specification for each library was based on knowledge gained from the definition and use of the 218-group and 27-group libraries developed for the SCALE code system using ENDF/B-IV data (Refs. 1, 12-16).

The 218-group library (**218GROUPNDF4**) is a fine-group library derived from ENDF/B-IV data. The library contains 140 fast groups and 78 thermal groups and includes explicit resonance data in the resolved resonance range. No unresolved resonance data are available in the library.

The 27-group library (**27GROUPNDF4**) is the broad-group library collapsed from the 218-group library and has 14 fast and 13 thermal groups. This library has been validated extensively against critical experiments. The 27-group depletion library (**27BURNUPLIB**) contains the same data as 27GROUPNDF4 plus pre-release ENDF/B-V data for a large number of fission products. This was the first library designed for use with the SAS2 depletion/decay sequence.

The 238-group library (**238GROUPNDF5**) is the most complete library in SCALE. This library contains data for all ENDF/B-V nuclides and has 148 fast and 90 thermal groups. Most resonance nuclides in the 238-group library have resonance data in the resolved resonance region and Bondarenko factors in the unresolved resonance region.

The 44-group library (**44GROUPNDF5**), a broad-group version of the fine-structure 238-group library, 238GROUPNDF5, was collapsed using a fuel cell spectrum based on a 17 x 17 fuel assembly for a Westinghouse pressurized-water reactor (PWR). The broad-group structure was designed to accommodate two windows in the oxygen cross-section spectrum, a window in the iron cross-section spectrum, the Maxwellian peak in the thermal range, and the 0.3-eV resonance in plutonium (which, due to low energy and lack of resonance data, cannot be modeled by the Nordheim Integral Treatment in NITAWL-II). The 44-group library has a group structure similar to the 27-group library. All boundaries in the 27-group ENDF/ B-IV library correspond to those in the 44-group ENDF/B-V library except for the upper bound of group 23. This library was designed for analysis of light-water-reactor (LWR) fresh and spent fuel systems and has been validated extensively against LWR critical experiments. The 238- and 44-group libraries are the preferred criticality safety analysis libraries in SCALE and are described in more detail below.

The Hansen-Roach 16-group library (**HANSEN-ROACH**) is based on the original Hansen and Roach data. Important nuclides not available in the library were added by collapsing the 218-group ENDF/B-IV library to the 16-group structure. Although the library was developed originally for fast systems, a modification to the data for $^{238}$U has allowed it to be used successfully as a general-purpose library.

More detailed information about these libraries is provided in the following subsections. Complete information on these libraries can be found in Reference 14. This reference documents the performance of the five SCALE criticality safety cross-section libraries for seven different types of systems. It provides information on the background and ORNL's experience with each library and recommendations on the use of the libraries for particular types of applications.

### 6.2.1 The 238-Group ENDF/B-V Library (238GROUPNDF5)

The 238-group ENDF/B-V library, a general-purpose criticality analysis library, is so far the most complete available in SCALE. This library is known also as the LAW (Library to Analyze radioactive Waste) library.

The LAW library is based on ENDF/B-V evaluations. One of the major tenets of ENDF is to reject adjustments that make evaluations produce "correct" results. This approach is taken to ensure that evaluations improve because of advances in the evaluation art and not because of some fortuitous (and often misunderstood) change in an associated calculation procedure.

All nuclides use a $P_5$ Legendre expansion to fit the elastic and discrete level inelastic scattering processes, thereby making the library suitable for both reactor and shielding applications. A $P_3$ fit was used for thermal-scattering matrices. All other scattering processes use $P_0$ fits (Ref. 13).

The library contains data for all nuclides (more than 300) available in ENDF/B-V processed by the AMPX-77 systems (Ref. 1). It also contains data for $^{14}$N, $^{15}$N, $^{16}$O, $^{154}$Eu, and $^{155}$Eu from ENDF/B-VI.

The library has 148 fast groups and 90 thermal groups (below 3 eV).

Most resonance nuclides in the 238 group and 44 group have resonance data (to be processed by NITAWL-II) in the resolved resonance range and Bondarenko factors (to be processed by BONAMI) for the unresolved range. Both libraries contain resolved resonance data for p-wave and d-wave resonances ($l$= 1 and $l$ = 2, respectively).

These data can have a significant effect on results for unmoderated, intermediate-energy problems. Resonance structures in several light- to intermediate-mass "nonresonance" ENDF nuclides (i.e., $^{7}$Li, $^{19}$F, $^{27}$Al, and $^{28}$Si) are accounted for using Bondarenko shielding factors.

All nuclides in the 238-group LAW Library use the same weighting spectrum, consisting of

- Maxwellian spectrum (peak at 300 K) from $10^{-5}$ to 0.125 eV
- a 1/E spectrum from 0.125 eV to 67.4 keV
- a fission spectrum (effective temperature at 1.273 MeV) from 67.4 keV to 10 MeV
- a 1/E spectrum from 10 to 20 MeV.

A special material is included in the library with an identifier of 99, which contains 238-group weighting spectra for collapsing the 238-group library using the MALOCS module to produce an application-specific collapsed library. Several spectra are included, as listed below:

1. spectrum based on a fuel cell from a 17 x 17 Westinghouse PWR assembly and identified by 9001

2. spectrum designed for use with the Molten Salt Reactor Experiment fuel storage tanks at ORNL and identified by 9002

3. average spectrum in a 27-cm carbon steel shield for use in cask shielding studies and identified by 9003

4. average spectrum in the lead region of an 18.6-cm lead/13-cm resin shield for use in shielding cask studies and identified by 9004

5. average spectrum in the resin region of an 18.6-cm lead/13-cm resin shield for use in shielding cask studies and identified by 9005
6. average spectrum in a 50-cm concrete shield for cask shielding studies and identified by 9006
7. spectrum in an infinite medium of hydrogen and uranium with H/X = 300.

In Cases 3 through 6, the spent fuel source was a 15 x 15 Westinghouse PWR assembly with initial enrichment of 3.0 wt%, burned to 30 GWd/MTU and cooled for 5 years.

Data testing has been performed for 33 benchmarks, including 28 benchmarks of the Cross Section Evaluation Working Group. Results obtained for these benchmarks are very close to those obtained by other data testers using different ENDF/B-V-based cross-section libraries. There is considerable improvement in the trend of $k_{eff}$ vs. leakage obtained with the use of the ENDF/B-VI oxygen evaluation. The LAW-238 library appears to be acceptable for general use in criticality and reactor physics applications. The library has had minimal testing for shielding applications and should be evaluated by the user for applicability.

### 6.2.2 The 44-Group ENDF/B-V Library (44GROUPNDF5)

The 44-group ENDF/B-V library has been developed for use in the analysis of fresh and spent fuel and radioactive waste systems. Collapsed from the fine-group 238GROUPNDF5 cross-section library, this broad-group library contains all nuclides (more than 300) from the ENDF/B-V data files. Broad-group boundaries were chosen as a subset of the parent 238GROUPNDF5 boundaries, emphasizing the key spectral aspects of a typical LWR fuel package. Specifically, the broad-group structure was designed to accommodate the following features:

- two windows in the oxygen cross-section spectrum; a window in the cross section of iron
- the Maxwellian peak in the thermal range
- the 0.3-eV resonance in $^{239}$Pu (which, due to its low energy, cannot be modeled properly via the SCALE Nordheim Integral Treatment module NITAWL-II).

The resulting boundaries represent 22 thermal energy groups below 3 eV and 22 fast energy groups. The fine-group 238GROUPNDF5 cross sections were collapsed into this broad-group structure using a fuel cell spectrum calculated based on a 17 x 17 Westinghouse PWR assembly.

Because of the significantly improved and conservative behavior of the ENDF/B-VI $^{16}$O evaluation under conditions where higher-order scattering terms are important (e.g., high leakage geometries), this cross section has been included in the 238-group and 44-group libraries as the default for $^{16}$O. Similarly, ENDF/B-VI evaluations of $^{14}$N and $^{15}$N are included in the library; however, ENDF/B-V versions remain the default for these isotopes.

The ENDF/B-VI nitrogen data were processed using the same methods used for $^{16}O$, and, like oxygen, were tested to see if significant differences between ENDF/B-V and ENDF/B-VI could be identified. No significant differences have been identified; however, because they already had been processed into AMPX master library format and were readily available, ENDF/B-VI $^{14}N$ and $^{15}N$ cross sections are included in the library as cross sections 701401 and 701501, respectively. Finally, ENDF/B-VI evaluations of $^{154}Eu$ and $^{155}Eu$ also are included as the default in the library because the more recent ENDF/B-VI evaluations include resonance parameters not included in previous evaluations and yield energy-dependent cross sections significantly different from those obtained using ENDF/B-V cross sections. Comparisons of depletion/decay calculations to experimental isotopic measurements have indicated that the ENDF/B-VI europium evaluations are more accurate than those available in ENDF/B-V. However, as with $^{16}O$, ENDF/B-V cross sections are also available within the library, as isotopes 631541 and 631551.

The 44GROUPNDF5 library was tested against its parent library using a set of 33 benchmark problems to demonstrate that the collapsed set was an acceptable representation of 238GROUPNDF5, except for intermediate energy systems. Validation of the library within the SCALE system was based on a comparison of calculated values of $k_{eff}$ with that of 93 experiments (92 critical and 1 subcritical). The experiments consisted primarily of various configurations of LWR-type fuel representative of transportation and storage conditions. Additional experiments were included to allow comparison with results obtained in earlier validation of the 27GROUPNDF4 library.

Results show that the broad 44-group structure is an acceptable representation of its parent 238-group library for thermal as well as hard fast spectrum systems. Accurate broad-group analyses of intermediate spectrum systems will require either a more detailed group structure in this energy range or a more appropriate collapsing spectrum. Further, validation calculations indicate that the 44-group library is an accurate tool in the prediction of criticality for arrays of LWR-type fuel assemblies, as would be encountered in fresh or spent fuel transportation or storage environments. Validation results for LWR-type $UO_2$ fuel show virtually no bias. A positive bias of 0.5% to 1% has been observed for very thermal mixed-oxide systems. The bias is caused by inadequate representation of plutonium cross sections, possibly in the ENDF/B-V data. These validation results are consistently better than those seen for the same cases using the 27GROUPNDF4 library and make the 44GROUPNDF5 library the recommended library for thermal and many hard fast spectrum systems. For intermediate energy systems, the parent 238GROUPNDF5 library is recommended.

### 6.2.3 The 218-Group ENDF/B-IV Library (218GROUPNDF4)

The 218-group ENDF/B-IV library is one of the more complete libraries available in SCALE. The source of the data was ENDF/B-IV, and the processing of the cross sections by XLACS in the AMPX system is well documented. The weighting function used in the $P_3$ cross-section generation was a fission-$1/E\sigma_t$-Maxwellian weighting (except for resonance nuclides, which were weighted $1/E$ instead of $1/E\sigma_t$).

One of the features of the library is that explicit resonance data carried with it can be used to generate problem-dependent, resonance-region group cross sections using NITAWL-II. This capability allows great flexibility in the use of the library as a general-purpose criticality analysis library. The library has 78 thermal energy groups below 3.05 eV and 140 fast energy groups. The group structure was designed to fit the cross-section variation and reaction thresholds of the light and intermediate nuclides and to fit the major resonances of the intermediate and heavy nuclides. No unresolved resonance data are carried in the library. The unresolved resonance region was processed at $\sigma_p = 50{,}000$.

The 218-group library routinely has not been validated because of its size and the related costs.

However, the 27-group ENDF/B-IV library was derived directly from the 218-group library and has been validated against a large number of critical experiments. The 218-fine-group structure of the library generally will give either the same or more precise results than its companion 27-broad-group library.

An obvious advantage of a fine-group library over a broad-group library is that the library is less sensitive to the weighting spectrum used to generate the library. The cross sections more closely represent the base data, and the group structure allows a more detailed determination of the energy dependence of the flux.

In past validations, it has been found useful to compare a fine-group calculation against a broad-group calculation when bias is observed.

### 6.2.4 The 27-Group ENDF/B-IV Library (27GROUPNDF4)

The 27-group ENDF/B-IV library is the broad-group companion library to the 218-group ENDF/B-IV library. The 218-group library was flux-collapsed using MALOCS and the MT 1099 flux file carried with the fine-group cross sections. (This flux file is the group representation of the original weighting spectrum used to generate the 218-group cross sections from ENDF/B-IV data.) The library has 13 thermal energy groups below 3 eV and 14 fast energy groups. The group structure was chosen to match the 16-group Hansen-Roach structure with two additional fast groups and seven additional thermal groups. The additional groups were chosen such that, for the systems considered, the broad-group calculations meet an acceptance criterion of $\Delta k_{eff} / k_{eff} < 0.3\%$ when compared with the reference 218-group calculation using the XSDRN code. This criterion was relaxed to 1% for uranium in systems where the median fission energy was greater than 1 eV and less than 100 eV. The 238 resonance data and the thermal scattering data carried with the 27- and 218-group libraries are the same and are processed by NITAWL-II. The library was conceived as a general-purpose criticality analysis library with a special interest in applicability toward shipping cask analysis and thermal neutron systems.

The 27-group library has been validated extensively against critical experiments. Areas of validation include highly enriched uranium-metal, compound and solution systems, moderated low-enriched uranium, heterogeneous and homogeneous systems, and plutonium metal and solution systems. The 27-group ENDF/B-IV cross-section set is known to have a 1% to 2% positive bias for highly thermal $^{239}$Pu systems.

Negative bias of 1% to 2% has been observed for LWR fuel lattice depending on the degree of lattice moderation. Other areas of bias tend to be geometry- and composition-dependent.

### 6.2.5 The 27-Group Depletion Library (27BURNUPLIB)

The 27-group depletion library is a criticality library originally developed for use in the SAS2 depletion/ shielding control module. The library consists of the 27-group ENDF/B-IV library supplemented with data from a pre-release version of ENDF/B-V for a large number of fission products. Prior to the release of the 44-group library, this library was the preferred library for use with SAS2 because of the large number of nuclides that can be processed explicitly in XSDRNPM for use in the ORIGEN-S depletion code. This processing eliminates the cross-section dependence on the ORIGEN-S library for those nuclides that are treated in XSDRNPM.

### 6.2.6 The Hansen-Roach Library (HANSEN-ROACH)

The Hansen-Roach 16-group library is based on the original Los Alamos report by Hansen and Roach (Ref. 16).

Important nuclides not available in the original library were added by collapsing the 218-group ENDF/B-IV library to the 16-group structure.

Resonance nuclides in the original Hansen-Roach library had cross sections tabulated at several $\gamma_p$ values. To make these cross sections compatible with the SCALE system, an infinite dilution library was defined for each resonance nuclide, and Bondarenko data were generated for the remaining values of $\sigma_p$. The implementation of the Hansen-Roach library in SCALE departs significantly from historical use of the Hansen-Roach library. In the past, the shielded cross-section set used in a Hansen-Roach calculation was determined by calculating a $\sigma_p$ value using a single value of the potential scatter cross section for each nuclide. As implemented in SCALE, $\sigma_p$ is calculated on a group-wise basis using the total cross section. Cross-section shielding is then done on a group-wise basis. The original Hansen-Roach library did not carry total cross sections per se, but had a total cross section that included a transport correction. To implement the Hansen-Roach library in SCALE, an infinite dilute 16-group total cross section was generated from the SCALE 27-group library and added to the Hansen-Roach library as MT-201. The Bondarenko iteration in BONAMI automatically uses MT-201 when it is present in a library. The addition of the 16-group total cross sections allowed the SCALE control modules to perform automatic problem-dependent cross-section processing using BONAMI.

The Hansen-Roach library was developed primarily for fast systems. There are 12 fast groups and 4 thermal groups (groups below 3 eV). However, thermal upscatter is not included in the original Hansen-Roach data. The cross sections are generally $P_0$ cross sections that are transport-corrected to account for leakage. The exceptions are hydrogen and deuterium, which are $P_1$ transport-corrected cross sections. All of the nuclides added to the original library were generated to $P_3$. One significant modification was made to $^{238}U$ in the original library such that the library more accurately calculated low-enriched uranium systems. This was the Knight modification to the $\sigma_p$ data for $^{238}U$ such that the 2% enriched green block experiments were accurately calculated.

Although the library originally was developed for fast systems, the Knight modification has allowed it to be used successfully as a general-purpose library. The areas of applicability have been documented periodically at the Oak Ridge facilities in validations against critical experiments. The library continues to be used widely because it is well known. Areas of validation include highly enriched uranium-metal, compounds and solutions, moderated low-enriched uranium systems, and plutonium-metal and solution systems. The Hansen-Roach cross-section set is known to have a 1.5% to 2% negative bias for some highly enriched uranyl nitrate systems and to have a 1% to 1.5% positive bias for highly thermal $^{239}$Pu systems. Other areas of bias tend to be geometry- and composition-dependent.

# 7 Overview of Calculation Results for the RBMK Critical Facility

The results of calculations for the RBMK critical facility experiments described in Section 3 are presented. For reference, the CSAS26 input files for SCALE 4.3 and SCALE 4.4a for these calculations are included in Appendix A. The CSAS26 control sequence was the primary tool used for these analyses.

## 7.1 Modeling and Calculation Techniques

Several techniques for modeling the fuel region of particular experiments are addressed in Section 7.1.1. KENO-VI parameter data are discussed in Section 7.1.2.

### 7.1.1 Fuel Region Modeling

The experiments listed in Section 3 were modeled explicitly by considering the fuel rod regions submerged in and protruding from the moderator region.

In some instances, more than one fissile mixture was present per experiment. Because only one CSAS unit cell specification is allowed per problem, the Dancoff factors and resonance data had to be calculated for the other unit cell descriptions using a CSASN "PARM=CHECK" case and then explicitly specified in the CSAS26 calculation using the "MORE DATA" option.

Control rod system detectors installed into off-core graphite block channels were not modeled during calculation. Experimental estimation of the detectors' impact upon the value of $k_{eff}$ was equal to 0.0022 (Ref. 3). This error was taken as the systematic error of experimental results.

Enrichment of fuel and its density were identified separately for each experiment, proceeding from geometry of fuel rods on the base of average $^{235}$U mass and average uranium mass values.

### 7.1.2 KENO-VI Parameter Data

Criticality calculations for the RBMK facility were run with 500 and 1000 generations and 1000 neutrons per generation for a total of 500,000 and 1,000,000 histories. The first 50 or 100 generations, respectively, were omitted when calculating the average eigenvalue of the system. Default values were used for all other parameters including the start option of flat neutron distribution over the entire system. Vacuum boundary conditions were applied to the outermost region of every problem. No biasing was used to track neutrons in the graphite-water reflector region of each problem.

## 7.2 Calculation Results

Two important calculated parameters in the presentation of results are the $k_{eff}$ and the energy of the average lethargy causing fission (EALF). The EALF has been added to the KENO-VI output in Versions 4.3 and 4.4a of SCALE and offers a single parameter in physical units (eV). The EALF is more useful in interlibrary comparisons because it is a physically real parameter and not as dependent on the group structure of a library.

Calculations were made for four basic libraries used in SCALE 4.3 and 4.4a to calculate criticality: 27GROUPNDF4, 44GROUPNDF5, 218GROUPNDF4, and 238GROUPNDF5. During these calculations, results of 30 critical experiments carried out at 10 different assemblies were modeled. These assemblies differ by their enrichment, fuel quantity, and geometry, as well as availability of water inside fuel channels. During these experiments, fuel assembly conditions were varied by movement of control rods, water discharge from fuel channels, or withdrawal or relocation of some fuel assemblies. The measured values of the multiplication factor during these experiments varied between 0.968 (Experiment A2-2) and 1.0038 (Experiment A6-1).

To improve credibility of the obtained results, the two starting experiments were modeled also with the use of the Monte Carlo N-Particle Transport program, MCNP-4a. These calculations used the ENDF/B-VI-based library, ENDF60. Their results are presented in Table 7.1.

The results of the calculations are presented in Table 7.2. Deviations of calculated results from experimental data are presented in Figures 7.1 and 7.2.

Some of the calculations were performed twice; the same input data files were used by both the SCALE 4.3 and SCALE 4.4a packages in order to test the SCALE 4.4a package. The results of these calculations of $k_{eff}$ and EALF are shown in Table 7.2. They coincide with each other within the limits of statistical inaccuracy.

## Table 7.1 SCALE Calculation Results of 30 RBMK Critical Experiments

| Cal. | Exp. | Exp. | 27GROUPNDF4 | | | | 44GROUPNDF5 | | | | 218GROUPNDF4 | | | | 238GROUPNDF5 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | No. | $k_{\text{eff exp}}$(a) | $k_{\text{eff calc}}$ | $dk_{\text{eff calc}}$ | EALF | dEALF | $k_{\text{eff calc}}$ | $dk_{\text{eff calc}}$ | EALF | dEALF | $k_{\text{eff calc}}$ | $dk_{\text{eff calc}}$ | EALF | dEALF | $k_{\text{eff calc}}$ | $dk_{\text{eff calc}}$ | EALF | dEALF |
| 1 | A1-0 | 1 | 1.0252 | 0.001 | 0.0794 | 0.0002 | 1.0181 | 0.001 | 0.0975 | 2E-04 | 1.0069 | 0.0011 | 0.0776 | 2E-04 | 1.01 | 0.0011 | 0.0981 | 3E-04 |
| 1(b) | A1-0 | 1 | 1.0238 | 0.0012 | 0.0793 | 0.0002 | 1.0163 | 0.001 | 0.0971 | 3E-04 | | | | | 1.008 | 0.0012 | 0.0983 | 3E-04 |
| 2 | A1-1 | 1.0029 | 1.0294 | 0.001 | 0.0787 | 3E-04 | 1.0239 | 0.001 | 0.0967 | 3E-04 | 1.0115 | 0.0011 | 0.0767 | 2E-04 | 1.0144 | 0.001 | 0.0978 | 2E-04 |
| 3 | A1-2 | 1.0014 | 1.0268 | 0.0009 | 0.0785 | 2E-04 | 1.019 | 0.001 | 0.0968 | 3E-04 | 1.0106 | 0.001 | 0.0772 | 2E-04 | 1.0135 | 0.0011 | 0.0974 | 2E-04 |
| 4 | A2-1 | 1.0014 | 1.0268 | 0.0007 | 0.0789 | 2E-04 | 1.0216 | 0.0008 | 0.0968 | 2E-04 | 1.0099 | 0.0007 | 0.0983 | 2E-04 | 1.0135 | 0.0007 | 0.0983 | 2E-04 |
| 5 | A2-2 | 0.9684 | 0.9493 | 0.0007 | 0.1712 | 4E-04 | 0.9807 | 0.0008 | 0.1454 | 3E-04 | 0.9644 | 0.0008 | 0.1408 | 4E-04 | 0.9889 | 0.0007 | 0.1416 | 3E-04 |
| 6 | A3-0 | 1 | 0.9767 | 0.0008 | 0.1687 | 4E-04 | 1.0071 | 0.0011 | 0.1434 | 4E-04 | 0.9917 | 0.0008 | 0.138 | 3E-04 | 1.016 | 0.0008 | 0.1388 | 3E-04 |
| 7 | A3-1 | 1.0016 | 0.9815 | 0.0012 | 0.1657 | 6E-04 | 1.0176 | 0.0009 | 0.1405 | 3E-04 | 0.9998 | 0.0011 | 0.1352 | 5E-04 | 1.0227 | 0.0012 | 0.1369 | 4E-04 |
| 8 | A4-0 | 1 | 1.0261 | 0.0012 | 0.0858 | 3E-04 | 1.0178 | 0.0012 | 0.1036 | 3E-04 | 1.0086 | 0.0012 | 0.083 | 2E-04 | 1.0123 | 0.001 | 0.1039 | 3E-04 |
| 9 | A4-1 | 1.0016 | 1.0307 | 0.0011 | 0.0849 | 3E-04 | 1.0222 | 0.0011 | 0.1031 | 3E-04 | 1.0144 | 0.0012 | 0.0829 | 3E-04 | 1.0135 | 0.0012 | 0.1032 | 3E-04 |
| 10 | A4-2 | 0.9911 | 1.0204 | 0.001 | 0.0863 | 3E-04 | 1.0158 | 0.0011 | 0.1039 | 3E-04 | 1.0034 | 0.0011 | 0.084 | 3E-04 | 1.0056 | 0.0011 | 0.1055 | 3E-04 |
| 11 | A5-0 | 1 | 0.9795 | 0.001 | 0.1809 | 6E-04 | 1.0152 | 0.0008 | 0.1509 | 3E-04 | 0.9981 | 0.0012 | 0.1469 | 5E-04 | 1.023 | 0.0011 | 0.1473 | 5E-04 |
| 12 | A5-1 | 0.9925 | 0.9749 | 0.0008 | 0.1835 | 4E-04 | 1.0076 | 0.0011 | 0.1535 | 4E-04 | 0.9934 | 0.0012 | 0.1479 | 5E-04 | 1.0161 | 0.0011 | 0.1483 | 4E-04 |
| 13 | A5-2 | 0.9973 | 0.9845 | 0.0008 | 0.18 | 4E-04 | 1.0137 | 0.0008 | 0.1521 | 3E-04 | 1.0009 | 0.0012 | 0.1465 | 5E-04 | 1.0223 | 0.0011 | 0.1569 | 4E-04 |
| 14 | A6-0 | 1 | 0.9904 | 0.001 | 0.1378 | 4E-04 | 1.0178 | 0.0009 | 0.1231 | 3E-04 | 1.0051 | 0.0012 | 0.113 | 3E-04 | 1.0256 | 0.0011 | 0.1192 | 3E-04 |
| 15 | A6-00 | 1 | 0.9877 | 0.0007 | 0.1380 | 3E-04 | | | | | 1.0038 | 0.0007 | 0.1138 | 3E-04 | | | | |
| 15(b) | A6-00 | 1 | 0.9883 | 0.0008 | 0.1377 | 3E-04 | 1.0176 | 0.0008 | 0.1208 | 2E-04 | 1.006 | 0.0009 | 0.1132 | 2E-04 | 1.0257 | 0.0008 | 0.119 | 2E-04 |
| 16 | A6-1 | 1.0038 | 0.9947 | 0.0012 | 0.1363 | 4E-04 | 1.023 | 0.0012 | 0.1213 | 3E-04 | 1.0088 | 0.0011 | 0.1129 | 3E-04 | 1.0305 | 0.001 | 0.1179 | 3E-04 |
| 17 | A6-2 | 1.0028 | 0.9963 | 0.0011 | 0.136 | 4E-04 | 1.0224 | 0.0011 | 0.1216 | 3E-04 | 1.0106 | 0.0012 | 0.1123 | 3E-04 | 1.0328 | 0.0011 | 0.1176 | 3E-04 |
| 18 | A7-11 | 1.0015 | 1.0185 | 0.0007 | 0.0774 | 1E-04 | 1.0122 | 0.0007 | 0.0953 | 1E-04 | 0.9997 | 0.0007 | 0.076 | 1E-04 | 1.0014 | 0.0008 | 0.0966 | 1E-04 |
| 19 | A7-12 | 0.9997 | 1.0157 | 0.0008 | 0.0782 | 1E-04 | 1.0084 | 0.0009 | 0.0959 | 1E-04 | 0.9981 | 0.0008 | 0.0764 | 1E-04 | 1.001 | 0.0008 | 0.0967 | 1E-04 |
| 20 | A7-13 | 0.998 | 1.014 | 0.0008 | 0.0784 | 1E-04 | 1.0078 | 0.0007 | 0.096 | 1E-04 | 0.9953 | 0.0008 | 0.076 | 1E-04 | 0.9968 | 0.0007 | 0.0974 | 1E-04 |
| 21 | A7-14 | 0.9999 | 1.016 | 0.0007 | 0.0776 | 1E-04 | 1.0086 | 0.0008 | 0.0958 | 1E-04 | 0.9973 | 0.0008 | 0.0761 | 1E-04 | 0.9981 | 0.0007 | 0.097 | 1E-04 |
| 22 | A7-21 | 0.9909 | 1.0089 | 0.0008 | 0.0783 | 1E-04 | 1.0038 | 0.0008 | 0.0964 | 1E-04 | 0.9918 | 0.0008 | 0.0767 | 1E-04 | 0.9937 | 0.0008 | 0.0973 | 1E-04 |
| 23 | A7-22 | 0.9710 | 0.9671 | 0.0008 | 0.1565 | 3E-04 | 1.0013 | 0.0007 | 0.1348 | 2E-04 | 0.9806 | 0.0008 | 0.1285 | 3E-04 | 1.0031 | 0.0007 | 0.1306 | 2E-04 |
| 24 | A7-3 | 0.9791 | | | | | 1.0023 | 0.0008 | 0.0967 | 2E-04 | 0.9926 | 0.0009 | 0.0768 | 2E-04 | 0.9932 | 0.0007 | 0.0975 | 2E-04 |
| 24(b) | A7-3 | 0.9791 | 1.0091 | 0.0008 | 0.0781 | 1E-04 | 1.0026 | 0.0008 | 0.0959 | 1E-04 | 0.9910 | 0.0008 | 0.0769 | 2E-04 | 0.9924 | 0.0008 | 0.0975 | 2E-04 |
| 25 | A8-1 | 1.0012 | 1.0244 | 0.0007 | 0.0784 | 1E-04 | 1.0166 | 0.0007 | 0.0966 | 1E-04 | 1.0047 | 0.0009 | 0.077 | 1E-04 | 1.0086 | 0.0007 | 0.0973 | 1E-04 |
| 26 | A8-2 | 0.9824 | 0.9596 | 0.0008 | 0.1672 | 4E-04 | 0.9928 | 0.0008 | 0.1419 | 3E-04 | 0.9731 | 0.0009 | 0.1367 | 3E-04 | 0.9964 | 0.0007 | 0.1376 | 3E-04 |
| 27 | A9-0 | 1 | 1.0247 | 0.0007 | 0.0735 | 1E-04 | 1.0198 | 0.0008 | 0.0905 | 1E-04 | 1.0089 | 0.0008 | 0.0718 | 1E-04 | 1.0124 | 0.0008 | 0.0915 | 1E-04 |
| 28 | A9-1 | 0.9917 | 1.0172 | 0.0007 | 0.0727 | 1E-04 | 1.0132 | 0.0007 | 0.0903 | 1E-04 | 1.0001 | 0.0008 | 0.0908 | 1E-04 | 1.0058 | 0.0008 | 0.0911 | 1E-04 |
| 29 | A9-2 | 0.999 | 1.0245 | 0.001 | 0.0719 | 2E-04 | 1.0214 | 0.0011 | 0.0887 | 2E-04 | 1.0085 | 0.0007 | 0.0704 | 1E-04 | 1.0124 | 0.0006 | 0.0904 | 1E-04 |

## Table 7.1 (Contd)

| Cal. Point | Exp. No. | Exp. | 27GROUPNDF4 | | | | 44GROUPNDF5 | | | | 218GROUPNDF4 | | | | 238GROUPNDF5 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $k_{eff\,exp}$[(a)] | $k_{eff\,calc}$ | $dk_{eff\,calc}$ | EALF | dEALF | $k_{eff\,calc}$ | $dk_{eff\,calc}$ | EALF | dEALF | $k_{eff\,calc}$ | $dk_{eff\,calc}$ | EALF | dEALF | $k_{eff\,calc}$ | $dk_{eff\,calc}$ | EALF | dEALF |
| 30 | A10-1 | 1.0021 | 1.0037 | 0.0008 | 0.0820 | 2E-04 | 0.9973 | 0.0007 | 0.1006 | 2E-04 | 0.9853 | 0.0007 | 0.0803 | 2E-04 | 0.988 | 0.0007 | 0.1014 | 2E-04 |
| 30[(b)] | A10-1 | 1.0021 | 1.0033 | 0.0007 | 0.0823 | 1E-04 | 0.9961 | 0.0008 | 0.1001 | 1E-04 | 0.9858 | 0.0008 | 0.0807 | 1E-04 | 0.986 | 0.0008 | 0.1016 | 1E-04 |
| STANDARD DEVIATION | | | 0.0207 | | | | 0.01745 | | | | 0.0077 | | | | 0.01712 | | | |
| MEAN VALUE | | 0.9960 | 1.0035 | | 0.1114 | | 1.01219 | | 0.113 | | 0.9993 | | 0.1 | | 1.00982 | | 0.1123 | |

(a) Uncertainty in the measured $k_{eff\,exp}$ is assumed to be ± 0.0028.

(b) Calculated with SCALE 4.4a.

**Table 7.2 MCNP Calculation Results of Some RBMK Critical Experiments**

| | Exp. | MCNP (ENDF60 library) | |
|---|---|---|---|
| Exp. No. | $k_{eff\ exp}$ | $k_{eff\ calc}$ | $dk_{eff\ calc}$ |
| A1-1 | 1.0029 | 1.0216 | 0.00052 |
| A1-2 | 1.0014 | 1.0175 | 0.00052 |
| A2-1 | 1.0014 | 1.0172 | 0.00051 |
| A2-2 | 0.9684 | 0.9744 | 0.00033 |

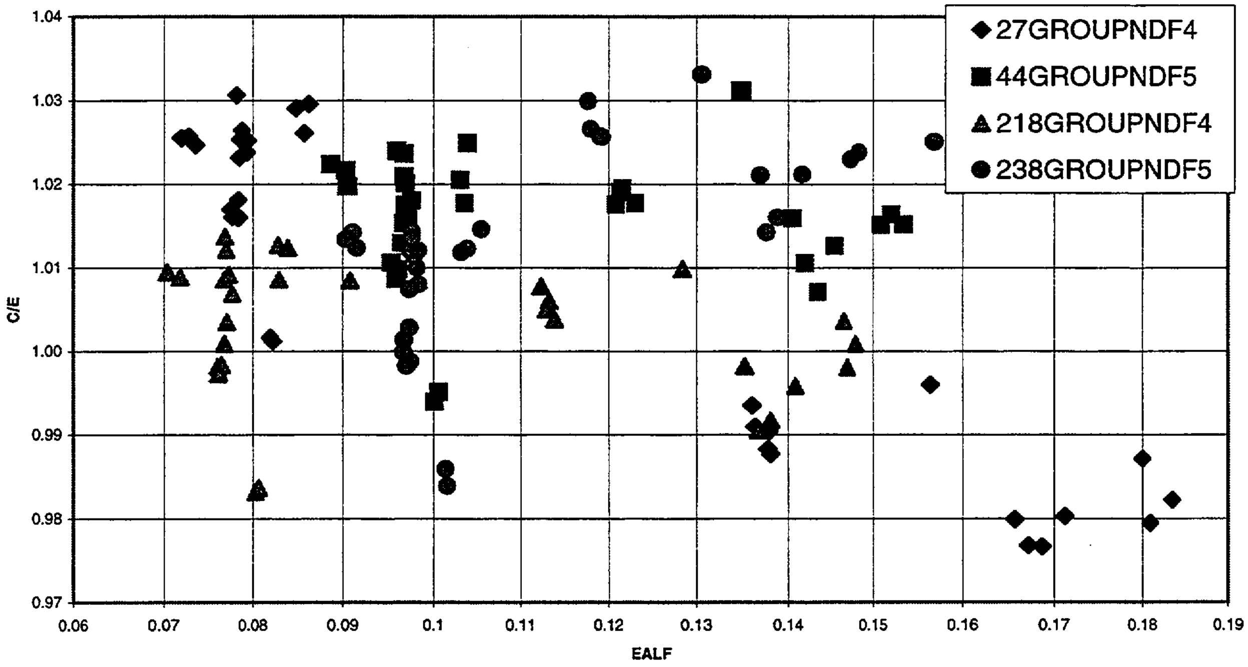


**Figure 7.1 Calculation/Experimental (C/E) Results Deviation**

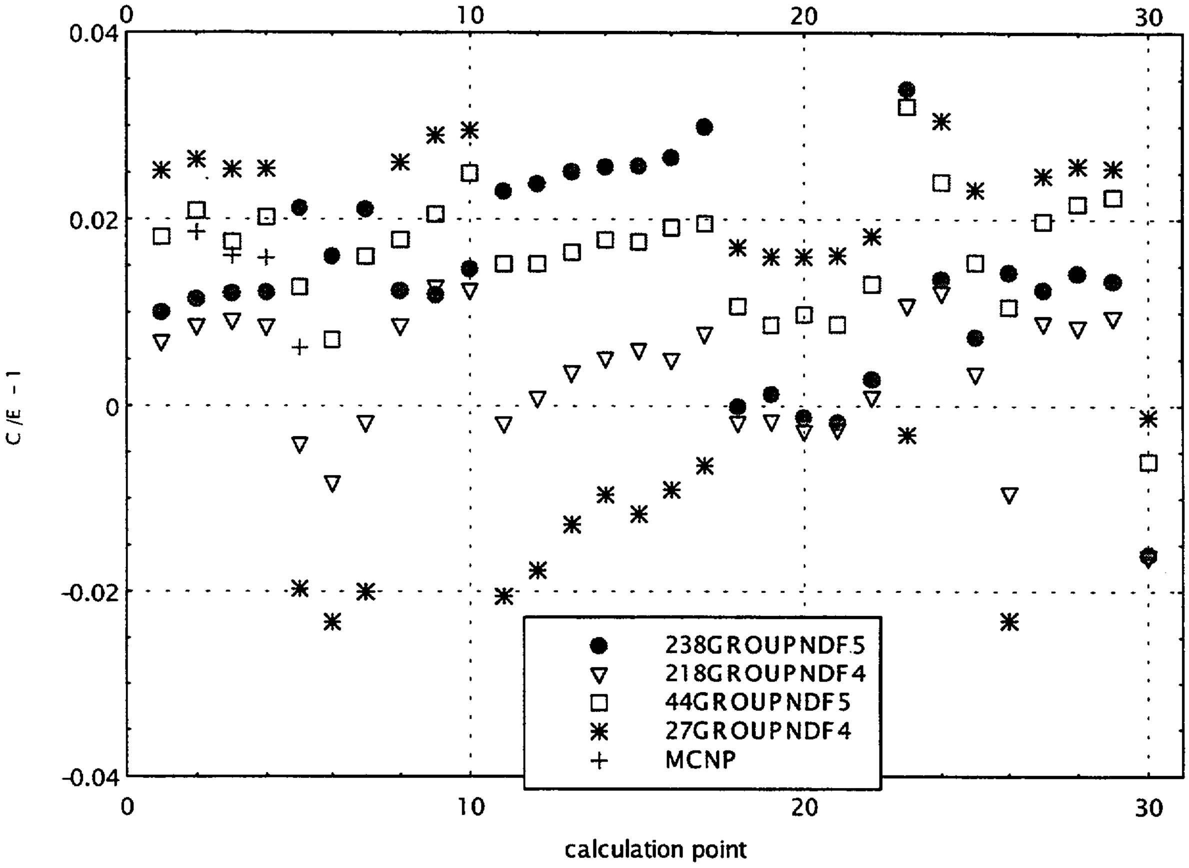


**Figure 7.2 Calculation/Experimental (C/E) Results Deviation vs. Calculation Point from Table 7.2**

# 8 Determination of Bias and Subcritical Limits Based on Calculation Results for the RBMK Critical Facility

As recommended in Reference 15, the USLSTATS program was used for statistical processing of results from the RBMK critical facility.

The USLSTATS computer program uses two methods—a confidence band with administrative margin and a single-sided uniform-width closed-interval—to calculate and print upper safety limit (USL) correlations based on a set of user-supplied k values and corresponding values of a single associated parameter X (e.g., lattice pitch, fuel enrichment, average lethargy causing fission) for a set of criticality benchmark calculations. The USLSTATS program provides a high degree of confidence that a given system is subcritical if a criticality calculation based on the system yields a multiplication factor (k) below the USL.

Under statistical processing of the results, two set of parameters were addressed in parallel—dependence between the calculated value of the multiplication factor, $k_{eff\,calc}$ and parameter EALF, as well as dependence between $k_{eff\,calc}$ and its experimental value $k_{eff\,exp}$.

Statistical processing results for these data sets are presented in Tables 8.1 and 8.2.

The most interesting result in Table 8.1 is that the highest coefficient of correlation between $k_{eff\,calc}$ and EALF (0.9343) is obtained for library 27GROUPNDF4, while the best correlation between calculated and experimental data is observed for library 218GROUPNDF4. The highest quality of the results obtained with the use of library 218GROUPNDF4 is confirmed also by the results presented in the last lines of Table 7.1. The mean-root-square deviation between calculated and experimental results for this library is considerably lower than those for the other three libraries addressed, while the average value of $k_{eff\,calc}$ most accurately (and, of no small importance, with some conservative margin) coincides with $k_{eff\,exp}$.

Typically in a criticality safety validation, the experimental $k_{eff}$ values are 1.0. In such cases, C/E = $k_{eff\,calc}$. In our validation, the experimental $k_{eff}$ values are not equal to 1.0. USLSTATS has no method to account for differing experimental values (only the calculated values are read by USLSTATS). For this reason, we also recalculated USLSTATS with the ratio of calculated values to the experimental values. These results are presented in Tables 8.3 and 8.4 and illustrated in Figures 8.1 through 8.4.

The results of re-calculation are the less conservative as compared with the previous ones. Therefore, to use them while assessing nuclear safety, it is necessary to perform additional analysis as to applicability of this approach.

### Table 8.1 Summary of USL Calculations for Different SCALE Libraries

| Library | $k_{eff\,calc}(x)$ | Correlation coefficient, r | Confidence band width, W | Minimum margin of subcriticality, C*s(p)-W ($USL_2$) |
|---|---|---|---|---|
| $k_{eff\,calc}$ vs EALF (X = EALF) | | | | |
| 27GROUPNDF4 | 1.0594 + (-5.0192E-01)*X | 0.9343 | 1.7687E-02 | 2.3815E-02 |
| 44GROUPNDF5 | 1.0288 + (-1.4716E-01)*X | 0.4033 | 1.7771E-02 | 2.411E-02 |
| 218GROUPNDF4 | 1.0179 + (-1.8549E-01)*X | 0.5231 | 1.9451E-02 | 2.6291E-02 |
| 238GROUPNDF5 | 0.9882 + ( 1.9223E-01)*X | 0.2359 | 2.221E-02 | 3.0303E-02 |

### Table 8.2 USL Results for Different SCALE Libraries

| Library | Confidence band with administrative margin of 0.05, $USL_1$ | Single-sided uniform width closed interval, $USL_2$ |
|---|---|---|
| $k_{eff\,calc}$ vs EALF | | |
| 27GROUPNDF4 | 0.9917 + (-5.0192E-01)*EALF (EALF > 0.118) | 1.0179 + (-5.0192E-01)*EALF (EALF > 0.118) |
| | 0.9323 (EALF <= 0.118) | 0.9585 (EALF <= 0.118) |
| 44GROUPNDF5 | 0.9322 ( 8.87000E-2< EALF < 0.15350) | 0.9581 (8.87000E-2< EALF < 0.15350) |
| 218GROUPNDF4 | 0.9484 + (-1.8549E-01)*EALF (EALF > 0.096) | 0.9721 + (-1.8549E-01)* EALF (EALF > 0.096) |
| | 0.9305 (EALF <= 0.096) | 0.9543 (EALF <= 0.096) |
| 238GROUPNDF5 | 0.9278 (9.04000E-2< EALF < 0.15690) | 0.9475 (9.04000E-2< X < 0.15690) |

### Table 8.3 Summary of USL Recalculations for Different SCALE Libraries

| Library | $k_{eff\,calc}(x)$ | Confidence band width, W | Minimum margin of subcriticality, C*s(p)-W ($USL_2$) |
|---|---|---|---|
| $k_{eff\,calc}$ vs EALF (X = EALF) | | | |
| 27GROUPNDF4 | 1.0563 + (-4.3880E-01)*X | 1.2666E-02 | 1.7046E-02 |
| 44GROUPNDF5 | 1.0182 + (-1.7218E-01)*X | 1.2505E-02 | 1.6966E-02 |
| 218GROUPNDF4 | 1.0113 + (-8.0504E-02)*X | 1.2740E-02 | 1.7219E-02 |
| 238GROUPNDF5 | 0.9767 + ( 3.3150E-01)*X | 1.5775E-02 | 2.1523E-02 |

### Table 8.4 USL Recalculation Results for Different SCALE Libraries

| Library | Confidence band with administrative margin of 0.05, $USL_1$ | Single-sided uniform width closed interval, $USL_2$ |
|---|---|---|
| $k_{eff\,calc}$ vs EALF | | |
| 27GROUPNDF4 | 0.9937 + (-4.3880E-01)*EALF (EALF > 0.128) | 1.0266 + (-4.3880E-01)*EALF (EALF > 0.128) |
| | 0.9373 (EALF <= 0.128) | 0.9703 (EALF <= 0.128) |
| 44GROUPNDF5 | 0.9375 ( 8.87000E-2< EALF < 0.15350) | 0.9705 (8.87000E-2< EALF < 0.15350) |
| 218GROUPNDF4 | 0.9486 + (-8.0504E-02)*EALF (EALF > 0.14047) | 0.9813 + (-8.0504E-02)* EALF (EALF > 0.14047) |
| | 0.9373 (EALF <= 0.14047) | 0.9700 (EALF <= 0.14047) |
| 238GROUPNDF5 | 0.9342 (9.04000E-2< EALF < 0.15690) | 0.9627 (9.04000E-2< X < 0.15690) |

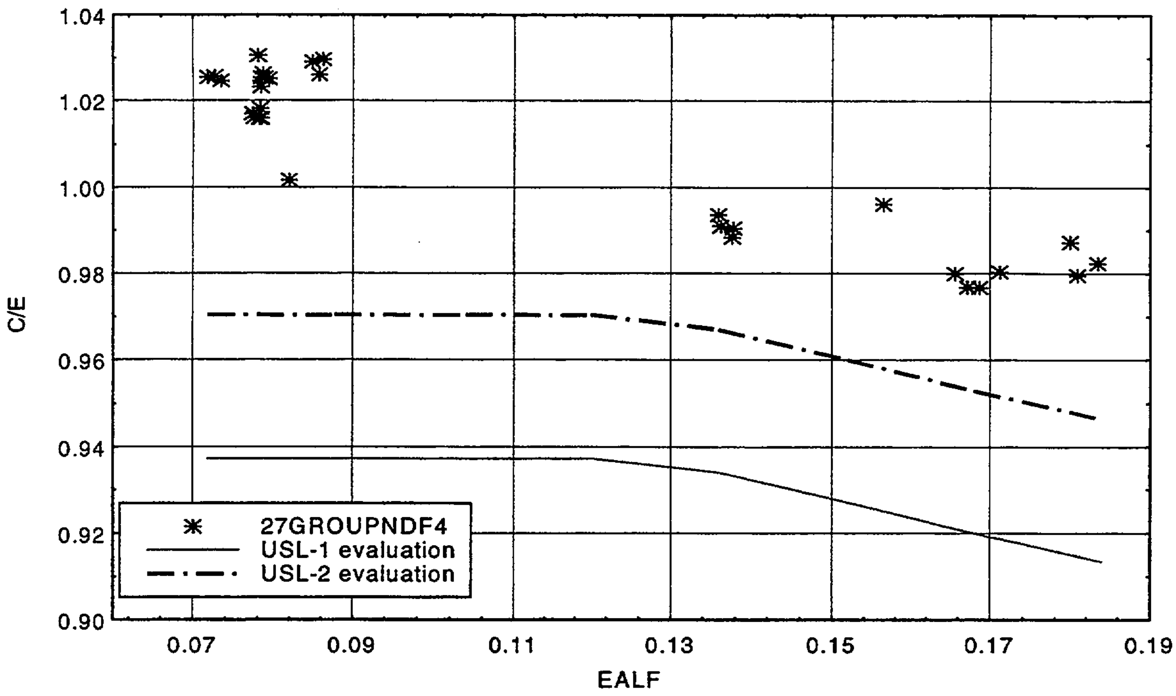


Figure 8.1 Calculation/Experimental (CE) $k_{eff}$ and USL Evaluation Results for 27GROUPNDF4

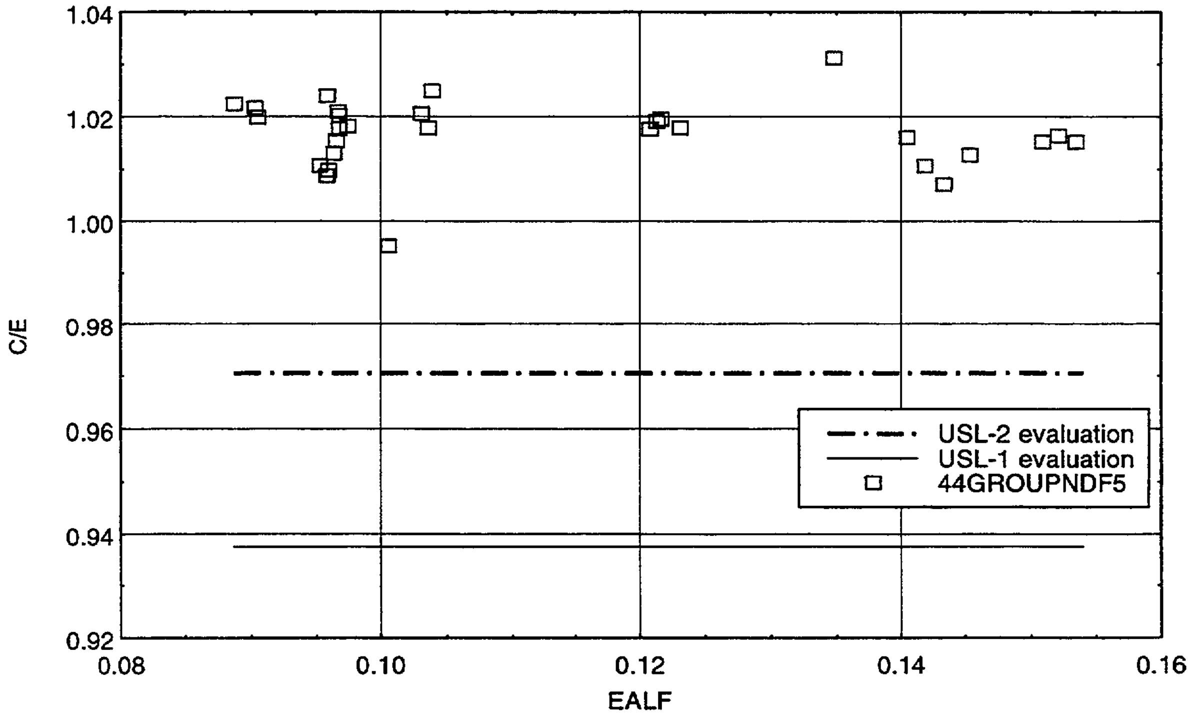


Figure 8.2 Calculation/Experimental (C/E) $k_{eff}$ and USL Evaluation Results for 44GROUPNDF5

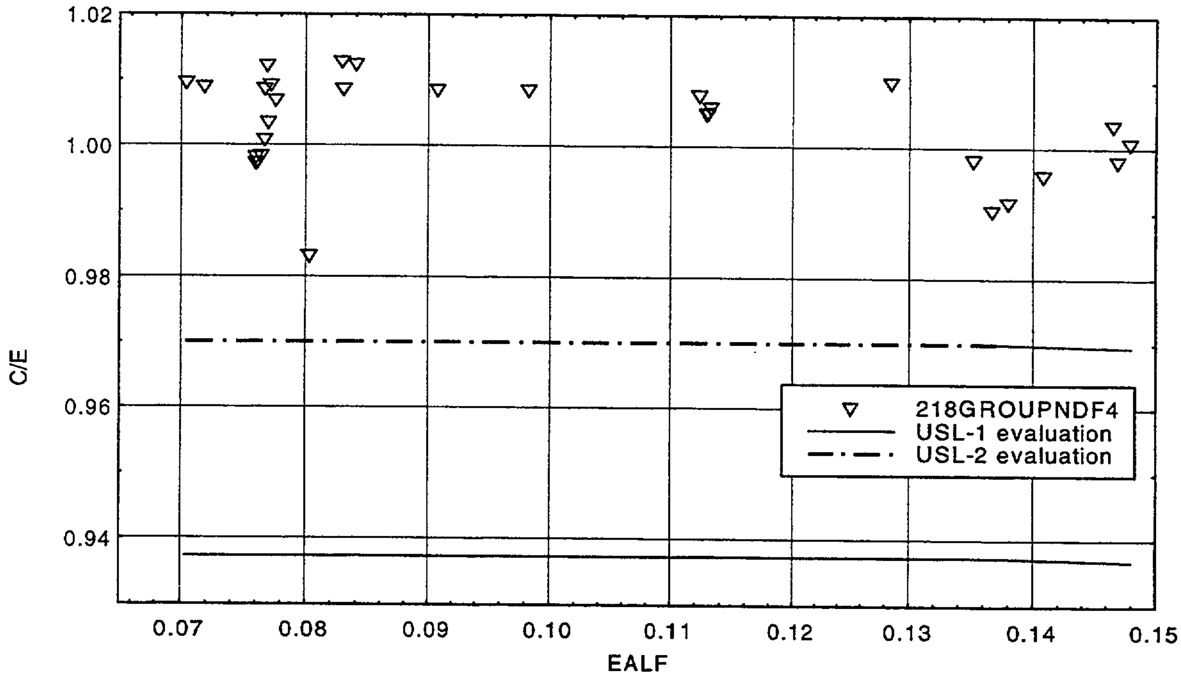


Figure 8.3 Calculation/Experimental (C/E) $k_{eff}$ and USL Evaluation Results for 218GROUPNDF4

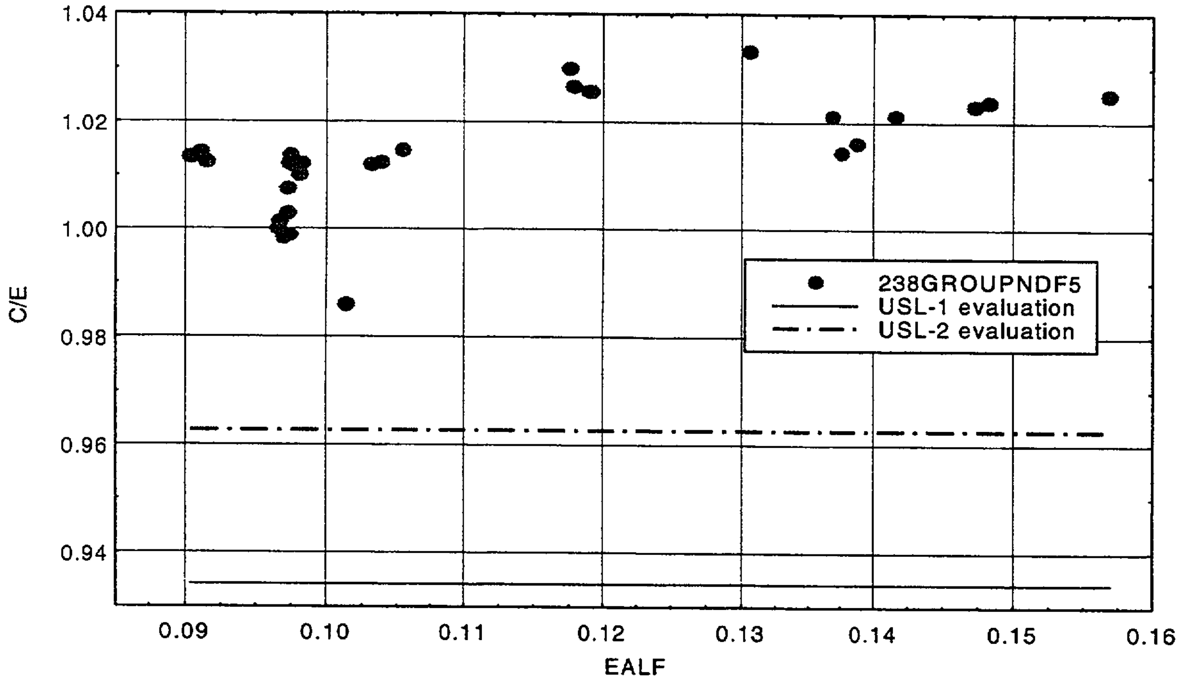


Figure 8.4 Calculation/Experimental (C/E) $k_{eff}$ and USL Evaluation Results for 238GROUPNDF5

# 9 Testing SCALE for Calculating VVER-1000 Triangular Fuel Array and Hexagonal Elements

A triangular pitched lattice of fuel pins and fuel assemblies, or elements, of VVER-1000 reactors may be modeled in the SCALE package by means of hexagonal arrays. These capabilities became available with the initial release of KENO-VI in SCALE 4.3. Prior to modeling actual benchmark experiments with VVER-1000 fuel, trial calculations were performed using different KENO-VI calculational models.

The calculations were performed with the SCALE 4.3 and SCALE 4.4a packages. These calculations were also a first stage in the validation of the new Version 4.4a that is intended to replace Version 4.3.

Calculations were performed for 125-cm-long fuel and construction elements (fuel pins, central channels, and control rod guide tubes of the VVER-1000 mock-up at the LR-0 facility [Section 5]). These elements are surrounded with water reflectors and contain structure and material compositions identical to appropriate VVER-1000 elements. Endfittings of fuel pins and assemblies have not been modeled.

The CSAS26 sequence and the 27GROUPNDF4 library from SCALE were applied. The 3-D criticality calculations were run with 300 generations and 1,000 neutrons per generation, for a total of 300,000 histories. Default values were used for parameters including the start option of flat neutron distribution over the entire system. Water boundary conditions were applied to the outermost region of every problem. No biasing was used to track neutrons in the water reflector region of each problem.

There are two methods for modeling lattices of fuel rods or assemblies in KENO-VI: the ARRAY operator and the HOLE operator. Calculational results within the limits of statistical accuracy should not depend on the modeling method. The calculations were performed with both SCALE 4.3 and SCALE 4.4a using the same input data files. The calculation results are shown in Table 9.1.

The system consisting of a central channel and 18 fuel pins located around it was modeled in the first series of calculations, test_101 through test_104 (Figure 9.1). A 25 x 25 hexagonal array was built in the calculations test_101 and test_102 by means of the ARRAY operator. The calculated system shown in Figure 9.1 was cut out from this array by a hexagonal boundary surface. In the calculations test_103 and test_104, the central channel and 18 fuel pins were located inside a hexagonal boundary surface by means of HOLE operators to form the same calculated system that was in the test_101 and test_102 cases. The calculation results within the limits of statistical accuracy (2σ) coincide and depend neither on the system modeling method nor on the version of SCALE package.

The system modeled in the second series of calculations (test_201 through test_205) represented a 3 x 3 hexagonal array (Figure 9.2). The array consisted of the elements that had been studied in the first two calculations (test_101 and test_102) (Figure 9.1). Thus, the calculated model was formed by means of two types of arrays, a 9 x 9 internal array used in modeling each of the 9 elements, and a 3 x 3 external array used in modeling the whole system. In calculation test_201, the external array was filled with elements of the same unit number. In the remaining calculations, the array was filled with identical

## Table 9.1 Effective Multiplication Factor ($k_{eff}$) Calculation Results

| Test | Description | SCALE 4.3 | | SCALE 4.4a | | Diff. |
|---|---|---|---|---|---|---|
| | | $k_{eff}$ | $\delta k_{eff}$ | $k_{eff}$ | $\delta k_{eff}$ | |
| 101 | Position of central channel and 18 fuel pins were modeled in the manner of triangular pitched lattices, which are located in the hexagonal cell. All fuel pins represented as one UNIT. | 0.2795 | 0.0006 | 0.2794 | 0.0006 | +0.0001 |
| 102 | Similar to test_001, but fuel pins represented were of identical compositions but different in number of UNITs. | 0.2795 | 0.0006 | 0.2794 | 0.0006 | +0.0001 |
| 103 | Central channel and 18 fuel pins were represented in the manner of HOLES set located in the hexagonal cell. All fuel pins represented as one UNIT. | 0.2798 | 0.0006 | 0.2809 | 0.0006 | -0.0011 |
| 104 | Similar to test_003, but fuel pins represented were identical in composition but different in number of UNITs. | 0.2798 | 0.0006 | 0.2809 | 0.0006 | -0.0011 |
| 201 | 9 assemblies (hexagonal cells as in test_001) arranged in triangular pitched lattices 3 x 3. All assemblies represented as one UNIT. | 0.3770 | 0.0008 | 0.3773 | 0.0008 | -0.0003 |
| 202 | All assemblies represented were identical in composition but different in number of UNITs. Triangular pitched fuel pin arrays in different assembly represented were of identical composition but different in number of ARRAYs. | 0.6187 | 0.0010 | 0.6155 | 0.0010 | +0.0032 |
| 203 | Similar to test_112, when all assemblies represented were identical composition but different in number of UNITs. The difference is the following: triangular pitched fuel pins arrays in different assembly represented by one ARRAY. | 0.6187 | 0.0010 | 0.6155 | 0.0010 | +0.0032 |
| 204 | 6 assemblies from 9 represented as one UNIT. 3 assemblies represented were identical (between itself and all other assemblies) in composition but different in number of UNITs. Triangular pitched fuel pin arrays in different UNITs represented were identical in composition but different in number of ARRAYs. | 0.5439 | 0.0011 | 0.5438 | 0.0009 | +0.0001 |
| 205 | 8 assemblies from 9 represented as one UNIT. Central assembly represented was identical (between all other assemblies) in composition but different in number of UNITs. Triangular pitched fuel pin arrays in different UNITs represented were identical in composition but different in number of ARRAYs. | 0.4382 | 0.0009 | 0.4396 | 0.0009 | +0.0014 |
| 301 | 9 full-scale VVER-1000 fuel assemblies arranged in triangular pitched lattices 3 x 3. All assemblies represented as one UNIT. | 0.8459 | 0.0010 | 0.8483 | 0.0012 | -0.0024 |
| 302 | All assemblies represented were identical in composition but different in number of UNITs. Triangular pitched fuel pin arrays in different assemblies represented were of identical composition but different in number of ARRAYs. | 1.1254 | 0.0010 | 1.1267 | 0.0012 | -0.0013 |
| 303 | Similar to test_012, when all assemblies represented were of identical composition but different in number of UNITs. The difference is the following: triangular pitched fuel pin arrays in different assembly represented by one ARRAY. | 1.1254 | 0.0010 | 1.1267 | 0.0012 | -0.0013 |
| 304 | Similar to test_012, but with other positions of fuel assembly UNIT in ARRAY. | 1.1254 | 0.0010 | 1.1267 | 0.0012 | -0.0013 |
| 305,<br>306 | Part of assemblies represented as one UNIT. The remaining assemblies represented were identical in composition but different in number of UNITs. Triangular pitched fuel pin arrays in different assemblies represented were of identical composition but different in number of ARRAYs. | 1.1254 | 0.0010 | 1.1267 | 0.0012 | -0.0013 |

## Table 9.1 (Contd)

| Test | Description | SCALE 4.3 | | SCALE 4.4a | | Diff. |
|---|---|---|---|---|---|---|
| | | $k_{eff}$ | $\delta k_{eff}$ | $k_{eff}$ | $\delta k_{eff}$ | |
| 307 | 6 assemblies from 9 represented as one UNIT. 3 assemblies represented were identical (between itself and all other assemblies) in composition but different in number of UNITs. Triangular pitched fuel pin arrays in different UNITs represented were identical in composition but different in number of ARRAYs. | 1.0809 | 0.0012 | 1.0841 | 0.0012 | -0.0032 |
| 308 | Similar to test_016 except that the triangular pitched fuel pin arrays in different assemblies were represented by one ARRAY. | 1.0809 | 0.0012 | 1.0841 | 0.0012 | -0.0032 |
| 309 | 8 assemblies from 9 represented as one UNIT. Central assembly represented was identical (between all other assemblies) in composition but different in number of UNITs. Triangular pitched fuel pin arrays in different UNITs represented were of identical compositions but different in number of ARRAYs. | 0.9790 | 0.0012 | 0.9775 | 0.0012 | +0.0015 |
| 310 | Similar to test_017. The difference is the following: triangular pitched fuel pins arrays in different assemblies represented by one ARRAY. | 0.9790 | 0.0012 | 0.9775 | 0.0012 | +0.0015 |
| 311 | Similar to test_017. The difference is the following: central assembly represented was of identical (between all other assemblies) composition but different (and the others, than in test_017) in number of UNITs. | 0.9790 | 0.0012 | 0.9775 | 0.0012 | +0.0015 |
| 401 | Similar to test_011, but 9 fuel assemblies represented in the manner of HOLES set located in the parallelepiped cell. All fuel assemblies represented as one UNIT. | 1.1241 | 0.0011 | 1.1249 | 0.0012 | -0.0008 |
| 402 | Similar to test_012, but 9 fuel assemblies represented in the manner of HOLES set located in the parallelepiped cell. As in test_012, all assemblies represented were of identical composition but different in number of UNITs. Triangular pitched fuel pin arrays in different UNITs represented were identical in compositions but different in number of ARRAYs. | 1.1241 | 0.0011 | 1.1249 | 0.0012 | -0.0008 |

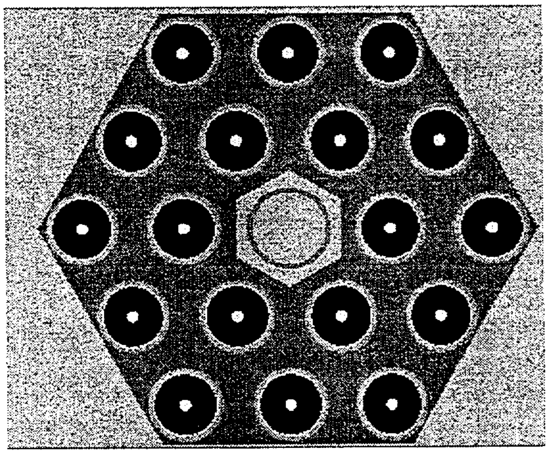


Figure 9.1 Calculated Model for test_101 through test_104

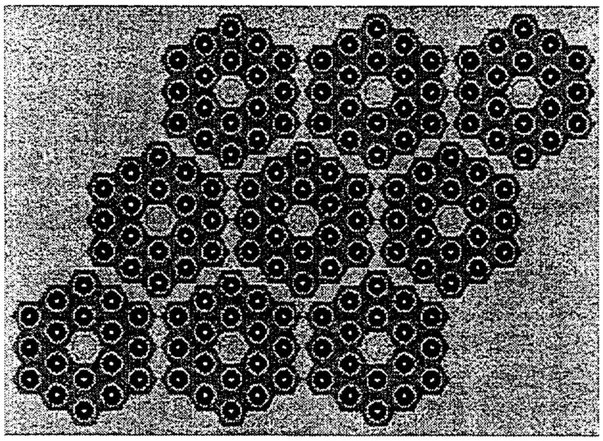


Figure 9.2 Calculated model for test_201 through test_205

elements that had different unit numbers. There are significant differences in the calculation results of both SCALE 4.3 and SCALE 4.4a depending on the method of the array setup. The SCALE 4.3 and SCALE 4.4a results differ by more than 3σ.

The central part of the LR-0 mock-up core (Section 5) has been modeled in the third series of the calculations, test_301 through test_311. These calculations consisted of 9 identical assemblies, as shown in Figure 5.2. As in the previous case, the core was modeled as arrays in an array. The core (see Figure 9.3) was represented as a hexagonal array filled with fuel assemblies of the relevant enrichment. In turn, each fuel assembly was represented as a hexagonal array filled with fuel elements and control rod guide tubes (see Figures 5.2 and 9.4). At the end of calculations test_301 through test_311, we once more noted that when the unit number was incremented without changing the contents of each unit, the calculated value of $k_{eff}$ was changed (e.g., when two identical fuel assemblies located inside the core are modeled by one and the same unit versus two identical units with different unit numbers).

To overcome this difficulty, in calculations test_401 and test_402 we changed the calculation model and represented the core not as arrays in an array but as arrays in holes. The positions of fuel assemblies inside the core were modeled as holes with accurate assignment of the coordinates of each fuel assembly (see Figures 9.3 and 9.4).

Calculation results coincide (within statistical limits) and depend neither on the system modeling method nor on the version of SCALE package.

Thus, on the basis of these test calculations, the potential difficulties of modeling a hexagonal array of hexagonal fuel assemblies have been demonstrated. The SCALE staff at ORNL has confirmed that KENO-VI in SCALE 4.3 and SCALE 4.4a does not correctly represent hexagonal arrays in a larger hexagonal array, if the same unit number is used for more than one assembly in the larger array. Oak Ridge researchers have corrected this error, and the correction will be available in the next public release of KENO-VI. To avoid potential errors, we have chosen to model the assemblies as arrays in holes.

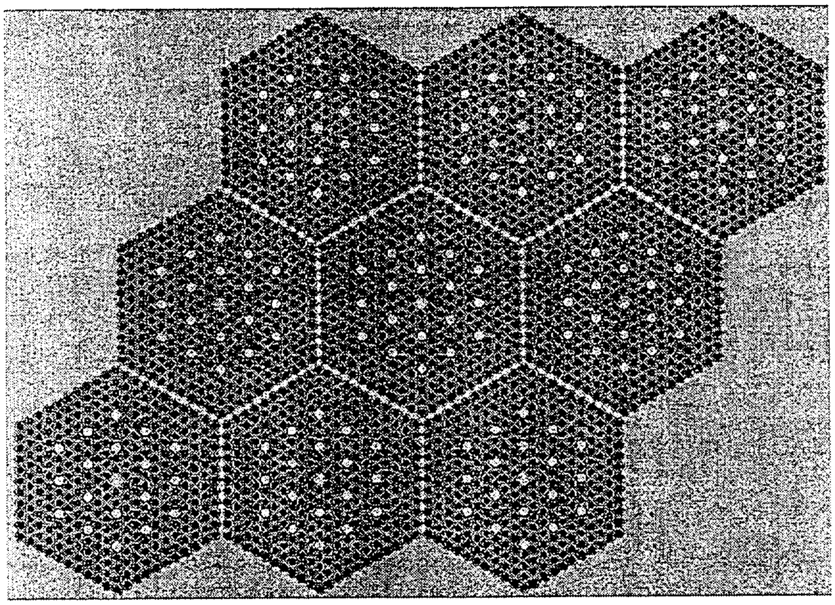


Figure 9.3 Calculated Model for test_301 through test_311 and for test_401, test_402

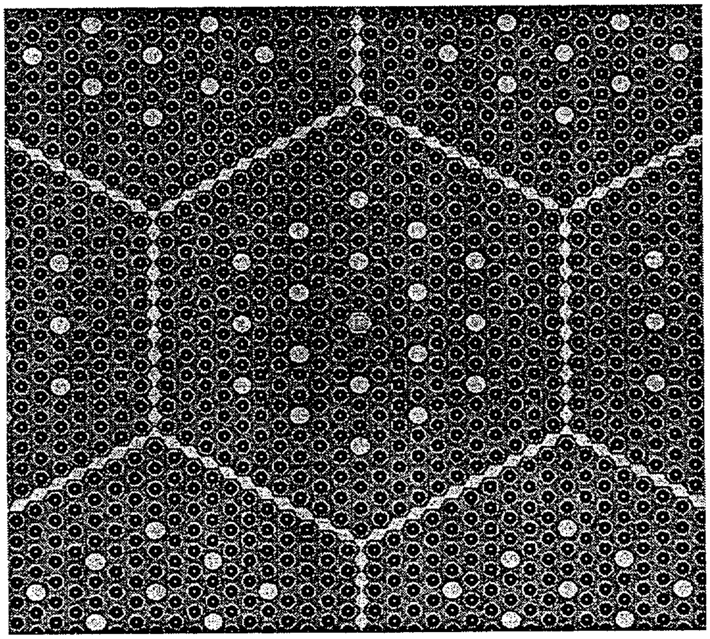


Figure 9.4 Central Part of Calculated Model for test_301 through test_311 and for test_401, test_402

# 10 Overview of Calculation Results for the VVER Critical Facility

The calculation results for the VVER critical facility experiments (in the LR-0 mock-up) described in Section 5 are presented. For reference, the SCALE input files for these experiments are included in Appendix B.

## 10.1 Modeling and Calculation Techniques

Several techniques for modeling the fuel region of particular experiments are addressed in Section 10.1.1. KENO-VI input parameters are discussed in Section 10.1.2.

Calculations were performed in two stages. In the first, full-scale 3-D mathematical modeling to simulate the critical condition of the LR-0 facility was performed with the use of five libraries: 16-GROUP HANSEN-ROACH library, 27GROUPNDF4, 44GROUPNDF5, 218GROUPNDF4, and 238GROUPNDF5.

Then 2-D calculations were performed for the central part of the core using the same libraries, to identify the relative power distribution. This approach enabled simplifying the calculations without decreasing accuracy of the results obtained for either modeling criticality or calculating the relative power distribution.

All the experimental fuel elements used to measure relative power distribution were modeled as separately numerable geometrical blocks (UNITs). If these experimental fuel elements were located symmetrically with respect to the axis of core symmetry, then they were modeled by one and the same geometrical block (UNIT), i.e., the results were averaged. The same averaging was performed also during processing and presenting of the experimental results. The total number of fuel elements used under measurement was equal to 491 (see Figure 5.4). Taking into account the symmetrical fuel elements under simulation of power density distribution, an additional 260 UNITs were used.

### 10.1.1 Fuel Region Modeling

The experiments listed in Section 5 were modeled explicitly by considering the fuel rod regions submerged in and protruding from the moderator region.

In the LR-0 facility, more than one fissile mixture was present in each experiment. Because only one CSAS unit cell specification is allowed per problem, the Dancoff factors and resonance data had to be calculated for the other unit cell descriptions using a CSASN "PARM=CHECK" case and then explicitly specified in the CSAS26 calculation using the "MORE DATA" option.

When modeling the fuel, the material of the spacing grates was homogeneously mixed into the region of the moderator around fuel elements.

Water boundary conditions were applied to the outermost region of every problem. No biasing was used to track neutrons in the water reflector region of each problem.

Two-dimensional pin-by-pin power distribution calculations were run with 1,000 generations and 10,000 neutrons per generation, for a total of 10,000,000 histories with SCALE 4.3 and with 1,000 generations and 50,000 neutrons per generation, for a total of 50,000,000 histories with SCALE 4.4a. The first 100 generations were omitted when calculating the average eigenvalue of the system.

In this case, conditions of reflection at the upper and lower boundaries of the system were used. Water boundary conditions were applied to the other outermost region of every problem.

The relative power distribution between fuel elements was estimated based on values of "source vector by unit." For this purpose, the MKU=YES parameter was assigned in input data. Values of source vector by unit obtained for experimental fuel elements were normalized with respect to a mean value of power per fuel element equal to 1,000 (see last paragraph of Section 5).

### 10.1.2 KENO-VI Parameter Data

Three-dimensional criticality calculations of the LR-0 facility were run with 1,000 generations and 1,000 neutrons per generation, for a total of 1,000,000 histories run with SCALE 4.3. The first 150 generations were omitted when calculating the average eigenvalue of the system. Default values were used for all other parameters, including the start option of flat neutron distribution over the entire system.

## 10.2 Calculation Results

The core of the LR-0 facility (see Figure 5.1) was modeled as the set of fuel assemblies of the relevant enrichment. Each fuel assembly was represented as a hexagonal array filled with fuel elements and control rod guide tubes (Figures 4.1, 5.2, and 5.3). In view of the results presented in Section 9, the positions of fuel assemblies inside the core were modeled as holes with accurate assignment of the coordinates of each fuel assembly. Under this approach, the input file becomes more cumbersome, which is of particular importance because the computer run time is increased considerably.

### 10.2.1 Test Calculation

In preparing for the formal calculations, we performed some test calculations to clarify the impact of the modeling method for the spacing grates upon the effective neutron multiplication factor ($k_{eff}$). For this reason, their detailed modeling was undertaken. In all cases, the results from the detailed models differed by less than 0.1% from those obtained under homogeneous mixing of spacing grate material into the region of moderator around fuel elements. For this reason, in subsequent calculations we used only the simplified approach.

As mentioned previously, Ukraine's SSTC NRS uses the PHYBER complex (KAB GmbH, Germany) for calculations related to licensing of fuel for Ukraine's VVER-1000 reactors. This complex contains the following programs:

- NESSEL-4 - multigroup spectrum and micro-burnup transport code for the calculation of few-group neutron cross-section libraries for reactor core materials
- PYTHIA-DERAB - 3-D coarse-mesh macro burnup and 2-D fine-mesh diffusion code for VVER core cycle calculation.

With the use of these programs, few-group neutron-physical constants libraries were prepared, and in-core power density distribution per fuel element was calculated for the LR-0 facility. These results, along with the experimental data, are presented in Tables 10.1 and 10.2 for comparison with the results of calculations made by SCALE 4.3.

### 10.2.2 Criticality and Relative Power Distribution Calculations

These results were obtained for five main libraries used in SCALE 4.3 and SCALE 4.4a to calculate criticality: 16-group HANSEN-ROACH library, 27GROUPNDF4, 44GROUPNDF5, 218GROUPNDF4, and 238GROUPNDF5.

Results of $k_{eff}$ calculations are presented in Table 10.1.

Results of calculations concerning power density distribution per fuel element as compared to the experimental data and results of diffusion calculation are presented in Tables 10.2, 10.3, and 10.4, as well as in Figures 10.1 through 10.12.

It is possible to determine fuel pin-by-fuel pin power distributions from the KENO-VI output file by two methods, based on the tables labeled "source vector by unit" in the matrix $k_{eff}$ by unit output and "total fissions" in the fission densities output. Tables 10.3 and 10.4 show the results obtained applying both methods for the 44GROUPNDF5 and 218GROUPNDF4 libraries in SCALE 4.3. These results coincide within statistical uncertainties of the calculations for SCALE 4.3. Therefore, for the other libraries (16-group HANSEN-ROACH, 27GROUPNDF4, and 238GROUPNDF5), Table 10.2 shows the results of SCALE 4.3 only for "source vector by unit".

Tables 10.1, 10.3, and 10.4 present the results of comparison of SCALE 4.3 and SCALE 4.4a packages. The calculated values of $k_{eff}$ for both versions practically coincide as for preceding calculations of RBMK test facilities. However, the fuel pin-by-fuel pin power distribution results are quite different. The results from Version 4.4a, in spite of a significant increase in the number of neutron histories ($5x10^7$ versus $10^7$ in Version 4.3) differ more significantly from the experiment. In addition, there is a very large difference between the results based on source vector by unit and total fissions. The accuracy of modeling the fuel pin-by-fuel pin power distribution is directly related to the accuracy of modeling the neutron flux distribution in the system. Therefore, the observed differences require more thorough analysis and examination to determine the applicability of Version 4.4a for modeling systems with VVER reactor fuel.

The diffusion theory calculation result shows a lower calculated value of the effective neutron multiplication factor. This finding is legitimate. The program used was tuned and arranged for calculations involving large cores of VVER-440 and VVER-1000 reactors. When applied to smaller nuclear facilities (e.g., the LR-0 mock-up), the program produces overly high estimates of neutron leakage because of the complexity connected with preparing the neutron-physical constants of the reflector. This phenomenon is clearly shown by the data in Table 10.2, which compares experimental and calculated values of relative power density distribution. In fuel assembly numbers 3 and 4 adjacent to the reflector, as well as in fuel assembly number 27 having a large central experimental channel, the calculated power densities taken as a total are considerably lower than the experimental ones. Overestimation of neutron leakage leads naturally to values of effective multiplication factor that are too small.

Calculations made with SCALE 4.3 show a high level of coincidence between calculated and experimental results. For all the libraries, the correlation coefficient value is equal to or exceeds 0.998. There is no statistically significant difference in the correlation coefficient values of the SCALE libraries. Considering the calculated values of $k_{eff}$, standard deviation, and maximum deviation for the calculated results, it is possible to conclude that the highest quality results were obtained using the 44GROUPNDF5 and 27GROUPNDF4 libraries. The 44GROUPNDF5 and 238GROUPNDF5 libraries give the best agreement between the 3-D calculated $k_{eff}$ values and the experimental $k_{eff}$ value of 1.0. Both libraries are within 0.2%.

To make the final decision concerning which of the addressed libraries enables us to obtain the best coincidence between calculated and experimental results while solving complex calculating tasks of such kind (32 fuel assemblies containing 312 fuel elements each), it is necessary to perform much more accurate calculations (for instance, for a total 100,000,000 histories as opposed to 10,000,000 in our SCALE 4.3 calculations).

**Table 10.1 Effective Multiplication Factor ($k_{eff}$) Calculation Results**

| | **3-D calculation** | **2-D calculation** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **SCALE 4.3** | | | **SCALE 4.4a** | | |
| | | | **$\Delta_{max}$ (power distrib.)** | | | **$\Delta_{max}$ (power distrib.)** | |
| **Library** | **$k_{eff}$** | **$k_{eff}$** | **Source vector** | **Fission densities** | **$k_{eff}$** | **Source vector** | **Fission densities** |
| 16-GROUP Hansen-Roach | 1.0030 ± 0.0005 | 1.0382 ± 0.0001 | 12.37% | | | | |
| 27GROUPNDF4 | 0.9920 ± 0.0006 | 1.0253 ± 0.0002 | 9.12% | | | | |
| 44GROUPNDF5 | 1.0023 ± 0.0007 | 1.0352 ± 0.0001 | 8.97% | 9.88% | 1.0355 ± 0.0001 | 23.00% | 14.66% |
| 218GROUPNDF4 | 0.9886 ± 0.0006 | 1.0210 ± 0.0001 | 12.85% | 15.49% | 1.0212 ± 0.0001 | 24.46% | 9.07% |
| 238GROUPNDF5 | 0.9989 ± 0.0005 | 1.0321 ± 0.0002 | 14.94% | | | | |
| Diffusion calculation | 0.9810 | | | | | | |

# Table 10.2 Comparison of Experimental and Calculation Results for Relative Power Distribution, Diffusion Calculation, 16-, 27- and 238-Group Library of SCALE

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | Diff. calculation | | Monte Carlo calculation, SCALE 4.3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 16-GROUP HANSEN-ROACH | | 27GROUP NDF4 | | 238GROUP NDF5 | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 1 | 31 | 326 | 1506 | 5 | 1610 | 6.92 | 1504 | -0.16 | 1449 | -3.75 | 1488 | -1.18 |
| 2 | | 302 | 1328 | 3 | 1397 | 5.18 | 1296 | -2.43 | 1279 | -3.66 | 1244 | -6.31 |
| 3 | | 242 | 1675 | 4 | 1623 | -3.09 | 1598 | -4.63 | 1539 | -8.15 | 1597 | -4.64 |
| 4 | | 206 | 1823 | 3 | 1772 | -2.79 | 1785 | -2.06 | 1735 | -4.83 | 1778 | -2.48 |
| 5 | | 156 | 2303 | 5 | 2218 | -3.70 | 2212 | -3.94 | 2176 | -5.51 | 2189 | -4.95 |
| 6 | | 126 | 2104 | 3 | 2011 | -4.41 | 2045 | -2.82 | 2119 | 0.69 | 2004 | -4.76 |
| 7 | | 90 | 2189 | 3 | 2102 | -3.98 | 2090 | -4.51 | 2134 | -2.52 | 2073 | -5.31 |
| 8 | | 30 | 2301 | 3 | 2275 | -1.14 | 2233 | -2.97 | 2186 | -4.99 | 2198 | -4.48 |
| 9 | | 6 | 2575 | 4 | 2492 | -3.21 | 2494 | -3.14 | 2468 | -4.17 | 2406 | -6.56 |
| 10 | 27 | 1 | 2711 | 4 | 2396 | -11.63 | 2753 | 1.54 | 2696 | -0.54 | 2686 | -0.92 |
| 11 | | 3 | 2600 | 4 | 2316 | -10.91 | 2628 | 1.09 | 2622 | 0.85 | 2588 | -0.46 |
| 12 | | 6 | 2603 | 4 | 2293 | -11.93 | 2667 | 2.46 | 2528 | -2.89 | 2601 | -0.09 |
| 13 | | 30 | 2470 | 3 | 2146 | -13.11 | 2389 | -3.27 | 2395 | -3.02 | 2414 | -2.27 |
| 14 | | 42 | 2456 | 3 | 2136 | -13.03 | 2395 | -2.50 | 2422 | -1.37 | 2398 | -2.34 |
| 15 | | 66 | 2662 | 3 | 2318 | -12.91 | 2625 | -1.37 | 2652 | -0.37 | 2601 | -2.31 |
| 16 | | 90 | 2485 | 4 | 2166 | -12.83 | 2417 | -2.74 | 2430 | -2.21 | 2430 | -2.20 |
| 17 | | 156 | 2824 | 4 | 2437 | -13.71 | 2795 | -1.04 | 2793 | -1.11 | 2741 | -2.95 |
| 18 | | 242 | 2454 | 3 | 2152 | -12.30 | 2357 | -3.95 | 2493 | 1.59 | 2369 | -3.46 |
| 19 | | 302 | 2443 | 3 | 2100 | -14.03 | 2354 | -3.66 | 2361 | -3.37 | 2381 | -2.55 |
| 20 | | 326 | 2555 | 4 | 2225 | -12.90 | 2531 | -0.95 | 2499 | -2.21 | 2443 | -4.38 |
| 21 | 21 | 3 | 1974 | 3 | 1995 | 1.08 | 1941 | -1.68 | 1963 | -0.58 | 1962 | -0.61 |
| 22 | | 6 | 1977 | 3 | 1977 | 0.02 | 1967 | -0.48 | 1898 | -3.98 | 1891 | -4.34 |
| 23 | | 30 | 1969 | 3 | 1930 | -2.01 | 1862 | -5.44 | 1866 | -5.23 | 1900 | -3.48 |
| 24 | | 86 | 2145 | 3 | 2081 | -2.98 | 2050 | -4.41 | 2093 | -2.44 | 2004 | -6.56 |
| 25 | | 90 | 2139 | 3 | 2060 | -3.69 | 2053 | -4.00 | 2067 | -3.37 | 2061 | -3.63 |
| 26 | | 126 | 2237 | 3 | 2134 | -4.62 | 2106 | -5.84 | 2129 | -4.84 | 2173 | -2.84 |
| 27 | | 156 | 2492 | 5 | 2421 | -2.86 | 2401 | -3.67 | 2432 | -2.40 | 2405 | -3.51 |
| 28 | | 159 | 2282 | 4 | 2216 | -2.91 | 2166 | -5.09 | 2173 | -4.76 | 2238 | -1.92 |
| 29 | | 161 | 2294 | 3 | 2206 | -3.85 | 2200 | -4.10 | 2198 | -4.17 | 2210 | -3.66 |
| 30 | | 165 | 2361 | 3 | 2236 | -5.31 | 2260 | -4.27 | 2239 | -5.17 | 2297 | -2.72 |
| 31 | | 206 | 2376 | 3 | 2249 | -5.35 | 2289 | -3.66 | 2261 | -4.84 | 2302 | -3.10 |
| 32 | | 302 | 2419 | 3 | 2392 | -1.11 | 2342 | -3.19 | 2407 | -0.52 | 2298 | -5.02 |
| 33 | | 326 | 2571 | 4 | 2589 | 0.68 | 2603 | 1.25 | 2563 | -0.30 | 2511 | -2.32 |
| 34 | 13 | 1 | 581 | 5 | 629 | 8.26 | 548 | -5.66 | 568 | -2.21 | 588 | 1.23 |
| 35 | | 2 | 533 | 5 | 590 | 10.61 | 510 | -4.32 | 521 | -2.17 | 525 | -1.50 |
| 36 | | 3 | 516 | 4 | 568 | 10.15 | 503 | -2.59 | 489 | -5.17 | 503 | -2.58 |
| 37 | | 4 | 514 | 4 | 556 | 8.22 | 526 | 2.38 | 504 | -1.89 | 506 | -1.54 |
| 38 | | 5 | 525 | 4 | 550 | 4.75 | 516 | -1.74 | 521 | -0.67 | 530 | 0.88 |
| 39 | | 6 | 515 | 4 | 548 | 6.41 | 507 | -1.64 | 515 | 0.03 | 514 | -0.29 |
| 40 | | 12 | 694 | 3 | 730 | 5.24 | 709 | 2.20 | 713 | 2.67 | 711 | 2.40 |
| 41 | | 13 | 638 | 3 | 684 | 7.24 | 636 | -0.32 | 672 | 5.36 | 659 | 3.25 |
| 42 | | 14 | 621 | 4 | 660 | 6.33 | 622 | 0.15 | 619 | -0.37 | 645 | 3.79 |
| 43 | | 15 | 612 | 4 | 647 | 5.65 | 611 | -0.12 | 629 | 2.73 | 632 | 3.24 |
| 44 | | 16 | 609 | 4 | 639 | 4.88 | 605 | -0.64 | 623 | 2.31 | 623 | 2.33 |
| 45 | | 17 | 606 | 4 | 635 | 4.83 | 615 | 1.51 | 628 | 3.68 | 613 | 1.18 |
| 46 | | 24 | 776 | 3 | 816 | 5.15 | 784 | 1.05 | 792 | 2.07 | 812 | 4.68 |
| 47 | | 26 | 708 | 3 | 745 | 5.23 | 709 | 0.16 | 708 | -0.01 | 743 | 4.96 |
| 48 | | 28 | 688 | 3 | 723 | 5.02 | 689 | 0.08 | 665 | -3.33 | 685 | -0.45 |
| 49 | | 30 | 691 | 4 | 717 | 3.79 | 696 | 0.68 | 719 | 4.02 | 712 | 2.98 |
| 50 | | 37 | 843 | 3 | 893 | 5.92 | 874 | 3.63 | 870 | 3.15 | 892 | 5.80 |

## Table 10.2 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | Diff. calculation | | Monte Carlo calculation, SCALE 4.3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 16-GROUP HANSEN-ROACH | | 27GROUP NDF4 | | 238GROUP NDF5 | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 51 | | 40 | 774 | 4 | 819 | 5.86 | 797 | 2.99 | 797 | 2.94 | 780 | 0.72 |
| 52 | | 41 | 776 | 4 | 811 | 4.55 | 796 | 2.62 | 795 | 2.48 | 823 | 6.10 |
| 53 | | 43 | 768 | 4 | 803 | 4.60 | 771 | 0.38 | 794 | 3.37 | 774 | 0.84 |
| 54 | | 52 | 859 | 3 | 914 | 6.39 | 900 | 4.83 | 912 | 6.15 | 899 | 4.68 |
| 55 | | 54 | 844 | 4 | 893 | 5.80 | 864 | 2.43 | 869 | 2.98 | 855 | 1.25 |
| 56 | | 56 | 834 | 4 | 883 | 5.82 | 863 | 3.51 | 864 | 3.63 | 870 | 4.36 |
| 57 | | 57 | 841 | 3 | 879 | 4.57 | 853 | 1.43 | 864 | 2.70 | 883 | 4.96 |
| 58 | | 67 | 909 | 3 | 982 | 7.99 | 955 | 5.07 | 929 | 2.23 | 932 | 2.52 |
| 59 | | 69 | 900 | 4 | 951 | 5.70 | 926 | 2.87 | 902 | 0.20 | 919 | 2.16 |
| 60 | | 70 | 915 | 4 | 958 | 4.68 | 938 | 2.56 | 925 | 1.09 | 941 | 2.89 |
| 61 | | 71 | 907 | 3 | 954 | 5.13 | 923 | 1.74 | 938 | 3.38 | 917 | 1.08 |
| 62 | | 72 | 897 | 3 | 941 | 4.89 | 950 | 5.89 | 913 | 1.83 | 910 | 1.47 |
| 63 | | 73 | 899 | 3 | 949 | 5.53 | 910 | 1.26 | 923 | 2.71 | 942 | 4.79 |
| 64 | | 82 | 1029 | 3 | 1104 | 7.31 | 1064 | 3.40 | 1076 | 4.60 | 1068 | 3.75 |
| 65 | | 85 | 970 | 3 | 1027 | 5.84 | 1009 | 4.06 | 977 | 0.70 | 964 | -0.57 |
| 66 | | 86 | 966 | 3 | 1023 | 5.88 | 992 | 2.68 | 1002 | 3.75 | 1024 | 6.02 |
| 67 | | 88 | 970 | 3 | 1016 | 4.74 | 994 | 2.48 | 978 | 0.82 | 1027 | 5.89 |
| 68 | | 89 | 958 | 4 | 1014 | 5.88 | 1005 | 4.88 | 991 | 3.45 | 1027 | 7.24 |
| 69 | | 90 | 943 | 4 | 1005 | 6.59 | 958 | 1.64 | 1002 | 6.29 | 1009 | 6.99 |
| 70 | | 99 | 1085 | 3 | 1174 | 8.16 | 1158 | 6.77 | 1142 | 5.27 | 1125 | 3.72 |
| 71 | | 102 | 1025 | 4 | 1092 | 6.57 | 1044 | 1.90 | 1073 | 4.64 | 1089 | 6.27 |
| 72 | | 104 | 1035 | 3 | 1085 | 4.81 | 1071 | 3.47 | 1059 | 2.31 | 1052 | 1.66 |
| 73 | | 105 | 1019 | 4 | 1082 | 6.18 | 1038 | 1.86 | 1069 | 4.88 | 1082 | 6.20 |
| 74 | | 118 | 1082 | 4 | 1180 | 9.10 | 1132 | 4.58 | 1135 | 4.87 | 1134 | 4.81 |
| 75 | | 119 | 1072 | 3 | 1153 | 7.53 | 1110 | 3.53 | 1119 | 4.37 | 1094 | 2.04 |
| 76 | | 121 | 1079 | 3 | 1153 | 6.88 | 1109 | 2.77 | 1126 | 4.35 | 1116 | 3.41 |
| 77 | | 122 | 1080 | 3 | 1149 | 6.43 | 1103 | 2.10 | 1135 | 5.05 | 1108 | 2.60 |
| 78 | | 125 | 1095 | 3 | 1148 | 4.84 | 1116 | 1.93 | 1128 | 2.97 | 1122 | 2.46 |
| 79 | | 126 | 1090 | 4 | 1138 | 4.43 | 1105 | 1.34 | 1089 | -0.11 | 1124 | 3.13 |
| 80 | | 136 | 1205 | 3 | 1323 | 9.82 | 1291 | 7.14 | 1253 | 3.98 | 1272 | 5.54 |
| 81 | | 140 | 1135 | 3 | 1215 | 7.09 | 1167 | 2.85 | 1180 | 3.95 | 1156 | 1.89 |
| 82 | | 142 | 1138 | 3 | 1208 | 6.16 | 1168 | 2.64 | 1161 | 2.01 | 1211 | 6.43 |
| 83 | | 143 | 1144 | 3 | 1207 | 5.52 | 1166 | 1.89 | 1173 | 2.50 | 1166 | 1.90 |
| 84 | | 145 | 1188 | 3 | 1223 | 2.97 | 1193 | 0.45 | 1189 | 0.08 | 1227 | 3.24 |
| 85 | | 156 | 1305 | 3 | 1417 | 8.59 | 1344 | 2.97 | 1352 | 3.60 | 1356 | 3.94 |
| 86 | | 159 | 1200 | 3 | 1286 | 7.20 | 1261 | 5.09 | 1209 | 0.72 | 1220 | 1.65 |
| 87 | | 165 | 1236 | 3 | 1285 | 3.96 | 1258 | 1.76 | 1262 | 2.08 | 1263 | 2.19 |
| 88 | | 206 | 1301 | 4 | 1378 | 5.95 | 1302 | 0.10 | 1368 | 5.15 | 1338 | 2.85 |
| 89 | | 237 | 1406 | 3 | 1508 | 7.25 | 1471 | 4.65 | 1435 | 2.04 | 1476 | 4.95 |
| 90 | | 242 | 1394 | 3 | 1488 | 6.76 | 1448 | 3.87 | 1452 | 4.18 | 1436 | 3.02 |
| 91 | | 251 | 1513 | 3 | 1655 | 9.39 | 1616 | 6.83 | 1584 | 4.68 | 1611 | 6.50 |
| 92 | | 256 | 1457 | 3 | 1562 | 7.21 | 1496 | 2.69 | 1529 | 4.93 | 1535 | 5.37 |
| 93 | | 285 | 1565 | 3 | 1683 | 7.57 | 1640 | 4.80 | 1596 | 1.95 | 1624 | 3.75 |
| 94 | | 302 | 1587 | 3 | 1717 | 8.19 | 1650 | 3.94 | 1628 | 2.59 | 1614 | 1.68 |
| 95 | | 321 | 1872 | 4 | 2009 | 7.34 | 1948 | 4.07 | 1952 | 4.25 | 1949 | 4.10 |
| 96 | | 326 | 1791 | 3 | 1938 | 8.19 | 1843 | 2.91 | 1858 | 3.72 | 1877 | 4.82 |
| 97 | 12 | 1 | 1288 | 4 | 1322 | 2.61 | 1322 | 2.64 | 1281 | -0.51 | 1258 | -2.33 |
| 98 | | 4 | 1248 | 2 | 1314 | 5.26 | 1288 | 3.23 | 1261 | 1.01 | 1284 | 2.90 |
| 99 | | 8 | 1269 | 2 | 1366 | 7.61 | 1361 | 7.27 | 1307 | 3.00 | 1314 | 3.57 |
| 100 | | 10 | 1288 | 3 | 1412 | 9.60 | 1359 | 5.51 | 1315 | 2.13 | 1335 | 3.62 |
| 101 | | 11 | 1347 | 2 | 1456 | 8.06 | 1429 | 6.11 | 1384 | 2.75 | 1356 | 0.70 |
| 102 | | 18 | 1264 | 2 | 1328 | 5.03 | 1274 | 0.76 | 1298 | 2.69 | 1313 | 3.85 |

## Table 10.2 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | Diff. calculation | | Monte Carlo calculation, SCALE 4.3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 16-GROUP HANSEN-ROACH | | 27GROUP NDF4 | | 238GROUP NDF5 | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 103 | | 23 | 1385 | 3 | 1479 | 6.79 | 1410 | 1.81 | 1416 | 2.23 | 1369 | -1.17 |
| 104 | | 29 | 1259 | 3 | 1332 | 5.78 | 1290 | 2.48 | 1310 | 4.06 | 1305 | 3.68 |
| 105 | | 30 | 1270 | 3 | 1345 | 5.92 | 1301 | 2.45 | 1282 | 0.94 | 1307 | 2.93 |
| 106 | | 34 | 1293 | 3 | 1410 | 9.02 | 1369 | 5.84 | 1354 | 4.71 | 1368 | 5.78 |
| 107 | | 41 | 1305 | 3 | 1371 | 5.07 | 1313 | 0.65 | 1298 | -0.55 | 1332 | 2.08 |
| 108 | | 46 | 1364 | 3 | 1435 | 5.18 | 1369 | 0.38 | 1375 | 0.78 | 1428 | 4.71 |
| 109 | | 47 | 1370 | 3 | 1451 | 5.90 | 1386 | 1.16 | 1391 | 1.54 | 1387 | 1.25 |
| 110 | | 49 | 1370 | 3 | 1487 | 8.52 | 1454 | 6.14 | 1451 | 5.88 | 1414 | 3.24 |
| 111 | | 65 | 1512 | 3 | 1615 | 6.84 | 1576 | 4.26 | 1592 | 5.30 | 1537 | 1.68 |
| 112 | | 77 | 1481 | 3 | 1538 | 3.85 | 1495 | 0.97 | 1440 | -2.79 | 1481 | 0.00 |
| 113 | | 84 | 1387 | 3 | 1442 | 3.99 | 1408 | 1.50 | 1431 | 3.18 | 1419 | 2.28 |
| 114 | | 87 | 1426 | 3 | 1483 | 4.02 | 1468 | 2.97 | 1441 | 1.05 | 1485 | 4.13 |
| 115 | | 91 | 1493 | 4 | 1550 | 3.79 | 1510 | 1.13 | 1530 | 2.51 | 1530 | 2.51 |
| 116 | | 92 | 1514 | 3 | 1563 | 3.21 | 1565 | 3.36 | 1515 | 0.04 | 1540 | 1.72 |
| 117 | | 95 | 1524 | 3 | 1598 | 4.86 | 1569 | 2.92 | 1568 | 2.87 | 1543 | 1.26 |
| 118 | | 96 | 1519 | 3 | 1598 | 5.21 | 1584 | 4.28 | 1563 | 2.90 | 1522 | 0.18 |
| 119 | | 97 | 1549 | 3 | 1635 | 5.56 | 1579 | 1.93 | 1567 | 1.17 | 1594 | 2.94 |
| 120 | | 116 | 1695 | 3 | 1781 | 5.06 | 1759 | 3.78 | 1713 | 1.05 | 1726 | 1.81 |
| 121 | | 118 | 1495 | 3 | 1531 | 2.39 | 1480 | -0.99 | 1526 | 2.10 | 1537 | 2.79 |
| 122 | | 126 | 1597 | 4 | 1620 | 1.46 | 1652 | 3.46 | 1615 | 1.15 | 1608 | 0.70 |
| 123 | | 129 | 1591 | 4 | 1650 | 3.69 | 1597 | 0.40 | 1615 | 1.53 | 1649 | 3.65 |
| 124 | | 146 | 1683 | 4 | 1703 | 1.19 | 1719 | 2.13 | 1717 | 2.04 | 1755 | 4.27 |
| 125 | | 153 | 1670 | 3 | 1759 | 5.34 | 1724 | 3.20 | 1691 | 1.26 | 1694 | 1.42 |
| 126 | | 155 | 1806 | 3 | 1915 | 6.06 | 1856 | 2.75 | 1901 | 5.27 | 1870 | 3.53 |
| 127 | 3 | 6 | 360 | 3 | 343 | -4.83 | 339 | -5.73 | 335 | -7.00 | 345 | -4.18 |
| 128 | | 7 | 376 | 3 | 364 | -3.28 | 347 | -7.72 | 347 | -7.61 | 355 | -5.54 |
| 129 | | 8 | 395 | 3 | 387 | -2.08 | 379 | -3.97 | 371 | -6.01 | 367 | -7.13 |
| 130 | | 10 | 441 | 3 | 448 | 1.52 | 401 | -9.16 | 415 | -5.97 | 423 | -4.06 |
| 131 | | 11 | 494 | 2 | 497 | 0.62 | 457 | -7.52 | 466 | -5.58 | 490 | -0.71 |
| 132 | | 20 | 494 | 2 | 469 | -5.06 | 462 | -6.49 | 475 | -3.79 | 478 | -3.31 |
| 133 | | 23 | 618 | 3 | 593 | -4.11 | 587 | -5.07 | 594 | -3.94 | 581 | -5.99 |
| 134 | | 30 | 513 | 3 | 469 | -8.61 | 486 | -5.23 | 498 | -2.94 | 487 | -5.10 |
| 135 | | 31 | 523 | 3 | 493 | -5.81 | 502 | -3.92 | 498 | -4.71 | 522 | -0.11 |
| 136 | | 34 | 608 | 4 | 577 | -5.14 | 555 | -8.67 | 585 | -3.76 | 591 | -2.76 |
| 137 | | 46 | 629 | 2 | 597 | -5.10 | 602 | -4.22 | 614 | -2.44 | 621 | -1.23 |
| 138 | | 59 | 648 | 2 | 614 | -5.23 | 628 | -3.15 | 642 | -0.97 | 649 | 0.19 |
| 139 | | 76 | 753 | 3 | 708 | -6.03 | 700 | -7.03 | 729 | -3.24 | 738 | -1.96 |
| 140 | | 77 | 761 | 2 | 735 | -3.48 | 731 | -3.95 | 735 | -3.46 | 761 | 0.02 |
| 141 | | 80 | 820 | 4 | 819 | -0.13 | 801 | -2.27 | 820 | 0.05 | 809 | -1.37 |
| 142 | | 81 | 894 | 4 | 884 | -1.13 | 910 | 1.76 | 893 | -0.16 | 859 | -3.92 |
| 143 | | 90 | 723 | 2 | 685 | -5.27 | 704 | -2.67 | 735 | 1.61 | 719 | -0.53 |
| 144 | | 91 | 760 | 3 | 718 | -5.58 | 721 | -5.18 | 758 | -0.26 | 729 | -4.13 |
| 145 | | 94 | 827 | 3 | 798 | -3.50 | 800 | -3.24 | 818 | -1.13 | 845 | 2.12 |
| 146 | | 96 | 850 | 3 | 845 | -0.64 | 806 | -5.19 | 835 | -1.81 | 846 | -0.49 |
| 147 | | 110 | 849 | 3 | 810 | -4.57 | 800 | -5.83 | 834 | -1.79 | 821 | -3.33 |
| 148 | | 115 | 949 | 3 | 950 | 0.13 | 935 | -1.48 | 951 | 0.22 | 926 | -2.41 |
| 149 | | 126 | 832 | 2 | 790 | -5.06 | 798 | -4.11 | 803 | -3.45 | 825 | -0.85 |
| 150 | | 127 | 859 | 2 | 824 | -4.10 | 828 | -3.58 | 820 | -4.58 | 840 | -2.22 |
| 151 | | 146 | 922 | 3 | 870 | -5.60 | 917 | -0.56 | 926 | 0.42 | 901 | -2.27 |
| 152 | | 153 | 1033 | 3 | 1043 | 0.93 | 1022 | -1.08 | 1003 | -2.91 | 1021 | -1.16 |
| 153 | | 155 | 1171 | 4 | 1175 | 0.34 | 1125 | -3.91 | 1149 | -1.89 | 1122 | -4.22 |
| 154 | 4 | 1 | 172 | 4 | 150 | -12.55 | 167 | -2.90 | 167 | -2.67 | 167 | -3.12 |

# Table 10.2 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | Diff. calculation $W_{calc}$ | Diff. calculation Dev. [%] | Monte Carlo calculation, SCALE 4.3: 16-GROUP HANSEN-ROACH $W_{calc}$ | 16-GROUP HANSEN-ROACH Dev. [%] | 27GROUP NDF4 $W_{calc}$ | 27GROUP NDF4 Dev. [%] | 238GROUP NDF5 $W_{calc}$ | 238GROUP NDF5 Dev. [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 155 | | 2 | 197 | 4 | 169 | -14.43 | 187 | -4.86 | 187 | -5.18 | 196 | -0.49 |
| 156 | | 3 | 209 | 4 | 179 | -14.32 | 191 | -8.42 | 198 | -5.28 | 199 | -4.79 |
| 157 | | 4 | 217 | 4 | 186 | -14.50 | 209 | -3.79 | 197 | -9.12 | 215 | -1.02 |
| 158 | | 5 | 224 | 3 | 189 | -15.51 | 205 | -8.36 | 214 | -4.48 | 214 | -4.49 |
| 159 | | 6 | 230 | 3 | 191 | -16.97 | 205 | -10.9 | 215 | -6.70 | 225 | -2.12 |
| 160 | | 7 | 221 | 4 | 191 | -13.59 | 210 | -4.95 | 223 | 1.09 | 224 | 1.37 |
| 161 | | 8 | 222 | 3 | 189 | -14.89 | 222 | 0.06 | 213 | -4.16 | 207 | -6.91 |
| 162 | | 9 | 218 | 4 | 184 | -15.50 | 207 | -5.22 | 211 | -3.22 | 212 | -2.77 |
| 163 | | 10 | 209 | 4 | 175 | -16.25 | 196 | -6.10 | 201 | -4.05 | 185 | -11.36 |
| 164 | | 11 | 184 | 4 | 158 | -14.36 | 168 | -8.75 | 175 | -4.98 | 157 | -14.94 |
| 165 | | 12 | 202 | 4 | 181 | -10.45 | 212 | 5.11 | 199 | -1.67 | 190 | -6.01 |
| 166 | | 13 | 235 | 3 | 208 | -11.39 | 238 | 1.39 | 241 | 2.66 | 240 | 2.33 |
| 167 | | 15 | 267 | 3 | 233 | -12.68 | 272 | 1.93 | 271 | 1.46 | 271 | 1.59 |
| 168 | | 17 | 276 | 2 | 242 | -12.20 | 271 | -1.70 | 284 | 2.86 | 270 | -2.10 |
| 169 | | 19 | 273 | 2 | 243 | -11.05 | 274 | 0.43 | 285 | 4.53 | 281 | 3.01 |
| 170 | | 21 | 263 | 2 | 232 | -11.66 | 261 | -0.94 | 254 | -3.35 | 255 | -3.00 |
| 171 | | 23 | 214 | 5 | 192 | -10.34 | 199 | -6.83 | 209 | -2.18 | 202 | -5.79 |
| 172 | | 30 | 316 | 3 | 290 | -8.09 | 314 | -0.77 | 333 | 5.31 | 321 | 1.71 |
| 173 | | 35 | 271 | 4 | 255 | -6.00 | 282 | 4.09 | 272 | 0.40 | 283 | 4.26 |
| 174 | | 36 | 240 | 4 | 221 | -7.73 | 222 | -7.69 | 223 | -7.28 | 237 | -1.30 |
| 175 | | 37 | 241 | 4 | 230 | -4.73 | 237 | -1.78 | 247 | 2.52 | 237 | -1.71 |
| 176 | | 42 | 357 | 2 | 330 | -7.62 | 345 | -3.49 | 382 | 7.12 | 351 | -1.74 |
| 177 | | 44 | 360 | 2 | 339 | -5.73 | 379 | 5.32 | 376 | 4.34 | 360 | 0.11 |
| 178 | | 46 | 359 | 2 | 336 | -6.28 | 354 | -1.42 | 366 | 1.90 | 373 | 3.99 |
| 179 | | 47 | 350 | 3 | 329 | -5.92 | 367 | 4.89 | 360 | 2.75 | 352 | 0.68 |
| 180 | | 50 | 265 | 5 | 250 | -5.70 | 255 | -3.94 | 252 | -5.02 | 255 | -3.92 |
| 181 | | 60 | 407 | 2 | 384 | -5.64 | 407 | -0.12 | 418 | 2.68 | 416 | 2.18 |
| 182 | | 62 | 391 | 2 | 370 | -5.44 | 375 | -4.11 | 398 | 1.67 | 393 | 0.45 |
| 183 | | 63 | 364 | 3 | 348 | -4.27 | 369 | 1.25 | 361 | -0.89 | 363 | -0.26 |
| 184 | | 64 | 338 | 3 | 322 | -4.79 | 323 | -4.49 | 326 | -3.69 | 337 | -0.31 |
| 185 | | 65 | 288 | 5 | 279 | -3.14 | 276 | -4.30 | 271 | -5.94 | 287 | -0.31 |
| 186 | | 66 | 287 | 4 | 277 | -3.44 | 272 | -5.05 | 289 | 0.80 | 299 | 4.17 |
| 187 | | 71 | 431 | 2 | 412 | -4.31 | 439 | 1.91 | 461 | 6.91 | 441 | 2.31 |
| 188 | | 75 | 444 | 3 | 425 | -4.32 | 429 | -3.42 | 455 | 2.57 | 437 | -1.54 |
| 189 | | 77 | 438 | 3 | 422 | -3.68 | 451 | 3.06 | 457 | 4.39 | 465 | 6.22 |
| 190 | | 81 | 319 | 5 | 310 | -2.91 | 297 | -6.88 | 299 | -6.20 | 309 | -3.20 |
| 191 | | 85 | 433 | 3 | 417 | -3.68 | 449 | 3.65 | 439 | 1.41 | 429 | -0.85 |
| 192 | | 88 | 481 | 3 | 458 | -4.72 | 463 | -3.78 | 471 | -2.15 | 489 | 1.68 |
| 193 | | 90 | 489 | 3 | 466 | -4.71 | 503 | 2.87 | 512 | 4.76 | 492 | 0.68 |
| 194 | | 91 | 495 | 2 | 472 | -4.60 | 515 | 4.01 | 484 | -2.14 | 489 | -1.12 |
| 195 | | 92 | 489 | 3 | 472 | -3.39 | 491 | 0.50 | 496 | 1.47 | 493 | 0.90 |
| 196 | | 94 | 470 | 3 | 463 | -1.39 | 485 | 3.17 | 482 | 2.47 | 493 | 4.86 |
| 197 | | 97 | 400 | 4 | 394 | -1.61 | 377 | -5.72 | 383 | -4.22 | 388 | -3.00 |
| 198 | | 98 | 353 | 5 | 343 | -2.75 | 339 | -3.83 | 329 | -6.75 | 318 | -9.95 |
| 199 | | 99 | 340 | 4 | 332 | -2.41 | 343 | 0.85 | 345 | 1.39 | 323 | -5.03 |
| 200 | | 101 | 432 | 2 | 420 | -2.74 | 429 | -0.69 | 439 | 1.55 | 428 | -0.82 |
| 201 | | 111 | 528 | 3 | 515 | -2.46 | 544 | 3.00 | 524 | -0.80 | 523 | -0.87 |
| 202 | | 113 | 505 | 3 | 494 | -2.17 | 497 | -1.64 | 494 | -2.11 | 503 | -0.37 |
| 203 | | 114 | 474 | 3 | 466 | -1.59 | 471 | -0.65 | 467 | -1.51 | 465 | -1.82 |
| 204 | | 116 | 379 | 5 | 381 | 0.56 | 356 | -6.04 | 365 | -3.80 | 369 | -2.51 |
| 205 | | 131 | 565 | 3 | 554 | -1.92 | 568 | 0.48 | 552 | -2.34 | 551 | -2.52 |
| 206 | | 134 | 477 | 3 | 478 | 0.29 | 479 | 0.33 | 466 | -2.25 | 468 | -1.80 |

## Table 10.2 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | Diff. calculation | | Monte Carlo calculation, SCALE 4.3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 16-GROUP HANSEN-ROACH | | 27GROUP NDF4 | | 238GROUP NDF5 | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 207 | | 135 | 428 | 4 | 426 | -0.46 | 402 | -6.17 | 400 | -6.54 | 405 | -5.34 |
| 208 | | 136 | 413 | 4 | 409 | -0.95 | 396 | -4.12 | 392 | -5.01 | 398 | -3.75 |
| 209 | | 146 | 653 | 3 | 618 | -5.34 | 647 | -0.87 | 645 | -1.22 | 625 | -4.23 |
| 210 | | 148 | 639 | 2 | 613 | -4.03 | 616 | -3.60 | 620 | -2.94 | 640 | 0.09 |
| 211 | | 149 | 631 | 2 | 612 | -3.03 | 621 | -1.66 | 610 | -3.29 | 619 | -1.86 |
| 212 | | 151 | 613 | 3 | 601 | -1.88 | 591 | -3.60 | 600 | -2.06 | 616 | 0.47 |
| 213 | | 155 | 479 | 4 | 483 | 0.86 | 443 | -7.50 | 444 | -7.37 | 455 | -5.08 |
| 214 | | 156 | 494 | 3 | 471 | -4.63 | 433 | -12.4 | 465 | -5.95 | 467 | -5.53 |
| 215 | | 158 | 537 | 3 | 536 | -0.24 | 539 | 0.34 | 554 | 3.08 | 575 | 7.00 |
| 216 | | 161 | 615 | 3 | 605 | -1.61 | 610 | -0.79 | 614 | -0.12 | 615 | 0.00 |
| 217 | | 162 | 642 | 3 | 618 | -3.74 | 647 | 0.71 | 636 | -0.93 | 645 | 0.40 |
| 218 | | 164 | 660 | 3 | 642 | -2.80 | 697 | 5.63 | 630 | -4.52 | 644 | -2.49 |
| 219 | | 165 | 690 | 3 | 657 | -4.77 | 686 | -0.64 | 691 | 0.13 | 663 | -3.98 |
| 220 | | 167 | 699 | 2 | 668 | -4.41 | 692 | -0.96 | 696 | -0.41 | 699 | -0.06 |
| 221 | | 171 | 661 | 3 | 659 | -0.23 | 645 | -2.35 | 650 | -1.69 | 644 | -2.56 |
| 222 | | 173 | 634 | 3 | 641 | 1.11 | 652 | 2.87 | 610 | -3.81 | 637 | 0.47 |
| 223 | | 174 | 615 | 2 | 617 | 0.34 | 611 | -0.61 | 595 | -3.19 | 617 | 0.26 |
| 224 | | 175 | 598 | 2 | 595 | -0.45 | 591 | -1.25 | 575 | -3.91 | 567 | -5.20 |
| 225 | | 176 | 568 | 3 | 564 | -0.77 | 534 | -6.01 | 533 | -6.10 | 524 | -7.76 |
| 226 | | 177 | 601 | 4 | 577 | -4.07 | 573 | -4.69 | 611 | 1.64 | 575 | -4.35 |
| 227 | | 181 | 660 | 3 | 646 | -2.08 | 657 | -0.47 | 683 | 3.43 | 656 | -0.54 |
| 228 | | 184 | 704 | 3 | 683 | -2.96 | 702 | -0.28 | 713 | 1.23 | 695 | -1.28 |
| 229 | | 190 | 734 | 3 | 714 | -2.68 | 740 | 0.77 | 725 | -1.18 | 745 | 1.48 |
| 230 | | 193 | 684 | 3 | 706 | 3.23 | 717 | 4.78 | 714 | 4.33 | 689 | 0.77 |
| 231 | | 196 | 685 | 3 | 685 | 0.03 | 684 | -0.14 | 664 | -3.12 | 674 | -1.65 |
| 232 | | 206 | 747 | 3 | 747 | 0.02 | 794 | 6.29 | 760 | 1.74 | 761 | 1.90 |
| 233 | | 209 | 754 | 3 | 758 | 0.51 | 747 | -0.88 | 754 | 0.02 | 759 | 0.66 |
| 234 | | 212 | 740 | 4 | 757 | 2.29 | 754 | 1.85 | 736 | -0.57 | 759 | 2.57 |
| 235 | | 215 | 760 | 4 | 777 | 2.22 | 767 | 0.89 | 784 | 3.15 | 764 | 0.54 |
| 236 | | 230 | 804 | 3 | 821 | 2.16 | 825 | 2.60 | 808 | 0.55 | 789 | -1.88 |
| 237 | | 232 | 824 | 4 | 824 | -0.03 | 802 | -2.73 | 796 | -3.45 | 814 | -1.21 |
| 238 | | 233 | 842 | 4 | 853 | 1.35 | 830 | -1.48 | 838 | -0.50 | 844 | 0.18 |
| 239 | | 238 | 804 | 3 | 814 | 1.26 | 843 | 4.87 | 804 | 0.03 | 837 | 4.11 |
| 240 | | 245 | 862 | 3 | 863 | 0.09 | 873 | 1.33 | 870 | 0.90 | 869 | 0.84 |
| 241 | | 251 | 869 | 4 | 858 | -1.22 | 873 | 0.43 | 852 | -2.00 | 894 | 2.83 |
| 242 | | 252 | 829 | 2 | 837 | 0.99 | 830 | 0.17 | 832 | 0.34 | 848 | 2.33 |
| 243 | | 255 | 875 | 2 | 870 | -0.55 | 886 | 1.27 | 869 | -0.66 | 847 | -3.18 |
| 244 | | 259 | 914 | 3 | 908 | -0.66 | 896 | -1.92 | 921 | 0.75 | 916 | 0.17 |
| 245 | | 261 | 919 | 3 | 922 | 0.31 | 929 | 1.11 | 949 | 3.21 | 932 | 1.43 |
| 246 | | 263 | 914 | 3 | 922 | 0.85 | 925 | 1.22 | 925 | 1.23 | 907 | -0.75 |
| 247 | | 273 | 956 | 3 | 949 | -0.78 | 928 | -2.93 | 963 | 0.72 | 960 | 0.46 |
| 248 | | 276 | 963 | 2 | 974 | 1.11 | 952 | -1.11 | 987 | 2.51 | 1006 | 4.49 |
| 249 | | 280 | 962 | 2 | 1002 | 4.15 | 986 | 2.45 | 987 | 2.61 | 983 | 2.22 |
| 250 | | 281 | 1023 | 3 | 1048 | 2.49 | 1008 | -1.48 | 1022 | -0.14 | 1030 | 0.71 |
| 251 | | 292 | 1036 | 3 | 1043 | 0.65 | 1036 | 0.02 | 999 | -3.59 | 1009 | -2.63 |
| 252 | | 293 | 1017 | 3 | 1041 | 2.34 | 1033 | 1.59 | 1021 | 0.44 | 988 | -2.81 |
| 253 | | 297 | 1010 | 3 | 1025 | 1.44 | 1040 | 2.97 | 1016 | 0.61 | 993 | -1.73 |
| 254 | | 304 | 1054 | 3 | 1076 | 2.05 | 1051 | -0.32 | 1066 | 1.11 | 1065 | 1.08 |
| 255 | | 308 | 1137 | 4 | 1175 | 3.37 | 1193 | 4.89 | 1179 | 3.69 | 1146 | 0.80 |
| 256 | | 312 | 1092 | 3 | 1106 | 1.24 | 1111 | 1.74 | 1088 | -0.35 | 1092 | 0.00 |
| 257 | | 315 | 1107 | 3 | 1134 | 2.48 | 1111 | 0.41 | 1135 | 2.56 | 1107 | -0.03 |
| 258 | | 319 | 1151 | 3 | 1194 | 3.72 | 1168 | 1.47 | 1179 | 2.46 | 1159 | 0.69 |

## Table 10.2 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | Diff. calculation | | Monte Carlo calculation, SCALE 4.3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 16-GROUP HANSEN-ROACH | | 27GROUP NDF4 | | 238GROUP NDF5 | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 259 | | 326 | 1242 | 4 | 1237 | -0.42 | 1215 | -2.21 | 1244 | 0.20 | 1259 | 1.38 |
| 260 | | 330 | 1256 | 3 | 1296 | 3.15 | 1280 | 1.90 | 1290 | 2.74 | 1278 | 1.74 |
| MAX. DEV. | | | | | | **-16.97** | | **-12.37** | | **-9.117** | | **-14.94** |
| STAND.DEV | | | | | | **6.36** | | **3.76** | | **3.42** | | **3.53** |
| Correlation coefficient | | | | | 0.9913 | | 0.9980 | | 0.9983 | | 0.9980 | |

## Table 10.3 Comparison of Experimental and Calculation Results for Relative Power Distribution, 44-Group Library of SCALE

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 | | | | SCALE 4.4a | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | "source vector by unit" table | | "total fissions" table | | "source vector by unit" table | | "total fissions" table | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 1 | 31 | 326 | 1506 | 5 | 1488 | -1.20 | 1512 | 0.42 | 1231 | -18.28 | 1436 | -4.64 |
| 2 | | 302 | 1328 | 3 | 1279 | -3.70 | 1282 | -3.49 | 1132 | -14.75 | 1264 | -4.83 |
| 3 | | 242 | 1675 | 4 | 1567 | -6.43 | 1577 | -5.85 | 1525 | -8.96 | 1574 | -6.04 |
| 4 | | 206 | 1823 | 3 | 1780 | -2.34 | 1792 | -1.70 | 1744 | -4.35 | 1742 | -4.44 |
| 5 | | 156 | 2303 | 5 | 2182 | -5.25 | 2206 | -4.20 | 1856 | -19.39 | 2195 | -4.68 |
| 6 | | 126 | 2104 | 3 | 2018 | -4.11 | 2029 | -3.57 | 2087 | -0.82 | 2001 | -4.90 |
| 7 | | 90 | 2189 | 3 | 2066 | -5.61 | 2089 | -4.55 | 2225 | 1.64 | 2098 | -4.17 |
| 8 | | 30 | 2301 | 3 | 2249 | -2.25 | 2274 | -1.18 | 2436 | 5.88 | 2238 | -2.75 |
| 9 | | 6 | 2575 | 4 | 2419 | -6.05 | 2433 | -5.52 | 2680 | 4.07 | 2452 | -4.79 |
| 10 | 27 | 1 | 2711 | 4 | 2691 | -0.73 | 2708 | -0.12 | 2984 | 10.09 | 2689 | -0.82 |
| 11 | | 3 | 2600 | 4 | 2572 | -1.07 | 2594 | -0.22 | 2867 | 10.28 | 2598 | -0.06 |
| 12 | | 6 | 2603 | 4 | 2513 | -3.45 | 2552 | -1.96 | 2850 | 9.49 | 2599 | -0.15 |
| 13 | | 30 | 2470 | 3 | 2409 | -2.45 | 2433 | -1.51 | 2643 | 7.00 | 2405 | -2.64 |
| 14 | | 42 | 2456 | 3 | 2409 | -1.93 | 2425 | -1.27 | 2667 | 8.61 | 2418 | -1.56 |
| 15 | | 66 | 2662 | 3 | 2571 | -3.43 | 2598 | -2.40 | 2936 | 10.30 | 2630 | -1.19 |
| 16 | | 90 | 2485 | 4 | 2391 | -3.79 | 2398 | -3.51 | 2718 | 9.37 | 2456 | -1.15 |
| 17 | | 156 | 2824 | 4 | 2799 | -0.88 | 2842 | 0.65 | 3097 | 9.68 | 2771 | -1.89 |
| 18 | | 242 | 2454 | 3 | 2450 | -0.15 | 2465 | 0.43 | 2700 | 10.02 | 2437 | -0.68 |
| 19 | | 302 | 2443 | 3 | 2360 | -3.38 | 2396 | -1.91 | 2603 | 6.53 | 2365 | -3.17 |
| 20 | | 326 | 2555 | 4 | 2524 | -1.20 | 2543 | -0.49 | 2736 | 7.08 | 2494 | -2.38 |
| 21 | 21 | 3 | 1974 | 3 | 1942 | -1.63 | 1941 | -1.69 | 2079 | 5.32 | 1935 | -1.97 |
| 22 | | 6 | 1977 | 3 | 1931 | -2.31 | 1935 | -2.12 | 2067 | 4.56 | 1926 | -2.59 |
| 23 | | 30 | 1969 | 3 | 1876 | -4.73 | 1865 | -5.27 | 2023 | 2.76 | 1869 | -5.06 |
| 24 | | 86 | 2145 | 3 | 2052 | -4.34 | 2045 | -4.67 | 2271 | 5.89 | 2072 | -3.42 |
| 25 | | 90 | 2139 | 3 | 2019 | -5.59 | 2040 | -4.63 | 2233 | 4.41 | 2043 | -4.47 |
| 26 | | 126 | 2237 | 3 | 2053 | -8.23 | 2064 | -7.74 | 2350 | 5.05 | 2145 | -4.11 |
| 27 | | 156 | 2492 | 5 | 2410 | -3.31 | 2422 | -2.82 | 2694 | 8.12 | 2412 | -3.22 |
| 28 | | 159 | 2282 | 4 | 2198 | -3.69 | 2217 | -2.87 | 2431 | 6.53 | 2192 | -3.95 |
| 29 | | 161 | 2294 | 3 | 2170 | -5.41 | 2178 | -5.04 | 2434 | 6.10 | 2203 | -3.99 |
| 30 | | 165 | 2361 | 3 | 2255 | -4.51 | 2278 | -3.53 | 2503 | 6.02 | 2281 | -3.37 |
| 31 | | 206 | 2376 | 3 | 2234 | -5.98 | 2274 | -4.30 | 2477 | 4.27 | 2256 | -5.06 |
| 32 | | 302 | 2419 | 3 | 2287 | -5.45 | 2309 | -4.56 | 2612 | 7.98 | 2370 | -2.02 |
| 33 | | 326 | 2571 | 4 | 2572 | 0.05 | 2590 | 0.75 | 2837 | 10.35 | 2584 | 0.51 |
| 34 | 13 | 1 | 581 | 5 | 584 | 0.50 | 573 | -1.35 | 470 | -19.09 | 568 | -2.17 |
| 35 | | 2 | 533 | 5 | 532 | -0.26 | 526 | -1.24 | 431 | -19.19 | 528 | -0.86 |
| 36 | | 3 | 516 | 4 | 497 | -3.70 | 496 | -3.96 | 410 | -20.58 | 508 | -1.46 |
| 37 | | 4 | 514 | 4 | 503 | -2.15 | 501 | -2.55 | 405 | -21.23 | 506 | -1.63 |
| 38 | | 5 | 525 | 4 | 522 | -0.64 | 511 | -2.61 | 404 | -23.00 | 509 | -3.00 |
| 39 | | 6 | 515 | 4 | 527 | 2.29 | 524 | 1.67 | 411 | -20.13 | 515 | 0.08 |
| 40 | | 12 | 694 | 3 | 697 | 0.37 | 688 | -0.79 | 593 | -14.60 | 704 | 1.44 |
| 41 | | 13 | 638 | 3 | 641 | 0.43 | 640 | 0.31 | 537 | -15.81 | 646 | 1.20 |
| 42 | | 14 | 621 | 4 | 626 | 0.80 | 623 | 0.31 | 519 | -16.36 | 633 | 1.86 |
| 43 | | 15 | 612 | 4 | 614 | 0.38 | 618 | 1.02 | 504 | -17.65 | 623 | 1.81 |
| 44 | | 16 | 609 | 4 | 624 | 2.54 | 621 | 1.97 | 496 | -18.52 | 615 | 1.01 |
| 45 | | 17 | 606 | 4 | 596 | -1.59 | 594 | -1.97 | 488 | -19.45 | 608 | 0.34 |
| 46 | | 24 | 776 | 3 | 813 | 4.80 | 801 | 3.27 | 685 | -11.72 | 800 | 3.14 |
| 47 | | 26 | 708 | 3 | 727 | 2.70 | 721 | 1.86 | 597 | -15.71 | 718 | 1.43 |
| 48 | | 28 | 688 | 3 | 718 | 4.35 | 710 | 3.13 | 575 | -16.46 | 702 | 2.01 |
| 49 | | 30 | 691 | 4 | 693 | 0.29 | 688 | -0.50 | 561 | -18.75 | 694 | 0.46 |
| 50 | | 37 | 843 | 3 | 876 | 3.86 | 874 | 3.65 | 758 | -10.14 | 872 | 3.49 |

## Table 10.3 (Contd)

| | | | | | SCALE 4.3 | | | | SCALE 4.4a | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | "source vector by unit" table | | "total fissions" table | | "source vector by unit" table | | "total fissions" table | |
| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 51 | | 40 | 774 | 4 | 806 | 4.09 | 802 | 3.64 | 663 | -14.32 | 790 | 2.09 |
| 52 | | 41 | 776 | 4 | 806 | 3.83 | 801 | 3.17 | 652 | -15.92 | 777 | 0.14 |
| 53 | | 43 | 768 | 4 | 783 | 1.89 | 778 | 1.25 | 643 | -16.21 | 780 | 1.56 |
| 54 | | 52 | 859 | 3 | 901 | 4.85 | 898 | 4.58 | 778 | -9.45 | 881 | 2.58 |
| 55 | | 54 | 844 | 4 | 871 | 3.16 | 870 | 3.05 | 743 | -11.95 | 868 | 2.86 |
| 56 | | 56 | 834 | 4 | 894 | 7.23 | 883 | 5.91 | 723 | -13.26 | 858 | 2.91 |
| 57 | | 57 | 841 | 3 | 870 | 3.50 | 868 | 3.23 | 718 | -14.67 | 855 | 1.68 |
| 58 | | 67 | 909 | 3 | 954 | 4.91 | 954 | 4.95 | 847 | -6.81 | 951 | 4.64 |
| 59 | | 69 | 900 | 4 | 925 | 2.73 | 915 | 1.68 | 801 | -10.96 | 921 | 2.38 |
| 60 | | 70 | 915 | 4 | 952 | 4.02 | 950 | 3.83 | 805 | -12.03 | 931 | 1.80 |
| 61 | | 71 | 907 | 3 | 941 | 3.72 | 936 | 3.17 | 798 | -12.06 | 927 | 2.23 |
| 62 | | 72 | 897 | 3 | 932 | 3.85 | 922 | 2.81 | 778 | -13.24 | 912 | 1.71 |
| 63 | | 73 | 899 | 3 | 933 | 3.79 | 925 | 2.85 | 791 | -11.97 | 925 | 2.87 |
| 64 | | 82 | 1029 | 3 | 1079 | 4.81 | 1076 | 4.54 | 981 | -4.68 | 1067 | 3.74 |
| 65 | | 85 | 970 | 3 | 991 | 2.18 | 989 | 1.96 | 887 | -8.55 | 994 | 2.48 |
| 66 | | 86 | 966 | 3 | 993 | 2.82 | 995 | 2.96 | 883 | -8.59 | 999 | 3.43 |
| 67 | | 88 | 970 | 3 | 999 | 2.95 | 989 | 1.96 | 868 | -10.52 | 992 | 2.29 |
| 68 | | 89 | 958 | 4 | 989 | 3.27 | 976 | 1.83 | 857 | -10.56 | 987 | 2.98 |
| 69 | | 90 | 943 | 4 | 976 | 3.49 | 971 | 2.97 | 855 | -9.32 | 982 | 4.18 |
| 70 | | 99 | 1085 | 3 | 1141 | 5.19 | 1135 | 4.64 | 1062 | -2.14 | 1135 | 4.64 |
| 71 | | 102 | 1025 | 4 | 1067 | 4.11 | 1061 | 3.55 | 963 | -6.10 | 1053 | 2.69 |
| 72 | | 104 | 1035 | 3 | 1069 | 3.30 | 1061 | 2.47 | 955 | -7.77 | 1062 | 2.65 |
| 73 | | 105 | 1019 | 4 | 1110 | 8.97 | 1109 | 8.84 | 954 | -6.37 | 1065 | 4.47 |
| 74 | | 118 | 1082 | 4 | 1138 | 5.15 | 1124 | 3.90 | 1066 | -1.49 | 1125 | 3.95 |
| 75 | | 119 | 1072 | 3 | 1117 | 4.16 | 1118 | 4.27 | 1037 | -3.29 | 1104 | 2.98 |
| 76 | | 121 | 1079 | 3 | 1108 | 2.73 | 1092 | 1.24 | 1036 | -3.97 | 1123 | 4.04 |
| 77 | | 122 | 1080 | 3 | 1147 | 6.17 | 1138 | 5.42 | 1028 | -4.84 | 1115 | 3.28 |
| 78 | | 125 | 1095 | 3 | 1127 | 2.91 | 1121 | 2.37 | 1024 | -6.52 | 1124 | 2.69 |
| 79 | | 126 | 1090 | 4 | 1098 | 0.73 | 1091 | 0.06 | 1016 | -6.75 | 1116 | 2.42 |
| 80 | | 136 | 1205 | 3 | 1290 | 7.02 | 1289 | 6.95 | 1227 | 1.80 | 1271 | 5.51 |
| 81 | | 140 | 1135 | 3 | 1171 | 3.13 | 1156 | 1.85 | 1109 | -2.31 | 1171 | 3.17 |
| 82 | | 142 | 1138 | 3 | 1153 | 1.33 | 1150 | 1.02 | 1107 | -2.72 | 1183 | 3.95 |
| 83 | | 143 | 1144 | 3 | 1186 | 3.71 | 1175 | 2.71 | 1107 | -3.23 | 1182 | 3.36 |
| 84 | | 145 | 1188 | 3 | 1225 | 3.14 | 1220 | 2.72 | 1123 | -5.44 | 1209 | 1.73 |
| 85 | | 156 | 1305 | 3 | 1353 | 3.70 | 1345 | 3.08 | 1330 | 1.91 | 1359 | 4.11 |
| 86 | | 159 | 1200 | 3 | 1243 | 3.55 | 1228 | 2.36 | 1198 | -0.17 | 1234 | 2.86 |
| 87 | | 165 | 1236 | 3 | 1302 | 5.32 | 1299 | 5.10 | 1212 | -1.93 | 1274 | 3.10 |
| 88 | | 206 | 1301 | 4 | 1349 | 3.70 | 1347 | 3.56 | 1323 | 1.70 | 1342 | 3.19 |
| 89 | | 237 | 1406 | 3 | 1436 | 2.15 | 1430 | 1.73 | 1475 | 4.90 | 1445 | 2.80 |
| 90 | | 242 | 1394 | 3 | 1478 | 6.04 | 1467 | 5.24 | 1474 | 5.73 | 1453 | 4.22 |
| 91 | | 251 | 1513 | 3 | 1584 | 4.71 | 1589 | 5.04 | 1622 | 7.23 | 1580 | 4.45 |
| 92 | | 256 | 1457 | 3 | 1514 | 3.92 | 1517 | 4.11 | 1554 | 6.67 | 1519 | 4.25 |
| 93 | | 285 | 1565 | 3 | 1575 | 0.66 | 1573 | 0.53 | 1686 | 7.74 | 1610 | 2.85 |
| 94 | | 302 | 1587 | 3 | 1618 | 1.98 | 1614 | 1.70 | 1723 | 8.58 | 1642 | 3.44 |
| 95 | | 321 | 1872 | 4 | 1910 | 2.04 | 1920 | 2.56 | 2058 | 9.96 | 1924 | 2.79 |
| 96 | | 326 | 1791 | 3 | 1843 | 2.91 | 1860 | 3.87 | 1981 | 10.61 | 1859 | 3.81 |
| 97 | 12 | 1 | 1288 | 4 | 1295 | 0.58 | 1290 | 0.18 | 1367 | 6.10 | 1289 | 0.11 |
| 98 | | 4 | 1248 | 2 | 1267 | 1.50 | 1271 | 1.86 | 1330 | 6.58 | 1280 | 2.57 |
| 99 | | 8 | 1269 | 2 | 1317 | 3.81 | 1315 | 3.62 | 1336 | 5.25 | 1327 | 4.55 |
| 100 | | 10 | 1288 | 3 | 1378 | 6.96 | 1372 | 6.54 | 1342 | 4.20 | 1477 | 14.66 |
| 101 | | 11 | 1347 | 2 | 1406 | 4.35 | 1393 | 3.41 | 1376 | 2.12 | 1395 | 3.55 |
| 102 | | 18 | 1264 | 2 | 1300 | 2.84 | 1303 | 3.09 | 1312 | 3.78 | 1283 | 1.53 |

### Table 10.3 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 | | | | SCALE 4.4a | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | "source vector by unit" table | | "total fissions" table | | "source vector by unit" table | | "total fissions" table | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 103 | | 23 | 1385 | 3 | 1398 | 0.94 | 1394 | 0.63 | 1410 | 1.82 | 1414 | 2.07 |
| 104 | | 29 | 1259 | 3 | 1301 | 3.31 | 1299 | 3.18 | 1347 | 6.98 | 1295 | 2.82 |
| 105 | | 30 | 1270 | 3 | 1303 | 2.59 | 1300 | 2.35 | 1354 | 6.63 | 1309 | 3.04 |
| 106 | | 34 | 1293 | 3 | 1339 | 3.55 | 1338 | 3.48 | 1360 | 5.21 | 1343 | 3.84 |
| 107 | | 41 | 1305 | 3 | 1333 | 2.16 | 1332 | 2.11 | 1422 | 8.99 | 1341 | 2.76 |
| 108 | | 46 | 1364 | 3 | 1388 | 1.74 | 1380 | 1.19 | 1434 | 5.15 | 1395 | 2.24 |
| 109 | | 47 | 1370 | 3 | 1401 | 2.28 | 1406 | 2.60 | 1434 | 4.70 | 1404 | 2.45 |
| 110 | | 49 | 1370 | 3 | 1411 | 3.01 | 1398 | 2.08 | 1445 | 5.44 | 1423 | 3.87 |
| 111 | | 65 | 1512 | 3 | 1563 | 3.34 | 1561 | 3.27 | 1599 | 5.77 | 1560 | 3.15 |
| 112 | | 77 | 1481 | 3 | 1502 | 1.40 | 1499 | 1.19 | 1565 | 5.66 | 1500 | 1.32 |
| 113 | | 84 | 1387 | 3 | 1427 | 2.86 | 1425 | 2.78 | 1563 | 12.70 | 1417 | 2.18 |
| 114 | | 87 | 1426 | 3 | 1455 | 2.07 | 1461 | 2.47 | 1602 | 12.33 | 1480 | 3.81 |
| 115 | | 91 | 1493 | 4 | 1530 | 2.49 | 1538 | 2.99 | 1632 | 9.31 | 1541 | 3.19 |
| 116 | | 92 | 1514 | 3 | 1552 | 2.54 | 1559 | 2.98 | 1632 | 7.80 | 1548 | 2.27 |
| 117 | | 95 | 1524 | 3 | 1587 | 4.13 | 1586 | 4.07 | 1634 | 7.20 | 1559 | 2.26 |
| 118 | | 96 | 1519 | 3 | 1541 | 1.47 | 1552 | 2.17 | 1618 | 6.55 | 1551 | 2.11 |
| 119 | | 97 | 1549 | 3 | 1564 | 0.94 | 1570 | 1.37 | 1644 | 6.10 | 1576 | 1.73 |
| 120 | | 116 | 1695 | 3 | 1722 | 1.58 | 1722 | 1.60 | 1828 | 7.86 | 1736 | 2.42 |
| 121 | | 118 | 1495 | 3 | 1483 | -0.79 | 1486 | -0.61 | 1678 | 12.27 | 1505 | 0.67 |
| 122 | | 126 | 1597 | 4 | 1636 | 2.46 | 1635 | 2.40 | 1752 | 9.72 | 1622 | 1.54 |
| 123 | | 129 | 1591 | 4 | 1653 | 3.89 | 1650 | 3.69 | 1749 | 9.96 | 1633 | 2.63 |
| 124 | | 146 | 1683 | 4 | 1728 | 2.69 | 1740 | 3.36 | 1876 | 11.44 | 1728 | 2.66 |
| 125 | | 153 | 1670 | 3 | 1685 | 0.90 | 1681 | 0.64 | 1820 | 8.98 | 1706 | 2.14 |
| 126 | | 155 | 1806 | 3 | 1835 | 1.62 | 1837 | 1.73 | 1985 | 9.91 | 1861 | 3.05 |
| 127 | 3 | 6 | 360 | 3 | 340 | -5.46 | 344 | -4.42 | 353 | -1.90 | 336 | -6.77 |
| 128 | | 7 | 376 | 3 | 359 | -4.45 | 362 | -3.71 | 363 | -3.56 | 350 | -6.92 |
| 129 | | 8 | 395 | 3 | 380 | -3.71 | 382 | -3.33 | 378 | -4.37 | 368 | -6.93 |
| 130 | | 10 | 441 | 3 | 411 | -6.70 | 413 | -6.44 | 424 | -3.88 | 414 | -6.11 |
| 131 | | 11 | 494 | 2 | 471 | -4.56 | 461 | -6.67 | 481 | -2.66 | 472 | -4.38 |
| 132 | | 20 | 494 | 2 | 466 | -5.65 | 461 | -6.61 | 486 | -1.66 | 469 | -5.11 |
| 133 | | 23 | 618 | 3 | 589 | -4.66 | 587 | -5.01 | 612 | -0.91 | 599 | -3.15 |
| 134 | | 30 | 513 | 3 | 493 | -3.94 | 498 | -2.88 | 517 | 0.78 | 488 | -4.94 |
| 135 | | 31 | 523 | 3 | 513 | -1.92 | 517 | -1.16 | 533 | 1.95 | 509 | -2.59 |
| 136 | | 34 | 608 | 4 | 562 | -7.59 | 568 | -6.56 | 604 | -0.59 | 583 | -4.12 |
| 137 | | 46 | 629 | 2 | 616 | -2.01 | 619 | -1.65 | 638 | 1.45 | 612 | -2.73 |
| 138 | | 59 | 648 | 2 | 614 | -5.30 | 616 | -4.96 | 668 | 3.16 | 631 | -2.63 |
| 139 | | 76 | 753 | 3 | 725 | -3.72 | 726 | -3.56 | 765 | 1.58 | 723 | -3.98 |
| 140 | | 77 | 761 | 2 | 746 | -1.94 | 746 | -2.02 | 782 | 2.75 | 742 | -2.44 |
| 141 | | 80 | 820 | 4 | 777 | -5.24 | 779 | -4.97 | 849 | 3.49 | 814 | -0.75 |
| 142 | | 81 | 894 | 4 | 886 | -0.94 | 890 | -0.49 | 913 | 2.13 | 875 | -2.12 |
| 143 | | 90 | 723 | 2 | 709 | -1.89 | 706 | -2.31 | 756 | 4.53 | 704 | -2.64 |
| 144 | | 91 | 760 | 3 | 731 | -3.82 | 730 | -4.00 | 791 | 4.05 | 739 | -2.79 |
| 145 | | 94 | 827 | 3 | 807 | -2.48 | 803 | -2.90 | 856 | 3.51 | 807 | -2.43 |
| 146 | | 96 | 850 | 3 | 835 | -1.73 | 833 | -1.98 | 880 | 3.48 | 834 | -1.84 |
| 147 | | 110 | 849 | 3 | 841 | -0.99 | 832 | -1.96 | 880 | 3.68 | 821 | -3.36 |
| 148 | | 115 | 949 | 3 | 912 | -3.88 | 914 | -3.66 | 984 | 3.71 | 929 | -2.07 |
| 149 | | 126 | 832 | 2 | 818 | -1.74 | 813 | -2.34 | 880 | 5.72 | 804 | -3.32 |
| 150 | | 127 | 859 | 2 | 815 | -5.08 | 807 | -6.06 | 915 | 6.47 | 842 | -1.97 |
| 151 | | 146 | 922 | 3 | 889 | -3.59 | 887 | -3.77 | 984 | 6.72 | 897 | -2.69 |
| 152 | | 153 | 1033 | 3 | 1015 | -1.75 | 1010 | -2.26 | 1085 | 5.02 | 1015 | -1.76 |
| 153 | | 155 | 1171 | 4 | 1156 | -1.31 | 1171 | 0.01 | 1218 | 3.99 | 1150 | -1.77 |
| 154 | 4 | 1 | 172 | 4 | 170 | -1.31 | 167 | -2.84 | 156 | -9.35 | 166 | -3.71 |

## Table 10.3 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 | | | | SCALE 4.4a | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | "source vector by unit" table | | "total fissions" table | | "source vector by unit" table | | "total fissions" table | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 155 | | 2 | 197 | 4 | 184 | -6.54 | 180 | -8.47 | 178 | -9.56 | 190 | -3.80 |
| 156 | | 3 | 209 | 4 | 210 | 0.53 | 208 | -0.72 | 193 | -7.62 | 206 | -1.50 |
| 157 | | 4 | 217 | 4 | 216 | -0.39 | 218 | 0.24 | 195 | -9.99 | 211 | -2.74 |
| 158 | | 5 | 224 | 3 | 221 | -1.45 | 219 | -2.22 | 200 | -10.69 | 218 | -2.68 |
| 159 | | 6 | 230 | 3 | 220 | -4.51 | 220 | -4.42 | 198 | -13.99 | 218 | -5.38 |
| 160 | | 7 | 221 | 4 | 202 | -8.49 | 199 | -9.88 | 196 | -11.51 | 218 | -1.54 |
| 161 | | 8 | 222 | 3 | 206 | -7.20 | 203 | -8.46 | 190 | -14.56 | 213 | -4.11 |
| 162 | | 9 | 218 | 4 | 210 | -3.51 | 208 | -4.56 | 184 | -15.49 | 210 | -3.58 |
| 163 | | 10 | 209 | 4 | 200 | -4.50 | 196 | -6.42 | 169 | -18.97 | 196 | -6.37 |
| 164 | | 11 | 184 | 4 | 172 | -6.52 | 170 | -7.62 | 145 | -21.46 | 169 | -7.95 |
| 165 | | 12 | 202 | 4 | 200 | -1.03 | 199 | -1.37 | 192 | -5.03 | 199 | -1.53 |
| 166 | | 13 | 235 | 3 | 242 | 2.98 | 239 | 1.66 | 226 | -3.82 | 237 | 0.74 |
| 167 | | 15 | 267 | 3 | 261 | -2.35 | 264 | -1.26 | 251 | -5.83 | 268 | 0.46 |
| 168 | | 17 | 276 | 2 | 277 | 0.33 | 276 | -0.16 | 253 | -8.25 | 277 | 0.30 |
| 169 | | 19 | 273 | 2 | 269 | -1.65 | 260 | -4.60 | 249 | -8.71 | 279 | 2.37 |
| 170 | | 21 | 263 | 2 | 276 | 5.08 | 279 | 6.10 | 231 | -12.35 | 262 | -0.54 |
| 171 | | 23 | 214 | 5 | 208 | -2.89 | 206 | -3.59 | 178 | -16.84 | 209 | -2.35 |
| 172 | | 30 | 316 | 3 | 324 | 2.66 | 325 | 3.00 | 296 | -6.38 | 323 | 2.36 |
| 173 | | 35 | 271 | 4 | 285 | 5.12 | 278 | 2.53 | 240 | -11.41 | 280 | 3.37 |
| 174 | | 36 | 240 | 4 | 227 | -5.36 | 224 | -6.65 | 200 | -16.80 | 232 | -3.25 |
| 175 | | 37 | 241 | 4 | 254 | 5.42 | 248 | 3.02 | 236 | -2.08 | 243 | 0.74 |
| 176 | | 42 | 357 | 2 | 375 | 4.98 | 372 | 4.09 | 345 | -3.40 | 370 | 3.56 |
| 177 | | 44 | 360 | 2 | 365 | 1.31 | 368 | 2.32 | 346 | -3.99 | 378 | 5.09 |
| 178 | | 46 | 359 | 2 | 364 | 1.27 | 365 | 1.54 | 325 | -9.59 | 364 | 1.50 |
| 179 | | 47 | 350 | 3 | 363 | 3.63 | 363 | 3.65 | 314 | -10.29 | 355 | 1.42 |
| 180 | | 50 | 265 | 5 | 253 | -4.53 | 252 | -5.02 | 220 | -16.94 | 258 | -2.74 |
| 181 | | 60 | 407 | 2 | 419 | 3.00 | 417 | 2.53 | 371 | -8.81 | 412 | 1.30 |
| 182 | | 62 | 391 | 2 | 411 | 5.09 | 407 | 3.98 | 348 | -11.05 | 392 | 0.26 |
| 183 | | 63 | 364 | 3 | 367 | 0.84 | 363 | -0.23 | 323 | -11.33 | 370 | 1.68 |
| 184 | | 64 | 338 | 3 | 329 | -2.58 | 330 | -2.22 | 285 | -15.71 | 331 | -1.99 |
| 185 | | 65 | 288 | 5 | 281 | -2.32 | 278 | -3.30 | 237 | -17.78 | 278 | -3.33 |
| 186 | | 66 | 287 | 4 | 296 | 3.21 | 298 | 3.88 | 280 | -2.45 | 284 | -1.13 |
| 187 | | 71 | 431 | 2 | 451 | 4.64 | 450 | 4.44 | 424 | -1.70 | 443 | 2.81 |
| 188 | | 75 | 444 | 3 | 450 | 1.46 | 443 | -0.12 | 410 | -7.64 | 448 | 1.01 |
| 189 | | 77 | 438 | 3 | 434 | -1.00 | 432 | -1.38 | 400 | -8.73 | 450 | 2.82 |
| 190 | | 81 | 319 | 5 | 314 | -1.63 | 310 | -2.80 | 262 | -18.02 | 307 | -3.73 |
| 191 | | 85 | 433 | 3 | 467 | 7.91 | 461 | 6.57 | 429 | -0.81 | 438 | 1.11 |
| 192 | | 88 | 481 | 3 | 488 | 1.36 | 494 | 2.76 | 466 | -3.20 | 484 | 0.70 |
| 193 | | 90 | 489 | 3 | 502 | 2.60 | 501 | 2.38 | 460 | -6.01 | 489 | 0.06 |
| 194 | | 91 | 495 | 2 | 496 | 0.13 | 490 | -0.92 | 462 | -6.57 | 498 | 0.63 |
| 195 | | 92 | 489 | 3 | 495 | 1.17 | 491 | 0.44 | 452 | -7.64 | 496 | 1.39 |
| 196 | | 94 | 470 | 3 | 481 | 2.39 | 475 | 1.07 | 430 | -8.49 | 483 | 2.85 |
| 197 | | 97 | 400 | 4 | 412 | 3.09 | 409 | 2.26 | 338 | -15.41 | 393 | -1.71 |
| 198 | | 98 | 353 | 5 | 337 | -4.55 | 337 | -4.60 | 284 | -19.49 | 334 | -5.38 |
| 199 | | 99 | 340 | 4 | 328 | -3.52 | 327 | -3.71 | 331 | -2.68 | 331 | -2.60 |
| 200 | | 101 | 432 | 2 | 424 | -1.84 | 425 | -1.52 | 434 | 0.42 | 436 | 1.03 |
| 201 | | 111 | 528 | 3 | 537 | 1.72 | 538 | 1.83 | 475 | -10.00 | 529 | 0.21 |
| 202 | | 113 | 505 | 3 | 521 | 3.08 | 514 | 1.84 | 441 | -12.74 | 502 | -0.53 |
| 203 | | 114 | 474 | 3 | 479 | 0.98 | 475 | 0.30 | 407 | -14.08 | 468 | -1.20 |
| 204 | | 116 | 379 | 5 | 369 | -2.63 | 363 | -4.20 | 310 | -18.10 | 366 | -3.54 |
| 205 | | 131 | 565 | 3 | 563 | -0.42 | 556 | -1.57 | 498 | -11.92 | 563 | -0.36 |
| 206 | | 134 | 477 | 3 | 479 | 0.49 | 475 | -0.50 | 396 | -17.03 | 464 | -2.69 |

## Table 10.3 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 |  |  |  | SCALE 4.4a |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | "source vector by unit" table |  | "total fissions" table |  | "source vector by unit" table |  | "total fissions" table |  |
|  |  |  |  |  | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 207 |  | 135 | 428 | 4 | 418 | -2.30 | 416 | -2.72 | 341 | -20.24 | 404 | -5.56 |
| 208 |  | 136 | 413 | 4 | 400 | -3.05 | 398 | -3.58 | 399 | -3.36 | 396 | -4.06 |
| 209 |  | 146 | 653 | 3 | 635 | -2.75 | 631 | -3.40 | 609 | -6.67 | 641 | -1.87 |
| 210 |  | 148 | 639 | 2 | 639 | -0.04 | 632 | -1.05 | 578 | -9.55 | 625 | -2.17 |
| 211 |  | 149 | 631 | 2 | 643 | 1.94 | 644 | 1.99 | 563 | -10.84 | 617 | -2.19 |
| 212 |  | 151 | 613 | 3 | 602 | -1.83 | 597 | -2.68 | 538 | -12.18 | 605 | -1.28 |
| 213 |  | 155 | 479 | 4 | 455 | -4.94 | 453 | -5.44 | 380 | -20.77 | 451 | -5.84 |
| 214 |  | 156 | 494 | 3 | 462 | -6.45 | 461 | -6.66 | 472 | -4.55 | 464 | -6.00 |
| 215 |  | 158 | 537 | 3 | 539 | 0.40 | 539 | 0.44 | 548 | 2.12 | 540 | 0.58 |
| 216 |  | 161 | 615 | 3 | 609 | -0.98 | 609 | -1.05 | 625 | 1.55 | 623 | 1.37 |
| 217 |  | 162 | 642 | 3 | 627 | -2.34 | 624 | -2.75 | 634 | -1.18 | 632 | -1.51 |
| 218 |  | 164 | 660 | 3 | 682 | 3.37 | 679 | 2.84 | 648 | -1.79 | 660 | 0.00 |
| 219 |  | 165 | 690 | 3 | 701 | 1.65 | 694 | 0.53 | 668 | -3.17 | 683 | -0.97 |
| 220 |  | 167 | 699 | 2 | 713 | 1.99 | 712 | 1.81 | 655 | -6.31 | 689 | -1.42 |
| 221 |  | 171 | 661 | 3 | 674 | 1.93 | 669 | 1.14 | 592 | -10.49 | 656 | -0.74 |
| 222 |  | 173 | 634 | 3 | 645 | 1.79 | 641 | 1.03 | 554 | -12.60 | 633 | -0.21 |
| 223 |  | 174 | 615 | 2 | 617 | 0.40 | 611 | -0.60 | 519 | -15.54 | 603 | -1.91 |
| 224 |  | 175 | 598 | 2 | 577 | -3.55 | 570 | -4.73 | 495 | -17.24 | 583 | -2.43 |
| 225 |  | 176 | 568 | 3 | 556 | -2.08 | 553 | -2.62 | 452 | -20.44 | 538 | -5.23 |
| 226 |  | 177 | 601 | 4 | 592 | -1.55 | 596 | -0.88 | 596 | -0.88 | 585 | -2.70 |
| 227 |  | 181 | 660 | 3 | 657 | -0.42 | 654 | -0.95 | 664 | 0.60 | 659 | -0.21 |
| 228 |  | 184 | 704 | 3 | 705 | 0.12 | 699 | -0.70 | 694 | -1.42 | 698 | -0.79 |
| 229 |  | 190 | 734 | 3 | 717 | -2.34 | 724 | -1.36 | 668 | -9.03 | 722 | -1.70 |
| 230 |  | 193 | 684 | 3 | 697 | 1.91 | 686 | 0.34 | 622 | -9.03 | 703 | 2.72 |
| 231 |  | 196 | 685 | 3 | 691 | 0.88 | 686 | 0.19 | 576 | -15.87 | 679 | -0.91 |
| 232 |  | 206 | 747 | 3 | 754 | 0.88 | 760 | 1.77 | 747 | -0.02 | 765 | 2.43 |
| 233 |  | 209 | 754 | 3 | 761 | 0.99 | 759 | 0.72 | 714 | -5.27 | 761 | 0.87 |
| 234 |  | 212 | 740 | 4 | 745 | 0.73 | 735 | -0.71 | 674 | -8.96 | 747 | 0.96 |
| 235 |  | 215 | 760 | 4 | 782 | 2.91 | 776 | 2.12 | 661 | -12.97 | 765 | 0.71 |
| 236 |  | 230 | 804 | 3 | 816 | 1.55 | 816 | 1.55 | 745 | -7.31 | 816 | 1.52 |
| 237 |  | 232 | 824 | 4 | 789 | -4.31 | 787 | -4.43 | 717 | -12.98 | 807 | -2.10 |
| 238 |  | 233 | 842 | 4 | 851 | 1.01 | 847 | 0.56 | 735 | -12.71 | 843 | 0.17 |
| 239 |  | 238 | 804 | 3 | 839 | 4.38 | 844 | 5.02 | 831 | 3.30 | 818 | 1.69 |
| 240 |  | 245 | 862 | 3 | 858 | -0.50 | 850 | -1.41 | 812 | -5.85 | 855 | -0.83 |
| 241 |  | 251 | 869 | 4 | 890 | 2.43 | 892 | 2.65 | 887 | 2.02 | 857 | -1.42 |
| 242 |  | 252 | 829 | 2 | 836 | 0.79 | 834 | 0.60 | 864 | 4.27 | 838 | 1.06 |
| 243 |  | 255 | 875 | 2 | 875 | -0.06 | 879 | 0.40 | 891 | 1.88 | 876 | 0.07 |
| 244 |  | 259 | 914 | 3 | 922 | 0.83 | 911 | -0.32 | 893 | -2.25 | 909 | -0.50 |
| 245 |  | 261 | 919 | 3 | 933 | 1.57 | 928 | 0.96 | 886 | -3.63 | 922 | 0.35 |
| 246 |  | 263 | 914 | 3 | 928 | 1.49 | 927 | 1.42 | 855 | -6.42 | 910 | -0.45 |
| 247 |  | 273 | 956 | 3 | 924 | -3.34 | 925 | -3.20 | 949 | -0.73 | 945 | -1.17 |
| 248 |  | 276 | 963 | 2 | 985 | 2.27 | 976 | 1.38 | 945 | -1.85 | 968 | 0.57 |
| 249 |  | 280 | 962 | 2 | 972 | 1.02 | 970 | 0.83 | 915 | -4.85 | 983 | 2.22 |
| 250 |  | 281 | 1023 | 3 | 1034 | 1.04 | 1030 | 0.64 | 956 | -6.54 | 1035 | 1.15 |
| 251 |  | 292 | 1036 | 3 | 1022 | -1.33 | 1014 | -2.08 | 992 | -4.21 | 1029 | -0.66 |
| 252 |  | 293 | 1017 | 3 | 1019 | 0.21 | 1020 | 0.30 | 974 | -4.22 | 1017 | 0.02 |
| 253 |  | 297 | 1010 | 3 | 1034 | 2.39 | 1031 | 2.09 | 1059 | 4.84 | 1017 | 0.66 |
| 254 |  | 304 | 1054 | 3 | 1063 | 0.82 | 1059 | 0.47 | 1030 | -2.24 | 1044 | -0.92 |
| 255 |  | 308 | 1137 | 4 | 1156 | 1.70 | 1158 | 1.88 | 1107 | -2.66 | 1161 | 2.13 |
| 256 |  | 312 | 1092 | 3 | 1089 | -0.28 | 1078 | -1.28 | 1132 | 3.67 | 1099 | 0.63 |
| 257 |  | 315 | 1107 | 3 | 1100 | -0.67 | 1099 | -0.75 | 1121 | 1.29 | 1115 | 0.76 |
| 258 |  | 319 | 1151 | 3 | 1148 | -0.27 | 1152 | 0.09 | 1126 | -2.19 | 1157 | 0.56 |

## Table 10.3 (Contd)

| **Calculation point** | **No. of FA** | **Fuel pin position** | **$W_{exp}$** | **Unc. [%]** | **SCALE 4.3** | | | | **SCALE 4.4a** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **"source vector by unit" table** | | **"total fissions" table** | | **"source vector by unit" table** | | **"total fissions" table** | |
| | | | | | **$W_{calc}$** | **Dev. [%]** | **$W_{calc}$** | **Dev. [%]** | **$W_{calc}$** | **Dev. [%]** | **$W_{calc}$** | **Dev. [%]** |
| 259 | | 326 | 1242 | 4 | 1220 | -1.79 | 1212 | -2.45 | 1244 | 0.15 | 1226 | -1.26 |
| 260 | | 330 | 1256 | 3 | 1271 | 1.22 | 1275 | 1.53 | 1252 | -0.29 | 1278 | 1.75 |
| **MAX. DEV.** | | | | | | **8.97** | | **9.88** | | **23.00** | | **14.66** |
| **STAND. DEV** | | | | | | **3.41** | | **3.32** | | **9.71** | | **3.05** |
| **Correlation coefficient** | | | | | 0.9981 | | 0.9983 | | 0.8688 | | 0.9984 | |

## Table 10.4 Comparison of Experimental and Calculation Results for Relative Power Distribution, 218-Group Library of SCALE

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 | | | | SCALE 4.4a | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | "source vector by unit" table | | "total fissions" table | | "source vector by unit" table | | "total fissions" table | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 1 | 31 | 326 | 1506 | 5 | 1454 | -3.46 | 1476 | -1.98 | 1249 | -17.09 | 1470 | -2.36 |
| 2 | | 302 | 1328 | 3 | 1261 | -5.03 | 1273 | -4.17 | 1161 | -12.57 | 1295 | -2.49 |
| 3 | | 242 | 1675 | 4 | 1631 | -2.63 | 1658 | -0.99 | 1563 | -6.69 | 1599 | -4.55 |
| 4 | | 206 | 1823 | 3 | 1781 | -2.28 | 1798 | -1.38 | 1764 | -3.25 | 1759 | -3.53 |
| 5 | | 156 | 2303 | 5 | 2229 | -3.20 | 2252 | -2.21 | 1884 | -18.20 | 2231 | -3.12 |
| 6 | | 126 | 2104 | 3 | 2078 | -1.23 | 2116 | 0.57 | 2109 | 0.22 | 2010 | -4.49 |
| 7 | | 90 | 2189 | 3 | 2099 | -4.11 | 2128 | -2.81 | 2230 | 1.87 | 2098 | -4.18 |
| 8 | | 30 | 2301 | 3 | 2237 | -2.76 | 2267 | -1.48 | 2446 | 6.31 | 2248 | -2.32 |
| 9 | | 6 | 2575 | 4 | 2493 | -3.20 | 2516 | -2.28 | 2708 | 5.15 | 2477 | -3.79 |
| 10 | 27 | 1 | 2711 | 4 | 2731 | 0.72 | 2746 | 1.29 | 2990 | 10.31 | 2696 | -0.56 |
| 11 | | 3 | 2600 | 4 | 2643 | 1.66 | 2652 | 2.02 | 2867 | 10.28 | 2603 | 0.11 |
| 12 | | 6 | 2603 | 4 | 2616 | 0.51 | 2641 | 1.46 | 2869 | 10.21 | 2613 | 0.37 |
| 13 | | 30 | 2470 | 3 | 2410 | -2.44 | 2428 | -1.71 | 2681 | 8.54 | 2443 | -1.09 |
| 14 | | 42 | 2456 | 3 | 2434 | -0.89 | 2445 | -0.45 | 2643 | 7.59 | 2399 | -2.32 |
| 15 | | 66 | 2662 | 3 | 2689 | 1.02 | 2699 | 1.40 | 2952 | 10.88 | 2650 | -0.45 |
| 16 | | 90 | 2485 | 4 | 2490 | 0.22 | 2533 | 1.92 | 2682 | 7.93 | 2428 | -2.28 |
| 17 | | 156 | 2824 | 4 | 2829 | 0.16 | 2861 | 1.30 | 3110 | 10.12 | 2792 | -1.14 |
| 18 | | 242 | 2454 | 3 | 2441 | -0.53 | 2449 | -0.20 | 2696 | 9.87 | 2432 | -0.91 |
| 19 | | 302 | 2443 | 3 | 2402 | -1.66 | 2438 | -0.22 | 2592 | 6.09 | 2347 | -3.93 |
| 20 | | 326 | 2555 | 4 | 2543 | -0.47 | 2570 | 0.60 | 2751 | 7.67 | 2518 | -1.45 |
| 21 | 21 | 3 | 1974 | 3 | 1951 | -1.16 | 1957 | -0.87 | 2080 | 5.38 | 1933 | -2.08 |
| 22 | | 6 | 1977 | 3 | 1965 | -0.62 | 1972 | -0.27 | 2086 | 5.49 | 1948 | -1.49 |
| 23 | | 30 | 1969 | 3 | 1894 | -3.80 | 1903 | -3.36 | 2018 | 2.48 | 1873 | -4.89 |
| 24 | | 86 | 2145 | 3 | 2083 | -2.91 | 2105 | -1.89 | 2255 | 5.14 | 2058 | -4.03 |
| 25 | | 90 | 2139 | 3 | 2046 | -4.33 | 2073 | -3.07 | 2249 | 5.16 | 2073 | -3.08 |
| 26 | | 126 | 2237 | 3 | 2164 | -3.24 | 2170 | -2.99 | 2352 | 5.15 | 2155 | -3.68 |
| 27 | | 156 | 2492 | 5 | 2410 | -3.28 | 2428 | -2.58 | 2702 | 8.41 | 2426 | -2.65 |
| 28 | | 159 | 2282 | 4 | 2218 | -2.80 | 2237 | -1.95 | 2430 | 6.47 | 2193 | -3.90 |
| 29 | | 161 | 2294 | 3 | 2227 | -2.94 | 2242 | -2.25 | 2451 | 6.84 | 2218 | -3.31 |
| 30 | | 165 | 2361 | 3 | 2292 | -2.91 | 2299 | -2.63 | 2532 | 7.25 | 2308 | -2.25 |
| 31 | | 206 | 2376 | 3 | 2247 | -5.42 | 2264 | -4.73 | 2505 | 5.44 | 2282 | -3.97 |
| 32 | | 302 | 2419 | 3 | 2407 | -0.52 | 2433 | 0.56 | 2621 | 8.34 | 2386 | -1.36 |
| 33 | | 326 | 2571 | 4 | 2599 | 1.08 | 2606 | 1.38 | 2845 | 10.67 | 2578 | 0.29 |
| 34 | 13 | 1 | 581 | 5 | 595 | 2.50 | 593 | 2.06 | 470 | -19.19 | 570 | -1.92 |
| 35 | | 2 | 533 | 5 | 534 | 0.27 | 529 | -0.80 | 422 | -20.75 | 521 | -2.29 |
| 36 | | 3 | 516 | 4 | 515 | -0.26 | 519 | 0.52 | 401 | -22.24 | 508 | -1.48 |
| 37 | | 4 | 514 | 4 | 517 | 0.65 | 511 | -0.50 | 402 | -21.69 | 509 | -0.97 |
| 38 | | 5 | 525 | 4 | 515 | -1.89 | 511 | -2.69 | 397 | -24.46 | 501 | -4.55 |
| 39 | | 6 | 515 | 4 | 496 | -3.65 | 497 | -3.56 | 406 | -21.14 | 521 | 1.14 |
| 40 | | 12 | 694 | 3 | 710 | 2.29 | 710 | 2.27 | 601 | -13.44 | 721 | 3.85 |
| 41 | | 13 | 638 | 3 | 647 | 1.37 | 648 | 1.62 | 544 | -14.76 | 654 | 2.54 |
| 42 | | 14 | 621 | 4 | 606 | -2.46 | 601 | -3.18 | 507 | -18.37 | 621 | -0.05 |
| 43 | | 15 | 612 | 4 | 601 | -1.83 | 600 | -1.90 | 496 | -18.90 | 618 | 0.98 |
| 44 | | 16 | 609 | 4 | 610 | 0.22 | 597 | -1.93 | 494 | -18.86 | 621 | 2.03 |
| 45 | | 17 | 606 | 4 | 618 | 1.94 | 619 | 2.07 | 484 | -20.07 | 607 | 0.24 |
| 46 | | 24 | 776 | 3 | 819 | 5.48 | 818 | 5.36 | 682 | -12.17 | 802 | 3.31 |
| 47 | | 26 | 708 | 3 | 718 | 1.45 | 706 | -0.34 | 586 | -17.29 | 709 | 0.19 |
| 48 | | 28 | 688 | 3 | 714 | 3.72 | 706 | 2.59 | 565 | -17.84 | 698 | 1.39 |
| 49 | | 30 | 691 | 4 | 700 | 1.33 | 674 | -2.51 | 565 | -18.24 | 699 | 1.09 |
| 50 | | 37 | 843 | 3 | 879 | 4.30 | 872 | 3.42 | 757 | -10.14 | 870 | 3.24 |

## Table 10.4 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 | | | | SCALE 4.4a | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | "source vector by unit" table | | "total fissions" table | | "source vector by unit" table | | "total fissions" table | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 51 | | 40 | 774 | 4 | 791 | 2.13 | 787 | 1.65 | 666 | -13.96 | 794 | 2.57 |
| 52 | | 41 | 776 | 4 | 802 | 3.34 | 797 | 2.70 | 661 | -14.83 | 793 | 2.18 |
| 53 | | 43 | 768 | 4 | 762 | -0.83 | 761 | -0.85 | 635 | -17.37 | 780 | 1.60 |
| 54 | | 52 | 859 | 3 | 896 | 4.30 | 893 | 3.98 | 771 | -10.26 | 883 | 2.74 |
| 55 | | 54 | 844 | 4 | 876 | 3.75 | 873 | 3.40 | 727 | -13.82 | 857 | 1.57 |
| 56 | | 56 | 834 | 4 | 858 | 2.84 | 855 | 2.47 | 713 | -14.47 | 856 | 2.60 |
| 57 | | 57 | 841 | 3 | 848 | 0.79 | 845 | 0.45 | 715 | -14.98 | 861 | 2.42 |
| 58 | | 67 | 909 | 3 | 921 | 1.35 | 923 | 1.51 | 847 | -6.86 | 940 | 3.45 |
| 59 | | 69 | 900 | 4 | 898 | -0.17 | 901 | 0.06 | 803 | -10.79 | 916 | 1.77 |
| 60 | | 70 | 915 | 4 | 929 | 1.50 | 924 | 0.93 | 806 | -11.90 | 931 | 1.80 |
| 61 | | 71 | 907 | 3 | 932 | 2.71 | 928 | 2.36 | 782 | -13.78 | 918 | 1.26 |
| 62 | | 72 | 897 | 3 | 931 | 3.77 | 934 | 4.14 | 770 | -14.17 | 906 | 1.02 |
| 63 | | 73 | 899 | 3 | 940 | 4.56 | 928 | 3.27 | 795 | -11.59 | 934 | 3.88 |
| 64 | | 82 | 1029 | 3 | 1066 | 3.57 | 1049 | 1.94 | 983 | -4.52 | 1067 | 3.67 |
| 65 | | 85 | 970 | 3 | 998 | 2.92 | 1001 | 3.24 | 892 | -8.04 | 1002 | 3.33 |
| 66 | | 86 | 966 | 3 | 980 | 1.41 | 976 | 1.03 | 886 | -8.30 | 997 | 3.26 |
| 67 | | 88 | 970 | 3 | 983 | 1.35 | 967 | -0.31 | 868 | -10.47 | 996 | 2.66 |
| 68 | | 89 | 958 | 4 | 998 | 4.13 | 989 | 3.25 | 863 | -9.90 | 992 | 3.52 |
| 69 | | 90 | 943 | 4 | 1013 | 7.46 | 1010 | 7.06 | 852 | -9.61 | 981 | 4.06 |
| 70 | | 99 | 1085 | 3 | 1102 | 1.55 | 1100 | 1.37 | 1045 | -3.66 | 1114 | 2.67 |
| 71 | | 102 | 1025 | 4 | 1072 | 4.58 | 1060 | 3.38 | 971 | -5.29 | 1063 | 3.75 |
| 72 | | 104 | 1035 | 3 | 1062 | 2.64 | 1056 | 1.99 | 944 | -8.78 | 1053 | 1.73 |
| 73 | | 105 | 1019 | 4 | 1068 | 4.85 | 1078 | 5.76 | 928 | -8.93 | 1041 | 2.12 |
| 74 | | 118 | 1082 | 4 | 1124 | 3.91 | 1113 | 2.86 | 1065 | -1.53 | 1124 | 3.86 |
| 75 | | 119 | 1072 | 3 | 1114 | 3.95 | 1111 | 3.59 | 1063 | -0.85 | 1135 | 5.89 |
| 76 | | 121 | 1079 | 3 | 1143 | 5.95 | 1133 | 5.05 | 1033 | -4.26 | 1113 | 3.17 |
| 77 | | 122 | 1080 | 3 | 1080 | 0.02 | 1080 | 0.01 | 1028 | -4.80 | 1117 | 3.45 |
| 78 | | 125 | 1095 | 3 | 1148 | 4.80 | 1142 | 4.26 | 1023 | -6.62 | 1129 | 3.07 |
| 79 | | 126 | 1090 | 4 | 1145 | 5.03 | 1153 | 5.78 | 1011 | -7.29 | 1122 | 2.98 |
| 80 | | 136 | 1205 | 3 | 1274 | 5.72 | 1269 | 5.29 | 1208 | 0.22 | 1250 | 3.74 |
| 81 | | 140 | 1135 | 3 | 1195 | 5.33 | 1179 | 3.91 | 1114 | -1.84 | 1174 | 3.46 |
| 82 | | 142 | 1138 | 3 | 1162 | 2.14 | 1163 | 2.20 | 1100 | -3.36 | 1177 | 3.40 |
| 83 | | 143 | 1144 | 3 | 1205 | 5.32 | 1211 | 5.89 | 1096 | -4.15 | 1174 | 2.65 |
| 84 | | 145 | 1188 | 3 | 1230 | 3.54 | 1229 | 3.42 | 1130 | -4.85 | 1215 | 2.28 |
| 85 | | 156 | 1305 | 3 | 1334 | 2.24 | 1327 | 1.69 | 1324 | 1.45 | 1358 | 4.03 |
| 86 | | 159 | 1200 | 3 | 1212 | 0.97 | 1218 | 1.50 | 1203 | 0.23 | 1237 | 3.09 |
| 87 | | 165 | 1236 | 3 | 1274 | 3.06 | 1279 | 3.52 | 1204 | -2.56 | 1275 | 3.18 |
| 88 | | 206 | 1301 | 4 | 1360 | 4.56 | 1353 | 4.02 | 1311 | 0.80 | 1328 | 2.11 |
| 89 | | 237 | 1406 | 3 | 1461 | 3.90 | 1454 | 3.42 | 1458 | 3.67 | 1437 | 2.18 |
| 90 | | 242 | 1394 | 3 | 1460 | 4.75 | 1454 | 4.34 | 1471 | 5.53 | 1458 | 4.57 |
| 91 | | 251 | 1513 | 3 | 1615 | 6.72 | 1604 | 6.03 | 1644 | 8.64 | 1604 | 6.00 |
| 92 | | 256 | 1457 | 3 | 1514 | 3.89 | 1510 | 3.63 | 1566 | 7.45 | 1529 | 4.93 |
| 93 | | 285 | 1565 | 3 | 1617 | 3.32 | 1612 | 3.03 | 1683 | 7.56 | 1617 | 3.31 |
| 94 | | 302 | 1587 | 3 | 1648 | 3.81 | 1660 | 4.60 | 1735 | 9.31 | 1651 | 4.03 |
| 95 | | 321 | 1872 | 4 | 1952 | 4.25 | 1962 | 4.80 | 2088 | 11.51 | 1957 | 4.56 |
| 96 | | 326 | 1791 | 3 | 1852 | 3.43 | 1865 | 4.13 | 2006 | 11.98 | 1887 | 5.38 |
| 97 | 12 | 1 | 1288 | 4 | 1294 | 0.46 | 1301 | 0.99 | 1372 | 6.50 | 1295 | 0.53 |
| 98 | | 4 | 1248 | 2 | 1292 | 3.56 | 1299 | 4.10 | 1346 | 7.81 | 1291 | 3.43 |
| 99 | | 8 | 1269 | 2 | 1296 | 2.13 | 1300 | 2.44 | 1326 | 4.51 | 1323 | 4.22 |
| 100 | | 10 | 1288 | 3 | 1365 | 5.98 | 1351 | 4.88 | 1349 | 4.75 | 1360 | 5.60 |
| 101 | | 11 | 1347 | 2 | 1397 | 3.73 | 1398 | 3.75 | 1388 | 3.04 | 1407 | 4.48 |
| 102 | | 18 | 1264 | 2 | 1252 | -0.96 | 1248 | -1.24 | 1322 | 4.61 | 1288 | 1.93 |

## Table 10.4 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 | | | | SCALE 4.4a | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | "source vector by unit" table | | "total fissions" table | | "source vector by unit" table | | "total fissions" table | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 103 | | 23 | 1385 | 3 | 1440 | 3.95 | 1441 | 4.05 | 1400 | 1.05 | 1410 | 1.79 |
| 104 | | 29 | 1259 | 3 | 1303 | 3.51 | 1300 | 3.25 | 1352 | 7.40 | 1292 | 2.66 |
| 105 | | 30 | 1270 | 3 | 1253 | -1.32 | 1263 | -0.55 | 1360 | 7.06 | 1310 | 3.18 |
| 106 | | 34 | 1293 | 3 | 1330 | 2.86 | 1334 | 3.14 | 1353 | 4.67 | 1342 | 3.80 |
| 107 | | 41 | 1305 | 3 | 1359 | 4.11 | 1363 | 4.45 | 1448 | 10.97 | 1358 | 4.03 |
| 108 | | 46 | 1364 | 3 | 1375 | 0.80 | 1380 | 1.14 | 1445 | 5.95 | 1409 | 3.30 |
| 109 | | 47 | 1370 | 3 | 1412 | 3.05 | 1415 | 3.27 | 1456 | 6.26 | 1429 | 4.27 |
| 110 | | 49 | 1370 | 3 | 1396 | 1.87 | 1397 | 1.95 | 1443 | 5.31 | 1417 | 3.44 |
| 111 | | 65 | 1512 | 3 | 1554 | 2.75 | 1554 | 2.79 | 1609 | 6.44 | 1562 | 3.32 |
| 112 | | 77 | 1481 | 3 | 1509 | 1.89 | 1504 | 1.57 | 1565 | 5.70 | 1508 | 1.79 |
| 113 | | 84 | 1387 | 3 | 1401 | 1.00 | 1396 | 0.64 | 1545 | 11.40 | 1402 | 1.11 |
| 114 | | 87 | 1426 | 3 | 1467 | 2.88 | 1457 | 2.15 | 1592 | 11.68 | 1471 | 3.15 |
| 115 | | 91 | 1493 | 4 | 1558 | 4.38 | 1555 | 4.15 | 1648 | 10.36 | 1561 | 4.58 |
| 116 | | 92 | 1514 | 3 | 1565 | 3.38 | 1562 | 3.20 | 1638 | 8.19 | 1556 | 2.81 |
| 117 | | 95 | 1524 | 3 | 1557 | 2.16 | 1539 | 1.01 | 1616 | 6.07 | 1549 | 1.65 |
| 118 | | 96 | 1519 | 3 | 1540 | 1.41 | 1539 | 1.29 | 1627 | 7.12 | 1561 | 2.74 |
| 119 | | 97 | 1549 | 3 | 1589 | 2.59 | 1592 | 2.77 | 1654 | 6.75 | 1588 | 2.53 |
| 120 | | 116 | 1695 | 3 | 1724 | 1.73 | 1730 | 2.05 | 1853 | 9.30 | 1768 | 4.28 |
| 121 | | 118 | 1495 | 3 | 1513 | 1.23 | 1507 | 0.83 | 1696 | 13.43 | 1517 | 1.44 |
| 122 | | 126 | 1597 | 4 | 1614 | 1.06 | 1608 | 0.66 | 1752 | 9.71 | 1623 | 1.65 |
| 123 | | 129 | 1591 | 4 | 1629 | 2.40 | 1630 | 2.48 | 1758 | 10.51 | 1644 | 3.36 |
| 124 | | 146 | 1683 | 4 | 1749 | 3.95 | 1761 | 4.63 | 1880 | 11.69 | 1739 | 3.33 |
| 125 | | 153 | 1670 | 3 | 1712 | 2.53 | 1713 | 2.55 | 1826 | 9.33 | 1704 | 2.03 |
| 126 | | 155 | 1806 | 3 | 1872 | 3.65 | 1866 | 3.32 | 1995 | 10.48 | 1872 | 3.65 |
| 127 | 3 | 6 | 360 | 3 | 322 | -10.68 | 317 | -11.86 | 351 | -2.61 | 336 | -6.67 |
| 128 | | 7 | 376 | 3 | 334 | -11.06 | 328 | -12.77 | 359 | -4.52 | 346 | -7.87 |
| 129 | | 8 | 395 | 3 | 357 | -9.68 | 356 | -9.76 | 373 | -5.62 | 362 | -8.28 |
| 130 | | 10 | 441 | 3 | 401 | -9.07 | 397 | -10.04 | 422 | -4.27 | 411 | -6.76 |
| 131 | | 11 | 494 | 2 | 471 | -4.65 | 466 | -5.63 | 477 | -3.35 | 466 | -5.69 |
| 132 | | 20 | 494 | 2 | 469 | -5.12 | 465 | -5.90 | 485 | -1.72 | 467 | -5.49 |
| 133 | | 23 | 618 | 3 | 594 | -3.93 | 588 | -4.90 | 609 | -1.42 | 594 | -3.91 |
| 134 | | 30 | 513 | 3 | 499 | -2.68 | 490 | -4.39 | 516 | 0.67 | 490 | -4.45 |
| 135 | | 31 | 523 | 3 | 490 | -6.32 | 486 | -7.02 | 525 | 0.39 | 499 | -4.59 |
| 136 | | 34 | 608 | 4 | 579 | -4.69 | 583 | -4.06 | 598 | -1.72 | 575 | -5.35 |
| 137 | | 46 | 629 | 2 | 595 | -5.34 | 591 | -6.00 | 645 | 2.60 | 616 | -2.11 |
| 138 | | 59 | 648 | 2 | 616 | -4.89 | 609 | -5.96 | 665 | 2.59 | 628 | -3.15 |
| 139 | | 76 | 753 | 3 | 705 | -6.39 | 697 | -7.37 | 763 | 1.33 | 721 | -4.26 |
| 140 | | 77 | 761 | 2 | 743 | -2.36 | 749 | -1.55 | 786 | 3.23 | 744 | -2.23 |
| 141 | | 80 | 820 | 4 | 822 | 0.24 | 823 | 0.32 | 841 | 2.54 | 800 | -2.43 |
| 142 | | 81 | 894 | 4 | 881 | -1.42 | 872 | -2.48 | 911 | 1.93 | 873 | -2.38 |
| 143 | | 90 | 723 | 2 | 692 | -4.27 | 682 | -5.61 | 751 | 3.94 | 697 | -3.56 |
| 144 | | 91 | 760 | 3 | 734 | -3.43 | 721 | -5.09 | 794 | 4.49 | 742 | -2.37 |
| 145 | | 94 | 827 | 3 | 815 | -1.47 | 823 | -0.53 | 850 | 2.80 | 806 | -2.54 |
| 146 | | 96 | 850 | 3 | 815 | -4.14 | 804 | -5.44 | 879 | 3.47 | 831 | -2.21 |
| 147 | | 110 | 849 | 3 | 822 | -3.15 | 824 | -2.91 | 881 | 3.76 | 821 | -3.25 |
| 148 | | 115 | 949 | 3 | 914 | -3.72 | 915 | -3.55 | 979 | 3.15 | 926 | -2.45 |
| 149 | | 126 | 832 | 2 | 804 | -3.35 | 808 | -2.93 | 878 | 5.52 | 807 | -2.95 |
| 150 | | 127 | 859 | 2 | 818 | -4.76 | 804 | -6.41 | 898 | 4.55 | 828 | -3.62 |
| 151 | | 146 | 922 | 3 | 887 | -3.84 | 885 | -4.02 | 990 | 7.37 | 900 | -2.33 |
| 152 | | 153 | 1033 | 3 | 1018 | -1.49 | 1021 | -1.15 | 1094 | 5.91 | 1019 | -1.31 |
| 153 | | 155 | 1171 | 4 | 1152 | -1.59 | 1150 | -1.80 | 1219 | 4.11 | 1150 | -1.81 |
| 154 | 4 | 1 | 172 | 4 | 153 | -11.25 | 154 | -10.74 | 156 | -9.21 | 162 | -5.62 |

## Table 10.4 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 | | | | SCALE 4.4a | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | "source vector by unit" table | | "total fissions" table | | "source vector by unit" table | | "total fissions" table | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 155 | | 2 | 197 | 4 | 189 | -4.03 | 188 | -4.49 | 179 | -8.94 | 189 | -3.99 |
| 156 | | 3 | 209 | 4 | 209 | -0.23 | 207 | -0.99 | 192 | -7.91 | 209 | -0.03 |
| 157 | | 4 | 217 | 4 | 211 | -2.75 | 208 | -4.34 | 196 | -9.57 | 210 | -3.30 |
| 158 | | 5 | 224 | 3 | 214 | -4.38 | 210 | -6.27 | 193 | -13.73 | 208 | -7.05 |
| 159 | | 6 | 230 | 3 | 208 | -9.57 | 204 | -11.28 | 193 | -16.30 | 211 | -8.45 |
| 160 | | 7 | 221 | 4 | 205 | -7.04 | 204 | -7.56 | 193 | -12.72 | 215 | -2.69 |
| 161 | | 8 | 222 | 3 | 209 | -5.95 | 208 | -6.38 | 190 | -14.31 | 211 | -5.00 |
| 162 | | 9 | 218 | 4 | 205 | -5.83 | 203 | -6.77 | 177 | -18.81 | 200 | -8.30 |
| 163 | | 10 | 209 | 4 | 187 | -10.40 | 183 | -12.49 | 167 | -20.30 | 190 | -9.07 |
| 164 | | 11 | 184 | 4 | 160 | -12.85 | 156 | -15.49 | 146 | -20.90 | 169 | -8.32 |
| 165 | | 12 | 202 | 4 | 186 | -7.70 | 184 | -8.97 | 192 | -5.02 | 199 | -1.53 |
| 166 | | 13 | 235 | 3 | 232 | -1.48 | 230 | -2.14 | 219 | -6.68 | 229 | -2.59 |
| 167 | | 15 | 267 | 3 | 264 | -1.03 | 264 | -1.09 | 250 | -6.53 | 264 | -1.23 |
| 168 | | 17 | 276 | 2 | 270 | -2.31 | 267 | -3.10 | 256 | -7.07 | 281 | 1.72 |
| 169 | | 19 | 273 | 2 | 262 | -3.86 | 256 | -6.27 | 245 | -10.14 | 275 | 0.62 |
| 170 | | 21 | 263 | 2 | 261 | -0.92 | 261 | -0.93 | 225 | -14.42 | 256 | -2.58 |
| 171 | | 23 | 214 | 5 | 213 | -0.33 | 211 | -1.39 | 174 | -18.55 | 203 | -5.22 |
| 172 | | 30 | 316 | 3 | 337 | 6.79 | 340 | 7.53 | 295 | -6.73 | 318 | 0.63 |
| 173 | | 35 | 271 | 4 | 261 | -3.53 | 259 | -4.39 | 234 | -13.67 | 269 | -0.65 |
| 174 | | 36 | 240 | 4 | 232 | -3.37 | 232 | -3.39 | 197 | -17.80 | 226 | -5.67 |
| 175 | | 37 | 241 | 4 | 235 | -2.57 | 230 | -4.54 | 233 | -3.41 | 239 | -0.66 |
| 176 | | 42 | 357 | 2 | 364 | 1.96 | 357 | 0.07 | 334 | -6.57 | 354 | -0.80 |
| 177 | | 44 | 360 | 2 | 365 | 1.29 | 363 | 0.90 | 345 | -4.15 | 374 | 3.99 |
| 178 | | 46 | 359 | 2 | 366 | 2.06 | 365 | 1.76 | 328 | -8.62 | 366 | 2.08 |
| 179 | | 47 | 350 | 3 | 334 | -4.64 | 330 | -5.80 | 314 | -10.35 | 356 | 1.75 |
| 180 | | 50 | 265 | 5 | 260 | -1.91 | 258 | -2.69 | 218 | -17.61 | 253 | -4.39 |
| 181 | | 60 | 407 | 2 | 397 | -2.34 | 388 | -4.66 | 374 | -8.06 | 416 | 2.17 |
| 182 | | 62 | 391 | 2 | 391 | 0.11 | 388 | -0.83 | 335 | -14.25 | 384 | -1.73 |
| 183 | | 63 | 364 | 3 | 350 | -3.71 | 352 | -3.32 | 308 | -15.26 | 356 | -2.10 |
| 184 | | 64 | 338 | 3 | 326 | -3.61 | 325 | -3.72 | 287 | -15.03 | 334 | -1.05 |
| 185 | | 65 | 288 | 5 | 276 | -4.06 | 272 | -5.42 | 234 | -18.70 | 275 | -4.59 |
| 186 | | 66 | 287 | 4 | 276 | -3.77 | 278 | -3.24 | 283 | -1.38 | 285 | -0.73 |
| 187 | | 71 | 431 | 2 | 426 | -1.07 | 422 | -2.19 | 416 | -3.38 | 430 | -0.32 |
| 188 | | 75 | 444 | 3 | 431 | -2.93 | 424 | -4.54 | 407 | -8.29 | 447 | 0.58 |
| 189 | | 77 | 438 | 3 | 425 | -3.06 | 423 | -3.45 | 386 | -11.86 | 435 | -0.67 |
| 190 | | 81 | 319 | 5 | 306 | -4.16 | 296 | -7.34 | 255 | -20.06 | 301 | -5.76 |
| 191 | | 85 | 433 | 3 | 432 | -0.26 | 430 | -0.75 | 434 | 0.15 | 440 | 1.53 |
| 192 | | 88 | 481 | 3 | 470 | -2.33 | 468 | -2.60 | 460 | -4.28 | 478 | -0.53 |
| 193 | | 90 | 489 | 3 | 478 | -2.29 | 479 | -2.10 | 453 | -7.44 | 481 | -1.59 |
| 194 | | 91 | 495 | 2 | 487 | -1.65 | 485 | -2.04 | 457 | -7.76 | 492 | -0.68 |
| 195 | | 92 | 489 | 3 | 472 | -3.56 | 470 | -3.83 | 444 | -9.23 | 487 | -0.34 |
| 196 | | 94 | 470 | 3 | 464 | -1.27 | 465 | -1.07 | 427 | -9.06 | 480 | 2.18 |
| 197 | | 97 | 400 | 4 | 394 | -1.55 | 391 | -2.15 | 334 | -16.61 | 387 | -3.19 |
| 198 | | 98 | 353 | 5 | 323 | -8.56 | 321 | -9.06 | 284 | -19.51 | 337 | -4.57 |
| 199 | | 99 | 340 | 4 | 314 | -7.68 | 310 | -8.72 | 330 | -2.81 | 328 | -3.41 |
| 200 | | 101 | 432 | 2 | 435 | 0.66 | 433 | 0.22 | 427 | -1.10 | 429 | -0.72 |
| 201 | | 111 | 528 | 3 | 523 | -0.87 | 520 | -1.50 | 475 | -9.95 | 527 | -0.14 |
| 202 | | 113 | 505 | 3 | 505 | 0.08 | 499 | -1.14 | 427 | -15.42 | 492 | -2.55 |
| 203 | | 114 | 474 | 3 | 456 | -3.83 | 450 | -4.97 | 406 | -14.38 | 469 | -1.01 |
| 204 | | 116 | 379 | 5 | 354 | -6.59 | 350 | -7.75 | 313 | -17.34 | 371 | -2.04 |
| 205 | | 131 | 565 | 3 | 557 | -1.42 | 555 | -1.74 | 494 | -12.49 | 557 | -1.37 |
| 206 | | 134 | 477 | 3 | 464 | -2.83 | 463 | -2.89 | 396 | -17.02 | 463 | -2.88 |

## Table 10.4 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 | | | | SCALE 4.4a | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | "source vector by unit" table | | "total fissions" table | | "source vector by unit" table | | "total fissions" table | |
| | | | | | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] | $W_{calc}$ | Dev. [%] |
| 207 | | 135 | 428 | 4 | 385 | -10.10 | 380 | -11.30 | 332 | -22.39 | 397 | -7.14 |
| 208 | | 136 | 413 | 4 | 381 | -7.77 | 382 | -7.54 | 394 | -4.56 | 390 | -5.64 |
| 209 | | 146 | 653 | 3 | 630 | -3.57 | 630 | -3.56 | 609 | -6.69 | 642 | -1.74 |
| 210 | | 148 | 639 | 2 | 627 | -1.87 | 615 | -3.74 | 585 | -8.50 | 631 | -1.28 |
| 211 | | 149 | 631 | 2 | 616 | -2.40 | 605 | -4.15 | 567 | -10.09 | 624 | -1.10 |
| 212 | | 151 | 613 | 3 | 608 | -0.86 | 604 | -1.50 | 532 | -13.17 | 595 | -2.86 |
| 213 | | 155 | 479 | 4 | 448 | -6.45 | 447 | -6.63 | 381 | -20.42 | 454 | -5.21 |
| 214 | | 156 | 494 | 3 | 443 | -10.41 | 438 | -11.28 | 465 | -5.89 | 456 | -7.67 |
| 215 | | 158 | 537 | 3 | 525 | -2.23 | 518 | -3.55 | 545 | 1.45 | 535 | -0.34 |
| 216 | | 161 | 615 | 3 | 614 | -0.09 | 614 | -0.13 | 620 | 0.80 | 617 | 0.31 |
| 217 | | 162 | 642 | 3 | 612 | -4.68 | 609 | -5.16 | 634 | -1.27 | 632 | -1.59 |
| 218 | | 164 | 660 | 3 | 651 | -1.41 | 651 | -1.42 | 646 | -2.14 | 656 | -0.62 |
| 219 | | 165 | 690 | 3 | 647 | -6.18 | 647 | -6.23 | 656 | -4.91 | 674 | -2.31 |
| 220 | | 167 | 699 | 2 | 689 | -1.49 | 685 | -1.98 | 659 | -5.74 | 695 | -0.52 |
| 221 | | 171 | 661 | 3 | 656 | -0.71 | 655 | -0.96 | 592 | -10.43 | 659 | -0.37 |
| 222 | | 173 | 634 | 3 | 622 | -1.83 | 619 | -2.36 | 545 | -14.00 | 622 | -1.94 |
| 223 | | 174 | 615 | 2 | 592 | -3.74 | 585 | -4.86 | 518 | -15.82 | 604 | -1.76 |
| 224 | | 175 | 598 | 2 | 569 | -4.87 | 563 | -5.90 | 483 | -19.29 | 572 | -4.34 |
| 225 | | 176 | 568 | 3 | 543 | -4.40 | 537 | -5.38 | 449 | -20.92 | 537 | -5.45 |
| 226 | | 177 | 601 | 4 | 569 | -5.30 | 566 | -5.84 | 595 | -1.02 | 584 | -2.78 |
| 227 | | 181 | 660 | 3 | 633 | -4.07 | 630 | -4.53 | 658 | -0.28 | 651 | -1.38 |
| 228 | | 184 | 704 | 3 | 680 | -3.42 | 674 | -4.32 | 688 | -2.27 | 692 | -1.74 |
| 229 | | 190 | 734 | 3 | 694 | -5.51 | 687 | -6.41 | 666 | -9.32 | 721 | -1.74 |
| 230 | | 193 | 684 | 3 | 688 | 0.62 | 690 | 0.90 | 618 | -9.61 | 695 | 1.59 |
| 231 | | 196 | 685 | 3 | 672 | -1.92 | 673 | -1.76 | 566 | -17.36 | 671 | -2.01 |
| 232 | | 206 | 747 | 3 | 771 | 3.20 | 768 | 2.87 | 736 | -1.48 | 752 | 0.70 |
| 233 | | 209 | 754 | 3 | 734 | -2.69 | 730 | -3.24 | 716 | -5.02 | 769 | 1.98 |
| 234 | | 212 | 740 | 4 | 743 | 0.45 | 744 | 0.51 | 670 | -9.49 | 745 | 0.74 |
| 235 | | 215 | 760 | 4 | 761 | 0.19 | 765 | 0.71 | 661 | -13.01 | 766 | 0.74 |
| 236 | | 230 | 804 | 3 | 828 | 3.05 | 828 | 2.93 | 728 | -9.48 | 793 | -1.31 |
| 237 | | 232 | 824 | 4 | 806 | -2.20 | 805 | -2.32 | 712 | -13.59 | 803 | -2.55 |
| 238 | | 233 | 842 | 4 | 832 | -1.19 | 826 | -1.91 | 740 | -12.09 | 847 | 0.56 |
| 239 | | 238 | 804 | 3 | 819 | 1.82 | 821 | 2.11 | 832 | 3.49 | 820 | 1.96 |
| 240 | | 245 | 862 | 3 | 855 | -0.85 | 857 | -0.57 | 807 | -6.35 | 853 | -1.02 |
| 241 | | 251 | 869 | 4 | 866 | -0.32 | 861 | -0.90 | 889 | 2.30 | 858 | -1.25 |
| 242 | | 252 | 829 | 2 | 842 | 1.59 | 851 | 2.69 | 867 | 4.59 | 835 | 0.76 |
| 243 | | 255 | 875 | 2 | 869 | -0.68 | 862 | -1.49 | 886 | 1.24 | 869 | -0.72 |
| 244 | | 259 | 914 | 3 | 912 | -0.24 | 897 | -1.83 | 896 | -1.94 | 905 | -0.94 |
| 245 | | 261 | 919 | 3 | 897 | -2.35 | 899 | -2.19 | 888 | -3.38 | 922 | 0.29 |
| 246 | | 263 | 914 | 3 | 923 | 1.01 | 918 | 0.41 | 866 | -5.28 | 914 | -0.05 |
| 247 | | 273 | 956 | 3 | 965 | 0.94 | 965 | 0.98 | 946 | -1.07 | 943 | -1.38 |
| 248 | | 276 | 963 | 2 | 975 | 1.28 | 967 | 0.41 | 942 | -2.22 | 968 | 0.53 |
| 249 | | 280 | 962 | 2 | 986 | 2.46 | 981 | 1.97 | 901 | -6.37 | 962 | 0.04 |
| 250 | | 281 | 1023 | 3 | 1023 | 0.00 | 1012 | -1.07 | 940 | -8.12 | 1020 | -0.27 |
| 251 | | 292 | 1036 | 3 | 1062 | 2.47 | 1056 | 1.89 | 979 | -5.51 | 1011 | -2.38 |
| 252 | | 293 | 1017 | 3 | 1006 | -1.08 | 1008 | -0.89 | 971 | -4.54 | 1022 | 0.48 |
| 253 | | 297 | 1010 | 3 | 1015 | 0.52 | 1012 | 0.21 | 1049 | 3.84 | 1004 | -0.60 |
| 254 | | 304 | 1054 | 3 | 1028 | -2.43 | 1027 | -2.58 | 1053 | -0.09 | 1061 | 0.67 |
| 255 | | 308 | 1137 | 4 | 1153 | 1.38 | 1149 | 1.06 | 1083 | -4.71 | 1139 | 0.20 |
| 256 | | 312 | 1092 | 3 | 1104 | 1.12 | 1097 | 0.49 | 1122 | 2.77 | 1080 | -1.12 |
| 257 | | 315 | 1107 | 3 | 1120 | 1.20 | 1115 | 0.76 | 1118 | 0.98 | 1116 | 0.78 |
| 258 | | 319 | 1151 | 3 | 1170 | 1.61 | 1156 | 0.47 | 1127 | -2.06 | 1161 | 0.89 |

## Table 10.4 (Contd)

| Calculation point | No. of FA | Fuel pin position | $W_{exp}$ | Unc. [%] | SCALE 4.3 "source vector by unit" table $W_{calc}$ | Dev. [%] | SCALE 4.3 "total fissions" table $W_{calc}$ | Dev. [%] | SCALE 4.4a "source vector by unit" table $W_{calc}$ | Dev. [%] | SCALE 4.4a "total fissions" table $W_{calc}$ | Dev. [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 259 |  | 326 | 1242 | 4 | 1238 | -0.36 | 1238 | -0.29 | 1240 | -0.18 | 1216 | -2.11 |
| 260 |  | 330 | 1256 | 3 | 1278 | 1.76 | 1275 | 1.54 | 1251 | -0.38 | 1274 | 1.41 |
| **MAX. DEV.** |  |  |  |  |  | **12.85** |  | **15.49** |  | **24.46** |  | **9.07** |
| **STAND. DEV** |  |  |  |  |  | **3.84** |  | **4.15** |  | **10.17** |  | **3.22** |
| **Correlation coefficient** |  |  |  |  | 0.9985 |  | 0.9988 |  | 0.9944 |  | 0.9986 |  |

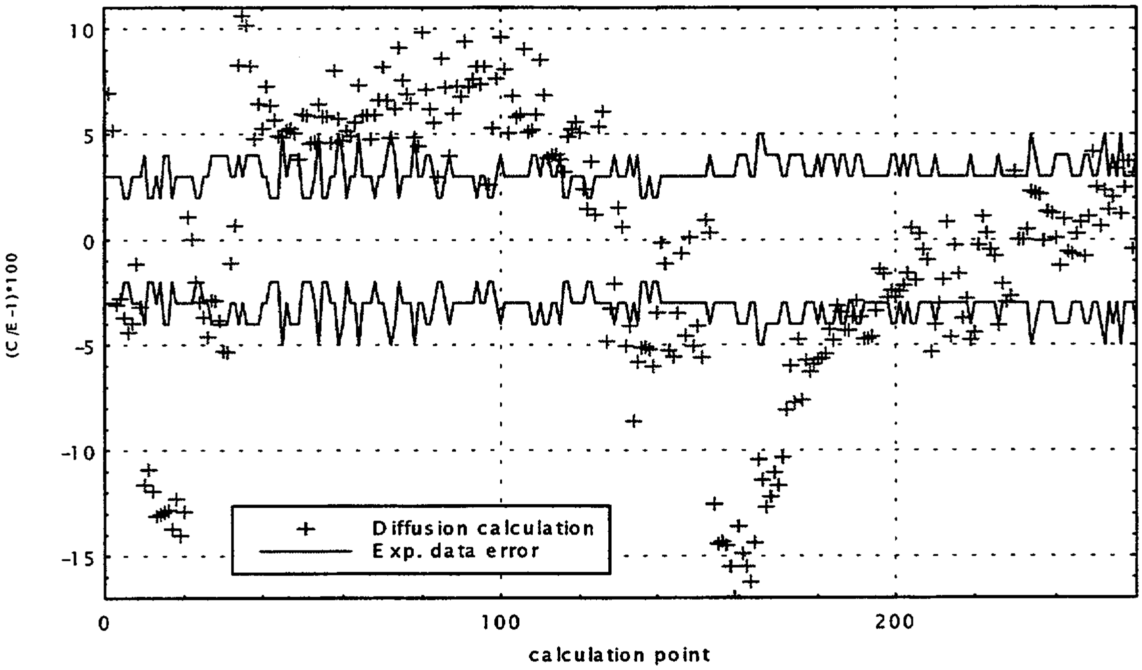


Figure 10.1 Calculation/Experimental Results for Diffusion Calculation

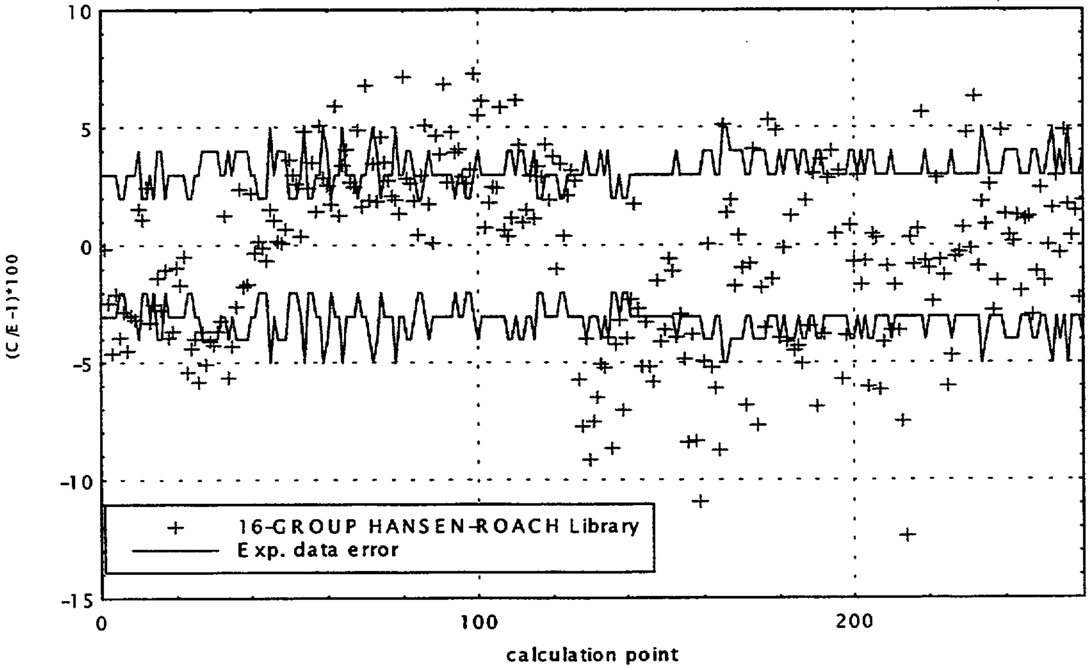


Figure 10.2 Calculation/Experimental Results for 16-GROUP HANSEN-ROACH Library ("source vector by unit" table of SCALE 4.3)

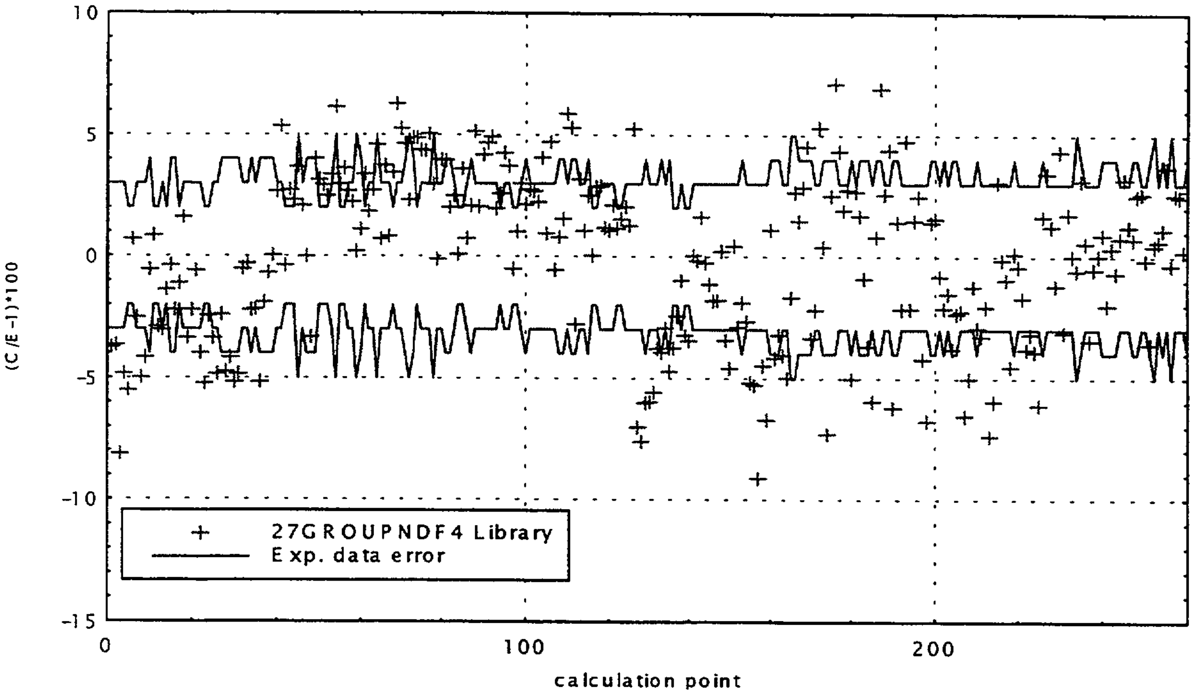


Figure 10.3 Calculation/Experimental Results for 27GROUPNDF4 Library ("source vector by unit" table of SCALE 4.3)

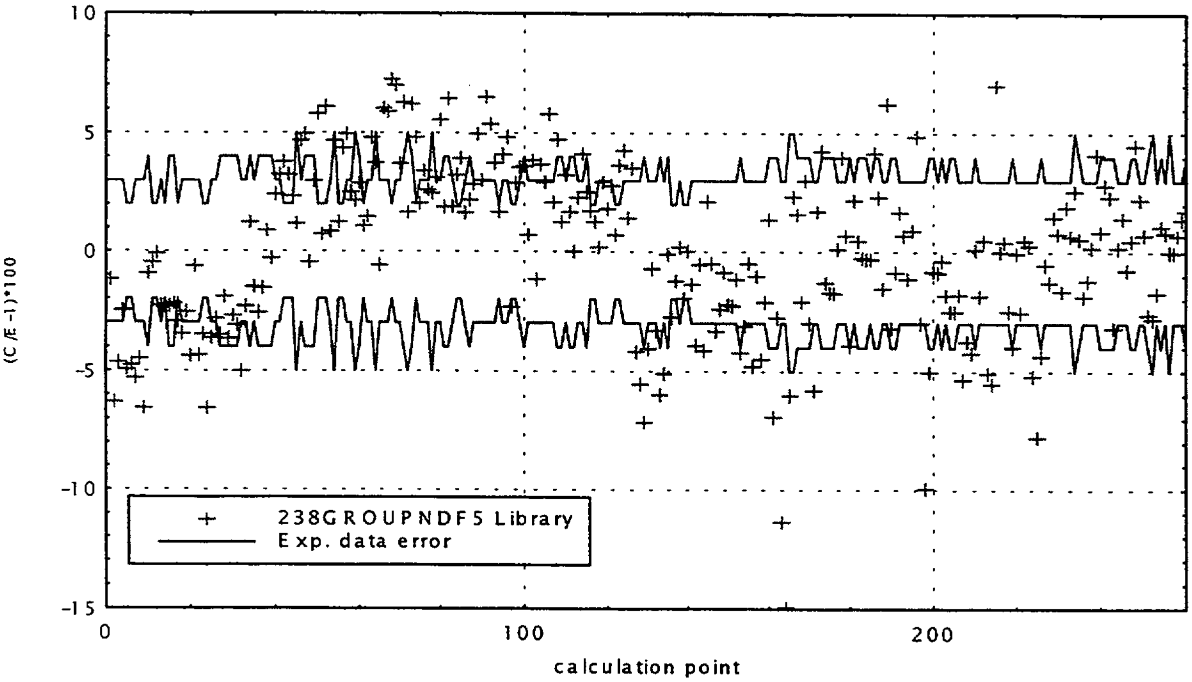


Figure 10.4 Calculation/Experimental Results for 238GROUPNDF5 Library, ("source vector by unit" table of SCALE 4.3)

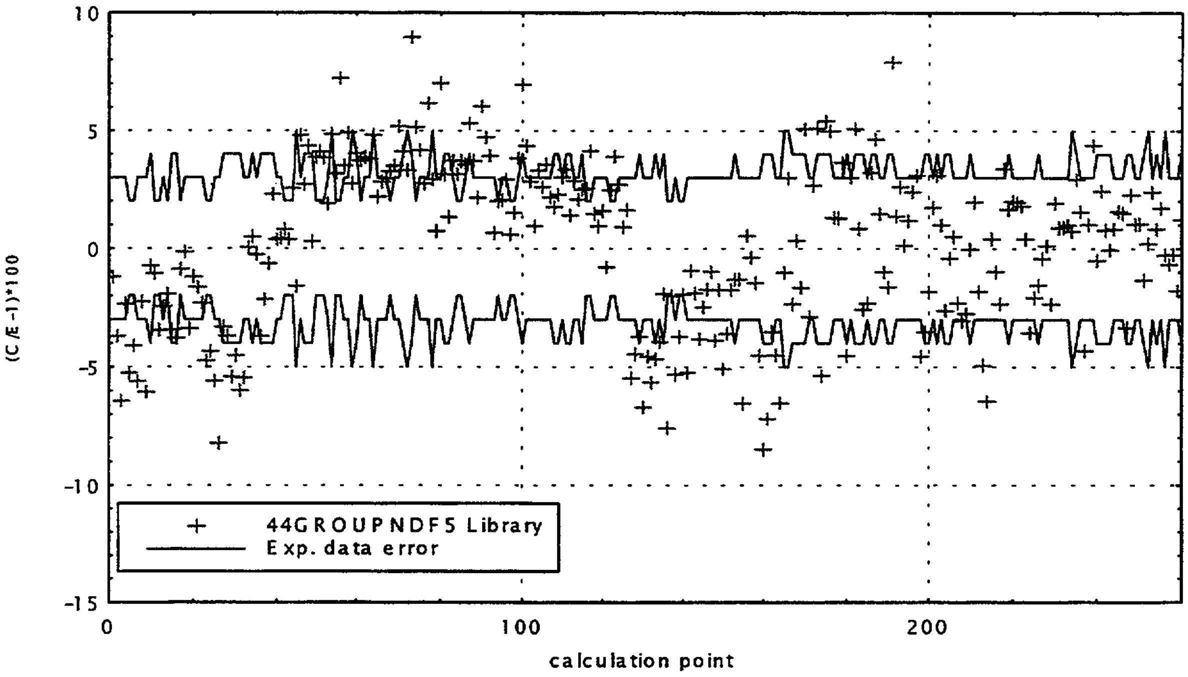


Figure 10.5 Calculation/Experimental Results for 44GROUPNDF5 Library, ("source vector by unit" table of SCALE 4.3)

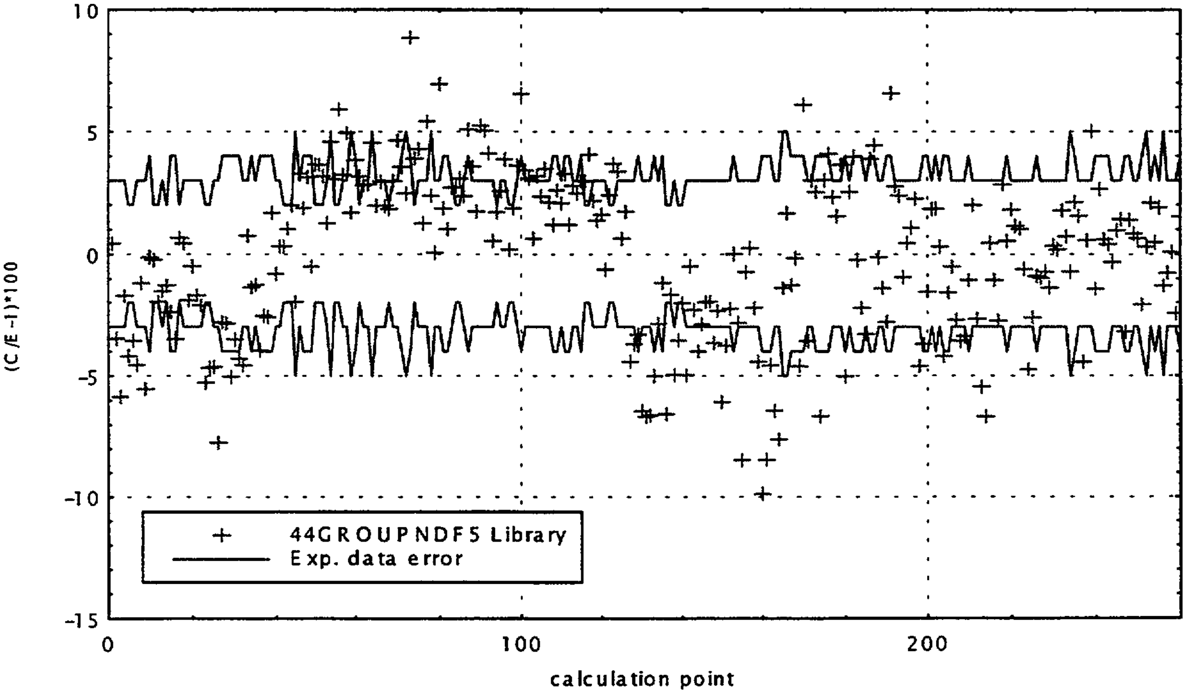


Figure 10.6 Calculation/Experimental Results for 44GROUPNDF5 Library, ("total fissions" table of SCALE 4.3)

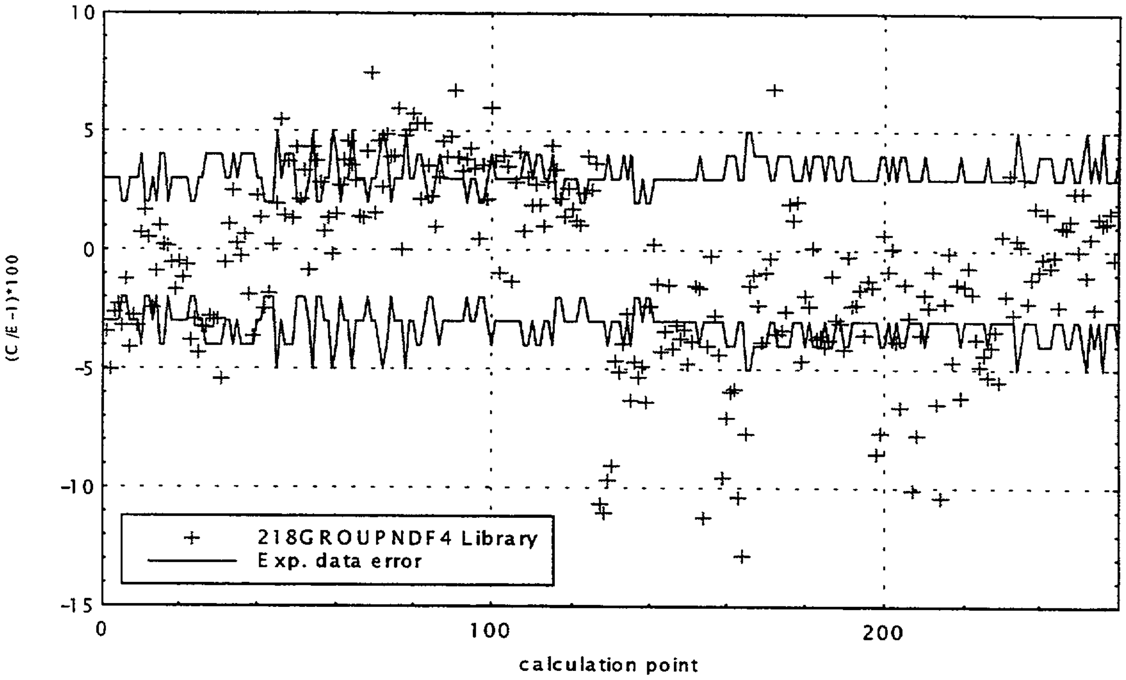


**Figure 10.7 Calculation/Experimental Results for 218GROUPNDF4 Library, ("source vector by unit" table of SCALE 4.3)**

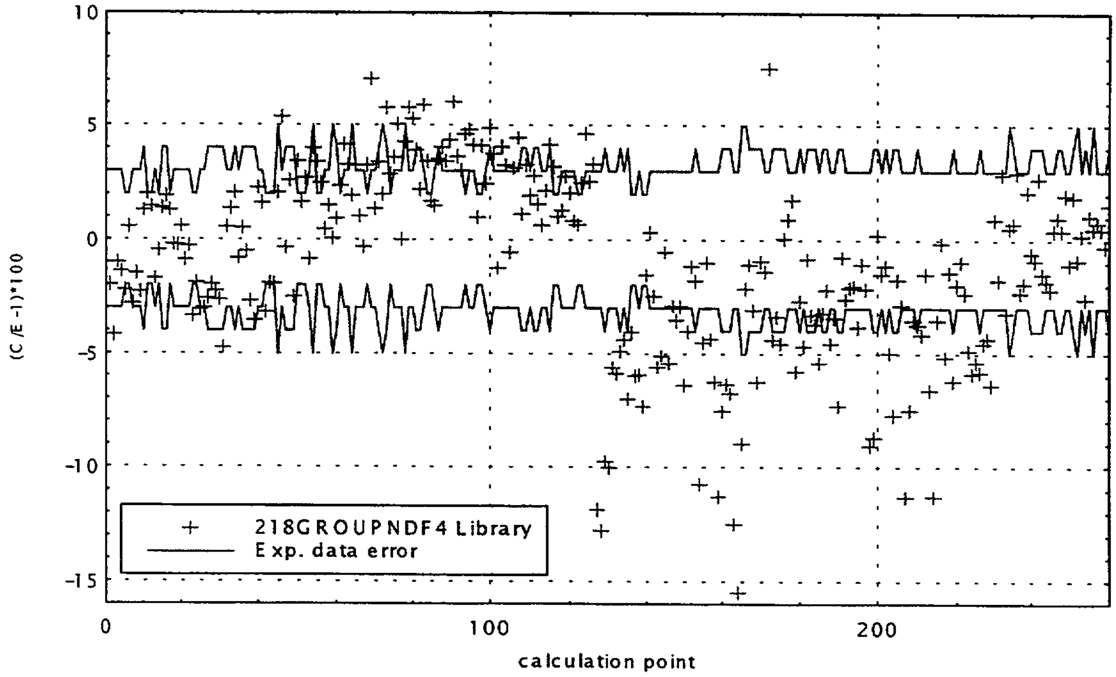


**Figure 10.8 Calculation/Experimental Results for 218GROUPNDF4 Library, ("total fissions" table of SCALE 4.3)**

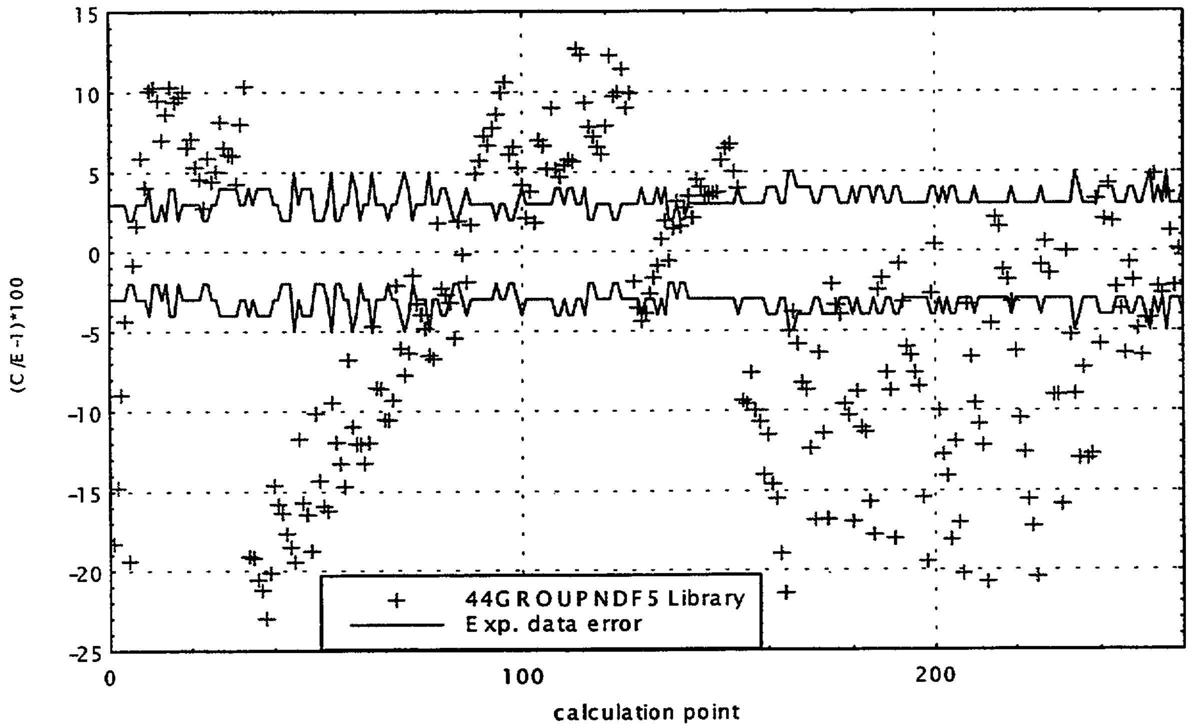


Figure 10.9 Calculation/Experimental Results for 44GROUPNDF5 Library, ("source vector by unit table of SCALE 4.4a)

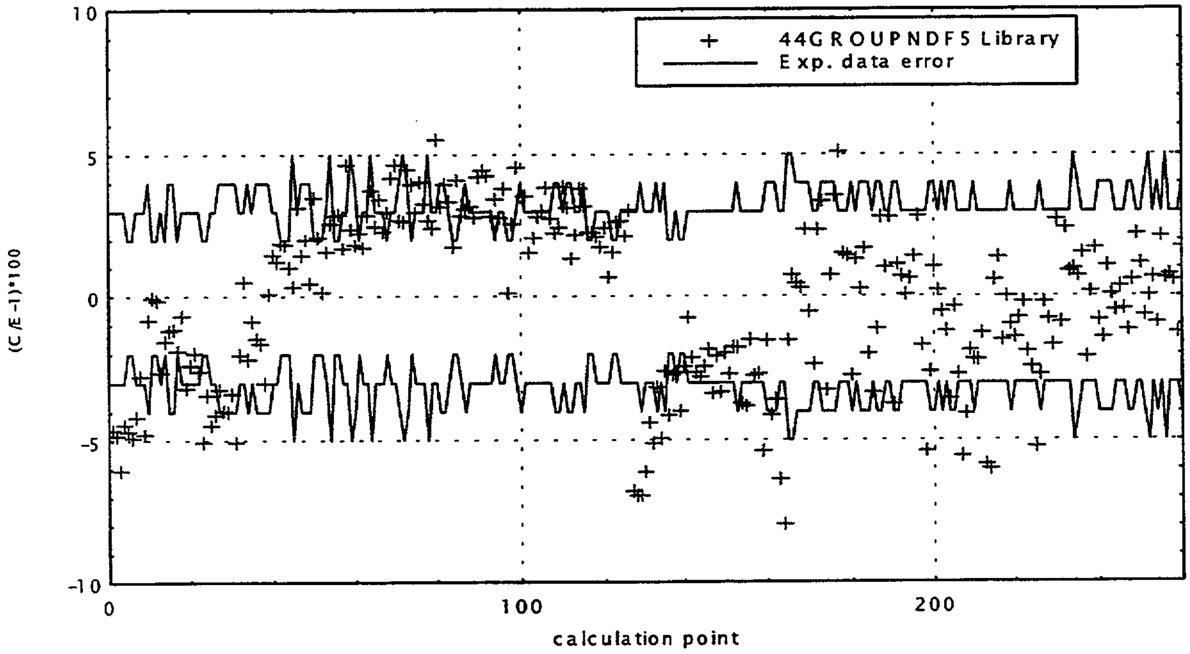


Figure 10.10 Calculation/Experimental Results for 44GROUPNDF5 Library, ("total fissions" table of SCALE 4.4a)

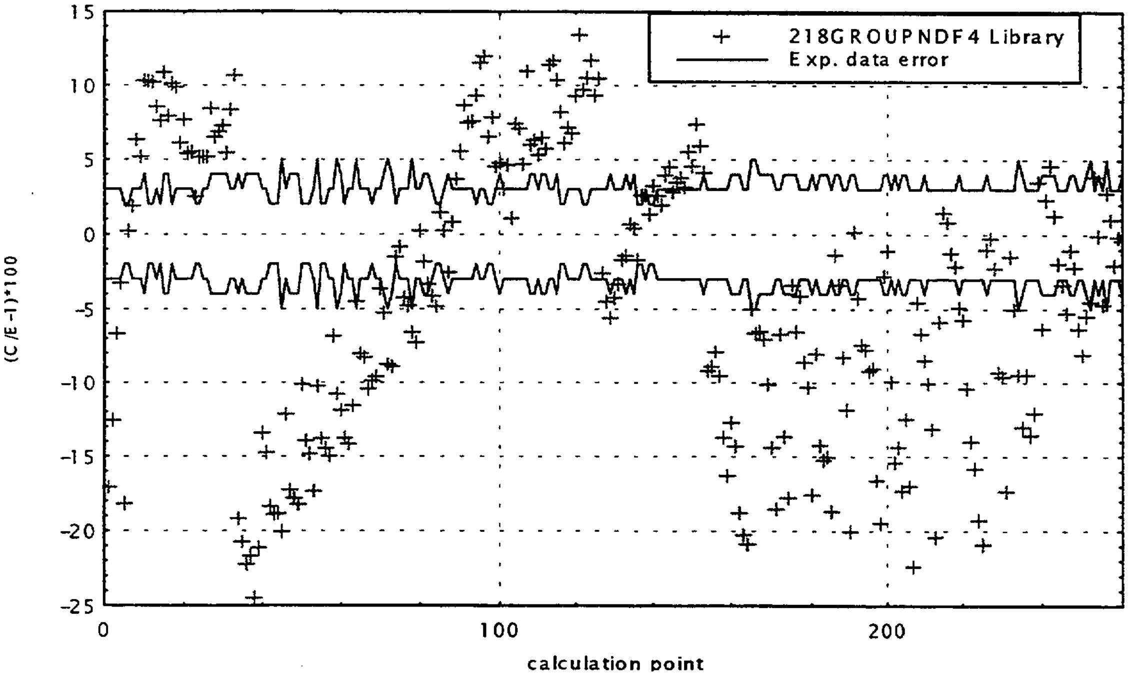


**Figure 10.11 Calculation/Experimental Results for 218GROUPNDF4 Library, ("source vector by unit" table of SCALE 4.4a)**

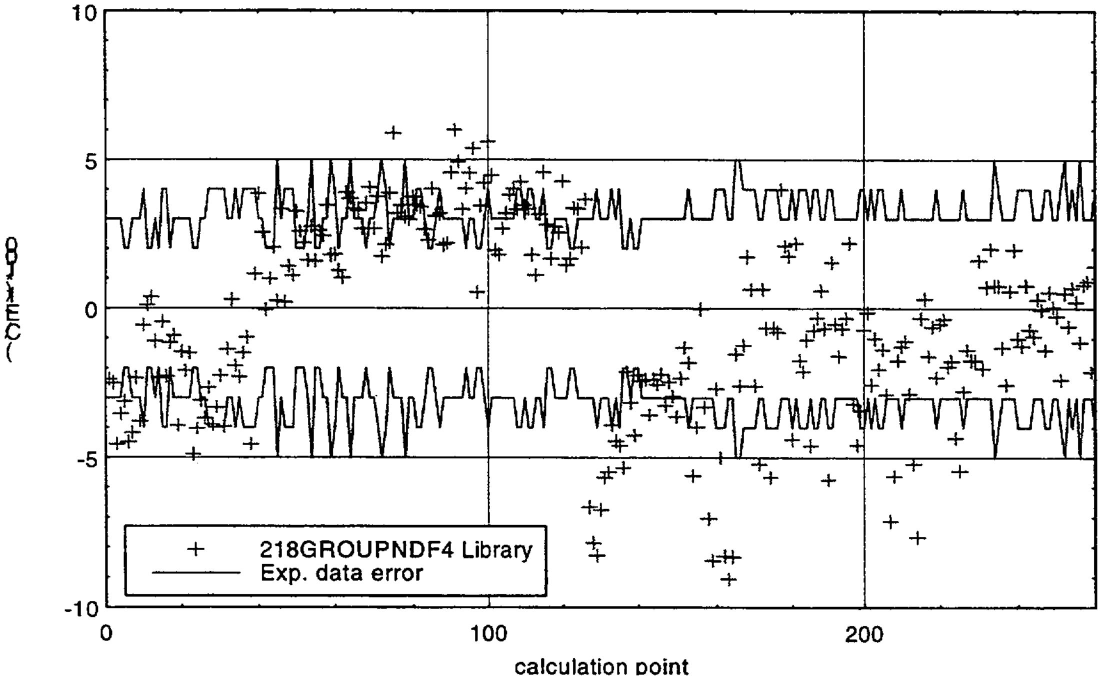


**Figure 10.12 Calculation/Experimental Results for 218GROUPNDF4 Library, ("total fissions" table of SCALE 4.4a)**

# 11 Summary

The detailed analysis of a number of critical experiments showed good applicability of the SCALE 4.3 and SCALE 4.4a code package for modeling fuel systems of the RBMK reactor containing fuel of different enrichment and different moderating media (i.e., water, graphite). For expert assessments, the 44GROUPNDF5 library is recommended. All the calculated $k_{eff}$ values obtained with the 44GROUPNDF5 library were slightly higher than experimental ones.

Two methods for statistical determination of calculation biases and USL were applied: 1) a 95% confidence band for a single future calculation with an administrative subcritical margin and 2) a lower tolerance band based on 95% confidence band on 99.5% of all future calculations. The highest values were obtained for the 218GROUPNDF4 and 44GROUPNDF5 libraries. This result is expected because of the values' higher correlation to experimental data.

Detailed analysis of criticality experiments conducted previously at the Czech Republic's LR-0 facility, followed by measurement of the relative power distribution, demonstrated good applicability of the SCALE code package to solve such complex tasks for fuel systems of VVER-1000 reactors. During this analysis, a specific error in KENO-VI in SCALE 4.3 and 4.4a was identified with respect to multiple uses of the same unit number when placing hexagonal arrays of fuel rods in a larger hexagonal array.

Results with much higher accuracy were obtained by Monte Carlo calculations as compared to similar diffusion theory calculations. These results confirm the possibility of using Monte Carlo programs for testing some aspects of diffusion theory programs when appropriate experimental material is unavailable.

Because very high correlation (starting from 0.998) between calculated and experimental results was observed in all the calculations, it is difficult to single out any one library of SCALE as the most applicable. However, based on the overall results for multiplication factor modeling along with the relative power distribution, the 44GROUPNDF5 library was selected. This conclusion is logical, because this library was generated for LWR fuel assemblies, which are very similar neutronically to VVER fuel assemblies.

Based on the studies completed and described here, we concluded that SCALE 4.3 (module CSAS26) along with its standard libraries 27GROUPNDF4, 44GROUPNDF5, 218GROUPNDF4, and 238GROUPNDF5 are valid for determining criticality of the fuel management systems for VVER and RBMK reactors. All the libraries provide for good coincidence between the calculated and experimental results. However, results of the completed testing recommend library 44GROUPNDF5 as the most suitable for such calculation.

# 12 References

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# Appendix A

## SCALE Input File Listing for RBMK Critical Facility Calculation

# Appendix A

# SCALE Input File Listing for RBMK Critical Facility Calculation

## A.1 A1-0

```
=CSAS26
RBMK CRITICAL EXPERIMENTS , A1-0
27GROUPNDF4   LATTICECELL
UO2   1 DEN=10.045061 1.0 293 92234 .02 92235 2.00055 92236 .1  92238 97.87945 END
B4C         2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O         3  1.0  293 END
ARBM-GR280-B 1.69 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3  22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 . 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 10.045061 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55
13027 9.09 20000 9.09 42000 4.55 15031 9.09 1 0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=500 NPG=1000 NSK=50 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
CYLINDER   2  0.585 173 -187.5
CYLINDER   3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
```

```
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER  1  0.325 174 -191
CYLINDER  2  0.75 174 -191
CYLINDER  3 4.  205.8 -204.2
CYLINDER  4 4.4 205.8 -204.2
CYLINDER  5 4.45 205.8 -204.2
CYLINDER  6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER  7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER  8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER  9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER  23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID    24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  25  3.94   174.8  174
CYLINDER  26  3.94  -191   -192.
CYLINDER  27  3.8    171    170.63
CYLINDER  28  3.8    135    134.63
CYLINDER  29  3.8     99     98.63
CYLINDER  30  3.8     63     62.63
CYLINDER  31  3.8     27     26.63
CYLINDER  32  3.8     -9     -9.37
CYLINDER  33  3.8    -45    -45.37
CYLINDER  34  3.8    -81    -81.37
CYLINDER  35  3.8   -117   -117.37
CYLINDER  36  3.8   -153   -153.37
CYLINDER  37  4.0  205.8   174.8
MEDIA 3 1 1
MEDIA 8 1 2 -1
MEDIA 3 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29 -
30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
```

```
MEDIA  0 1 5 -4
HOLE  1  6   ORIGIN x=1.6
HOLE  1  7   ORIGIN x=0.8      y=1.38564
HOLE  1  8   ORIGIN x=-0.8     y=1.38564
HOLE  1  9   ORIGIN x=-1.6
HOLE  1  10  ORIGIN x=-0.8     y=-1.38564
HOLE  1  11  ORIGIN x=0.8      y=-1.38564
HOLE  1  12  ORIGIN x=2.99437  y=0.80234
HOLE  1  13  ORIGIN x=2.19203  y=2.19203
HOLE  1  14  ORIGIN x=0.80234  y=2.99437
HOLE  1  15  ORIGIN x=-0.80234 y=2.99437
HOLE  1  16  ORIGIN x=-2.19203 y=2.19203
HOLE  1  17  ORIGIN x=-2.99437 y=0.80234
HOLE  1  18  ORIGIN x=-2.99437 y=-0.80234
HOLE  1  19  ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20  ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21  ORIGIN x=0.80234  y=-2.99437
HOLE  1  22  ORIGIN x=2.19203  y=-2.19203
HOLE  1  23  ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER  1  2.3 151.8 -151.8
CYLINDER  2  2.5 151.8 -151.8
CYLINDER  3  2.5225  151.8 -151.8
CYLINDER  4  3.2825  151.8 -151.8
CYLINDER  5  3.3 151.8 -151.8
CYLINDER  6  3.5 151.8 -151.8
CYLINDER  7  3.5 55.6 48.1
CYLINDER  8  3.5 -48.1 -55.6
CYLINDER  9  3.5 -151.8 -157.8
```

```
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=125.6
HOLE  3   5                ORIGIN z=125.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
GLOBAL UNIT 6  COM=!CRIT STEND A1!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1  1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
```

```
FILL 96*4 5 5*4 5 12*4 4*2 14*4 5*2 13*4 5*2 13*4 4*2 31*4 5 5*4 5 113*4
END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
 END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A1, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!      UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.2 A1-1

```
=CSAS26
RBMK CRITICAL EXPERIMENTS , A1-1
27GROUPNDF4   LATTICECELL
UO2   1 DEN=10.045061 1.0 293 92234 .02 92235 2.00055 92236 .1  92238 97.87945 END
B4C           2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O           3  1.0  293 END
ARBM-GR280-B 1.69 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 10.045061 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027
9.09 20000 9.09 42000 4.55 15031 9.09 1 0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=500 NPG=1000 NSK=50 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
```

```
CYLINDER  2  0.585 173 -187.5
CYLINDER  3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER  1  0.325 174 -191
CYLINDER  2  0.75 174 -191
CYLINDER  3 4.  205.8 -204.2
CYLINDER  4 4.4 205.8 -204.2
CYLINDER  5 4.45 205.8 -204.2
CYLINDER  6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER  7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER  8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER  9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER  23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID    24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  25  3.94   174.8  174
CYLINDER  26  3.94  -191   -192.
CYLINDER  27  3.8    171    170.63
CYLINDER  28  3.8    135    134.63
CYLINDER  29  3.8     99     98.63
CYLINDER  30  3.8     63     62.63
CYLINDER  31  3.8     27     26.63
CYLINDER  32  3.8     -9     -9.37
CYLINDER  33  3.8    -45    -45.37
CYLINDER  34  3.8    -81    -81.37
CYLINDER  35  3.8   -117   -117.37
CYLINDER  36  3.8   -153   -153.37
```

```
CYLINDER 37 4.0 205.8  174.8
MEDIA 3 1 1
MEDIA 8 1 2 -1
MEDIA 3 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19  -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE 1  6   ORIGIN x=1.6
HOLE 1  7  ORIGIN x=0.8     y=1.38564
HOLE 1  8  ORIGIN x=-0.8    y=1.38564
HOLE 1  9  ORIGIN x=-1.6
HOLE 1  10  ORIGIN x=-0.8    y=-1.38564
HOLE 1  11  ORIGIN x=0.8     y=-1.38564
HOLE 1  12  ORIGIN x=2.99437  y=0.80234
HOLE 1  13  ORIGIN x=2.19203  y=2.19203
HOLE 1  14  ORIGIN x=0.80234  y=2.99437
HOLE 1  15  ORIGIN x=-0.80234 y=2.99437
HOLE 1  16  ORIGIN x=-2.19203 y=2.19203
HOLE 1  17  ORIGIN x=-2.99437 y=0.80234
HOLE 1  18  ORIGIN x=-2.99437 y=-0.80234
HOLE 1  19  ORIGIN x=-2.19203 y=-2.19203
HOLE 1  20  ORIGIN x=-0.80234 y=-2.99437
HOLE 1  21  ORIGIN x=0.80234  y=-2.99437
HOLE 1  22  ORIGIN x=2.19203  y=-2.19203
HOLE 1  23  ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER  1  2.3 151.8 -151.8
CYLINDER  2  2.5 151.8 -151.8
```

```
CYLINDER  3  2.5225  151.8 -151.8
CYLINDER  4  3.2825  151.8 -151.8
CYLINDER  5  3.3 151.8 -151.8
CYLINDER  6  3.5 151.8 -151.8
CYLINDER  7  3.5 55.6 48.1
CYLINDER  8  3.5 -48.1 -55.6
CYLINDER  9  3.5 -151.8 -157.8
CYLINDER 10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=125.6
HOLE  3   5                ORIGIN z=125.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
GLOBAL UNIT 6  COM=!CRIT STEND A1!
```

```
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1 1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 96*4 4 5*4 4 12*4 4*2 14*4 5*2 13*4 5*2 13*4 4*2 31*4 4 5*4 4 113*4
END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
 END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A1, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!     UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.3 A1-2

```
=CSAS26    PARM=SIZE=1500000
RBMK CRITICAL EXPERIMENTS , A1-2
27GROUPNDF4   LATTICECELL
UO2   1 DEN=10.045061 1.0 293 92234 .02 92235 2.00055 . 92236 .1  92238 97.87945 END
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O          3  1.0  293 END
ARBM-GR280-B 1.69 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 . 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 10.045061 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027
9.09 20000 9.09 42000 4.55 15031 9.09 1 0.0022 293 END
```

```
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=500 NPG=1000 NSK=50 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
CYLINDER   2  0.585 173 -187.5
CYLINDER   3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER   1  0.325 174 -191
CYLINDER   2  0.75 174 -191
CYLINDER   3 4.  205.8 -204.2
CYLINDER   4 4.4 205.8 -204.2
CYLINDER   5 4.45 205.8 -204.2
CYLINDER   6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER   7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER   8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER   9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER  23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID    24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  25  3.94   174.8  174
CYLINDER  26  3.94  -191   -192.
CYLINDER  27  3.8    171    170.63
CYLINDER  28  3.8    135    134.63
CYLINDER  29  3.8     99     98.63
```

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CYLINDER 30 3.8   63    62.63
CYLINDER 31 3.8   27    26.63
CYLINDER 32 3.8   -9    -9.37
CYLINDER 33 3.8  -45   -45.37
CYLINDER 34 3.8  -81   -81.37
CYLINDER 35 3.8 -117  -117.37
CYLINDER 36 3.8 -153  -153.37
CYLINDER 37 4.0 205.8  174.8
MEDIA 3 1 1
MEDIA 8 1 2 -1
MEDIA 3 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE 1  6   ORIGIN x=1.6
HOLE 1  7  ORIGIN x=0.8      y=1.38564
HOLE 1  8  ORIGIN x=-0.8     y=1.38564
HOLE 1  9  ORIGIN x=-1.6
HOLE 1  10  ORIGIN x=-0.8     y=-1.38564
HOLE 1  11  ORIGIN x=0.8      y=-1.38564
HOLE 1  12  ORIGIN x=2.99437  y=0.80234
HOLE 1  13  ORIGIN x=2.19203  y=2.19203
HOLE 1  14  ORIGIN x=0.80234  y=2.99437
HOLE 1  15  ORIGIN x=-0.80234 y=2.99437
HOLE 1  16  ORIGIN x=-2.19203 y=2.19203
HOLE 1  17  ORIGIN x=-2.99437 y=0.80234
HOLE 1  18  ORIGIN x=-2.99437 y=-0.80234
HOLE 1  19  ORIGIN x=-2.19203 y=-2.19203
HOLE 1  20  ORIGIN x=-0.80234 y=-2.99437
HOLE 1  21  ORIGIN x=0.80234  y=-2.99437
HOLE 1  22  ORIGIN x=2.19203  y=-2.19203
HOLE 1  23  ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
```

```
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER  1  2.3 151.8 -151.8
CYLINDER  2  2.5 151.8 -151.8
CYLINDER  3  2.5225  151.8 -151.8
CYLINDER  4  3.2825  151.8 -151.8
CYLINDER  5  3.3 151.8 -151.8
CYLINDER  6  3.5 151.8 -151.8
CYLINDER  7  3.5 55.6 48.1
CYLINDER  8  3.5 -48.1 -55.6
CYLINDER  9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=125.6
```

```
HOLE 3  5              ORIGIN z=125.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
GLOBAL UNIT 6  COM=!CRIT STEND A1!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1 1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 96*4 4 5*4 4 12*4 4*2 2 13*4 5*2 13*4 4*2 4 13*4 4*2 31*4 4 5*4 4 113*4
END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
 END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A1, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!     UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.4 A2-1

```
=CSAS26
RBMK CRITICAL EXPERIMENTS , A2-1
27GROUPNDF4   LATTICECELL
UO2   1 DEN=10.10.10725 1.0 293 92234 .02 92235 2.00055 . 92236 .1  92238 97.87945 END
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O          3  1.0  293 END
ARBM-GR280-B 1.69 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 . 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 . 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
```

```
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 . 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 10.045061 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027
9.09 20000 9.09 42000 4.55 15031 9.09 1 0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=1000 NPG=1000 NSK=100 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
CYLINDER   2  0.585 173 -187.5
CYLINDER   3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER   1  0.325 174 -191
CYLINDER   2  0.75 174 -191
CYLINDER   3 4.  205.8 -204.2
CYLINDER   4 4.4 205.8 -204.2
CYLINDER   5 4.45 205.8 -204.2
CYLINDER   6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER   7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER   8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER   9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
```

```
CYLINDER 23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID   24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER 25  3.94  174.8  174
CYLINDER 26  3.94  -191   -192.
CYLINDER 27  3.8   171    170.63
CYLINDER 28  3.8   135    134.63
CYLINDER 29  3.8    99     98.63
CYLINDER 30  3.8    63     62.63
CYLINDER 31  3.8    27     26.63
CYLINDER 32  3.8    -9     -9.37
CYLINDER 33  3.8   -45    -45.37
CYLINDER 34  3.8   -81    -81.37
CYLINDER 35  3.8  -117   -117.37
CYLINDER 36  3.8  -153   -153.37
CYLINDER 37  4.0  205.8   174.8
MEDIA 3 1 1
MEDIA 8 1 2 -1
MEDIA 3 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  1   6   ORIGIN x=1.6
HOLE  1   7  ORIGIN x=0.8      y=1.38564
HOLE  1   8  ORIGIN x=-0.8     y=1.38564
HOLE  1   9  ORIGIN x=-1.6
HOLE  1  10  ORIGIN x=-0.8     y=-1.38564
HOLE  1  11  ORIGIN x=0.8      y=-1.38564
HOLE  1  12  ORIGIN x=2.99437  y=0.80234
HOLE  1  13  ORIGIN x=2.19203  y=2.19203
HOLE  1  14  ORIGIN x=0.80234  y=2.99437
HOLE  1  15  ORIGIN x=-0.80234 y=2.99437
HOLE  1  16  ORIGIN x=-2.19203 y=2.19203
HOLE  1  17  ORIGIN x=-2.99437 y=0.80234
HOLE  1  18  ORIGIN x=-2.99437 y=-0.80234
HOLE  1  19  ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20  ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21  ORIGIN x=0.80234  y=-2.99437
HOLE  1  22  ORIGIN x=2.19203  y=-2.19203
HOLE  1  23  ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
```

```
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER  1  2.3 151.8 -151.8
CYLINDER  2  2.5 151.8 -151.8
CYLINDER  3  2.5225  151.8 -151.8
CYLINDER  4  3.2825  151.8 -151.8
CYLINDER  5  3.3 151.8 -151.8
CYLINDER  6  3.5 151.8 -151.8
CYLINDER  7  3.5 55.6 48.1
CYLINDER  8  3.5 -48.1 -55.6
CYLINDER  9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
```

```
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID   4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=125.6
HOLE  3   5                 ORIGIN z=125.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
GLOBAL UNIT 6  COM=!CRIT STEND A2!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1 1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 115*4 5*2 13*4 5*2 13*4 4*2 14*4 4*2 151*4
END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
  END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A1, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!     UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.5 A2-2

```
=CSAS26
RBMK CRITICAL EXPERIMENTS , A2-2
27GROUPNDF4   LATTICECELL
UO2   1 DEN=10.10.10725 1.0 293 92234 .02 92235 2.00055 . 92236 .1  92238 97.87945 END
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O          3  1.0  293 END
```

```
ARBM-GR280-B 1.69 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 . 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 10.045061 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027
9.09 20000 9.09 42000 4.55 15031 9.09 1 0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=1000 NPG=1000 NSK=100 RUN=YES
WRS=35 RES=100 END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
CYLINDER   2  0.585 173 -187.5
CYLINDER   3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER   1  0.325 174 -191
CYLINDER   2  0.75 174 -191
CYLINDER   3 4.  205.8 -204.2
CYLINDER   4 4.4 205.8 -204.2
CYLINDER   5 4.45 205.8 -204.2
CYLINDER   6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER   7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER   8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER   9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
```

```
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER  23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID    24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  25  3.94   174.8  174
CYLINDER  26  3.94  -191   -192.
CYLINDER  27  3.8    171    170.63
CYLINDER  28  3.8    135    134.63
CYLINDER  29  3.8     99     98.63
CYLINDER  30  3.8     63     62.63
CYLINDER  31  3.8     27     26.63
CYLINDER  32  3.8     -9     -9.37
CYLINDER  33  3.8    -45    -45.37
CYLINDER  34  3.8    -81    -81.37
CYLINDER  35  3.8   -117   -117.37
CYLINDER  36  3.8   -153   -153.37
CYLINDER  37  4.0  205.8    174.8
MEDIA 0 1 1
MEDIA 8 1 2 -1
MEDIA 0 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  1   6    ORIGIN x=1.6
HOLE  1   7   ORIGIN x=0.8      y=1.38564
HOLE  1   8   ORIGIN x=-0.8     y=1.38564
HOLE  1   9   ORIGIN x=-1.6
HOLE  1  10   ORIGIN x=-0.8     y=-1.38564
HOLE  1  11   ORIGIN x=0.8      y=-1.38564
HOLE  1  12   ORIGIN x=2.99437  y=0.80234
HOLE  1  13   ORIGIN x=2.19203  y=2.19203
HOLE  1  14   ORIGIN x=0.80234  y=2.99437
HOLE  1  15   ORIGIN x=-0.80234 y=2.99437
HOLE  1  16   ORIGIN x=-2.19203 y=2.19203
HOLE  1  17   ORIGIN x=-2.99437 y=0.80234
HOLE  1  18   ORIGIN x=-2.99437 y=-0.80234
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```
HOLE  1  19   ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20   ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21   ORIGIN x=0.80234  y=-2.99437
HOLE  1  22   ORIGIN x=2.19203  y=-2.19203
HOLE  1  23   ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER   1  2.3 151.8 -151.8
CYLINDER   2  2.5 151.8 -151.8
CYLINDER   3  2.5225  151.8 -151.8
CYLINDER   4  3.2825  151.8 -151.8
CYLINDER   5  3.3 151.8 -151.8
CYLINDER   6  3.5 151.8 -151.8
CYLINDER   7  3.5 55.6 48.1
CYLINDER   8  3.5 -48.1 -55.6
CYLINDER   9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
```

```
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=125.6
HOLE  3   5                ORIGIN z=125.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
GLOBAL UNIT 6  COM=!CRIT STEND A2!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1 1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 115*4 5*2 13*4 5*2 13*4 4*2 14*4 4*2 151*4
END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
 END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A1, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!     UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.6 A3-0

```
=CSAS26
RBMK CRITICAL EXPERIMENTS , A3-0
27GROUPNDF4    LATTICECELL
UO2   1 DEN=10.047682 1.0 293 92234 .02 92235 2. 92236 .1 92238 97.88 END
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O          3  0.0001 293 END
ARBM-GR280-B 1.7 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 10.047682 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027
9.09 20000 9.09 42000 4.55 15031 9.09 1 0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=1000 NPG=1000 NSK=100 RUN=YES
 RES=25 WRS=35 END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
CYLINDER   2  0.585 173 -187.5
CYLINDER   3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER   1  0.325 174 -191
CYLINDER   2  0.75 174 -191
CYLINDER   3 4.  205.8 -204.2
CYLINDER   4 4.4 205.8 -204.2
CYLINDER   5 4.45 205.8 -204.2
```

```
CYLINDER  6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER  7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER  8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER  9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER 10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER 11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER 12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER 13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER 14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER 15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER 16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER 17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER 18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER 19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER 20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER 21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER 22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER 23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID   24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER 25  3.94   174.8  174
CYLINDER 26  3.94  -191   -192.
CYLINDER 27  3.8    171    170.63
CYLINDER 28  3.8    135    134.63
CYLINDER 29  3.8     99     98.63
CYLINDER 30  3.8     63     62.63
CYLINDER 31  3.8     27     26.63
CYLINDER 32  3.8     -9     -9.37
CYLINDER 33  3.8    -45    -45.37
CYLINDER 34  3.8    -81    -81.37
CYLINDER 35  3.8   -117   -117.37
CYLINDER 36  3.8   -153   -153.37
CYLINDER 37  4.0  205.8   174.8
MEDIA 0 1 1
MEDIA 8 1 2 -1
MEDIA 0 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  1  6   ORIGIN x=1.6
HOLE  1  7  ORIGIN x=0.8      y=1.38564
HOLE  1  8  ORIGIN x=-0.8     y=1.38564
HOLE  1  9  ORIGIN x=-1.6
HOLE  1  10  ORIGIN x=-0.8     y=-1.38564
```

```
HOLE  1  11   ORIGIN x=0.8      y=-1.38564
HOLE  1  12   ORIGIN x=2.99437  y=0.80234
HOLE  1  13   ORIGIN x=2.19203  y=2.19203
HOLE  1  14   ORIGIN x=0.80234  y=2.99437
HOLE  1  15   ORIGIN x=-0.80234 y=2.99437
HOLE  1  16   ORIGIN x=-2.19203 y=2.19203
HOLE  1  17   ORIGIN x=-2.99437 y=0.80234
HOLE  1  18   ORIGIN x=-2.99437 y=-0.80234
HOLE  1  19   ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20   ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21   ORIGIN x=0.80234  y=-2.99437
HOLE  1  22   ORIGIN x=2.19203  y=-2.19203
HOLE  1  23   ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER   1  2.3 151.8 -151.8
CYLINDER   2  2.5 151.8 -151.8
CYLINDER   3  2,5225  151.8 -151.8
CYLINDER   4  3.2825  151.8 -151.8
CYLINDER   5  3.3 151.8 -151.8
CYLINDER   6  3.5 151.8 -151.8
CYLINDER   7  3.5 55.6 48.1
CYLINDER   8  3.5 -48.1 -55.6
CYLINDER   9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
```

```
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=155.6
HOLE  3   5                ORIGIN z=155.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
GLOBAL UNIT 6  COM=!CRIT STEND A3!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1 1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 96*4 5 5*4 5 12*4 5*2 13*4 5*2 13*4 5*2 13*4 5*2 16*4 2*2 12*4 5 5*4
5 113*4 END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
  END BNDS
'READ PLOT
```

```
'TTL=!TOTAL VIEW OF CRITICAL STAND A5, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!     UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.7 A3-1

```
=CSAS26
RBMK CRITICAL EXPERIMENTS , A3-1
27GROUPNDF4     LATTICECELL
UO2   1 DEN=10.047682 1.0 293 92234 .02 92235 2. 92236 .1 92238 97.88 END
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O          3  0.0001 293 END
ARBM-GR280-B 1.7 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 10.047682 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027
9.09 20000 9.09 42000 4.55 15031 9.09 1 0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=500 NPG=1000 NSK=50 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
CYLINDER   2  0.585 173 -187.5
CYLINDER   3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
```

```
UNIT 2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER  1 0.325 174 -191
CYLINDER  2 0.75 174 -191
CYLINDER  3 4.  205.8 -204.2
CYLINDER  4 4.4 205.8 -204.2
CYLINDER  5 4.45 205.8 -204.2
CYLINDER  6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER  7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER  8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER  9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER 10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER 11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER 12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER 13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER 14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER 15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER 16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER 17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER 18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER 19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER 20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER 21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER 22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER 23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID   24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER 25  3.94   174.8  174
CYLINDER 26  3.94  -191   -192.
CYLINDER 27  3.8   171    170.63
CYLINDER 28  3.8   135    134.63
CYLINDER 29  3.8    99     98.63
CYLINDER 30  3.8    63     62.63
CYLINDER 31  3.8    27     26.63
CYLINDER 32  3.8    -9     -9.37
CYLINDER 33  3.8   -45    -45.37
CYLINDER 34  3.8   -81    -81.37
CYLINDER 35  3.8  -117   -117.37
CYLINDER 36  3.8  -153   -153.37
CYLINDER 37  4.0  205.8   174.8
MEDIA 0 1 1
MEDIA 8 1 2 -1
MEDIA 0 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
```

```
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  1  6   ORIGIN x=1.6
HOLE  1  7  ORIGIN x=0.8      y=1.38564
HOLE  1  8  ORIGIN x=-0.8     y=1.38564
HOLE  1  9  ORIGIN x=-1.6
HOLE  1  10  ORIGIN x=-0.8     y=-1.38564
HOLE  1  11  ORIGIN x=0.8      y=-1.38564
HOLE  1  12  ORIGIN x=2.99437  y=0.80234
HOLE  1  13  ORIGIN x=2.19203  y=2.19203
HOLE  1  14  ORIGIN x=0.80234  y=2.99437
HOLE  1  15  ORIGIN x=-0.80234 y=2.99437
HOLE  1  16  ORIGIN x=-2.19203 y=2.19203
HOLE  1  17  ORIGIN x=-2.99437 y=0.80234
HOLE  1  18  ORIGIN x=-2.99437 y=-0.80234
HOLE  1  19  ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20  ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21  ORIGIN x=0.80234  y=-2.99437
HOLE  1  22  ORIGIN x=2.19203  y=-2.19203
HOLE  1  23  ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER  1  2.3 151.8 -151.8
CYLINDER  2  2.5 151.8 -151.8
CYLINDER  3  2.5225  151.8 -151.8
CYLINDER  4  3.2825  151.8 -151.8
CYLINDER  5  3.3 151.8 -151.8
CYLINDER  6  3.5 151.8 -151.8
CYLINDER  7  3.5 55.6 48.1
CYLINDER  8  3.5 -48.1 -55.6
```

```
CYLINDER  9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID   4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID   4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=155.6
HOLE  3   5                ORIGIN z=155.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
GLOBAL UNIT 6  COM=!CRIT STEND A3!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1 1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
```

```
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 96*4 4 5*4 4 12*4 5*2 13*4 5*2 13*4 5*2 13*4 5*2 16*4 2*2 12*4 4 5*4
4 113*4 END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
 END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A5, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!    UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.8 A4-0

```
=CSAS26
RBMK CRITICAL EXPERIMENTS, A4-0
27GROUPNDF4   LATTICECELL
UO2   1 DEN=9.9066 1.0 293 92234 .02 92235 2.4 92236 .1 92238 97.48 END
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O          3  1.0 293 END
ARBM-GR280-B 1.7 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 9.9080 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027 9.09
20000 9.09 42000 4.55 15031 9.09 1  0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=500 NPG=1000 NSK=50 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
```

```
CYLINDER  1  0.576 173 -173
CYLINDER  2  0.585 173 -187.5
CYLINDER  3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER  1  0.325 174 -191
CYLINDER  2  0.75 174 -191
CYLINDER  3 4.  205.8 -204.2
CYLINDER  4 4.4 205.8 -204.2
CYLINDER  5 4.45 205.8 -204.2
CYLINDER  6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER  7 .6815 173.8 -190.2  ORIGIN x=0.8     y=1.38564
CYLINDER  8 .6815 173.8 -190.2  ORIGIN x=-0.8    y=1.38564
CYLINDER  9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8    y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8     y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER  23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID   24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  25  3.94   174.8  174
CYLINDER  26  3.94  -191   -192.
CYLINDER  27  3.8   171    170.63
CYLINDER  28  3.8   135    134.63
CYLINDER  29  3.8    99     98.63
CYLINDER  30  3.8    63     62.63
CYLINDER  31  3.8    27     26.63
CYLINDER  32  3.8    -9     -9.37
CYLINDER  33  3.8   -45    -45.37
CYLINDER  34  3.8   -81    -81.37
CYLINDER  35  3.8  -117   -117.37
```

```
CYLINDER  36  3.8  -153   -153.37
CYLINDER  37  4.0  205.8   174.8
MEDIA 3 1 1
MEDIA 8 1 2 -1
MEDIA 3 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  1   6    ORIGIN x=1.6
HOLE  1   7   ORIGIN x=0.8      y=1.38564
HOLE  1   8   ORIGIN x=-0.8     y=1.38564
HOLE  1   9   ORIGIN x=-1.6
HOLE  1  10   ORIGIN x=-0.8     y=-1.38564
HOLE  1  11   ORIGIN x=0.8      y=-1.38564
HOLE  1  12   ORIGIN x=2.99437  y=0.80234
HOLE  1  13   ORIGIN x=2.19203  y=2.19203
HOLE  1  14   ORIGIN x=0.80234  y=2.99437
HOLE  1  15   ORIGIN x=-0.80234 y=2.99437
HOLE  1  16   ORIGIN x=-2.19203 y=2.19203
HOLE  1  17   ORIGIN x=-2.99437 y=0.80234
HOLE  1  18   ORIGIN x=-2.99437 y=-0.80234
HOLE  1  19   ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20   ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21   ORIGIN x=0.80234  y=-2.99437
HOLE  1  22   ORIGIN x=2.19203  y=-2.19203
HOLE  1  23   ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER   1  2.3 151.8 -151.8
```

```
CYLINDER  2  2.5 151.8 -151.8
CYLINDER  3  2.5225  151.8 -151.8
CYLINDER  4  3.2825  151.8 -151.8
CYLINDER  5  3.3 151.8 -151.8
CYLINDER  6  3.5 151.8 -151.8
CYLINDER  7  3.5 55.6 48.1
CYLINDER  8  3.5 -48.1 -55.6
CYLINDER  9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=155.6
HOLE  3   5               ORIGIN z=155.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
```

```
GLOBAL UNIT 6  COM=!CRIT STEND A4!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1 1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 96*4 5 5*4 5 12*4 4*2 15*4 3*2 15*4 3*2 15*4 4*2 30*4 5 5*4 5 113*4
END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
 END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A4, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!     UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.9 A4-1

```
=CSAS26
RBMK CRITICAL EXPERIMENTS, A4-1
27GROUPNDF4   LATTICECELL
UO2   1 DEN=9.9066 1.0 293 92234 .02 92235 2.4 92236 .1 92238 97.48 END
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O          3  1.0 293 END
ARBM-GR280-B 1.7 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
```

```
ARBM-PRIM1 9.9080 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027 9.09
20000 9.09 42000 4.55 15031 9.09 1  0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=500 NPG=1000 NSK=50 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER  1  0.576 173 -173
CYLINDER  2  0.585 173 -187.5
CYLINDER  3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER  1  0.325 174 -191
CYLINDER  2  0.75 174 -191
CYLINDER  3 4.  205.8 -204.2
CYLINDER  4 4.4 205.8 -204.2
CYLINDER  5 4.45 205.8 -204.2
CYLINDER  6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER  7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER  8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER  9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER  23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID    24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  25  3.94   174.8  174
CYLINDER  26  3.94  -191   -192.
CYLINDER  27  3.8   171    170.63
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CYLINDER  28  3.8   135    134.63
CYLINDER  29  3.8    99     98.63
CYLINDER  30  3.8    63     62.63
CYLINDER  31  3.8    27     26.63
CYLINDER  32  3.8    -9     -9.37
CYLINDER  33  3.8   -45    -45.37
CYLINDER  34  3.8   -81    -81.37
CYLINDER  35  3.8  -117   -117.37
CYLINDER  36  3.8  -153   -153.37
CYLINDER  37  4.0  205.8   174.8
MEDIA 3 1 1
MEDIA 8 1 2 -1
MEDIA 3 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  1   6   ORIGIN x=1.6
HOLE  1   7   ORIGIN x=0.8      y=1.38564
HOLE  1   8   ORIGIN x=-0.8     y=1.38564
HOLE  1   9   ORIGIN x=-1.6
HOLE  1  10   ORIGIN x=-0.8     y=-1.38564
HOLE  1  11   ORIGIN x=0.8      y=-1.38564
HOLE  1  12   ORIGIN x=2.99437  y=0.80234
HOLE  1  13   ORIGIN x=2.19203  y=2.19203
HOLE  1  14   ORIGIN x=0.80234  y=2.99437
HOLE  1  15   ORIGIN x=-0.80234 y=2.99437
HOLE  1  16   ORIGIN x=-2.19203 y=2.19203
HOLE  1  17   ORIGIN x=-2.99437 y=0.80234
HOLE  1  18   ORIGIN x=-2.99437 y=-0.80234
HOLE  1  19   ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20   ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21   ORIGIN x=0.80234  y=-2.99437
HOLE  1  22   ORIGIN x=2.19203  y=-2.19203
HOLE  1  23   ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
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MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER   1  2.3 151.8 -151.8
CYLINDER   2  2.5 151.8 -151.8
CYLINDER   3  2.5225  151.8 -151.8
CYLINDER   4  3.2825  151.8 -151.8
CYLINDER   5  3.3 151.8 -151.8
CYLINDER   6  3.5 151.8 -151.8
CYLINDER   7  3.5 55.6 48.1
CYLINDER   8  3.5 -48.1 -55.6
CYLINDER   9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
```

```
CUBOID   4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=155.6
HOLE 3  5                ORIGIN z=155.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
GLOBAL UNIT 6  COM=!CRIT STEND A4!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1 1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 96*4 4 5*4 4 12*4 4*2 15*4 3*2 15*4 3*2 15*4 4*2 30*4 4 5*4 4 113*4
END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
 END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A4, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!     UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.10  A4-2

```
=CSAS26
RBMK CRITICAL EXPERIMENTS, A4-2
27GROUPNDF4   LATTICECELL
UO2   1 DEN=9.9066 1.0 293 92234 .02 92235 2.4 92236 .1 92238 97.48 END
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O          3  1.0 293 END
ARBM-GR280-B 1.7 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
```

```
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 9.9080 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027 9.09
20000 9.09 42000 4.55 15031 9.09 1  0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
READ PARAM TME=9000 TBA=90 GEN=500 NPG=1000 NSK=50 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
CYLINDER   2  0.585 173 -187.5
CYLINDER   3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER   1  0.325 174 -191
CYLINDER   2  0.75 174 -191
CYLINDER   3 4.  205.8 -204.2
CYLINDER   4 4.4 205.8 -204.2
CYLINDER   5 4.45 205.8 -204.2
CYLINDER   6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER   7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER   8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER   9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
```

```
CYLINDER 21 .6815 173.8 -190.2 ORIGIN x=0.80234 y=-2.99437
CYLINDER 22 .6815 173.8 -190.2 ORIGIN x=2.19203 y=-2.19203
CYLINDER 23 .6815 173.8 -190.2 ORIGIN x=2.99437 y=-0.80234
CUBOID   24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER 25 3.94  174.8  174
CYLINDER 26 3.94  -191   -192.
CYLINDER 27 3.8   171    170.63
CYLINDER 28 3.8   135    134.63
CYLINDER 29 3.8    99     98.63
CYLINDER 30 3.8    63     62.63
CYLINDER 31 3.8    27     26.63
CYLINDER 32 3.8    -9     -9.37
CYLINDER 33 3.8   -45    -45.37
CYLINDER 34 3.8   -81    -81.37
CYLINDER 35 3.8  -117   -117.37
CYLINDER 36 3.8  -153   -153.37
CYLINDER 37 4.0  205.8   174.8
MEDIA 3 1 1
MEDIA 8 1 2 -1
MEDIA 3 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  1  6   ORIGIN x=1.6
HOLE  1  7   ORIGIN x=0.8      y=1.38564
HOLE  1  8   ORIGIN x=-0.8     y=1.38564
HOLE  1  9   ORIGIN x=-1.6
HOLE  1  10  ORIGIN x=-0.8     y=-1.38564
HOLE  1  11  ORIGIN x=0.8      y=-1.38564
HOLE  1  12  ORIGIN x=2.99437  y=0.80234
HOLE  1  13  ORIGIN x=2.19203  y=2.19203
HOLE  1  14  ORIGIN x=0.80234  y=2.99437
HOLE  1  15  ORIGIN x=-0.80234 y=2.99437
HOLE  1  16  ORIGIN x=-2.19203 y=2.19203
HOLE  1  17  ORIGIN x=-2.99437 y=0.80234
HOLE  1  18  ORIGIN x=-2.99437 y=-0.80234
HOLE  1  19  ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20  ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21  ORIGIN x=0.80234  y=-2.99437
HOLE  1  22  ORIGIN x=2.19203  y=-2.19203
HOLE  1  23  ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
```

```
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER   1  2.3 151.8 -151.8
CYLINDER   2  2.5 151.8 -151.8
CYLINDER   3  2.5225  151.8 -151.8
CYLINDER   4  3.2825  151.8 -151.8
CYLINDER   5  3.3 151.8 -151.8
CYLINDER   6  3.5 151.8 -151.8
CYLINDER   7  3.5 55.6 48.1
CYLINDER   8  3.5 -48.1 -55.6
CYLINDER   9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID   4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
```

```
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=155.6
HOLE  3   5                ORIGIN z=155.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
GLOBAL UNIT 6  COM=!CRIT STEND A4!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1  1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 96*4 4 5*4 4 12*4 4*2 15*4 3*2 15*4 3*2 15*4 3*2 4 30*4 4 5*4 4 113*4
END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
 END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A4, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
'NCH=!     UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.11  A5-0

```
=CSAS26
RBMK CRITICAL EXPERIMENTS, A5-0
27GROUPNDF4   LATTICECELL
UO2  1 DEN=9.9080 1.0 293 92234 .02 92235 2.4 92236 .1 92238 97.48 END
UO2  12 DEN=10.1046 1.0 293 92234 .02 92235 2.001 92236 .1 92238 97.879 END
```

```
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O           3  DEN=0.0001 1.0 293 END
ARBM-GR280-B 1.7 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 9.9080 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027 9.09
20000 9.09 42000 4.55 15031 9.09 1  0.0022 293 END
ARBM-PRIM2 10.1046 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027 9.09
20000 9.09 42000 4.55 15031 9.09 12  0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
MORE DATA
RES=12  CYLINDER 1.152 DAN(12)=8.2666E-5
END MORE DATA
READ PARAM TME=9000 TBA=90 GEN=500 NPG=1000 NSK=50 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
CYLINDER   2  0.585 173 -187.5
CYLINDER   3  0.6815 173.8 -190.2
MEDIA  1 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER   1  0.325 174 -191
CYLINDER   2  0.75 174 -191
CYLINDER   3 4.  205.8 -204.2
CYLINDER   4 4.4 205.8 -204.2
CYLINDER   5 4.45 205.8 -204.2
CYLINDER   6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER   7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
```

```
CYLINDER  8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER  9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER  23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID   24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  25  3.94   174.8  174
CYLINDER  26  3.94  -191   -192
CYLINDER  27  3.8    171    170.63
CYLINDER  28  3.8    135    134.63
CYLINDER  29  3.8     99     98.63
CYLINDER  30  3.8     63     62.63
CYLINDER  31  3.8     27     26.63
CYLINDER  32  3.8     -9     -9.37
CYLINDER  33  3.8    -45    -45.37
CYLINDER  34  3.8    -81    -81.37
CYLINDER  35  3.8   -117   -117.37
CYLINDER  36  3.8   -153   -153.37
CYLINDER  37  4.0  205.8   174.8
MEDIA 0 1 1
MEDIA 8 1 2 -1
MEDIA 0 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  1   6   ORIGIN x=1.6
HOLE  1   7   ORIGIN x=0.8      y=1.38564
HOLE  1   8   ORIGIN x=-0.8     y=1.38564
HOLE  1   9   ORIGIN x=-1.6
HOLE  1  10   ORIGIN x=-0.8     y=-1.38564
HOLE  1  11   ORIGIN x=0.8      y=-1.38564
HOLE  1  12   ORIGIN x=2.99437  y=0.80234
```

```
HOLE  1  13   ORIGIN x=2.19203  y=2.19203
HOLE  1  14   ORIGIN x=0.80234  y=2.99437
HOLE  1  15   ORIGIN x=-0.80234 y=2.99437
HOLE  1  16   ORIGIN x=-2.19203 y=2.19203
HOLE  1  17   ORIGIN x=-2.99437 y=0.80234
HOLE  1  18   ORIGIN x=-2.99437 y=-0.80234
HOLE  1  19   ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20   ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21   ORIGIN x=0.80234  y=-2.99437
HOLE  1  22   ORIGIN x=2.19203  y=-2.19203
HOLE  1  23   ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER   1  2.3 151.8 -151.8
CYLINDER   2  2.5 151.8 -151.8
CYLINDER   3  2.5225  151.8 -151.8
CYLINDER   4  3.2825  151.8 -151.8
CYLINDER   5  3.3 151.8 -151.8
CYLINDER   6  3.5 151.8 -151.8
CYLINDER   7  3.5 55.6 48.1
CYLINDER   8  3.5 -48.1 -55.6
CYLINDER   9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
```

```
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=165.6
HOLE  3   5                ORIGIN z=165.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  6
COM=!FUEL PIN!
CYLINDER   1  0.576 173 -173
CYLINDER   2  0.585 173 -187.5
CYLINDER   3  0.6815 173.8 -190.2
MEDIA  12 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  7
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER   1  0.325 174 -191
CYLINDER   2  0.75 174 -191
CYLINDER   3 4.  205.8 -204.2
CYLINDER   4 4.4 205.8 -204.2
CYLINDER   5 4.45 205.8 -204.2
```

```
CYLINDER  6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER  7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER  8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER  9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER  23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID   24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  25  3.94  174.8  174
CYLINDER  26  3.94  -191   -192.
CYLINDER  27  3.8   171    170.63
CYLINDER  28  3.8   135    134.63
CYLINDER  29  3.8   99     98.63
CYLINDER  30  3.8   63     62.63
CYLINDER  31  3.8   27     26.63
CYLINDER  32  3.8   -9     -9.37
CYLINDER  33  3.8   -45    -45.37
CYLINDER  34  3.8   -81    -81.37
CYLINDER  35  3.8  -117   -117.37
CYLINDER  36  3.8  -153   -153.37
CYLINDER  37  4.0  205.8   174.8
MEDIA 0 1 1
MEDIA 8 1 2 -1
MEDIA 0 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  6  6   ORIGIN x=1.6
HOLE  6  7   ORIGIN x=0.8      y=1.38564
HOLE  6  8   ORIGIN x=-0.8     y=1.38564
HOLE  6  9   ORIGIN x=-1.6
HOLE  6  10   ORIGIN x=-0.8     y=-1.38564
```

```
HOLE  6  11   ORIGIN x=0.8      y=-1.38564
HOLE  6  12   ORIGIN x=2.99437  y=0.80234
HOLE  6  13   ORIGIN x=2.19203  y=2.19203
HOLE  6  14   ORIGIN x=0.80234  y=2.99437
HOLE  6  15   ORIGIN x=-0.80234 y=2.99437
HOLE  6  16   ORIGIN x=-2.19203 y=2.19203
HOLE  6  17   ORIGIN x=-2.99437 y=0.80234
HOLE  6  18   ORIGIN x=-2.99437 y=-0.80234
HOLE  6  19   ORIGIN x=-2.19203 y=-2.19203
HOLE  6  20   ORIGIN x=-0.80234 y=-2.99437
HOLE  6  21   ORIGIN x=0.80234  y=-2.99437
HOLE  6  22   ORIGIN x=2.19203  y=-2.19203
HOLE  6  23   ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
GLOBAL UNIT 8  COM=!CRIT STEND A5-0!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1 1 1 -212.5 -212.5 0
BOUNDARY 1
END GEOM
READ ARRAY ARA=1 NUX=18 NUY=18 NUZ=1
FILL 96*4 5 7 4*4 5 12*4 4*2 14*4 4*2 14*4 4*2 14*4 4*2 17*4 7 13*4 5
5*4 5 113*4 END FILL END ARRAY
READ BNDS +XB=VACUUM -XB=VACUUM +YB=VACUUM -YB=VACUUM +ZB=VACUUM -
ZB=VACUUM
  END BNDS
'READ PLOT
'TTL=!TOTAL VIEW OF CRITICAL STAND A4, X-Y PLOT! SCR=YES PIC=UNIT
'XUL=-225 YUL=225 ZUL=0. XLR=225 YLR=-225 ZLR=0 UAX=1 VAX=0
'WAX=0 UDN=0 VDN=-1 WDN=0 NAX=400 LPI=10
```

```
'NCH=!     UNIT  X-Y VIEW                    !
'END PLOT
END DATA
END
```

## A.12 A5-1

```
=CSAS26    PARM=SIZE=1500000
RBMK CRITICAL EXPERIMENTS, A5-1
27GROUPNDF4   LATTICECELL
UO2  1 DEN=9.9080 1.0 293 92234 .02 92235 2.4 92236 .1 92238 97.48 END
UO2  12 DEN=10.1046 1.0 293 92234 .02 92235 2.001 92236 .1 92238 97.879 END
B4C          2  DEN=1.65 1.0 293 5010 19.9 5011 80.1 END
H2O           3  DEN=0.0001 1.0 293 END
ARBM-GR280-B 1.7 7  0 0 1  6012 99.9958 1001 .0011 8016 .0018 14000 .0007 7014 .0004 24000
.0001 20000 .0001 4 1.0 293 END
ARBM-AL-CAB6 2.15 7  0 0 1  12000 .6 14000 .8 29000 .9 25055 .3  26000 .3 22000 .1  13027 97.
5  1.0 293 END
ARBM-AL-CAB1 2.7 4  0 0 1  12000 .5 14000 1 29000 .1 13027 98.4 6  1.0 293 END
ARBM-ZR110 6.55 6  0 0 1  72000 .04 41093 1 26000 .018 28000 .011 13027 .0048 40000 98.9262
7  1.0 293 END
ARBM-ZR125 6.55 6  0 0 1  72000 .04 41093 2.5 26000 .018 28000 .011 13027 .0046 40000 97.4264
8  1.0 293 END
ARBM-CT06X18H10T 7.8 5  0 0 1  6012 .06 24000 18 28000 10 22000 1 26000 70.94 9  1.0 293 END
ARBM-CT12X18H10T 7.8 5  0 0 1  6012 .12 24000 18 28000 10 22000 1 26000 70.88 10  1.0 293 END
ARBM-CT-CBJ2 7.8 7  1 0 1  5000 2 24000 18.7 28000 34 6012 .009 13027 2.25 14000 2.55 26000
40.491 11  1.0 293 5010 19.9 5011 80.1 END
ARBM-PRIM1 9.9080 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027 9.09
20000 9.09 42000 4.55 15031 9.09 1  0.0022 293 END
ARBM-PRIM2 10.1046 9  0 0 1  7014 9.09 26000 36.36 14000 11.36 28000 6.82 24000 4.55 13027 9.09
20000 9.09 42000 4.55 15031 9.09 12  0.0022 293 END
END COMP
SQUAREPITCH 25 4.9 1  4  8.9  3  5.093 7  END
MORE DATA
RES=12  CYLINDER 1.152 DAN(12)=8.2666E-5
END MORE DATA
READ PARAM TME=9000 TBA=90 GEN=1000 NPG=1000 NSK=100 RUN=YES END PARAM
READ GEOM
UNIT  1
COM=!FUEL PIN!
CYLINDER  1  0.576 173 -173
CYLINDER  2  0.585 173 -187.5
CYLINDER  3  0.6815 173.8 -190.2
MEDIA  1 1 1
```

```
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  2
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER   1  0.325 174 -191
CYLINDER   2  0.75 174 -191
CYLINDER   3 4.  205.8 -204.2
CYLINDER   4 4.4 205.8 -204.2
CYLINDER   5 4.45 205.8 -204.2
CYLINDER   6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER   7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER   8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER   9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER  10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER  11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER  12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER  13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER  14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER  15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER  16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER  17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER  18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER  19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER  20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER  21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER  22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER  23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID    24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  25  3.94   174.8  174
CYLINDER  26  3.94  -191   -192.
CYLINDER  27  3.8    171    170.63
CYLINDER  28  3.8    135    134.63
CYLINDER  29  3.8     99     98.63
CYLINDER  30  3.8     63     62.63
CYLINDER  31  3.8     27     26.63
CYLINDER  32  3.8     -9     -9.37
CYLINDER  33  3.8    -45    -45.37
CYLINDER  34  3.8    -81    -81.37
CYLINDER  35  3.8   -117   -117.37
CYLINDER  36  3.8   -153   -153.37
CYLINDER  37  4.0   205.8   174.8
MEDIA 0 1 1
MEDIA 8 1 2 -1
```

```
MEDIA 0 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19  -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  1   6   ORIGIN x=1.6
HOLE  1   7  ORIGIN x=0.8      y=1.38564
HOLE  1   8  ORIGIN x=-0.8     y=1.38564
HOLE  1   9  ORIGIN x=-1.6
HOLE  1  10   ORIGIN x=-0.8     y=-1.38564
HOLE  1  11   ORIGIN x=0.8      y=-1.38564
HOLE  1  12   ORIGIN x=2.99437  y=0.80234
HOLE  1  13   ORIGIN x=2.19203  y=2.19203
HOLE  1  14   ORIGIN x=0.80234  y=2.99437
HOLE  1  15   ORIGIN x=-0.80234 y=2.99437
HOLE  1  16   ORIGIN x=-2.19203 y=2.19203
HOLE  1  17   ORIGIN x=-2.99437 y=0.80234
HOLE  1  18   ORIGIN x=-2.99437 y=-0.80234
HOLE  1  19   ORIGIN x=-2.19203 y=-2.19203
HOLE  1  20   ORIGIN x=-0.80234 y=-2.99437
HOLE  1  21   ORIGIN x=0.80234  y=-2.99437
HOLE  1  22   ORIGIN x=2.19203  y=-2.19203
HOLE  1  23   ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
UNIT  3
COM=!CONTROL ROD!
CYLINDER   1  2.3 151.8 -151.8
CYLINDER   2  2.5 151.8 -151.8
CYLINDER   3  2.5225  151.8 -151.8
CYLINDER   4  3.2825  151.8 -151.8
CYLINDER   5  3.3 151.8 -151.8
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CYLINDER  6  3.5 151.8 -151.8
CYLINDER  7  3.5 55.6 48.1
CYLINDER  8  3.5 -48.1 -55.6
CYLINDER  9  3.5 -151.8 -157.8
CYLINDER  10  3.5 163.5  -157.8
MEDIA 0 1 1 -7 -8
MEDIA 6 1 2 -1 -7 -8
MEDIA 0 1 3 -2 -1 -7 -8
MEDIA 2 1 4 -3 -2 -1 -7 -8
MEDIA 0 1 5  -4 -3 -2 -1 -7 -8
MEDIA 6 1 6 -5 -4 -3 -2 -1 -7 -8
MEDIA 6 1 7
MEDIA 6 1 8
MEDIA 6 1 9 -6 -5 -4 -3 -2 -1
MEDIA 6 1 10 -9 -8 -7 -6 -5 -4 -3 -2 -1
BOUNDARY 10
UNIT  4
COM=!GRAPHITE BLOCK!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
MEDIA 0 1 1
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  5
COM=!GRAPHITE BLOCK AND CHANNEL WITH CONTROL ROD!
CYLINDER  1 4.  205.8 -204.2
CYLINDER  2 4.4 205.8 -204.2
CYLINDER  3 4.45 205.8 -204.2
CUBOID    4 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER  5  3.5 163.5 -157.8  ORIGIN  z=165.6
HOLE  3   5                ORIGIN z=165.6
MEDIA 0 1 1 -5
MEDIA 5 1 2 -1
MEDIA 0 1 3 -2 -1
MEDIA 4 1 4 -3 -2 -1
BOUNDARY 4
UNIT  6
COM=!FUEL PIN!
CYLINDER  1  0.576 173 -173
CYLINDER  2  0.585 173 -187.5
```

```
CYLINDER  3 0.6815 173.8 -190.2
MEDIA  12 1 1
MEDIA  0 1 2 -1
MEDIA  7 1 3 -2 -1
BOUNDARY 3
UNIT  7
COM=!GRAPHITE BLOCK AND CHANNEL WITH FUEL ASSEMBLY!
CYLINDER  1  0.325 174 -191
CYLINDER  2  0.75 174 -191
CYLINDER  3 4.  205.8 -204.2
CYLINDER  4 4.4 205.8 -204.2
CYLINDER  5 4.45 205.8 -204.2
CYLINDER  6 .6815 173.8 -190.2  ORIGIN x=1.6
CYLINDER  7 .6815 173.8 -190.2  ORIGIN x=0.8      y=1.38564
CYLINDER  8 .6815 173.8 -190.2  ORIGIN x=-0.8     y=1.38564
CYLINDER  9 .6815 173.8 -190.2  ORIGIN x=-1.6
CYLINDER 10 .6815 173.8 -190.2  ORIGIN x=-0.8     y=-1.38564
CYLINDER 11 .6815 173.8 -190.2  ORIGIN x=0.8      y=-1.38564
CYLINDER 12 .6815 173.8 -190.2  ORIGIN x=2.99437  y=0.80234
CYLINDER 13 .6815 173.8 -190.2  ORIGIN x=2.19203  y=2.19203
CYLINDER 14 .6815 173.8 -190.2  ORIGIN x=0.80234  y=2.99437
CYLINDER 15 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=2.99437
CYLINDER 16 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=2.19203
CYLINDER 17 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=0.80234
CYLINDER 18 .6815 173.8 -190.2  ORIGIN x=-2.99437 y=-0.80234
CYLINDER 19 .6815 173.8 -190.2  ORIGIN x=-2.19203 y=-2.19203
CYLINDER 20 .6815 173.8 -190.2  ORIGIN x=-0.80234 y=-2.99437
CYLINDER 21 .6815 173.8 -190.2  ORIGIN x=0.80234  y=-2.99437
CYLINDER 22 .6815 173.8 -190.2  ORIGIN x=2.19203  y=-2.19203
CYLINDER 23 .6815 173.8 -190.2  ORIGIN x=2.99437  y=-0.80234
CUBOID   24 12.5 -12.5 12.5 -12.5 205.8 -204.2
CYLINDER 25  3.94  174.8  174
CYLINDER 26  3.94  -191   -192.
CYLINDER 27  3.8   171    170.63
CYLINDER 28  3.8   135    134.63
CYLINDER 29  3.8    99     98.63
CYLINDER 30  3.8    63     62.63
CYLINDER 31  3.8    27     26.63
CYLINDER 32  3.8    -9    -9.37
CYLINDER 33  3.8   -45   -45.37
CYLINDER 34  3.8   -81   -81.37
CYLINDER 35  3.8  -117  -117.37
CYLINDER 36  3.8  -153  -153.37
CYLINDER 37  4.0  205.8  174.8
```

```
MEDIA 0 1 1
MEDIA 8 1 2 -1
MEDIA 0 1 3 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -25 -26 -27 -28 -29
-30 -31 -32 -33 -34 -35 -36 -37
MEDIA  0 1 37 3
MEDIA  5 1 4 -3
MEDIA  0 1 5 -4
HOLE  6   6   ORIGIN x=1.6
HOLE  6   7   ORIGIN x=0.8      y=1.38564
HOLE  6   8   ORIGIN x=-0.8     y=1.38564
HOLE  6   9   ORIGIN x=-1.6
HOLE  6  10   ORIGIN x=-0.8     y=-1.38564
HOLE  6  11   ORIGIN x=0.8      y=-1.38564
HOLE  6  12   ORIGIN x=2.99437  y=0.80234
HOLE  6  13   ORIGIN x=2.19203  y=2.19203
HOLE  6  14   ORIGIN x=0.80234  y=2.99437
HOLE  6  15   ORIGIN x=-0.80234 y=2.99437
HOLE  6  16   ORIGIN x=-2.19203 y=2.19203
HOLE  6  17   ORIGIN x=-2.99437 y=0.80234
HOLE  6  18   ORIGIN x=-2.99437 y=-0.80234
HOLE  6  19   ORIGIN x=-2.19203 y=-2.19203
HOLE  6  20   ORIGIN x=-0.80234 y=-2.99437
HOLE  6  21   ORIGIN x=0.80234  y=-2.99437
HOLE  6  22   ORIGIN x=2.19203  y=-2.19203
HOLE  6  23   ORIGIN x=2.99437  y=-0.80234
MEDIA  8 1 25 -2 -37
MEDIA  8 1 26 -2
MEDIA  9 1 27 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 28 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 29 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 30 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 31 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 32 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 33 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 34 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 35 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  9 1 36 -2 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23
MEDIA  4 1 24 -5
BOUNDARY 24
GLOBAL UNIT 8  COM=!CRIT STEND A4!
CUBOID  1 225 -225 225 -225 205.8 -204.2
CYLINDER  2  4.95  225.  -225.  ORIGIN  Z=-25. ROTATE  A1=90. A2=90.
MEDIA 0 1 2
ARRAY 1 1 -2  PLACE 1  1  1 -212.5 -212.5 0
```