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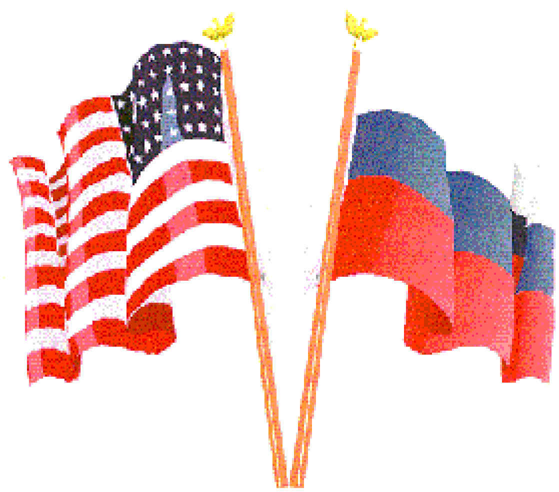
FOR THE DEPARTMENT OF ENERGY

CRITICALITY CALCULATIONS OF FRESH LEU AND MOX ASSEMBLIES FOR TRANSPORT AND STORAGE AT THE BALAKOVO NUCLEAR POWER PLANT

Sedat Goluoglu



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Criticality Calculations of Fresh LEU and MOX Assemblies for Transport and Storage at the Balakovo Nuclear Power Plant

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ABSTRACT

Transportation of low-enriched uranium (LEU) and mixed-oxide (MOX) assemblies to and within the VVER-1000-type Balakovo Nuclear Power Plant is investigated. Effective multiplication factors for fresh fuel assemblies on the railroad platform, fresh fuel assemblies in the fuel transportation vehicle, and fresh fuel assemblies in the spent fuel storage pool are calculated. If there is no absorber between the units, the configurations with all MOX assemblies result in higher effective multiplication factors than the configurations with all LEU assemblies when the system is dry. When the system is flooded, the configurations with all LEU assemblies result in higher effective multiplication factors. For normal operating conditions, effective multiplication factors for all configurations are below the presumed upper subcritical limit of 0.95. For an accident condition of a fully loaded fuel transportation vehicle that is flooded with low-density water (possibly from a fire suppression system), the presumed upper subcritical limit is exceeded by configurations containing LEU assemblies.

1. INTRODUCTION

US/RF Task 00-6, LTA Fuel Cycle Analyses, Part 1 is a multiyear task to study mixed-oxide (MOX) fuel decay heat, radiation, and criticality safety issues. Fresh and spent lead test assemblies (LTA) and mission fuel must be stored at the Balakovo reactor site. All operations must be licensed by performing shielding, criticality safety and decay-heat calculations. FY 2000 studies include criticality safety calculations for fresh MOX storage for one or two equilibrium reloads (20 to 40 assemblies). Studies will also include storage of spent MOX fuel assemblies (20 to 200 assemblies). The U.S. milestones for US/RF Task 00-6, LTA Fuel Cycle Analyses, Part 1, for FY 2000 are: (1) review problem description, (2) calculate fresh fuel storage at Balakovo site, (3) calculate spent fuel storage at Balakovo site, and (4) document the results. Calculations reported in Sect. 3 satisfy the FY 2000 U.S. milestones 2 and 3. This document satisfies the FY 2000 U.S. milestone 4. Decay heat and radiation shielding calculations of the MOX fuel assemblies are not addressed in this document.

2. PROBLEM DESCRIPTION

2.1 COMPUTATIONAL METHODS AND DATA

The frozen version of Standardized Computer Analysis for Licensing Evaluation (SCALE)[1] known as SCALE4.3r, maintained by the Fissile Material Disposition Program, is used to perform the criticality calculations. This version is validated for MOX systems that are similar to the systems analyzed in this report and runs on IBM RS/6000 workstations in the Computational Physics and Engineering Division at Oak Ridge National Laboratory (ORNL).[2-11] All calculations used the ENDF/B-V-based 238-energy-group library, which has 148 fast and 90 thermal groups below 3 eV. The sequence known as Criticality Safety Analysis Sequence six (CSAS6) is used to automate the cross-section processing and criticality calculations. This sequence executes the modules BONAMI, NITAWL-II, and KENO-VI. BONAMI performs resonance self-shielding of the cross sections in the unresolved energy range for nuclides that have Bondarenko factors. NITAWL-II uses the Nordheim Integral Treatment for performing resonance self-shielding of cross sections in the resolved energy range. Effective multiplication factors (k_{eff}) of the configurations are then calculated by using the three-dimensional, multi-group Monte Carlo code KENO-VI.

The convergences of the KENO-VI calculations are determined by observing the plot of average k_{eff} by generation run and the plot of average k_{eff} by generation skipped. No trends were observed in these plots. In addition, the frequency distribution plots were examined. These frequency distribution plots showed single k_{eff} peaks, which is also an indication of convergence.

When the calculation cases involved dry fuel assemblies, cell-weighted cross sections are calculated with very-low-density water as the moderator. Also, the highest enriched fuel is used as the fuel material in the lattice cell calculations. For cases that involved both low-enriched uranium (LEU) and MOX assemblies, the highest enriched fuel in the LEU assembly is used as the fuel in the lattice cell calculations.

2.2 VVER-1000 LEU and MOX FUEL ASSEMBLIES

VVER assemblies are hexagonal in shape and consist of a total of 331 pins in a hexagonal array. The assemblies are 457 cm long and do not contain any shrouds. Each assembly contains 312 fuel pins, 18 guide tubes, and 1 instrumentation tube. The pins are cylindrical and clad in zirconium. Fuel pins comprise annular fuel pellets with inner and outer diameters of 0.15 cm and 0.755 cm, respectively. Cladding inside and outside diameters are 0.772 cm and 0.910 cm, respectively. Active fuel length is 353 cm. The MOX fuel density is specified as 10.4 to 10.7 g/cm^3. The geometry data for the assembly (both LEU and MOX) are provided in Table 1.

The assembly is loaded with several different types of fuel pins with different fuel enrichments. The LEU assembly contains 3.7-wt % and 4.2-wt %-enriched (in ^{235}U) fuel pins, as well as uranium-gadolinium fuel pins. The MOX assembly contains 2.4-wt %, 2.7-wt % and 3.6-wt %-enriched (in ^{239}Pu) fuel pins, as well as uranium-gadolinium fuel pins. The pin loading for LEU and MOX assemblies are shown in Figs. 1 and 2, respectively.

The uranium-gadolinium pins contain 3.6-wt %-enriched (in ^{235}U) uranium. Gadolinium is in the form of gadolinium oxide (Gd_2O_3), which composes 4 wt % of the fuel in the uranium-gadolinium pin.

Table 1. General assembly data

	Parameter	Value
Fuel pins	Number of fuel pins	312
	Number of guide tubes	18
	Number of instrumentation tubes	1
	Pin pitch, cm	1.275
	Pellet inner diameter, cm	0.15
	Pellet outer diameter, cm	0.755
	Clad inside diameter, cm	0.772
	Clad outside diameter, cm	0.910
	Clad material	Zr
	Active fuel length, cm	353.0
Guide tubes	Inside diameter, cm	1.090
	Outside diameter, cm	1.265
	Material	Zr
Central instrumentation tube	Inside diameter, cm	0.960
	Outside diameter, cm	1.125
	Material	Zr
Assembly dimension	Flat-to-flat spacing, cm	23.6

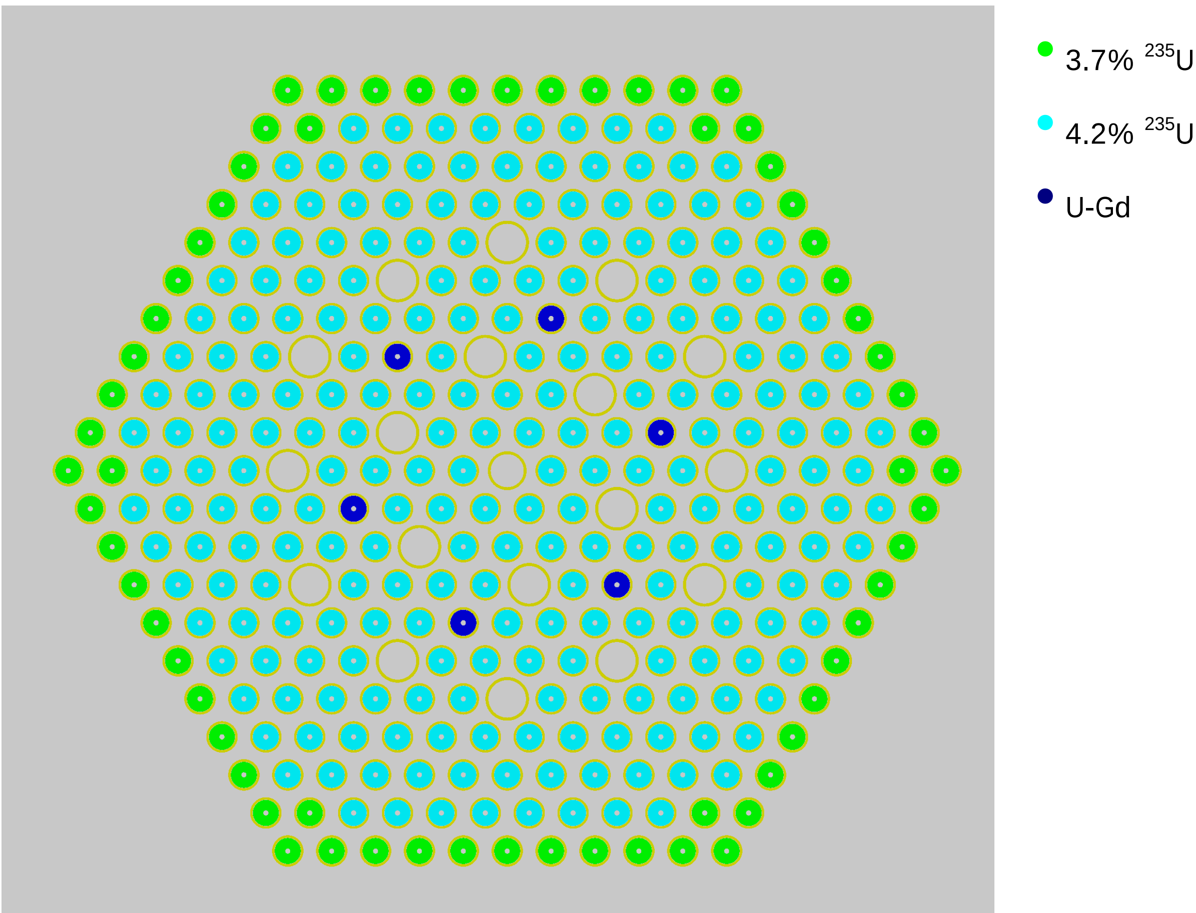

Fig. 1. VVER-1000 LEU fuel assembly of type U41G6.

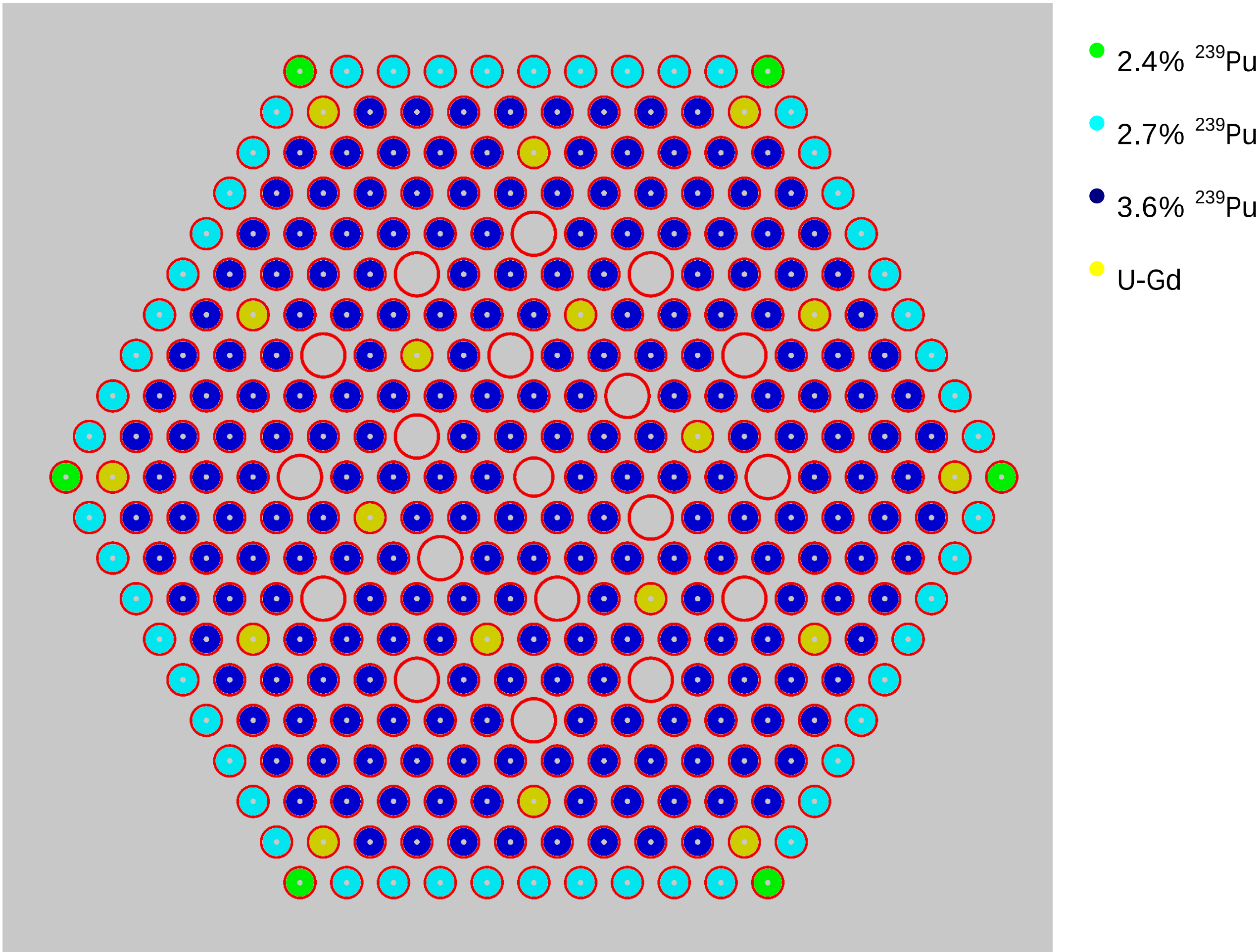

Fig. 2. VVER-1000 MOX fuel assembly of type P2G18.

3. PROBLEM 00-6a: FRESH FUEL ON RAILROAD PLATFORM AND FRESH FUEL STORAGE INSIDE THE PLANT

Fresh fuel is received at the plant by rail with units stacked on railroad cars. Two stainless steel canisters are welded together to a support structure to form a so-called *tyk* *(package-set*). Each canister contains one assembly (MOX or LEU). A cross-sectional view of a tyk is shown in Fig. 3. The details of the support structure are not known. Since it will have a very small effect on the k_{eff}, it has been ignored in the calculations.

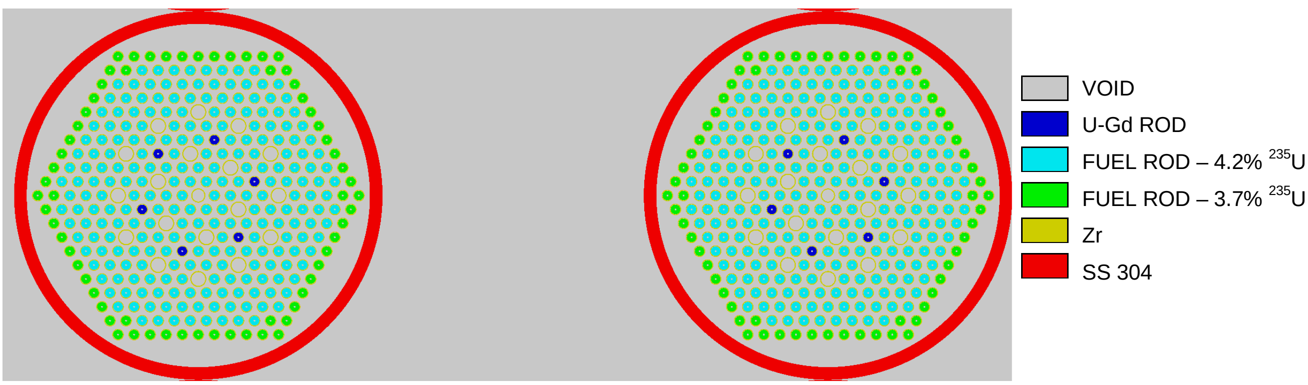

Fig. 3. Fresh LEU assemblies in the fuel transport unit (TYK).

These tyks travel on railroad cars and are stacked 3-high and 2-wide. Upon arrival at the reactor site, the tyks are unloaded and stacked in the reactor building. The length, width, and height of the stacked array are not known at this time.

The k_{eff}'s for three cases are calculated. Case 1 is an array of six tyks containing all fresh LEU assemblies corresponding to Fig. 4. Case 2 is an array of six tyks containing all fresh MOX assemblies as shown in Fig. 5. Case 3 is for an array of six tyks contaning fresh LEU assemblies, except the middle three are replaced by MOX assemblies to account for the case of a maximum of three lead test MOX assemblies being present at the site. This case is shown in Fig. 6.

Because the size of the fresh fuel storage area inside the plant (the length, width, and height of the stacked array) is not known, a critical array search with fresh LEU assemblies is performed. A previous study[12] has shown that a water density of 0.2 g/cm^3 between the canisters in an array of canisters containing VVER assemblies yields the highest k_{eff}. This situation might conceivably correspond to some type of fire-suppression condition. This case is designated as Case 4. To determine if a critical array could exist, an infinite-array calculation is performed.

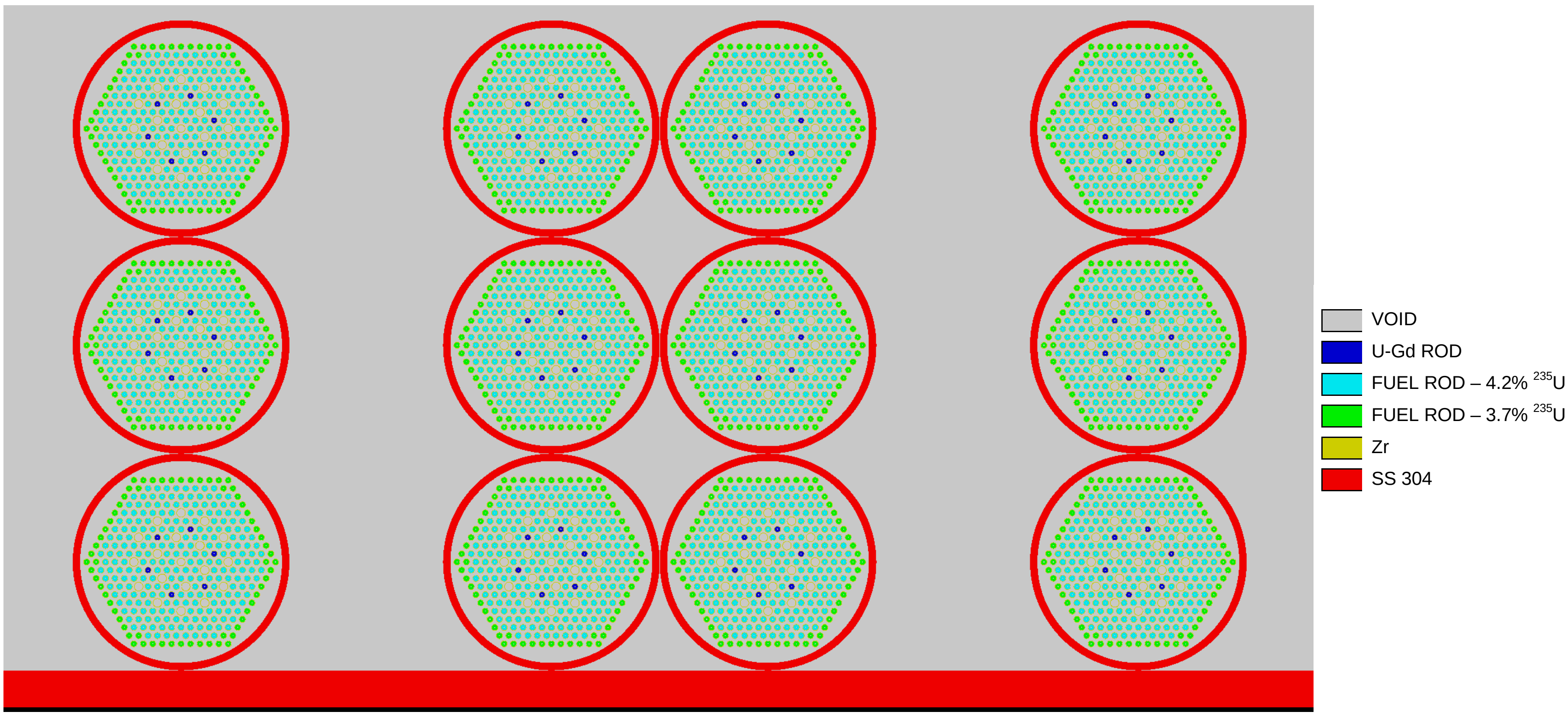

Fig. 4. Fresh LEU assemblies on the railroad platform.

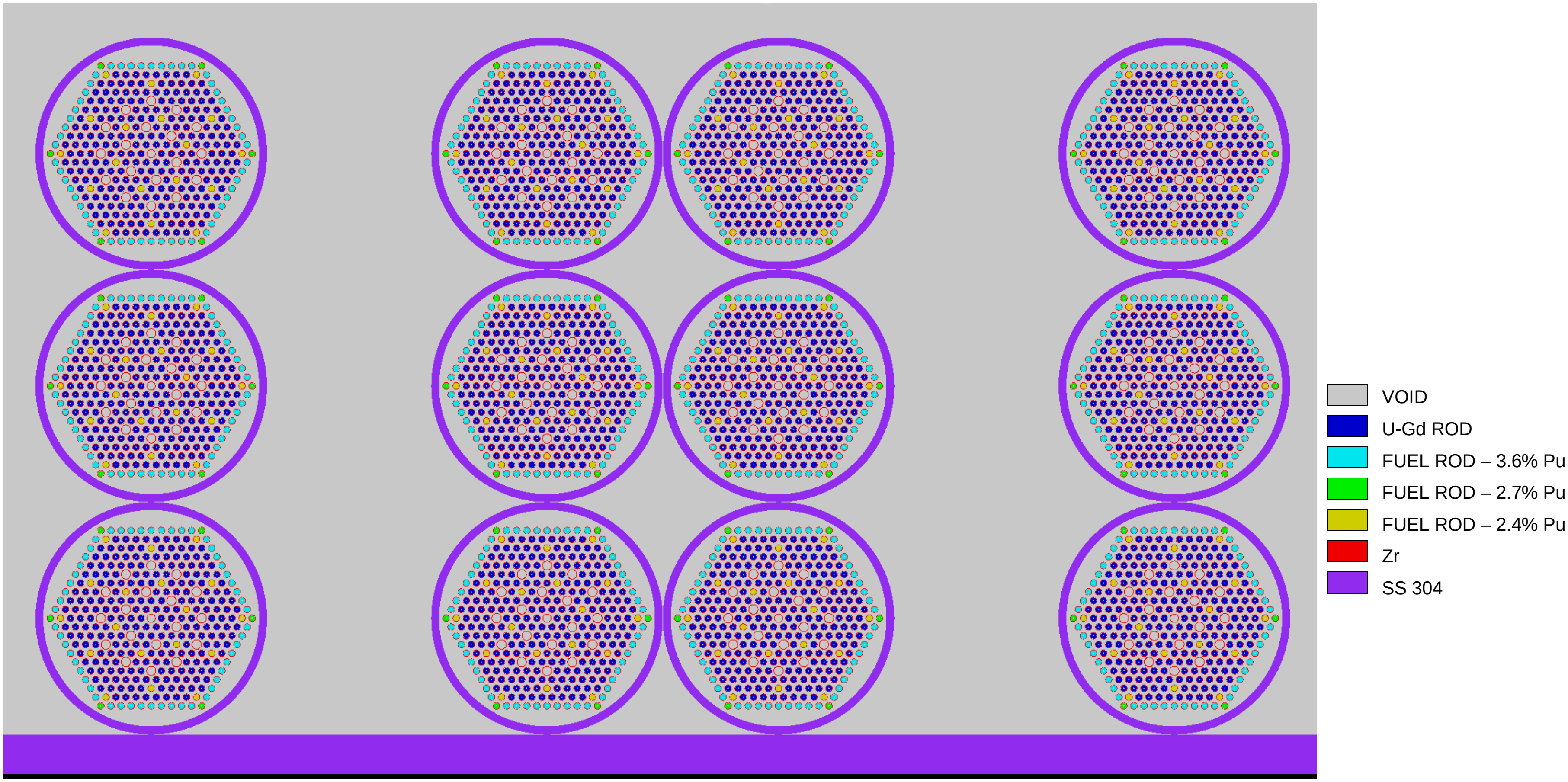

Fig. 5. Fresh MOX assemblies on the railroad platform.

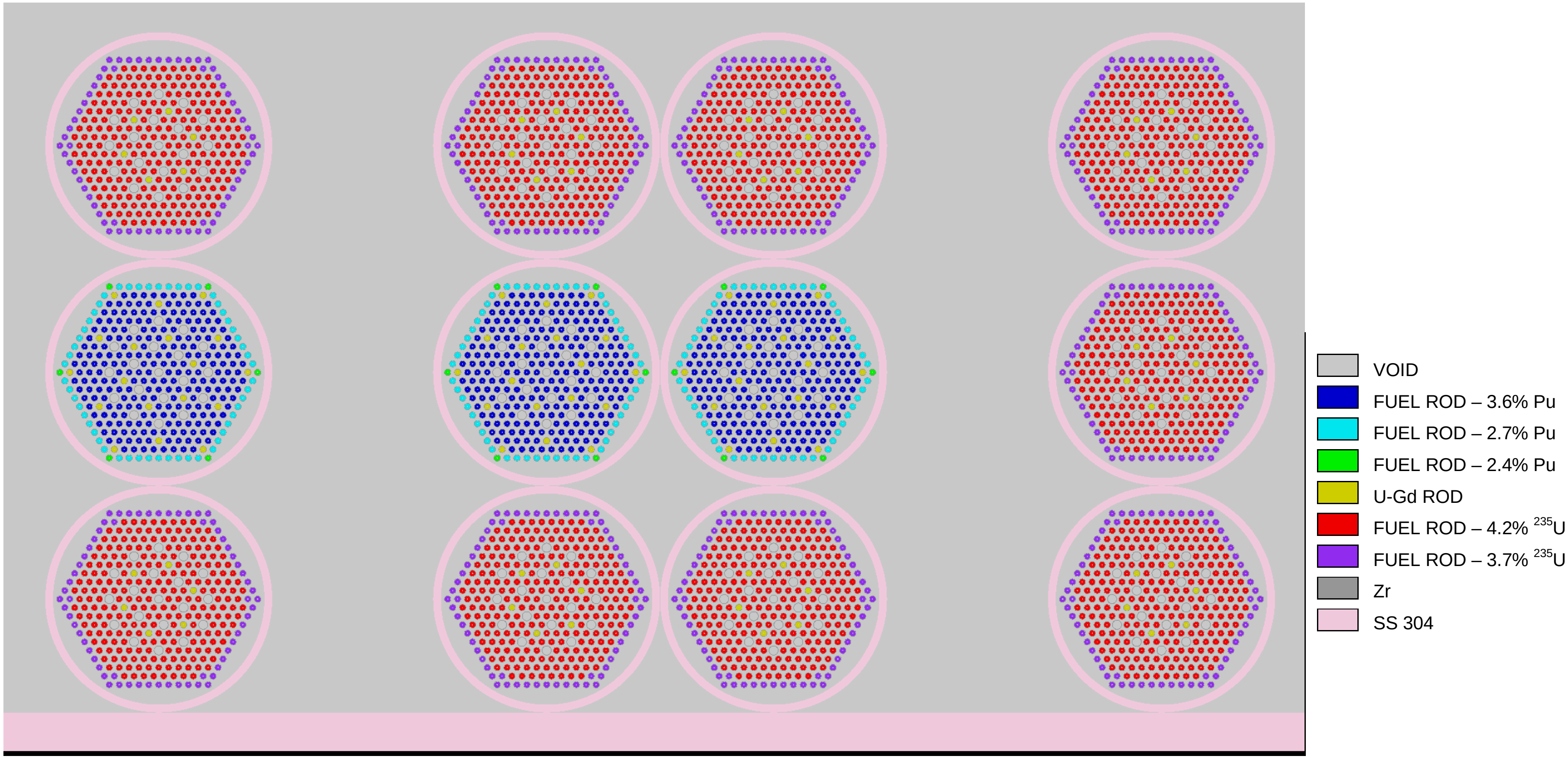

Fig. 6. Fresh LEU and MOX assemblies on the railroad platform.

3.1 ASSUMPTIONS

The following is a list of assumptions made for Problem 00-6a series problems:

1. Since the thickness or the material composition of the canisters that contain the assemblies are not known, it was assumed that these canisters are 1-cm-thick, stainless steel Type 304 cylindrical canisters (the drawings from Russia indicate that the canisters are actually elliptical).

2. Since the end fittings on the top and bottom of the fuel assemblies are not known, the end fittings are not modeled and the canisters are assumed to be slightly longer than the active fuel length.

3. The canisters are sealed, and therefore modeled as being dry.

4. The tyks are assumed to be touching in all stacked array configurations.

5. There was no information about the railroad car platform. The platform is modeled as 5-cm-thick stainless steel Type 304 that is slightly longer and wider than the footprint of the stacked array of tyks.

6. The MOX fuel density is assumed to be 10.7 g/cm^3 throughout the calculations reported in this document.

Although these assumptions have to be verified in the future, it is not expected that the k_{eff}'s will vary significantly.

3.2 RESULTS

The calculations were performed using KENO-VI with approximately 500,000 particles. The results of all four cases are given in Table 2. The data indicate that for these arrays of tyks with dry assemblies, the array of tyks with all MOX assemblies results in approximately 16% higher k_{eff} values than the array of tyks with all LEU assemblies. However, even the array of tyks with all MOX assemblies is well below the presumed upper subcritical limit. Case 4 data indicate that an infinite array (in three dimensions) of tyks results in k_{eff} well below the presumed upper subcritical limit of 0.95. Therefore, a critical array of tyks in this configuration does not exist. Since a critical configuration does not exist, infinite array calculations with full array of MOX assemblies or with three MOX assemblies are not performed. An additional calculation with full-density water was also performed. The result of this calculation agrees with previous findings that full-density water causes the units to be isolated.

Table 2. Problem 00-6a results

Description	**Filename**	k_{eff}	**σ**	$k_{eff} + 2\sigma$
Case 1: 12 LEU assemblies on railroad platform	p006ac1.inp	0.1834	0.0003	0.1840
Case 2: 12 MOX assemblies on railroad platform	p006ac2.inp	0.2121	0.0003	0.2127
Case 3: 9 LEU and 3 MOX assemblies on railroad platform	p006ac3.inp	0.1972	0.0003	0.1978
Case 4: LEU assemblies on railroad platform – optimum array search; infinite array; $\rho_{water} = 0.2$ g/cm^3	p006ac4.inp	0.7484	0.0007	0.7498
Case 4: LEU assemblies on railroad platform – optimum array search; infinite array; $\rho_{water} = 1.0$ g/cm^3	p006ac4a.inp	0.5141	0.0007	0.5155

4. PROBLEM 00-6b: FRESH FUEL TRANSPORT WITHIN PLANT

Before the fuel is loaded to the reactor, the tyks are up-ended and opened. Fresh fuel assemblies are then removed and placed in a transportation device called the fresh fuel transportation vehicle (FTV). The FTV has an inside diameter of 200 cm, and a wall thickness of 30 cm. The FTV height is 567 cm. Assemblies are assumed to rest on the floor of the FTV. The FTV contains two stainless steel grids to space the assemblies inside the vehicle. Since the details of these grids are not known, they are not modeled in the calculations. The FTV can hold 18 assemblies. However, only 16 of these 18 positions are filled with assemblies. The controls on ensuring this partial fill are unknown at this time. In the center of the FTV, there is a hexagonal support structure that is also used for grappling connection. The center-to-center pitch measured along the flat-to-flat distance of the assemblies is 40 cm. Radial and axial cross-sectional views of the FTV containing full array of 16 LEU assemblies are shown in Figs. 7 and 8, respectively.

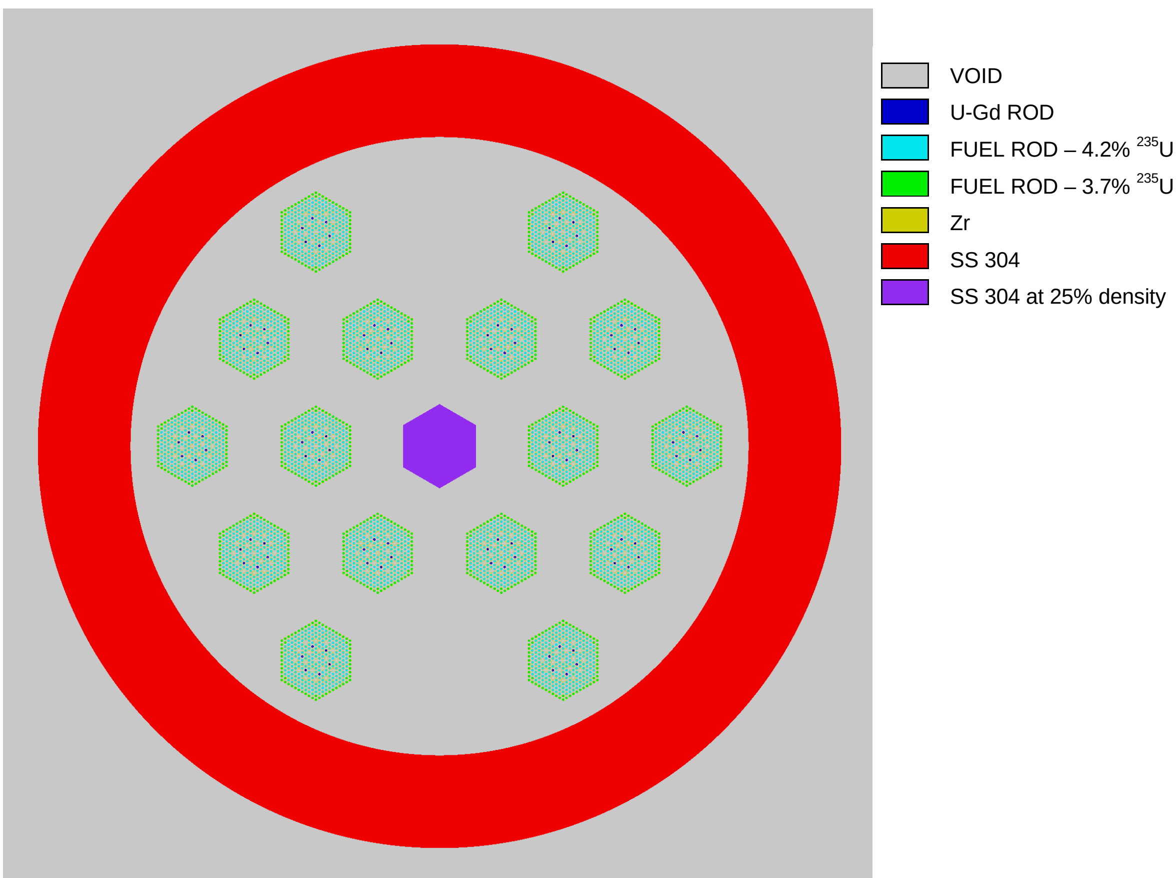

Fig. 7. Sixteen LEU assemblies in the fuel transportation vehicle.

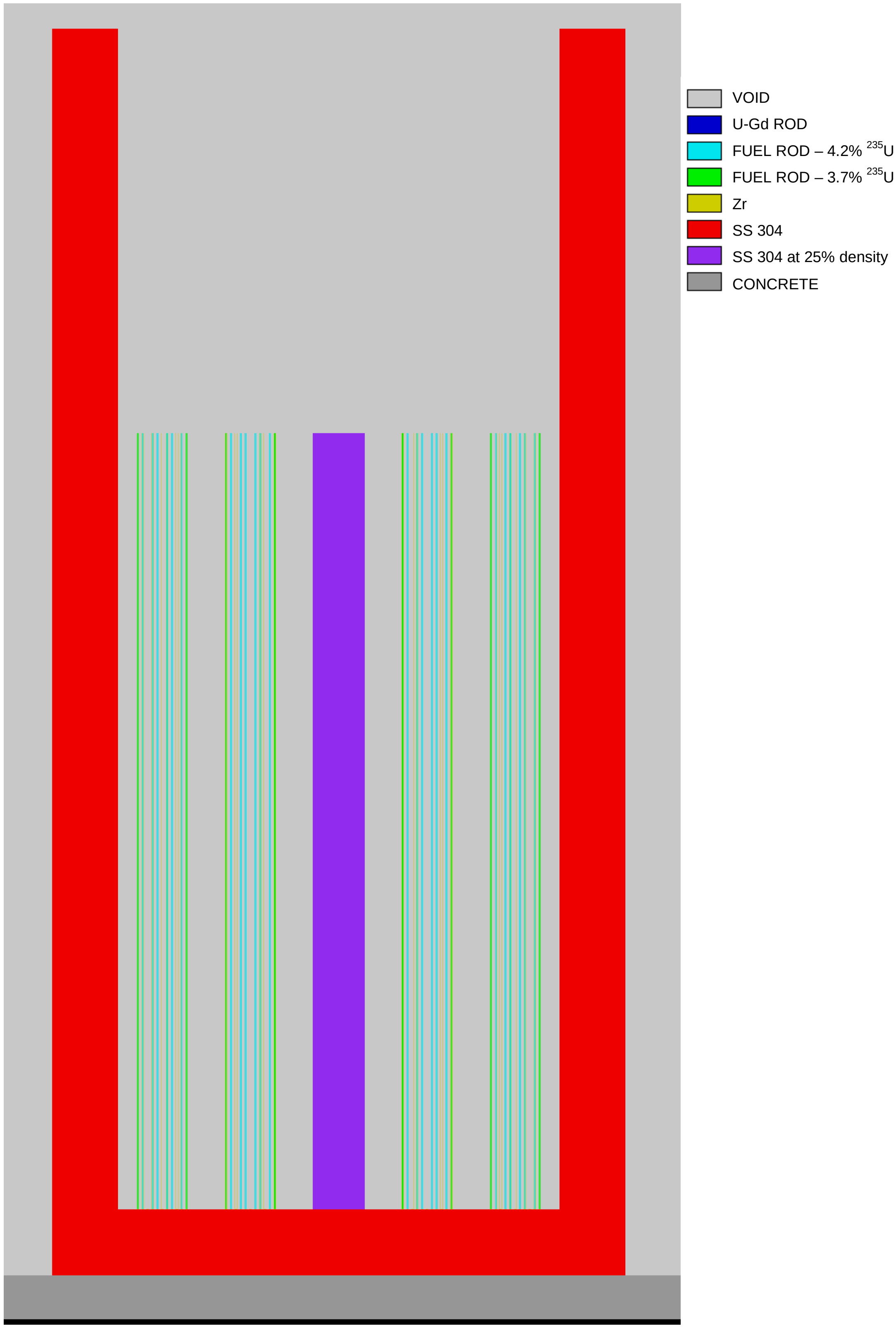

Fig. 8. Sixteen LEU assemblies in the fuel transportation vehicle – side view.

The k_{eff}'s for nine cases are calculated. Case 1 is full array of 16 fresh LEU assemblies corresponding to Fig. 7. Case 2 is for full array of 16 fresh MOX assemblies as shown in Fig. 9. Case 3 is for a full array of fresh LEU assemblies, except the middle three are replaced by MOX assemblies. This case is shown in Fig. 10. Cases 1–3 do not contain any water. Cases 4–6 are the same configurations as 1–3, except the interstitial regions in the FTV and the fuel assemblies are occupied with full-density water. For Cases 7–9 the water density is assumed to be 0.2 g/cm^3. Cases 4–9 are fully reflected by water with the same density as the water in the FTV.

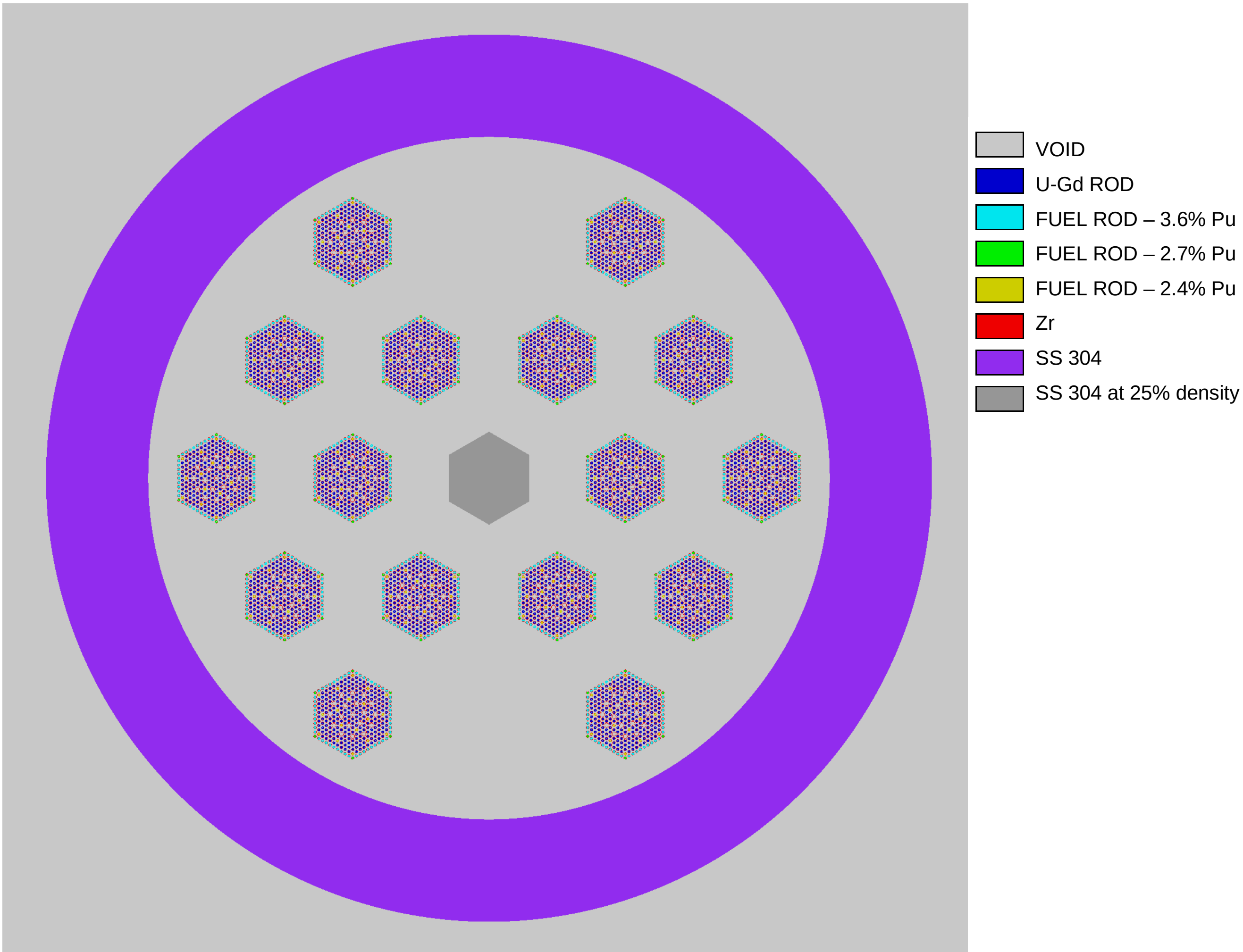

Fig. 9. Sixteen MOX assemblies in the fuel transportation vehicle.

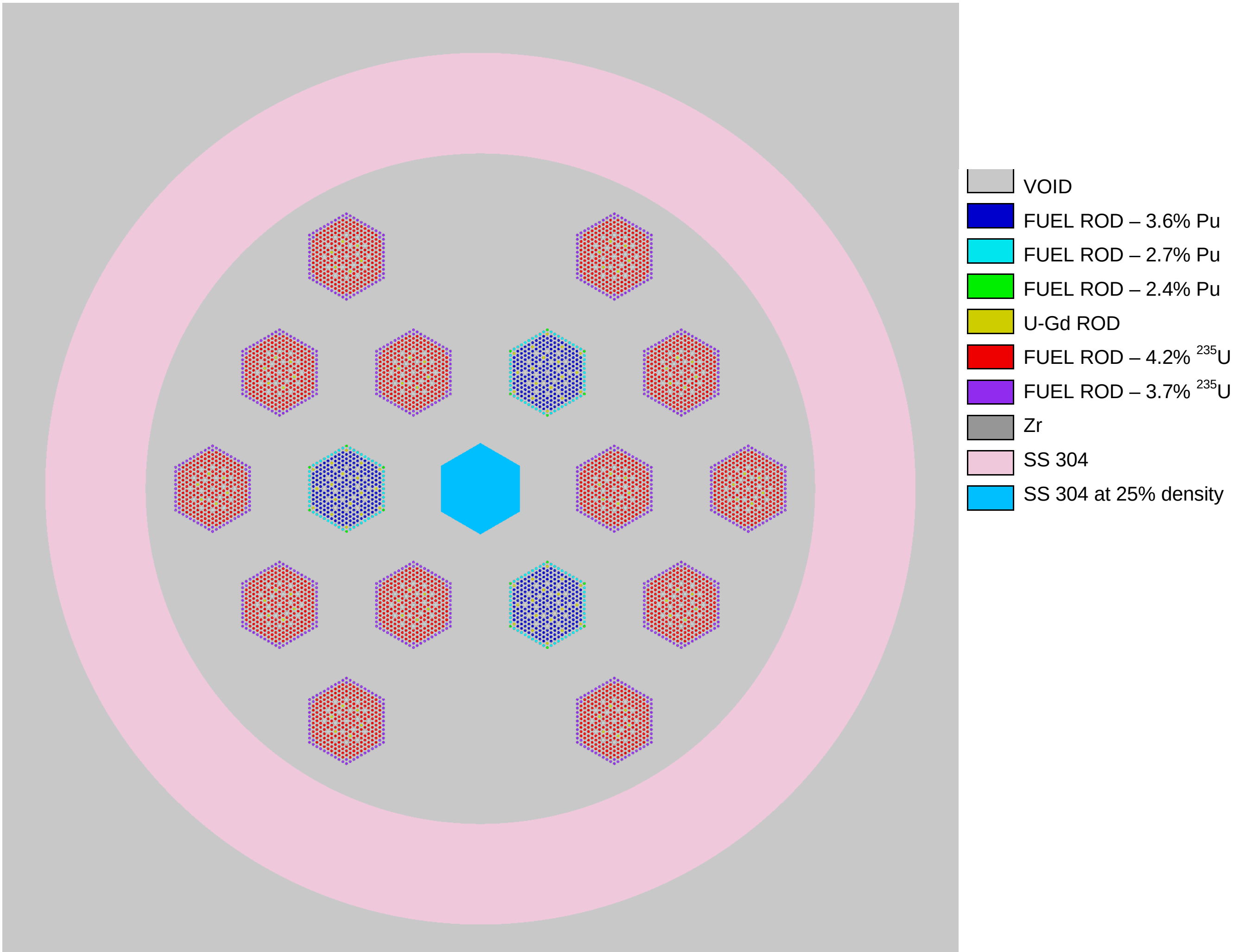

Fig. 10. Thirteen LEU and three MOX assemblies in the fuel transportation vehicle.

4.1 ASSUMPTIONS

The following is a list of assumptions made for Problem 00-6b series problems:

1. Because the thickness and the material composition of the central support structure are not known, it was assumed that this central structure is stainless steel Type 304 at 25% density and has the same shape and dimensions as a fuel assembly.

2. The FTV is assumed to be cylindrical.

3. It was assumed that the FTV stands on a 20-cm-thick concrete floor.

4. The assemblies are assumed to be in a triangular array.

4.2 RESULTS

The calculations were performed using KENO-VI with approximately 1,200,000 particles. The results of all nine cases are given in Table 3. The data indicate that for the FTV with dry assemblies, the array of all MOX assemblies results in approximately 9% higher k_{eff} than the array of all LEU assemblies. For flooded FTV, however, the array of all LEU assemblies results in 3% higher k_{eff} than the array of all MOX assemblies. The highest $k_{eff} + 2\sigma$ of 0.9356 was calculated when the water density was 0.2 g/cm^3 and the FTV contained an array of all LEU assemblies. The k_{eff}'s from a single LEU assembly and an array of all LEU assemblies in the FTV differ only by 3% when the FTV is flooded with full-density water. This percentage difference indicates that in this case the assemblies are almost isolated from each other. When the FTV is flooded with water at 0.2 g/cm^3 density, the k_{eff}'s from a single LEU assembly and an array of all LEU assemblies in the FTV differ by as much as 141%. When the water density in the FTV is 0.1 g/cm^3 or 0.3 g/cm^3, the k_{eff} decreases. Hence, the assemblies reach optimum moderation with a water density of 0.2 g/cm^3 in the assembly interstitial spaces and in the FTV. A higher k_{eff} may be obtained with different water densities in the assembly interstitial regions and inside the FTV. However, this configuration is not considered credible.

Table 3. Problem 00-6b results

Description	Filename	k_{eff}	σ	$k_{eff} + 2\sigma$
Case 1: 16 LEU assemblies in fuel transportation vehicle; dry	p006bc1.inp	0.2805	0.0002	0.2809
Case 2: 16 MOX assemblies in fuel transportation vehicle; dry	p006bc2.inp	0.3061	0.0002	0.3065
Case 3: 13 LEU and 3 MOX assemblies in fuel transportation vehicle; dry	p006bc3.inp	0.2867	0.0003	0.2873
Case 4: 16 LEU assemblies in fuel transportation vehicle; full-density water in interstitial regions and in the fuel assemblies	p006bc4.inp	0.8704	0.0007	0.8718
Case 5: 16 MOX assemblies in fuel transportation vehicle; full-density water in interstitial regions and in the fuel assemblies	p006bc5.inp	0.8440	0.0008	0.8456
Case 6: 13 LEU and 3 MOX assemblies in fuel transportation vehicle; full-density water in interstitial regions and in the fuel assemblies	p006bc6.inp	0.8675	0.0007	0.8689
Case 7: 16 LEU assemblies in fuel transportation vehicle; low-density (0.2-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc7.inp	0.9342	0.0007	0.9356
Case 8: 16 MOX assemblies in fuel transportation vehicle; low-density (0.2-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc8.inp	0.8731	0.0007	0.8745

Table 3 (continued)

Description	Filename	k_{eff}	σ	$k_{eff} + 2\sigma$
Case 9: 13 LEU and 3 MOX assemblies in fuel transportation vehicle; low-density (0.2-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc9.inp	0.9189	0.0006	0.9201
Single LEU assembly in fuel transportation vehicle; full-density water in interstitial regions and in the fuel assemblies	p006bc10.inp	0.8488	0.0008	0.8504
Single LEU assembly in fuel transportation vehicle; low-density (0.2-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc12.inp	0.3872	0.0006	0.3884
16 LEU assemblies in fuel transportation vehicle; low-density (0.1-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc71.inp	0.8903	0.0007	0.8917
16 LEU assemblies in fuel transportation vehicle; low-density (0.3-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc73.inp	0.8912	0.0007	0.8926

4.3.1 Misload

Because the controls on ensuring that the FTV is loaded with less than 16 assemblies are not known, the calculations were repeated with 18 assemblies to simulate a misload scenario. An example of an FTV loaded with 18 LEU assemblies is shown in Fig. 11. The results of calculations are given in Table 4. The data indicate the same trends as with maximum 16 assemblies in the FTV. However, the worst case with 18 LEU assemblies in the FTV with 0.2-g/cm^3-density water in the interstitial regions and in the FTV results in $k_{eff} + 2\sigma$ of 0.9840, which is well above the presumed upper subcritical limit of 0.95. The case with 15 LEU assemblies and 3 MOX assemblies results in $k_{eff} + 2\sigma$ of 0.9686, which is also above the presumed upper subcritical limit.

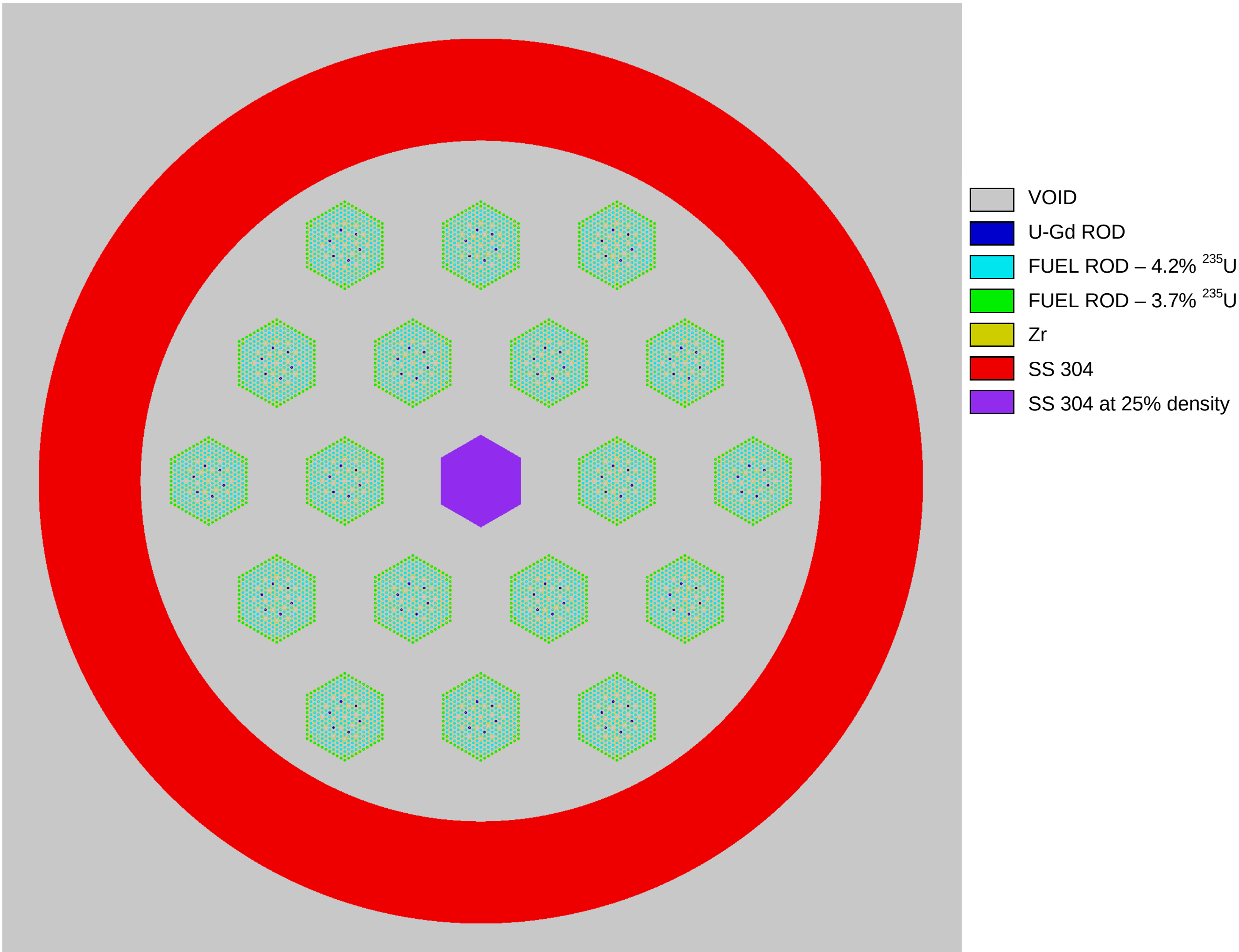

Fig. 11. Eighteen LEU assemblies in the fuel transportation vehicle.

Table 4. Problem 00-6b results for misload scenario

Description	Filename	k_{eff}	σ	$k_{eff} + 2\sigma$
Case 1: 18 LEU assemblies in fuel transportation vehicle; dry	p006bc1m.inp	0.3001	0.0003	0.3007
Case 2: 18 MOX assemblies in fuel transportation vehicle; dry	p006bc2m.inp	0.3262	0.0002	0.3266
Case 3: 15 LEU and 3 MOX assemblies in fuel transportation vehicle; dry	p006bc3m.inp	0.3060	0.0003	0.3066
Case 4: 18 LEU assemblies in fuel transportation vehicle; full-density water in interstitial regions and in the fuel assemblies	p006bc4m.inp	0.8724	0.0007	0.8738

Table 4 (continued)

Description	**Filename**	k_{eff}	**σ**	$k_{eff} + 2\sigma$
Case 5: 18 MOX assemblies in fuel transportation vehicle; full-density water in interstitial regions and in the fuel assemblies	p006bc5m.inp	0.8469	0.0008	0.8485
Case 6: 15 LEU and 3 MOX assemblies in fuel transportation vehicle; full-density water in interstitial regions and in the fuel assemblies	p006bc6m.inp	0.8736	0.0008	0.8752
Case 7: 18 LEU assemblies in fuel transportation vehicle; low-density (0.2-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc7m.inp	0.9826	0.0007	0.9840
Case 8: 18 MOX assemblies in fuel transportation vehicle; low-density (0.2-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc8m.inp	0.9144	0.0007	0.9158
Case 9: 15 LEU and 3 MOX assemblies in fuel transportation vehicle; low-density (0.2-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc9m.inp	0.9674	0.0006	0.9686
Single LEU assembly in fuel transportation vehicle; full-density water in interstitial regions and in the fuel assemblies	p006bc10m.inp	0.8476	0.0007	0.8490
Single LEU assembly in fuel transportation vehicle; low-density (0.2-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc12m.inp	0.3882	0.0007	0.3896
18 LEU assemblies in fuel transportation vehicle; low-density (0.1-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc71m.inp	0.9263	0.0007	0.9277
18 LEU assemblies in fuel transportation vehicle; low-density (0.3-g/cm^3) water in interstitial regions and in the fuel assemblies	p006bc73m.inp	0.9296	0.0007	0.9310

5. PROBLEM 00-6c: STORAGE POOL

The spent fuel storage pool holds 400 fuel assemblies having a total fuel weight of 165 MT. The pool measures 1325 cm long, 621 cm wide, and 1620 cm deep. The fuel assemblies are stored in hexagonal canning tubes made of 1% borated-stainless steel, which makes it possible to increase the capacity of the storage pool by a factor of 2 over the original pool design capacity. The calculated values for the design of the spacing of spent fuel in the spent fuel storage pool are based on a burnup of 40 MWd/kg for VVER-1000 spent fuel. The storage pool operates under atmospheric pressure.

The k_{eff}'s for three cases are calculated. Case 1 is the array of fresh LEU assemblies corresponding to Fig. 12. Case 2 is the array of fresh MOX assemblies, as shown in Fig. 13. Case 3 is for an array of fresh LEU assemblies, except the three LEU assemblies in the center of the array are replaced by MOX assemblies. This case is shown in Fig. 14. Figure 15 shows the center three LEU assemblies replaced by MOX assemblies.

5.1 ASSUMPTIONS

The following is a list of assumptions made for Problem 00-6c series problems:

1. Each fuel assembly is assumed to be surrounded by a close-fitting, 0.5-cm-thick, hexagonal, 1% borated-stainless steel can.

2. Since the can is not water-tight, it was assumed that all assembly interstitial spaces are filled with water.

3. The flat-to-flat assembly pitch is 40 cm.

4. The assemblies are assumed to be in a triangular array.

5. Although the Problem 00-6c series problems concern the spent fuel in the spent fuel storage pool, all assemblies are assumed to be fresh (i.e., beginning-of-life compositions). This assumption is conservative because the fresh fuel has more fissile material.

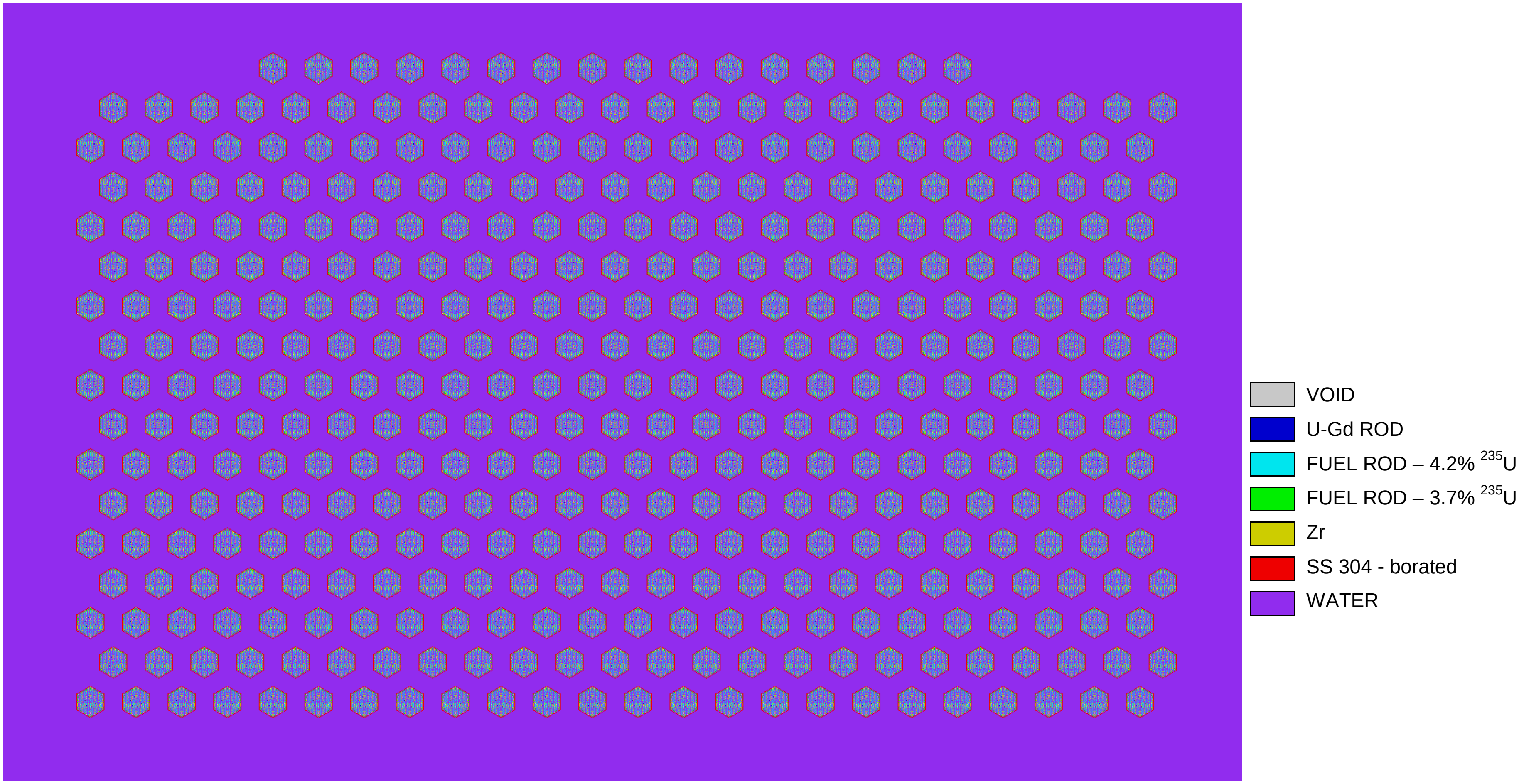

Fig. 12. Fresh LEU assemblies (24 × 16 + 16 × 1) in the spent fuel storage pool.

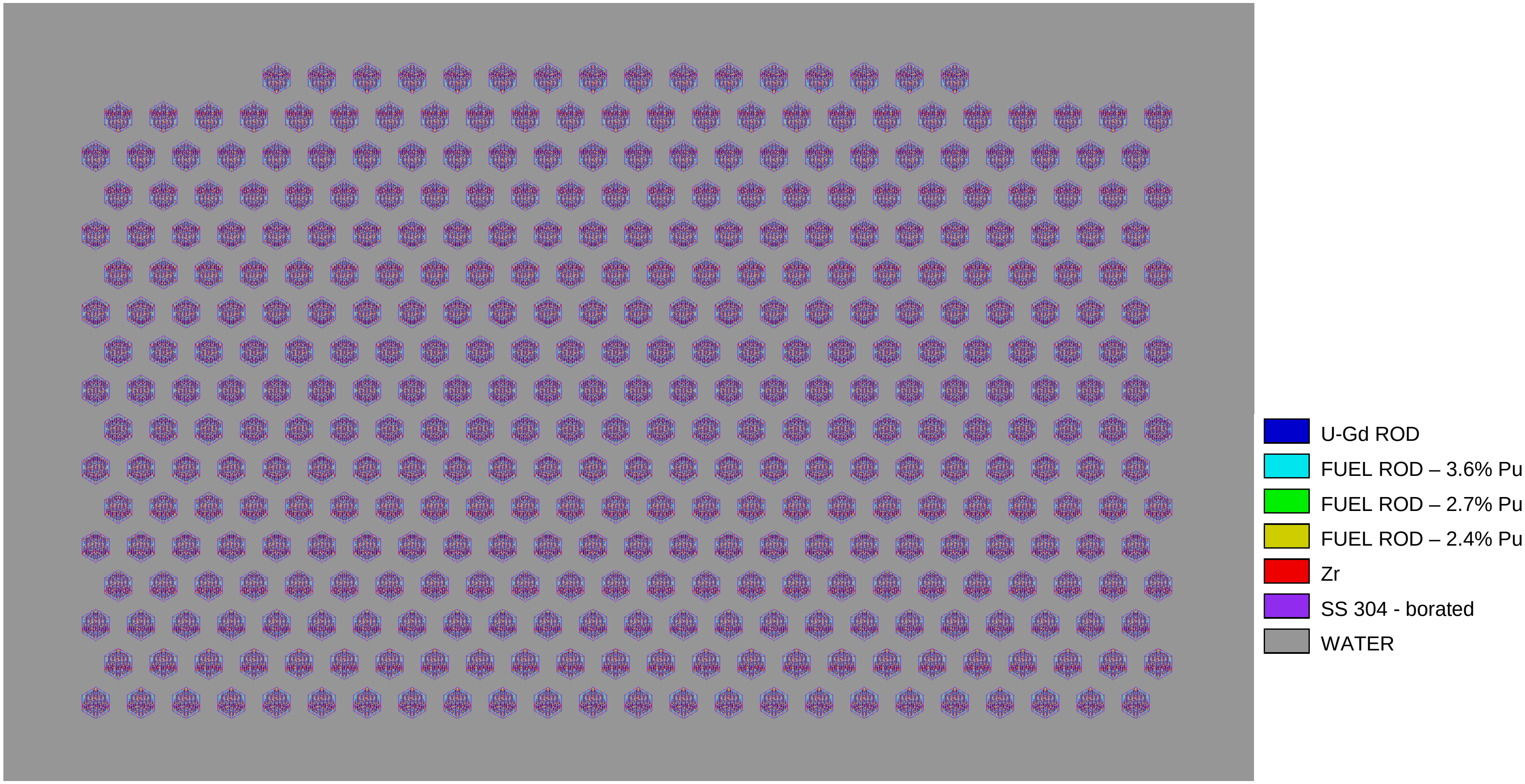

Fig. 13. Fresh MOX assemblies (24 × 16 + 16 × 1) in the spent fuel storage pool.

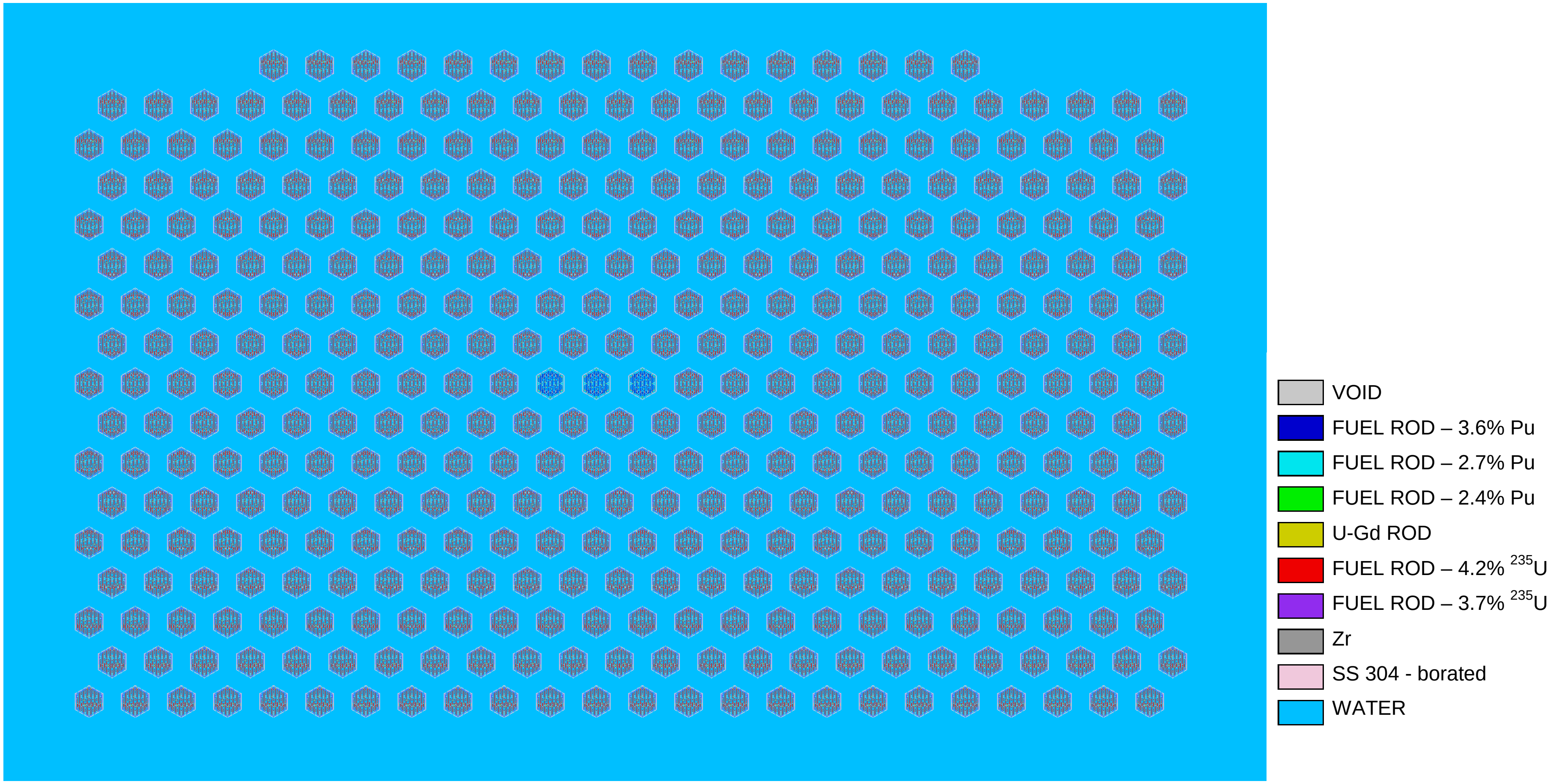

Fig. 14. Fresh LEU (24 × 16 + 16 × 1) and MOX assemblies in the spent fuel storage pool.

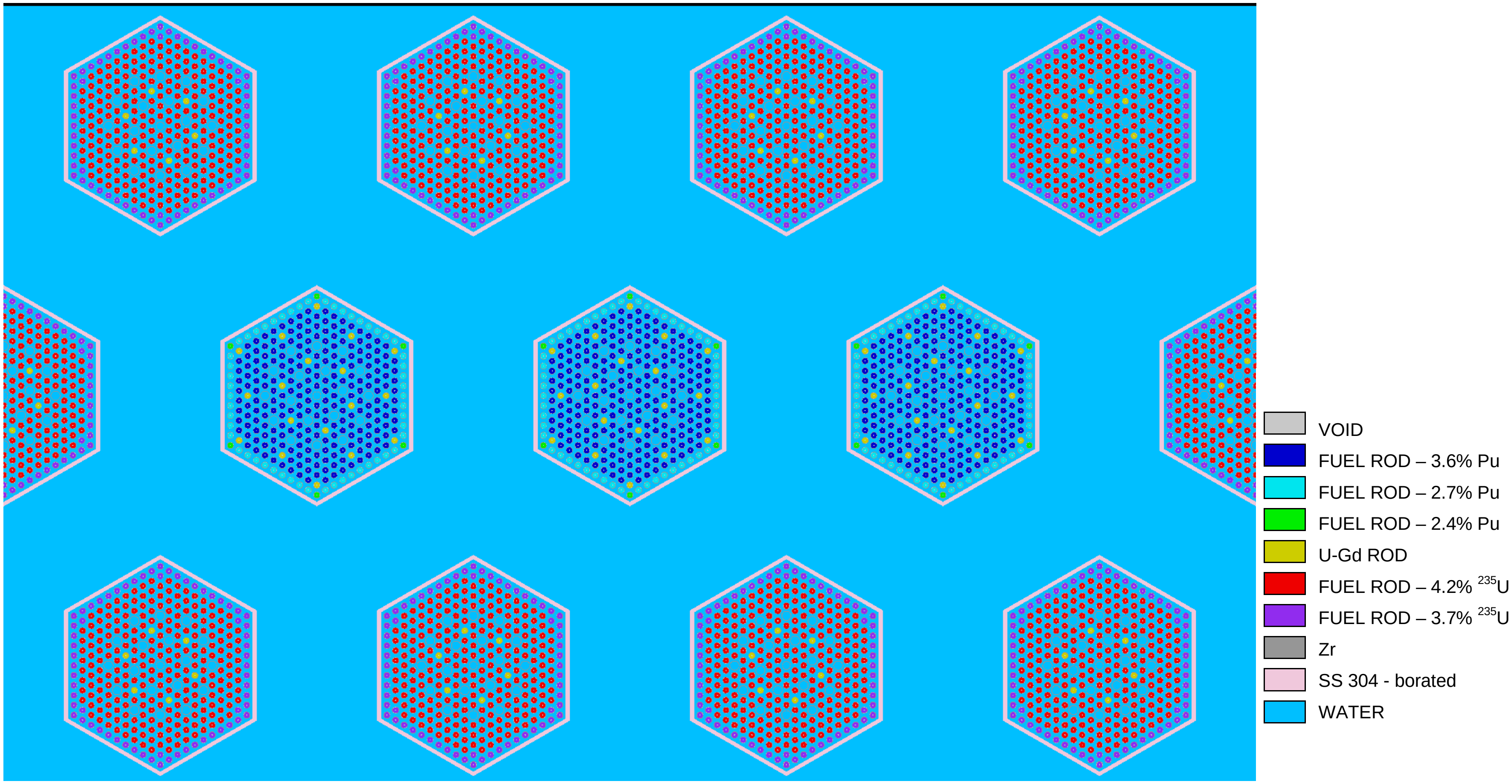

Fig. 15. Fresh LEU and MOX assemblies in the spent fuel storage pool.

5.2 RESULTS

The calculations were performed using KENO-VI with approximately 1,200,000 particles. The results of all three cases are given in Table 5. The spent fuel storage pool can contain up to 32 × 17 assemblies with a flat-to-flat pitch of 40 cm. Filling all these positions results in 544 assemblies. Since there can only be 400 assemblies in the storage pool, the number of assemblies in rows and columns is varied for each case. First, each row is filled with 24 assemblies only. This results in a square-like array of 16 rows with 24 assemblies, and 1 partially filled row with 16 assemblies in the middle. This configuration is shown in Figs. 12 and 13 for a full array of all LEU and MOX assemblies, respectively. Second, each row is filled completely. This results in a rectangular-shaped array with 12 completely filled rows and 1 partially filled row (16 assemblies in the middle of the row), as shown in Fig. 16 (for a full array of all MOX assemblies).

The results indicate that the shape of the array has no effect on the system k_{eff} (all data are within statistical uncertainty). To see the effect of misload, additional cases with all possible slots in the storage pool filled with fresh fuel assemblies are run. The results show that this misload is not a concern, since increasing the total number of assemblies from 400 to 544 had no effect on the system k_{eff}'s. This is due to the fact that the assemblies in borated stainless steel cans are isolated from each other, and even a single assembly results in approximately the same k_{eff}.

Table 5. Problem 00-6c results

Description	Filename	k_{eff}	σ	$k_{eff} + 2\sigma$
Case 1: 32 × 17 × 1 array (total 544) of LEU assemblies in storage pool	p006cc1.inp	0.7063	0.0007	0.7077
Case 1: 24 × 16 × 1 + 16 × 1 × 1 array (total 400) of LEU assemblies in storage pool	p006cc1a.inp	0.7080	0.0007	0.7094
Case 1: 32 × 12 × 1 + 16 × 1 × 1 array (total 400) of LEU assemblies in storage pool	p006cc1b.inp	0.7072	0.0007	0.7086
Case 2: 32 × 17 × 1 array (total 544) of MOX assemblies in storage pool	p006cc2.inp	0.7219	0.0007	0.7233
Case 2: 24 × 16 × 1 + 16 × 1 × 1 array (total 400) of MOX assemblies in storage pool	p006cc2a.inp	0.7228	0.0007	0.7242
Case 2: 32 × 12 × 1 + 16 × 1 × 1 array (total 400) of MOX assemblies in storage pool	p006cc2b.inp	0.7232	0.0007	0.7246
Case 3: 24 × 16 × 1 + 16 × 1 × 1 array (total 400) of LEU assemblies with 3 MOX assemblies in the middle in storage pool	p006cc3a.inp	0.7090	0.0008	0.7106
Single LEU assembly in storage pool	p006cc1x.inp	0.6954	0.0008	0.6970

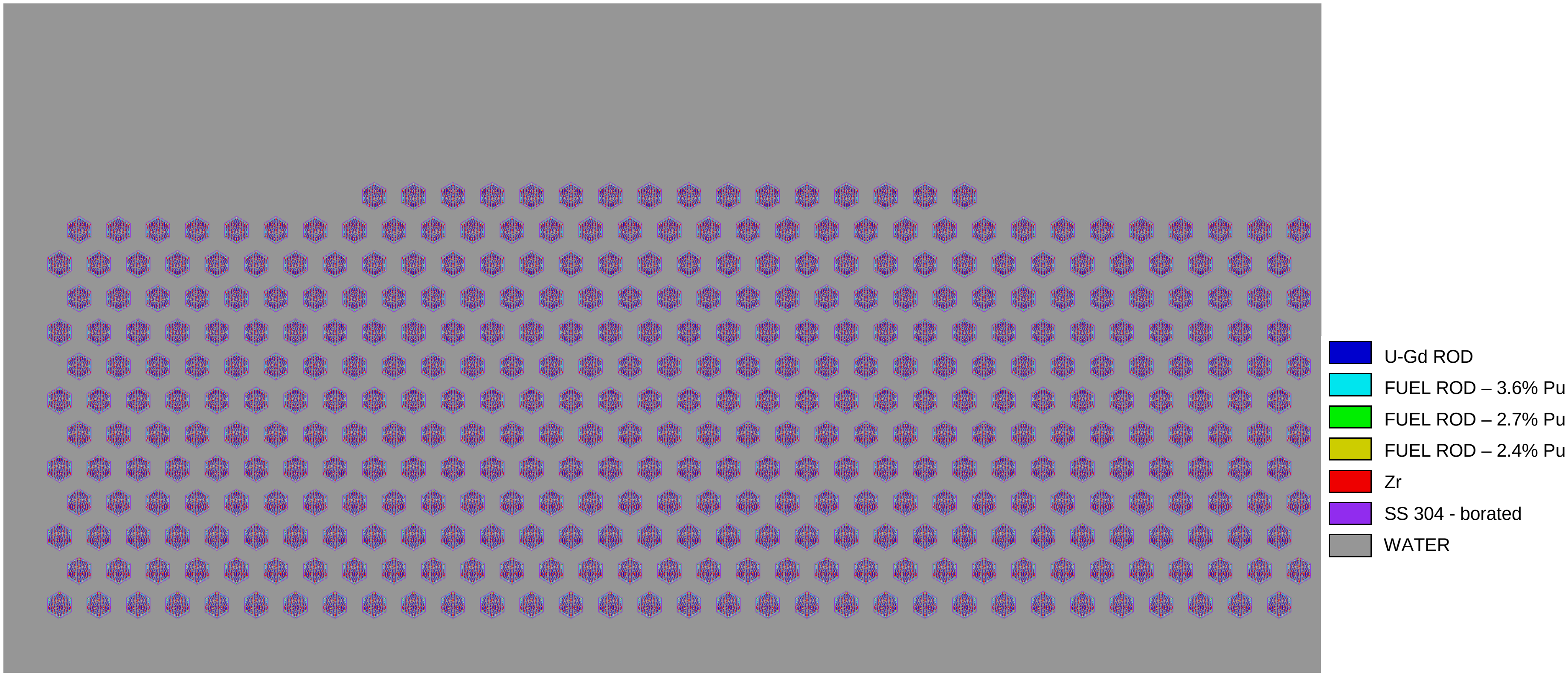

Fig. 16. Fresh MOX assemblies (32 × 12 + 16 × 1) in the spent fuel storage pool.

6. CONCLUSIONS AND SUMMARY

Fresh fuel assemblies on the railroad platform, in fresh fuel storage, in the FTV, or in the spent fuel storage pool result in k_{eff}'s below the presumed upper subcritical limit and do not pose any concerns under normal operating conditions. However, for an accident condition of fully loaded FTV that is flooded with low-density water (possibly from a fire-suppression system), the presumed upper subcritical limit is exceeded by configurations containing LEU assemblies or LEU assemblies and 3 MOX LTAs. Administrative or geometric controls to prevent this misload scenario need to be identified. The misload scenario in the spent fuel storage pool, on the other hand, does not cause any significant change in the system k_{eff}, and therefore is not a concern.

If there is no absorber between the units, the configurations with all MOX assemblies result in higher effective multiplication factors than the configurations with all LEU assemblies when the system is dry. When the system is flooded, the configurations with all LEU assemblies result in higher effective multiplication factors.

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APPENDIX A

SAMPLE INPUTS

APPENDIX A

SAMPLE INPUTS

A.1 FRESH FUEL ON RAILROAD PLATFORM

p006ac1.inp

```
=csas26          parm=size=1000000
VVER assemblies in Balakovo, 2 canister unit,1 assembly per canister
' Base file that contains all MOX and LEU info
' Create new configurations by changing units used in array definitions
' Sedat Goluoglu ---- 8/07/2000
238groupndf5  latticecell
'MOX with 4.08 wt% PuO2 (3.6 wt percent Pu), assume max. density
uo2    1  den=10.7000 0.9592 300  92235 0.2  92238 99.8 end
puo2   1  den=10.7000 0.0408 300  94238 2.009E-02 94239 93.98
  94240 5.798 94241 0.1786 94242 2.964E-02 end
'MOX with 3.06 wt% PuO2 (2.7 wt percent Pu), assume max. density
uo2    2  den=10.7000 0.9694 300  92235 0.2  92238 99.8 end
puo2   2  den=10.7000 0.0306 300  94238 2.009E-02 94239 93.98
  94240 5.798 94241 0.1786 94242 2.964E-02 end
'MOX with 2.72 wt% PuO2 (2.4 wt percent Pu), assume max. density
uo2    3  den=10.7000 0.9728 300  92235 0.2  92238 99.8 end
puo2   3  den=10.7000 0.0272 300  94238 2.009E-02 94239 93.98
               94240 5.798 94241 0.1786 94242 2.964E-02 end
'UO2-GdO2 w/4% GdO2 and 96% fuel which is 3.6 wt% enriched
u-235  4  0 8.0203E-04  300 end
u-238  4  0 2.1477E-02  300 end
gd-152 4  0 1.9666E-06  300 end
gd-154 4  0 2.1462E-05  300 end
gd-155 4  0 1.4569E-04  300 end
gd-156 4  0 2.0151E-04  300 end
gd-157 4  0 1.5405E-04  300 end
gd-158 4  0 2.4452E-04  300 end
gd-160 4  0 2.1519E-04  300 end
o      4  0 4.6034E-02  300 end
'LEU w/ 4.2% enriched UO2
uo2    5  den=10.4025 1.0 300  92235 4.2  92238 95.8 end
'LEU w/ 3.7% enriched UO2
uo2    6  den=10.4025 1.0 300  92235 3.7  92238 96.3 end
zr     7  1.0 300 end
ss304  8  1.0 300 end
'very low density water for lattice cell calculations
h2o    9  den=0.001 1.0 300 end
end comp
'use UO2 for lattice cell
triangpitch  1.2750 0.7550 5 9 0.9100 7 0.772 0 end
more data
dab=400
end more
```

```
read param
 tme=1000 gen=263 nsk=13 npg=2000  plt=yes
 nub=yes lng=1500000 nb8=500  far=yes run=yes
end param
read bounds all=vacuum end bounds
read geom
unit 1
com='MOX fuel pin 3.6 wt% Pu'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 1 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 2
com='MOX fuel pin 2.7 wt% Pu'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 2 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 3
com='MOX fuel pin 2.4 wt% Pu'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 3 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 4
com='MOX fuel pin U-Gd'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 4 1 102 -101
media 0 1 103 -102
```

```
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 5
com='guide tube'
cylinder 501 0.545  176.5   -176.5
cylinder 502 0.6325 176.569 -176.569
hexprism 503 0.6375  176.569 -176.569
media 0 1 501
media 7 1 502 -501
media 0 1 503 -502
boundary 503
unit 6
com='instrumentation tube'
cylinder 601 0.480  176.5   -176.5
cylinder 602 0.5625 176.569 -176.569
hexprism 603 0.6375  176.569 -176.569
media 0 1 601
media 7 1 602 -601
media 0 1 603 -602
boundary  603
unit 7
com='dummy cell'
hexprism  701 0.6375  176.569 -176.569
media 0 1 701
boundary  701
unit 8
com='MOX Assembly'
hexprism  801 11.8 176.569 -176.569  rotate a1=90
array 1   801 place 12 12 1 0.0 0.0 0.0
boundary  801
unit 10
com='dummy assembly'
hexprism  1001 11.8 176.569 -176.569
media 0 1 1001
boundary  1001
unit 11
com='LEU fuel pin 4.2%'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 5 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 12
com='LEU fuel pin 3.7%'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
```

```
media 0 1 101
media 6 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 18
com='LEU Assembly'
hexprism  1801 11.8 176.569 -176.569 rotate a1=90
array 5   1801 place 12 12 1 0.0 0.0 0.0
boundary  1801
unit 21
com=' 1cm thick canister containing 1 assembly'
hexprism  2100 11.8 176.569 -176.569 rotate a1=90
hole 18
cylinder  2101 13.6255 176.569 -176.569
cylinder  2102 14.6255 177.569 -177.569
cuboid    2103 2p25.0000 2p14.6255 2p177.569
media 0 1 2101 2101 -2100
media 8 1 2102 2102 -2101
media 0 1 2103 2103 -2102
boundary  2103
unit 22
com=' 2 canisters called a unit - pitch is 50cm'
cuboid    2201 2p39.6255 2p14.6255 2p177.569
array 3   2201 place 1 1 1 -25.0000 2*0.0
boundary  2201
global unit 23
com=' units stacked 3-high 2-wide on a 5cm thick SS platform'
cuboid    2301 2p79.251 2p43.8765 2p177.569
cuboid    2302 2p89.251 -43.8765 -48.8765 2p187.569
cuboid    2303 2p89.251  48.8765 -48.8765 2p187.569
array 4   2301 place 1 2 1 -39.6255 2*0.0
media 8 1 2302 -2301
media 0 1 2303 -2302 -2301
boundary  2303
end geom
read array
'MOX Assembly
ara=1 typ=triangular nux=23 nuy=23 nuz=1
fill
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
 7 7 7 7 7 7 7 7 7 7 7 3 2 2 2 2 2 2 2 2 2 3 7
  7 7 7 7 7 7 7 7 7 7 2 4 1 1 1 1 1 1 1 1 4 2 7
   7 7 7 7 7 7 7 7 7 2 1 1 1 1 1 4 1 1 1 1 1 2 7
    7 7 7 7 7 7 7 7 2 1 1 1 1 1 1 1 1 1 1 1 1 2 7
     7 7 7 7 7 7 7 2 1 1 1 1 1 1 5 1 1 1 1 1 1 2 7
      7 7 7 7 7 7 2 1 1 1 1 5 1 1 1 1 5 1 1 1 1 2 7
       7 7 7 7 7 2 1 4 1 1 1 1 4 1 1 1 1 1 1 4 1 2 7
        7 7 7 7 2 1 1 1 5 1 1 1 1 5 1 4 1 5 1 1 1 2 7
         7 7 7 2 1 1 1 1 1 1 5 1 1 1 1 1 1 1 1 1 1 2 7
          7 7 2 1 1 1 1 1 4 1 1 1 1 1 5 1 1 1 1 1 1 2 7
           7 3 4 1 1 1 5 1 1 1 1 6 1 1 1 1 5 1 1 1 4 3 7
            7 2 1 1 1 1 1 1 5 1 1 1 1 1 4 1 1 1 1 1 2 7 7
             7 2 1 1 1 1 1 1 1 1 1 1 5 1 1 1 1 1 1 2 7 7 7
              7 2 1 1 1 5 1 4 1 5 1 1 1 1 5 1 1 1 2 7 7 7 7
               7 2 1 4 1 1 1 1 1 1 4 1 1 1 1 4 1 2 7 7 7 7 7
```

```
                7 2 1 1 1 1 5 1 1 1 1 5 1 1 1 1 2 7 7 7 7 7 7
                 7 2 1 1 1 1 1 1 5 1 1 1 1 1 1 2 7 7 7 7 7 7 7
                  7 2 1 1 1 1 1 1 1 1 1 1 1 1 2 7 7 7 7 7 7 7 7
                   7 2 1 1 1 1 1 4 1 1 1 1 1 2 7 7 7 7 7 7 7 7 7
                    7 2 4 1 1 1 1 1 1 1 1 4 2 7 7 7 7 7 7 7 7 7 7
                     7 3 2 2 2 2 2 2 2 2 2 3 7 7 7 7 7 7 7 7 7 7 7
                      7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
end fill
'2 Canisters
ara=3 nux=2 nuy=1 nuz=1
fill 21 21 end fill
'2x3 stack of units
ara=4 nux=2 nuy=3 nuz=1
fill 22 22
     22 22
     22 22 end fill
'LEU Assembly
ara=5 typ=triangular nux=23 nuy=23 nuz=1
fill
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
7 7 7 7 7 7 7 7 7 7 7 12 12 12 12 12 12 12 12 12 12 12 7
7 7 7 7 7 7 7 7 7 7 12 12 11 11 11 11 11 11 11 11 12 12 7
7 7 7 7 7 7 7 7 7 12 11 11 11 11 11 11 11 11 11 11 11 12 7
7 7 7 7 7 7 7 7 12 11 11 11 11 11 11 11 11 11 11 11 11 12 7
7 7 7 7 7 7 7 12 11 11 11 11 11 11  5 11 11 11 11 11 11 12 7
7 7 7 7 7 7 12 11 11 11 11  5 11 11 11 11  5 11 11 11 11 12 7
7 7 7 7 7 12 11 11 11 11 11 11  4 11 11 11 11 11 11 11 11 12 7
7 7 7 7 12 11 11 11  5 11 11 11 11  5 11  4 11  5 11 11 11 12 7
7 7 7 12 11 11 11 11 11 11  5 11 11 11 11 11 11 11 11 11 11 12 7
7 7 12 11 11 11 11 11  4 11 11 11 11 11  5 11 11 11 11 11 11 12 7
7 12 12 11 11 11  5 11 11 11 11  6 11 11 11 11  5 11 11 11 12 12 7
7 12 11 11 11 11 11 11  5 11 11 11 11 11  4 11 11 11 11 11 12 7 7
7 12 11 11 11 11 11 11 11 11 11 11  5 11 11 11 11 11 11 12 7 7 7
7 12 11 11 11  5 11  4 11  5 11 11 11 11  5 11 11 11 12 7 7 7 7
7 12 11 11 11 11 11 11 11 11  4 11 11 11 11 11 11 12 7 7 7 7 7
7 12 11 11 11 11  5 11 11 11 11  5 11 11 11 11 12 7 7 7 7 7 7
7 12 11 11 11 11 11 11  5 11 11 11 11 11 11 12 7 7 7 7 7 7 7
7 12 11 11 11 11 11 11 11 11 11 11 11 11 12 7 7 7 7 7 7 7 7
7 12 11 11 11 11 11 11 11 11 11 11 11 12 7 7 7 7 7 7 7 7 7
7 12 12 11 11 11 11 11 11 11 11 12 12 7 7 7 7 7 7 7 7 7 7
7 12 12 12 12 12 12 12 12 12 12 12 7 7 7 7 7 7 7 7 7 7 7
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
end fill
end array
read plot lpi=10 scr=yes
  ttl='Fresh LEU Assemblies on Railroad Platform'
  xul=-90  yul=50 zul=0 xlr=90  ylr=-50  zlr=0
  uax=1 vdn=-1.0 nax=640 pic=mat end
  ttl='Fresh LEU Assembly in a Canister'
  xul=-30  yul=15 zul=0 xlr=0   ylr=-15  zlr=0
  uax=1 vdn=-1.0 nax=640 pic=mat end
  ttl='Fresh LEU Assemblies on Railroad Platform'
  xul=-90  yul=50 zul=0 xlr=90  ylr=-50  zlr=0
  uax=1 vdn=-1.0 nax=640 pic=unt end
end plot
end data
end
```

A.2 FRESH FUEL TRANSPORT WITHIN PLANT

p006bc1.inp

```
=csas26          parm=size=1000000
VVER assemblies in Balakovo, fuel transportation vehicle
' Base file that contains all MOX and LEU info
' Create new configurations by changing units used in array definitions
' Sedat Goluoglu ---- 8/07/2000
' correction: there are 16 assemblies only  8/14/2000
238groupndf5  latticecell
'MOX with 4.08 wt% PuO2 (3.6 wt percent Pu), assume max. density
uo2    1  den=10.7000 0.9592 300  92235 0.2  92238 99.8 end
puo2   1  den=10.7000 0.0408 300  94238 2.009E-02 94239 93.98
  94240 5.798 94241 0.1786 94242 2.964E-02 end
'MOX with 3.06 wt% PuO2 (2.7 wt percent Pu), assume max. density
uo2    2  den=10.7000 0.9694 300  92235 0.2  92238 99.8 end
puo2   2  den=10.7000 0.0306 300  94238 2.009E-02 94239 93.98
  94240 5.798 94241 0.1786 94242 2.964E-02 end
'MOX with 2.72 wt% PuO2 (2.4 wt percent Pu), assume max. density
uo2    3  den=10.7000 0.9728 300  92235 0.2  92238 99.8 end
puo2   3  den=10.7000 0.0272 300  94238 2.009E-02 94239 93.98
               94240 5.798 94241 0.1786 94242 2.964E-02 end
'UO2-GdO2 w/4% GdO2 and 96% fuel which is 3.6 wt% enriched
u-235  4  0 8.0203E-04  300 end
u-238  4  0 2.1477E-02  300 end
gd-152 4  0 1.9666E-06  300 end
gd-154 4  0 2.1462E-05  300 end
gd-155 4  0 1.4569E-04  300 end
gd-156 4  0 2.0151E-04  300 end
gd-157 4  0 1.5405E-04  300 end
gd-158 4  0 2.4452E-04  300 end
gd-160 4  0 2.1519E-04  300 end
o      4  0 4.6034E-02  300 end
'LEU w/ 4.2% enriched UO2
uo2    5  den=10.4025 1.0 300  92235 4.2  92238 95.8 end
'LEU w/ 3.7% enriched UO2
uo2    6  den=10.4025 1.0 300  92235 3.7  92238 96.3 end
zr     7  1.0 300 end
ss304  8  1.0 300 end
'very low density water for lattice cell calculations - dry case only
h2o    9  den=0.001 1.0 300 end
h2o   10  den=1.0   1.0 300 end
'SS304 center structure @25% density (100%=7.94)
ss304 11  den=1.985 1.0 300 end
orconcrete 12  1.0 300 end
end comp
'use UO2 for lattice cell
triangpitch  1.2750 0.7550 5 9 0.9100 7 0.772 0 end
more data
dab=400
end more
```

```
read param
 tme=1000 gen=313 nsk=13 npg=4000  plt=yes
 nub=yes lng=1500000 nb8=500  far=yes run=yes
 tba=1.0
end param
read bounds all=vacuum end bounds
read geom
unit 1
com='MOX fuel pin 3.6 wt% Pu'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 1 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 2
com='MOX fuel pin 2.7 wt% Pu'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 2 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 3
com='MOX fuel pin 2.4 wt% Pu'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 3 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 4
com='MOX fuel pin U-Gd'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 4 1 102 -101
```

```
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 5
com='guide tube'
cylinder 501 0.545  176.5   -176.5
cylinder 502 0.6325 176.569 -176.569
hexprism 503 0.6375  176.569 -176.569
media 0 1 501
media 7 1 502 -501
media 0 1 503 -502
boundary 503
unit 6
com='instrumentation tube'
cylinder 601 0.480  176.5   -176.5
cylinder 602 0.5625 176.569 -176.569
hexprism 603 0.6375  176.569 -176.569
media 0 1 601
media 7 1 602 -601
media 0 1 603 -602
boundary  603
unit 7
com='dummy cell'
hexprism  701 0.6375  176.569 -176.569
media 0 1 701
boundary  701
unit 8
com='MOX Assembly'
hexprism  801 11.8 176.569 -176.569  rotate a1=90
array 1   801 place 12 12 1 0.0 0.0 0.0
boundary  801
unit 9
hexprism  901 11.8 176.569 -176.569
hole 8    rotate a1=-90
hexprism  902 20.0 176.569 -176.569
media 0 1 902 -901
boundary  902
unit 10
com='dummy assembly'
hexprism  1001 20.0 176.569 -176.569
media 0 1 1001
boundary  1001
unit 11
com='LEU fuel pin 4.2%'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 5 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
```

```
unit 12
com='LEU fuel pin 3.7%'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 6 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 0 1 105 -104
boundary  105
unit 15
com='dummy assembly for center position in the vehicle'
hexprism   1501 11.8 176.569 -176.569
hexprism   1502 20.0 176.569 -176.569
media 11 1 1501
media 0 1  1502 -1501
boundary   1502
unit 18
com='LEU Assembly'
hexprism  1801 11.8 176.569 -176.569 rotate a1=90
array 5   1801 place 12 12 1 0.0 0.0 0.0
boundary  1801
unit 19
hexprism  1901 11.8 176.569 -176.569
hole 18   rotate a1=-90
hexprism  1902 20.0 176.569 -176.569
media 0 1 1902 -1901
boundary  1902
unit 21
com='30cm thick transportation vehicle with 18 assemblies'
cylinder   2101 100.00 176.569 -176.569
cylinder   2100 100.00 360.431  176.569
cylinder   2102 130.00 360.431 -206.569
cuboid     2103 2p160.00 2p160.00  360.431 -206.569
cuboid     2104 2p160.00 2p160.00  360.431 -226.569
cuboid     2105 2p160.00 2p160.00  390.431 -226.569
array  2   2101 place 4 4 1 0.0 0.0 0.0
media  0 1 2100
media  8 1 2102 2102 -2101 -2100
media  0 1 2103 2103 -2102 -2101 -2100
media 12 1 2104 2104 -2103 -2102 -2101 -2100
media  0 1 2105 2105 -2104 -2103 -2102 -2101 -2100
boundary   2105
global unit 22
com='surround with void'
cuboid    2201 2p160.00 2p160.00 390.431 -226.569
array  3  2201 place 1 1 1 3*0.0
boundary  2201
end geom
read array
'MOX Assembly
ara=1 typ=triangular nux=23 nuy=23 nuz=1
fill
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
```

```
 7 7 7 7 7 7 7 7 7 7 7 3 2 2 2 2 2 2 2 2 2 3 7
  7 7 7 7 7 7 7 7 7 7 2 4 1 1 1 1 1 1 1 1 4 2 7
   7 7 7 7 7 7 7 7 7 2 1 1 1 1 1 4 1 1 1 1 1 2 7
    7 7 7 7 7 7 7 7 2 1 1 1 1 1 1 1 1 1 1 1 1 2 7
     7 7 7 7 7 7 7 2 1 1 1 1 1 1 5 1 1 1 1 1 1 2 7
      7 7 7 7 7 7 2 1 1 1 1 5 1 1 1 1 5 1 1 1 1 2 7
       7 7 7 7 7 2 1 4 1 1 1 1 4 1 1 1 1 1 1 4 1 2 7
        7 7 7 7 2 1 1 1 5 1 1 1 1 5 1 4 1 5 1 1 1 2 7
         7 7 7 2 1 1 1 1 1 1 5 1 1 1 1 1 1 1 1 1 1 2 7
          7 7 2 1 1 1 1 1 4 1 1 1 1 1 5 1 1 1 1 1 1 2 7
           7 3 4 1 1 1 5 1 1 1 1 6 1 1 1 1 5 1 1 1 4 3 7
            7 2 1 1 1 1 1 1 5 1 1 1 1 1 4 1 1 1 1 1 2 7 7
             7 2 1 1 1 1 1 1 1 1 1 1 5 1 1 1 1 1 1 2 7 7 7
              7 2 1 1 1 5 1 4 1 5 1 1 1 1 5 1 1 1 2 7 7 7 7
               7 2 1 4 1 1 1 1 1 1 4 1 1 1 1 4 1 2 7 7 7 7 7
                7 2 1 1 1 1 5 1 1 1 1 5 1 1 1 1 2 7 7 7 7 7 7
                 7 2 1 1 1 1 1 1 5 1 1 1 1 1 1 2 7 7 7 7 7 7 7
                  7 2 1 1 1 1 1 1 1 1 1 1 1 1 2 7 7 7 7 7 7 7 7
                   7 2 1 1 1 1 1 4 1 1 1 1 1 2 7 7 7 7 7 7 7 7 7
                    7 2 4 1 1 1 1 1 1 1 1 4 2 7 7 7 7 7 7 7 7 7 7
                     7 3 2 2 2 2 2 2 2 2 2 3 7 7 7 7 7 7 7 7 7 7 7
                      7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
end fill
'2 Assemblies - use unit 9 for MOX; unit 19 for LEU
ara=2 typ=triangular nux=7 nuy=7 nuz=1
fill 10  10  10  10  10  10  10
       10  10  10  19  10  19  10
         10  10  19  19  19  19  10
           10  19  19  15  19  19  10
             10  19  19  19  19  10  10
               10  19  10  19  10  10  10
                 10  10  10  10  10  10  10
end fill
'dummy unit
ara=3  nux=1 nuy=1 nuz=1
fill 21 end fill
'LEU Assembly
ara=5 typ=triangular nux=23 nuy=23 nuz=1
fill
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
7 7 7 7 7 7 7 7 7 7 7 12 12 12 12 12 12 12 12 12 12 12 7
7 7 7 7 7 7 7 7 7 7 12 12 11 11 11 11 11 11 11 11 12 12 7
7 7 7 7 7 7 7 7 7 12 11 11 11 11 11 11 11 11 11 11 11 12 7
7 7 7 7 7 7 7 7 12 11 11 11 11 11 11 11 11 11 11 11 11 12 7
7 7 7 7 7 7 7 12 11 11 11 11 11 11  5 11 11 11 11 11 11 12 7
7 7 7 7 7 7 12 11 11 11 11  5 11 11 11 11  5 11 11 11 11 12 7
7 7 7 7 7 12 11 11 11 11 11 11  4 11 11 11 11 11 11 11 11 12 7
7 7 7 7 12 11 11 11  5 11 11 11 11  5 11  4 11  5 11 11 11 12 7
7 7 7 12 11 11 11 11 11 11  5 11 11 11 11 11 11 11 11 11 11 12 7
7 7 12 11 11 11 11 11  4 11 11 11 11 11  5 11 11 11 11 11 11 12 7
7 12 12 11 11 11  5 11 11 11 11  6 11 11 11 11  5 11 11 11 12 12 7
7 12 11 11 11 11 11 11  5 11 11 11 11 11  4 11 11 11 11 11 12 7 7
7 12 11 11 11 11 11 11 11 11 11 11  5 11 11 11 11 11 11 12 7 7 7
7 12 11 11 11  5 11  4 11  5 11 11 11 11  5 11 11 11 12 7 7 7 7
7 12 11 11 11 11 11 11 11 11  4 11 11 11 11 11 11 12 7 7 7 7 7
7 12 11 11 11 11  5 11 11 11 11  5 11 11 11 11 12 7 7 7 7 7 7
```

```
7 12 11 11 11 11 11 11  5 11 11 11 11 11 11 12 7 7 7 7 7 7 7
7 12 11 11 11 11 11 11 11 11 11 11 11 11 12 7 7 7 7 7 7 7 7
7 12 11 11 11 11 11 11 11 11 11 11 11 12 7 7 7 7 7 7 7 7 7
7 12 12 11 11 11 11 11 11 11 11 12 12 7 7 7 7 7 7 7 7 7 7
7 12 12 12 12 12 12 12 12 12 12 12 7 7 7 7 7 7 7 7 7 7 7
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
end fill
end array
read plot lpi=10 scr=yes
  ttl='Fresh LEU Assemblies in the Fuel Transportation Vehicle (dry)'
  xul=-165 yul=165 zul=0   xlr=165 ylr=-165  zlr=0
  uax=1 vdn=-1.0 nax=640 pic=mat end
  ttl='Fresh LEU Assemblies in the Fuel Transportation Vehicle (dry)'
  xul=-40  yul=55  zul=0   xlr=0   ylr=20    zlr=0
  uax=1 vdn=-1.0 nax=640 pic=mat end
  ttl='Fresh LEU Assemblies in the Fuel Transportation Vehicle (dry)'
  xul=-165 yul=0   zul=400 xlr=165  ylr=0    zlr=-230
  uax=1 wdn=-1.0 nax=640 pic=mat end
end plot
end data
end
```

A.3 STORAGE POOL

p006cc1.inp

```
=csas26          parm=size=1000000
VVER assemblies in Balakovo, Storage Pool
' Base file that contains all MOX and LEU info
' Create new configurations by changing units used in array definitions
' Sedat Goluoglu ---- 8/08/2000
238groupndf5  latticecell
'MOX with 4.08 wt% PuO2 (3.6 wt percent Pu), assume max. density
uo2    1  den=10.7000 0.9592 300  92235 0.2  92238 99.8 end
puo2   1  den=10.7000 0.0408 300  94238 2.009E-02 94239 93.98
  94240 5.798 94241 0.1786 94242 2.964E-02 end
'MOX with 3.06 wt% PuO2 (2.7 wt percent Pu), assume max. density
uo2    2  den=10.7000 0.9694 300  92235 0.2  92238 99.8 end
puo2   2  den=10.7000 0.0306 300  94238 2.009E-02 94239 93.98
  94240 5.798 94241 0.1786 94242 2.964E-02 end
'MOX with 2.72 wt% PuO2 (2.4 wt percent Pu), assume max. density
uo2    3  den=10.7000 0.9728 300  92235 0.2  92238 99.8 end
puo2   3  den=10.7000 0.0272 300  94238 2.009E-02 94239 93.98
               94240 5.798 94241 0.1786 94242 2.964E-02 end
'UO2-GdO2 w/4% GdO2 and 96% fuel which is 3.6 wt% enriched
u-235  4  0 8.0203E-04  300 end
u-238  4  0 2.1477E-02  300 end
gd-152 4  0 1.9666E-06  300 end
gd-154 4  0 2.1462E-05  300 end
gd-155 4  0 1.4569E-04  300 end
gd-156 4  0 2.0151E-04  300 end
gd-157 4  0 1.5405E-04  300 end
```

```
gd-158 4  0 2.4452E-04  300 end
gd-160 4  0 2.1519E-04  300 end
o      4  0 4.6034E-02  300 end
'LEU w/ 4.2% enriched UO2
uo2    5  den=10.4025 1.0 300  92235 4.2  92238 95.8 end
'LEU w/ 3.7% enriched UO2
uo2    6  den=10.4025 1.0 300  92235 3.7  92238 96.3 end
zr     7  1.0 300 end
'1% borated SS, assume density is same as that of SS304
ss304  8  den=7.94 0.99 300 end
boron  8  den=7.94 0.01 300 end
h2o    9  den=1.0   1.0 300 end
end comp
'use UO2 for lattice cell
triangpitch  1.2750 0.7550 5 9 0.9100 7 0.772 0 end
more data
dab=400
end more
read param
 tme=1000 gen=313 nsk=13 npg=4000  plt=yes
 nub=yes lng=1500000 nb8=500  far=yes run=yes
end param
read bounds all=vacuum end bounds
read geom
unit 1
com='MOX fuel pin 3.6 wt% Pu'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 1 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 9 1 105 -104
boundary  105
unit 2
com='MOX fuel pin 2.7 wt% Pu'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 2 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 9 1 105 -104
boundary  105
unit 3
com='MOX fuel pin 2.4 wt% Pu'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
```

```
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 3 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 9 1 105 -104
boundary  105
unit 4
com='MOX fuel pin U-Gd'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 4 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 9 1 105 -104
boundary  105
unit 5
com='guide tube'
cylinder 501 0.545  176.5   -176.5
cylinder 502 0.6325 176.569 -176.569
hexprism 503 0.6375  176.569 -176.569
media 9 1 501
media 7 1 502 -501
media 9 1 503 -502
boundary 503
unit 6
com='instrumentation tube'
cylinder 601 0.480  176.5   -176.5
cylinder 602 0.5625 176.569 -176.569
hexprism 603 0.6375  176.569 -176.569
media 9 1 601
media 7 1 602 -601
media 9 1 603 -602
boundary  603
unit 7
com='dummy cell'
hexprism  701 0.6375  176.569 -176.569
media 9 1 701
boundary  701
unit 8
com='MOX Assembly'
hexprism  801 11.8 176.569 -176.569  rotate a1=90
array 1   801 place 12 12 1 0.0 0.0 0.0
boundary  801
unit 9
com='MOX Assembly in hexagonal borated SS can'
hexprism  901 11.8 176.569 -176.569
hole 8    rotate a1=-90
hexprism  902 12.3 177.069 -177.069
hexprism  903 20.0 177.069 -177.069
media 8 1 902 -901
media 9 1 903 -902
boundary  903
```

```
unit 10
com='dummy assembly'
hexprism  1001 20.0 177.069 -177.069
media 9 1 1001
boundary  1001
unit 11
com='LEU fuel pin 4.2%'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 5 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 9 1 105 -104
boundary  105
unit 12
com='LEU fuel pin 3.7%'
cylinder 101 0.075 176.5   -176.5
cylinder 102 0.3775 176.5   -176.5
cylinder 103 0.386 176.5   -176.5
cylinder 104 0.455 176.569 -176.569
hexprism 105 0.6375 176.569 -176.569
media 0 1 101
media 6 1 102 -101
media 0 1 103 -102
media 7 1 104 -103
media 9 1 105 -104
boundary  105
unit 18
com='LEU Assembly'
hexprism  1801 11.8 176.569 -176.569 rotate a1=90
array 5   1801 place 12 12 1 0.0 0.0 0.0
boundary  1801
unit 19
com='LEU Assembly in hexagonal borated SS can'
hexprism  1901 11.8 176.569 -176.569
hole 18   rotate a1=-90
hexprism  1902 12.3 177.069 -177.069
hexprism  1903 20.0 177.069 -177.069
media 8 1 1902 -1901
media 9 1 1903 -1902
boundary  1903
unit 20
com='dummy cell for can'
hexprism   2001 20.0 177.069 -177.069
media  9 1 2001
boundary   2001
global unit 23
com='put it in the storage pool'
cuboid     2301 2p662.50 2p310.50 2p177.069
cuboid     2302 2p700.00 2p350.00 2p230.069
array  2   2301 place 24 12 1 20 0.0 0.0
media  9 1 2302 2302 -2301
boundary   2302
```

```
end geom
read array
'MOX Assembly
ara=1 typ=triangular nux=23 nuy=23 nuz=1
fill
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
 7 7 7 7 7 7 7 7 7 7 7 3 2 2 2 2 2 2 2 2 2 3 7
  7 7 7 7 7 7 7 7 7 7 2 4 1 1 1 1 1 1 1 1 4 2 7
   7 7 7 7 7 7 7 7 7 2 1 1 1 1 1 4 1 1 1 1 1 2 7
    7 7 7 7 7 7 7 7 2 1 1 1 1 1 1 1 1 1 1 1 1 2 7
     7 7 7 7 7 7 7 2 1 1 1 1 1 1 5 1 1 1 1 1 1 2 7
      7 7 7 7 7 7 2 1 1 1 1 5 1 1 1 1 5 1 1 1 1 2 7
       7 7 7 7 7 2 1 4 1 1 1 1 4 1 1 1 1 1 1 4 1 2 7
        7 7 7 7 2 1 1 1 5 1 1 1 1 5 1 4 1 5 1 1 1 2 7
         7 7 7 2 1 1 1 1 1 1 5 1 1 1 1 1 1 1 1 1 1 2 7
          7 7 2 1 1 1 1 1 4 1 1 1 1 1 5 1 1 1 1 1 1 2 7
           7 3 4 1 1 1 5 1 1 1 1 6 1 1 1 1 5 1 1 1 4 3 7
            7 2 1 1 1 1 1 1 5 1 1 1 1 1 4 1 1 1 1 1 2 7 7
             7 2 1 1 1 1 1 1 1 1 1 1 5 1 1 1 1 1 1 2 7 7 7
              7 2 1 1 1 5 1 4 1 5 1 1 1 1 5 1 1 1 2 7 7 7 7
               7 2 1 4 1 1 1 1 1 1 4 1 1 1 1 4 1 2 7 7 7 7 7
                7 2 1 1 1 1 5 1 1 1 1 5 1 1 1 1 2 7 7 7 7 7 7
                 7 2 1 1 1 1 1 1 5 1 1 1 1 1 1 2 7 7 7 7 7 7 7
                  7 2 1 1 1 1 1 1 1 1 1 1 1 1 2 7 7 7 7 7 7 7 7
                   7 2 1 1 1 1 1 4 1 1 1 1 1 2 7 7 7 7 7 7 7 7 7
                    7 2 4 1 1 1 1 1 1 1 1 4 2 7 7 7 7 7 7 7 7 7 7
                     7 3 2 2 2 2 2 2 2 2 2 3 7 7 7 7 7 7 7 7 7 7 7
                      7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
end fill
'32by17 cans in the storage pool ; total of 544
ara=2 typ=triangular nux=59 nuy=23 nuz=1
fill
59r20
59r20
59r20
11r20 32r19 16r20
11r20 32r19 16r20
10r20 32r19 17r20
10r20 32r19 17r20
 9r20 32r19 18r20
 9r20 32r19 18r20
 8r20 32r19 19r20
 8r20 32r19 19r20
 7r20 32r19 20r20
 7r20 32r19 20r20
 6r20 32r19 21r20
 6r20 32r19 21r20
 5r20 32r19 22r20
 5r20 32r19 22r20
 4r20 32r19 23r20
 4r20 32r19 23r20
 3r20 32r19 24r20
59r20
59r20
59r20
end fill
```

```
'LEU Assembly
ara=5 typ=triangular nux=23 nuy=23 nuz=1
fill
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
7 7 7 7 7 7 7 7 7 7 7 12 12 12 12 12 12 12 12 12 12 12 7
7 7 7 7 7 7 7 7 7 7 12 12 11 11 11 11 11 11 11 11 12 12 7
7 7 7 7 7 7 7 7 7 12 11 11 11 11 11 11 11 11 11 11 11 12 7
7 7 7 7 7 7 7 7 12 11 11 11 11 11 11 11 11 11 11 11 11 12 7
7 7 7 7 7 7 7 12 11 11 11 11 11 11  5 11 11 11 11 11 11 12 7
7 7 7 7 7 7 12 11 11 11 11  5 11 11 11 11  5 11 11 11 11 12 7
7 7 7 7 7 12 11 11 11 11 11 11  4 11 11 11 11 11 11 11 11 12 7
7 7 7 7 12 11 11 11  5 11 11 11 11  5 11  4 11  5 11 11 11 12 7
7 7 7 12 11 11 11 11 11 11  5 11 11 11 11 11 11 11 11 11 11 12 7
7 7 12 11 11 11 11 11  4 11 11 11 11 11  5 11 11 11 11 11 11 12 7
7 12 12 11 11 11  5 11 11 11 11  6 11 11 11 11  5 11 11 11 12 12 7
7 12 11 11 11 11 11 11  5 11 11 11 11 11  4 11 11 11 11 11 12 7 7
7 12 11 11 11 11 11 11 11 11 11 11  5 11 11 11 11 11 11 12 7 7 7
7 12 11 11 11  5 11  4 11  5 11 11 11 11  5 11 11 11 12 7 7 7 7
7 12 11 11 11 11 11 11 11 11  4 11 11 11 11 11 11 12 7 7 7 7 7
7 12 11 11 11 11  5 11 11 11 11  5 11 11 11 11 12 7 7 7 7 7 7
7 12 11 11 11 11 11 11  5 11 11 11 11 11 11 12 7 7 7 7 7 7 7
7 12 11 11 11 11 11 11 11 11 11 11 11 11 12 7 7 7 7 7 7 7 7
7 12 11 11 11 11 11 11 11 11 11 11 11 12 7 7 7 7 7 7 7 7 7
7 12 12 11 11 11 11 11 11 11 11 12 12 7 7 7 7 7 7 7 7 7 7
7 12 12 12 12 12 12 12 12 12 12 12 7 7 7 7 7 7 7 7 7 7 7
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
end fill
end array
read plot lpi=10 scr=yes
  ttl='Fresh LEU Assemblies in the Storage Pool'
  xul=-20  yul=50  zul=0   xlr=20  ylr=15    zlr=0
  uax=1 vdn=-1.0 nax=640 pic=mat end
  ttl='Fresh LEU Assemblies in the Storage Pool'
  xul=-700  yul=350 zul=0 xlr=700  ylr=-350  zlr=0
  uax=1 vdn=-1.0 nax=640 pic=mat end
end plot
end data
end
```

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