Criticality Safety Evaluation: Experiments with Plutonium and Depleted Uranium Reflectors

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1. Introduction

This document is a Nuclear Criticality Evaluation conducted in regarding a series of processes requiring the use of a 5-kilogram sphere of plutonium (95% 239Pu and 5% 240Pu) metal and hemishells of depleted uranium which are placed around the plutonium sphere acting as a reflector.

2. Description

2.1. Fissile parts

In this section, fissile parts used during the experiment are discussed. Throughout the experiment, there is a 5 kg sphere of plutonium with a chemical composition of 95% of Pu-239 and 5% of Pu-240. The phase of the plutonium sphere is the alpha phase and the phase remains constant. The radius of the sphere is calculated using its density (19.84g/cc) and mass.

$$V = \frac{m}{p} = \frac{4}{3}\pi R^3$$

$$R = \sqrt[3]{\frac{3V}{4\pi}} = \sqrt[3]{\frac{3m}{4\pi p}}$$

$$R = \sqrt[3]{\frac{3*(5000g)}{4*\pi*19.84g/cc}} = 3.91844 \text{ cm}$$

2.2. Depleted Uranium parts

In this part, depleted uranium parts are described. Throughout the experiment, there are hemishells of depleted uranium with varying diameters. The thickness of each hemishells is 0.5

inches. The total thickness of hemishells is 12 inches and there are 12/0.5 = 24 hemishells. There are top and bottom reflection to be accounted for, therefore the total number of hemishells is 24*2 = 48 shells. The weight percentage of U-235 ranges from 0.50% to 0.70%. Depending on configuration for an operation, there can be a void in hemishells. For instance, if shells 1,3, and 5 are used, shells 2, and 4 are skipped with rubber stoppers to help the alignment of the shells.

2.3. Material-handling equipment and workstation

In this section, the different assembly components that comprise the holding fixtures of the experiment are discussed. These parts are meant to hold the material parts such as the plutonium sphere and the depleted uranium during the conduction of the experiment in a set position on the table area.

Two different parts should be differentiated. On one hand, the top part consisting of the 24 hemishells is supported on a 0.015-inch stainless steel diaphragm with a radius of 16 inches. Therefore, accounting for the thickness of the hemishells (24 inches in total) as well as for the diameter of the sphere, the diameter of the diaphragm is 4.9 inches larger. A hole equal to the diameter of the Pu core is needed to accommodate the sphere in the center of the diaphragm. Additionally, in case hemishells are skipped in one configuration, spacers placed through holes on the diaphragm are used to maintain alignment consistently. Regarding the bottom part, where the other half of the hemishells are placed, the holding fixture consists of a thin-walled (0.030-in thick) aluminum cylinder on which the hemishells rest. To allow movement into the system, a crack will be used to raise/lower the cylinder during assembling and dismantling operations. Moreover, different cylinder diameters are available depending on the outer diameter of the last hemishell.

The different configurations will take place on a 6 ft x 4 ft experimental table ~1/8 inches thick and 4 ft above the ground. For this experiment, the table is located greater than 12 ft away from the walls of the room. Concerning materials, stainless steel is the primary material in use.

Regarding the location of the assembly with the table, it should be considered that the diaphragm represents a stationary platform placed 26 inches above the table and this measurement is maintained throughout the different configurations. At the moment of lowering the manual crank during the loading process, the distance between the outer shell and the table is 2 inches.

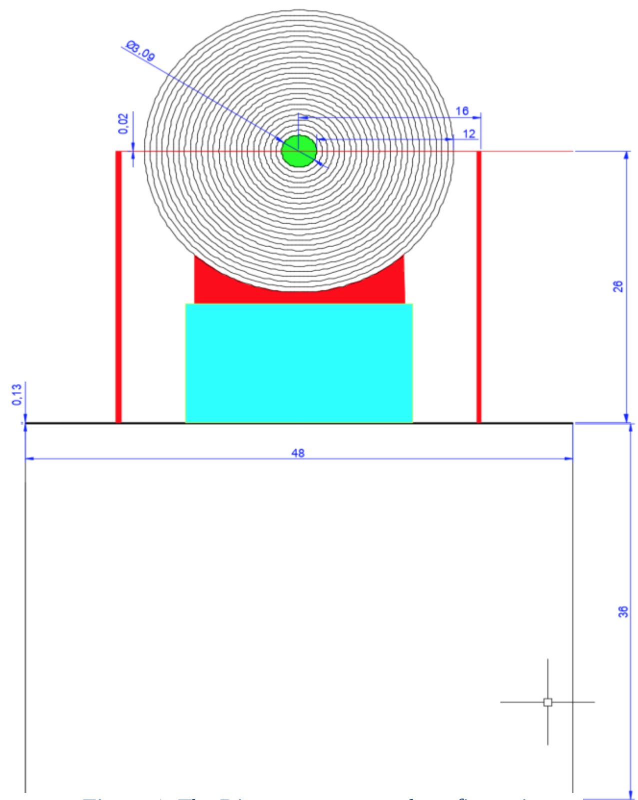

Figure 1. The Diagram on general configuration

The below figure represents the position of the system during loading operations and the 2 inches height between the table and the bottom part of the shells.

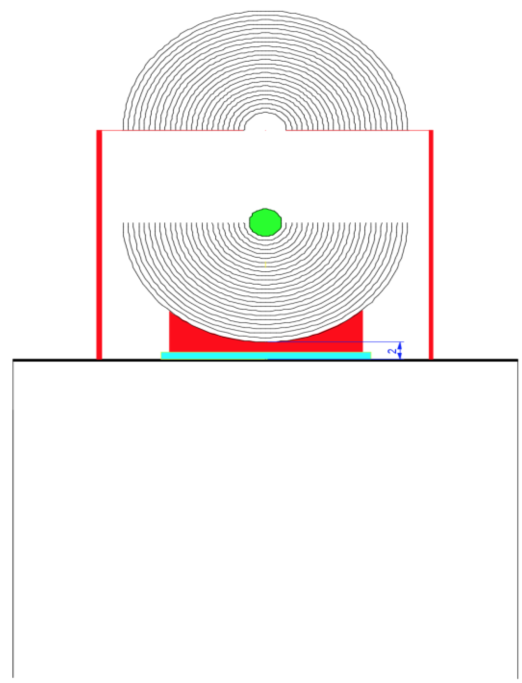

Figure 2. The Diagram about the position of the system during loading operation

2.4 Operations

The following description depicts how the experiment will be conducted starting from the storage room to the realization of different configurations in the experimental area.

Staging of Materials: Both the plutonium sphere and the DU hemishells are stored in a different room called the storage location. When they are needed to experiment, they are transferred into stainless steel containers with walls 0.05 inches thick to prevent water from entering when the containers are closed. Once in the experimental room, the materials are placed on a marked floor location. After opening the containers, the material is moved towards the assembly area.

- Equipment: Personnel will wear latex gloves when handling the material. A lab coat or coveralls and safety glasses are also required.

Assembling Configurations:

- Description: The main experiment consists of trying different configurations by changing DU hemishells and performing counting measurements. It should be noted that not all configurations include the same amount of hemishells on each side of the plutonium sphere.

  Process: First, the desired configuration should be determined so that the appropriate aluminum cylinder is selected according to the configuration to be tested. Once the bottom holding fixture is set, the diaphragm is assembled and connected to the spacers. The DU hemishells are stacked from the outer diameter one to the smallest. It is important that during this operation the shells are well nested on each surface. Once the bottom hemishells are placed, the Pu sphere rests on top of the first half waiting for the top half to be mounted. For the top part, the shells are piled up in the opposite direction from smallest to largest. When the material is correctly set then a manual crank is operated to raise the bottom part and meet the top.

2.5. Location and surroundings

The area where the experiment is taking place is located in the middle of the room and the storage locker for containers is 5 ft away. Other experiments are separated from both the stacking and storage area around 15 ft.

In the surrounding area, there will be neutron detectors and counting equipment around the assembly.

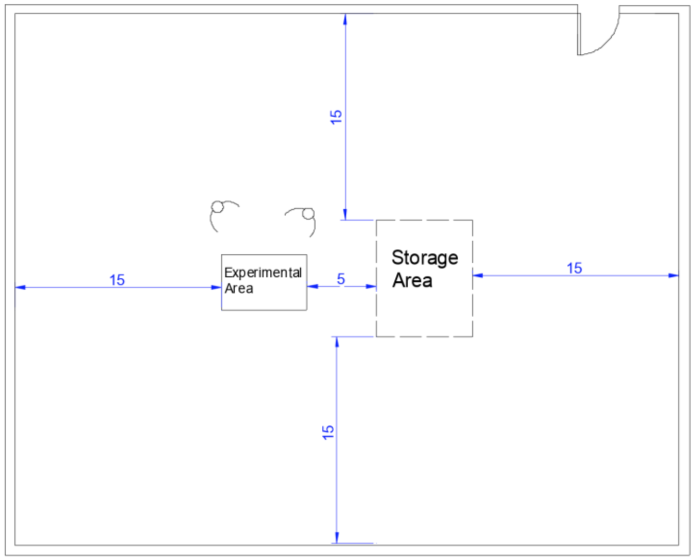

Figure 3. The 2-D map of location

3. Process Analysis

3.1 Parameters

Mass: The mass of the Pu sphere would remain constant, and the mass of the whole assembly being used can be different depending on how many shells are used during the experiment. The minimum critical mass can be different depending on the number of reflectors which would be hemishells.

Enrichment: Pu-240 enrichment should remain constant. It is enriched with 5% of Pu-240. Regarding Uranium enrichment, the weight percentage ranges from 0.50% to 0.70%.

Reflection: The main reflectors of this experiment are the DU hemishells and will vary throughout the different configurations to be performed. Additionally, the holding equipment (stainless steel diaphragm, aluminum cylinder), rubber stoppers, latex gloves, lab coats and operator's hands are likely to be reflectors. However, for modelling of the experiment, we will not consider handling equipment such as gloves and overalls from operators.

Moderation: There is no moderator in this experiment.

Absorption: The probability of absorption of neutrons remains constant.

Interaction: The distance between the workstation area and other potential experiments is around 15 ft. Therefore, there will be no interaction with other fissile materials to consider.

Density: The density of the sphere is 19.84g/cc, whereas for the DU hemishells is 19.05 g/cc.

Volume: The volume of the system will remain constant since we count on rubber stoppers when shells are skipped. As part of the volume, we include top and bottom fixtures (diaphragm, cylinder), plutonium sphere, 48 hemishells (either DU or rubber stoppers).

4. Discussion of contingencies

4.1 Normal conditions

The stacking of hemishells surrounding the plutonium sphere will be conducted in a room where no other experiments will be performed, so no other fissile material is expected to get close to the setup. The transportation process of the containers into the experimental room will not be discussed in this criticality evaluation report.

In the normal operation, no water or other liquid is near the table of the experiment, therefore no moderator is considered as part of our evaluation for normal conditions.

To assess the critical evaluation quantitatively, MCNP code is being used in which the following components are being considered as part of the model: plutonium sphere, depleted uranium hemishells, aluminum cylinder, stainless steel table, and the stationary platform.

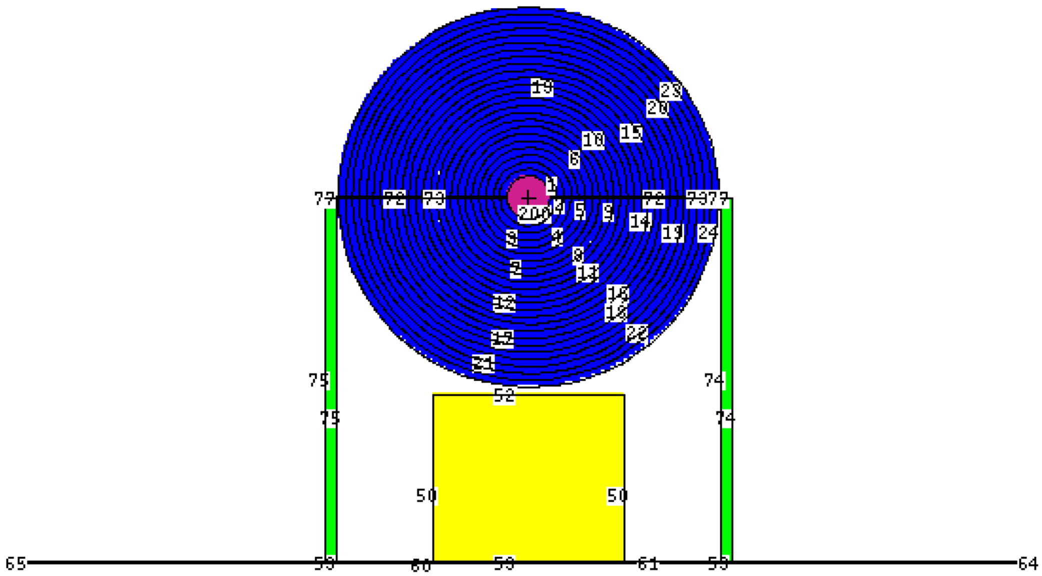

Figure 4. Detailed configuration with MCNP

In the following table, we outline the material composition for each of the elements within the setup.

Element	Material composition
Pu sphere	95%239-Pu, 5%240-Pu
DU hemishells	0.5-0.7%235-U, 99.5-99.3%238-U
Aluminum cylinder	100%Al
Table	61%Fe, 8%C, 20%Cr, 11%Ni
Stationary platform	61%Fe, 8%C, 20%Cr, 11%Ni

Figure 5. The table of material composition

4.1.1. Effect of hemishells reflectors

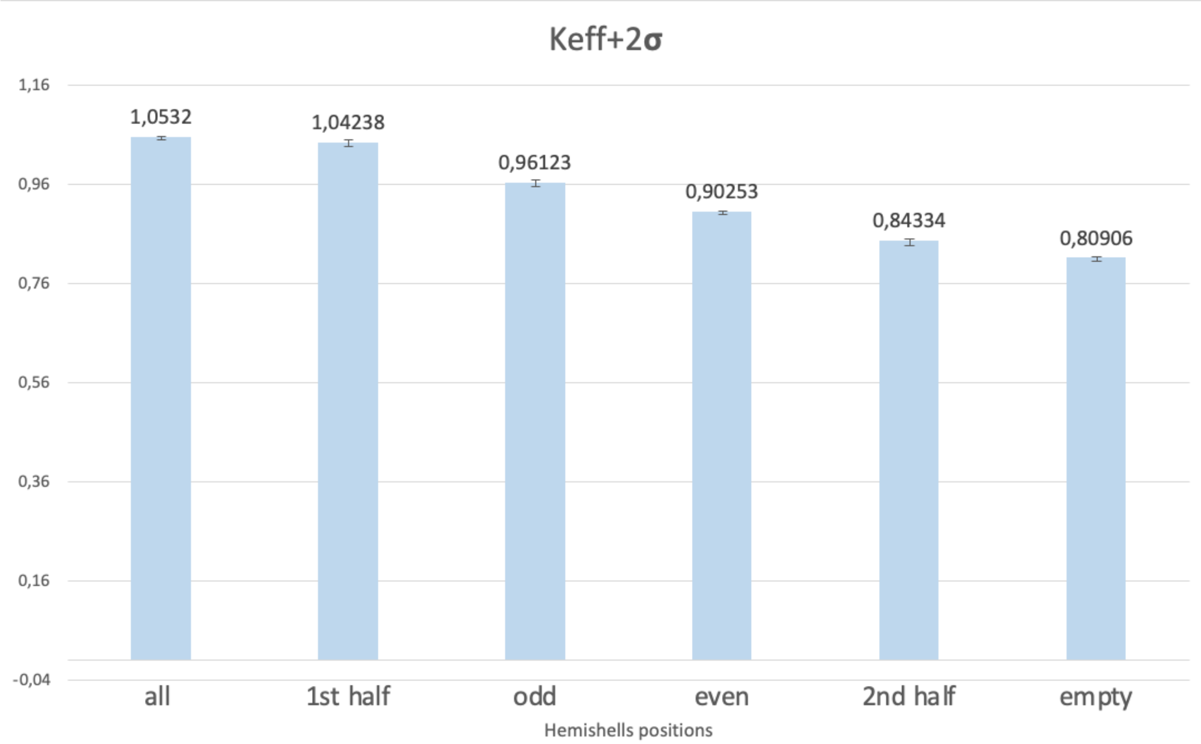

Figure 6. Keff values graph depending on different hemishell configuration

As part of a normal condition operation, the experiment consists of combining different subsets of reflectors on the top and bottom of the assembly. Therefore, to determine the dependence of critical conditions on the reflectors, different hemishell combinations will be executed to determine the variation of keff+2**σ**. In case of skipping an hemishell, a vacuum gap will be modeled in replacement of the DU hemishell.

Upon utilizing MCNP6, a different subset of hemishells is used based on the previous model. The four different combinations include all reflectors, leaving hemishells in both even and odd positions, and leaving 1st and 2nd half empty.

The highest keff that the system can reach is 1.0532 when all the reflectors are stacked on top and bottom. There are two cases, when all hemishells are stacked and when only the first half is mounted in which the experiment reaches the supercriticality. For the remaining cases which are odd positions, even positions, and the second half stacked, the subcriticality is guaranteed since in all situations keff is below 0.97. Therefore, not all normal conditions remain subcritical. Keff decreases in the following order of configurations from highest to lowest value:

all, the first half with hemishells, odd, even and finally the second half with hemishells. For the case in which no reflectors are used, keff is expected to be lowest.

Based on the study, for all and first half cases, the experiment exceeds the USL limit of 0.97.

4.1.2. Effect of uranium - 235 present in hemishells

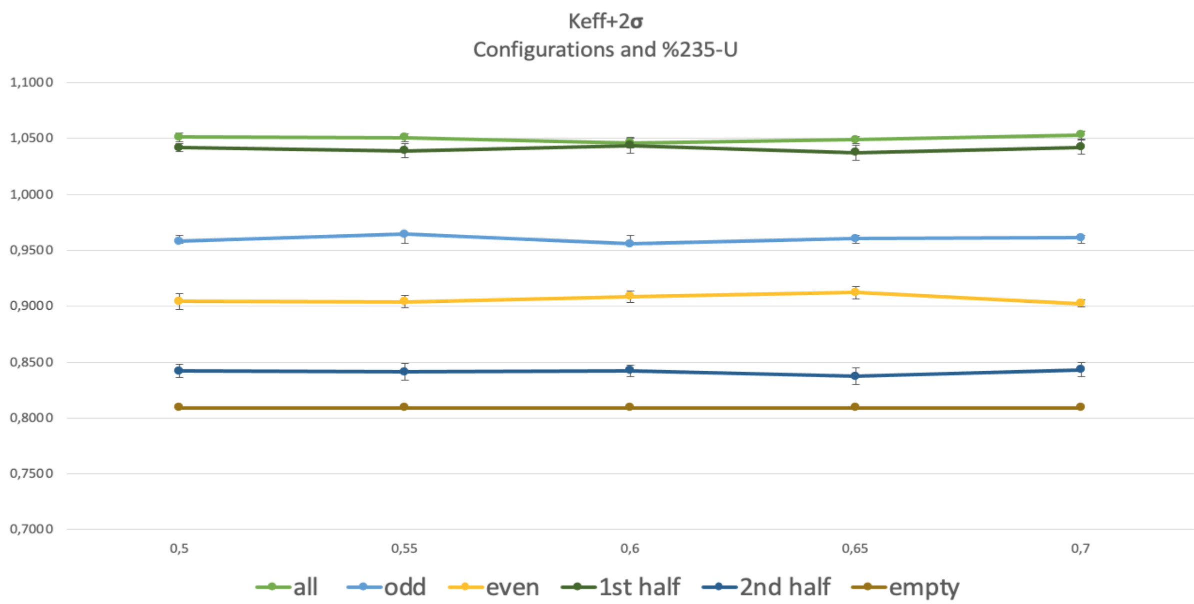

Figure 7. Graph of k_{eff} value depending on configuraion and U-235%

As part of the experiment, hemishells can vary the amount of uranium 235 present, hence, for each of the four combination cases, a different amount of uranium 235 is added ranging from 0.5 to 0.7%. As a result, the effect of uranium 235 present in the hemishells has little impact regarding the criticality of the system. There is no clear tendency therefore we conclude that the % of uranium is not a major factor given that in every case scenario the change in keff is almost imperceptible. One probable reason is the narrow spectrum of uranium 235 changes ranging from 0.5 to 0.7%.

4.2. Controls and barriers

4.2.1. 1st scenario: Limit of number of hemishells for all stacked

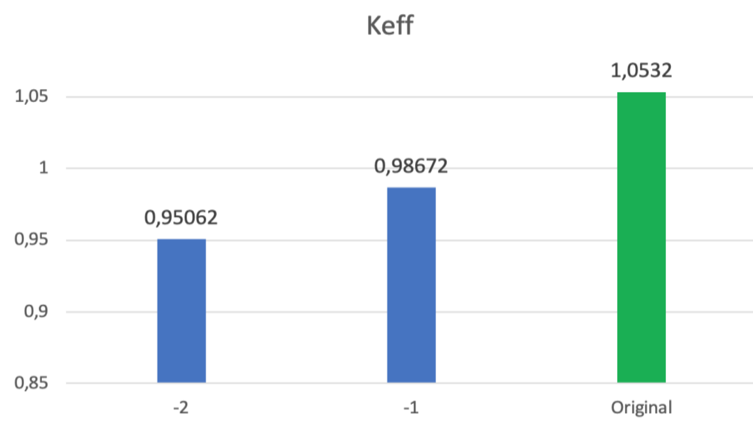

Figure 8. The graph of k_{eff} value when shells are removed from inward for full stacked

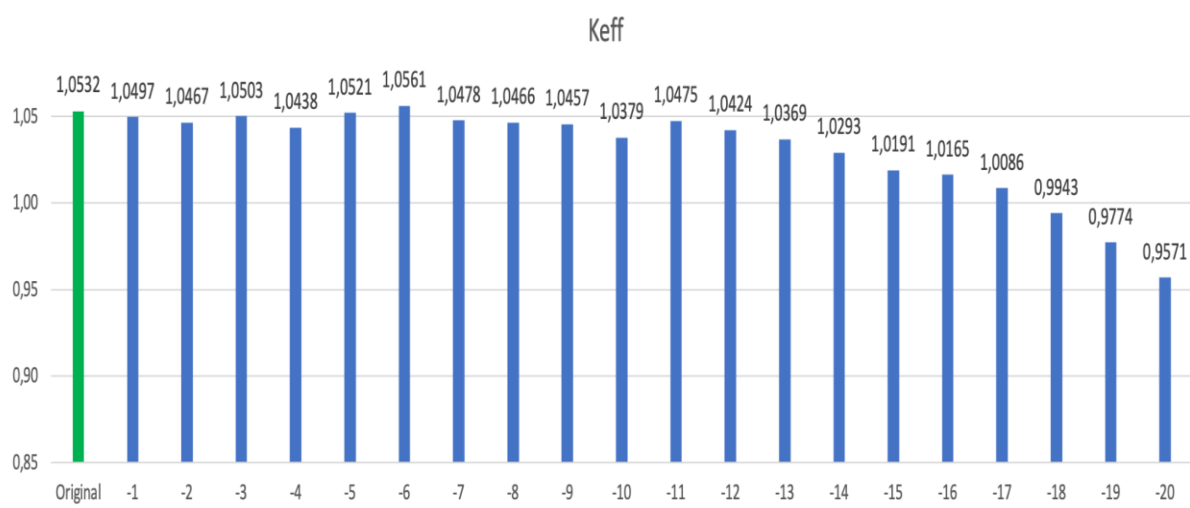

Figure 9. The graph of k_{eff} value when shells are removed from inward for full stacked

As discussed above, there are two cases in which the USL limit of 0.97 is exceeded, therefore, control measures must be taken to ensure subcriticality in every experimental setup scenario.

When mounting all the hemishells on both sizes of the plutonium sphere, a total of 48 hemishells, and the first half closest to the sphere, a total of 24 hemishells, keff results to be above the USL upper limit.

To remain subcritical, the control mechanism will be limiting the number of hemishells that are meant to be stacked surrounding the plutonium sphere. MCNP code has been used to find the restricting number of hemishells that are allowed in the experiment for the two cases: all stacked, and first half stacked hemishells.

Considering the initial condition when all hemishells surround the plutonium sphere, there are two different approaches to remove the hemishells. The first one is removing hemishells from inward to outward for which rubber stoppers will be placed in replacement (MCNP model considers the rubber stoppers as void). The second approach consists of removing hemishells from the outside.

As shown in the above figures, the former represents the evolution of keff when hemishells are removed from the inside. Upon reaching keff below 0.97, the required number of shells to be removed to meet this restriction is a total of 2 (4 hemishells) leading to keff equal to 0.95. The second graph represents the evolution of keff when hemishells are taken off from the outside. In this case, a total number of 20 shells (40 hemishells) are to be eliminated to reach an acceptable value of keff below the threshold of 0.97. The resulting keff is 0.9571.

4.2.2. 2nd scenario: Limit of number of hemishells for first half stacked

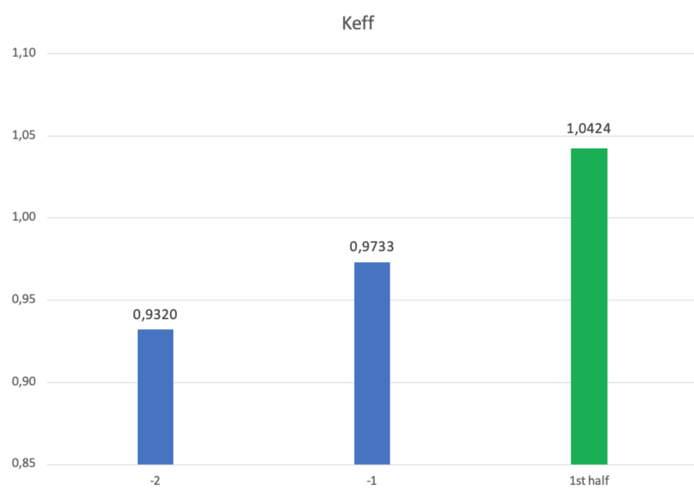

Figure 10. The graph of k_{eff} value when shells are removed from inward for first half (inner half) stacked

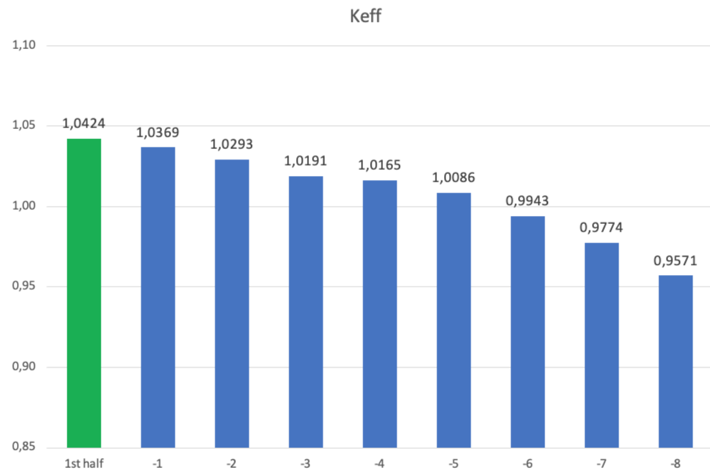

Figure 11. The graph of k_{eff} value when shells are removed from outward for first half (inner half) stacked

As stated in the previous case, the initial condition is the setting in which all hemishells are stacked for the 1st half, meaning that a total of 25 hemishells are mounted closest to the plutonium sphere.

First, from figure 10, shells are removed from inward to outward leading to a total of 2 shells (4 hemishells) which must be taken off the system to remain subcritical under a keff value of 0.97. The resulting keff equals 0.932 giving a reasonable margin of 0.038. In the case of removing shells from the outside for this configuration, the total number of shells is 8 (16 hemishells) as shown in figure 11.

4.3 Abnormal conditions

What-if is the methodology used to assess upset conditions in which the causes and consequences of the possible abnormal events are analyzed as well as to justify the importance of accounting for them in terms of credibility.

What-if	Consequences	Justification	Further Consideration
What if an operator misses to mount the last hemishell on the top part dropping the hemishell on the table	Reactivity would decrease	Possible geometry change such as dent. Out of optimal geometry. Reflecting less and less neutrons bounding back.	Yes
What if the storage location is surrounded by water from the water sprinklers?	Reactivity would increase	Water would work as moderator, and if water happens to be in contact with a fissile material, it will slow down neutrons, indicating k_{eff} would increase.	Yes
What if the water or isopropanol are spilled on the experimental table and surrounding the hemishells?	Reactivity would increase	Water would work as moderator, and if water or isopropanol happen to be in contact with a fissile material, it would slow down neutrons, indicating k_{eff} would increase.	Yes

Figure 12. What-if table for abnormal analysis

Next, we will consider these cases in further detail using MCNP modeling:

4.3.1. Dropping of hemishells

Considering the initial experiment condition when all hemishells are stacked expect for the 4 inner hemishells to assure subcriticality, we suppose that the outer hemishell on the top can be dropped by an operator while setting up the experiment.

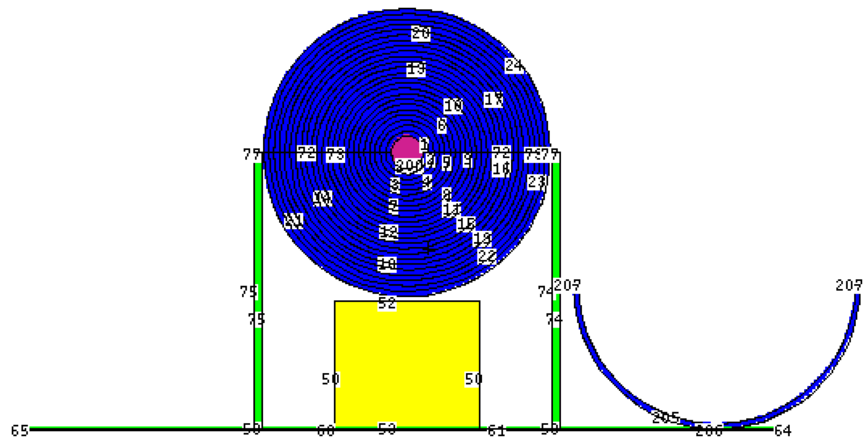

Figure 13. MCNP diagram for dropping hemishell case

It was observed that keff increases with respect to that initial keff value.

Initial Keff	Abnormal Keff	ΔKeff
0.95062	0.95283	-2.81×10^{-3}

Figure 14. The k_{eff} table for dropping hemishell case

4.3.2. Addition of water in storage location

Both plutonium sphere and depleted uranium hemishells are stored together in containers. For evaluating the effect of adding water on the concrete floor on which these containers stand, we will consider the configuration of the sphere and hemi-shells along with a slab of water representing the leaking of water onto the experimental room floor.

The largest number of hemishells that a container can include in addition to the sphere is 40 and they should be arranged in a way that 4 inner hemishells need to be removed. Considering this initial geometrical configuration in the storage room, the Pu sphere surrounded by the number of DU shells on a concrete floor is fully reflected by water.

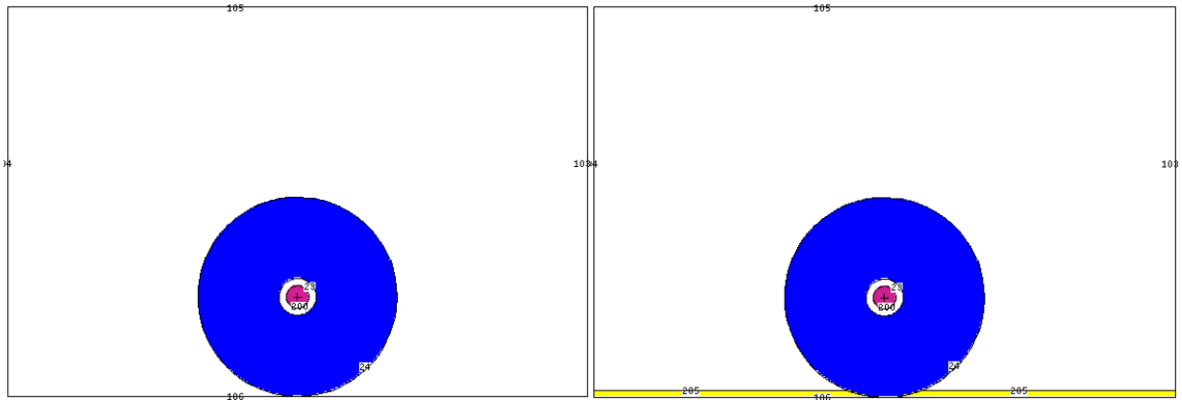

Figure 15. MCNP diagram for addition of water in storage case

Initial Keff	Abnormal Keff	ΔKeff
0.94560	0.95116	$5.56x10^{-3}$

Figure 16. The k_{eff} table for addition of water in storage case

4.3.3. Addition of moderator

There are two cases of the addition of moderators in this experiment. The first case with the water sprinkler is already mentioned above in the what-if analysis table. The second case would be when isopropanol may interact with the Pu sphere or depleted uranium hemishells. Since we assume that the addition of isopropanol is kept to 1 liter at the most in the scenario, we can perform our MCNP modeling with the condition that depleted uranium hemishells are fully stacked and geometry of 1L of isopropanol is a slab with a thickness of 0.448 cm and having the same width and length as the table. A similar geometry is defined for water.

The study case to be considered when adding moderator of isopropanol and water separately will be when hemishells are mounted in odd positions given that this is the normal situation for which the highest keff is achieved (keff=0.96123) considering the restricting control measures for all and first half scenarios. Two cases are to be studied: isopropanol and water from the sprinklers. The MCNP models the liquids as to be surrounding the outer layer of hemishells as well as the table with a slab of the geometry previously defined.

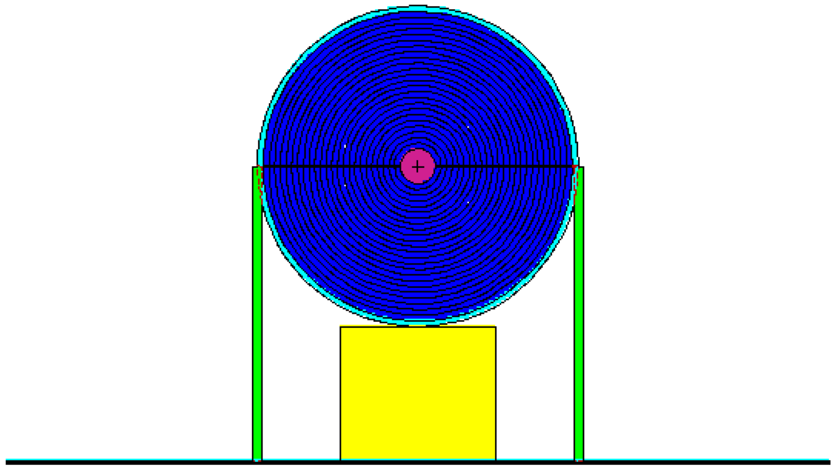

Figure 17. MCNP diagram for addition of moderator case

Moderator	Keff	ΔKeff
Isopropanol	0.96199	+0.03076
Water	0.96355	$+2.32\times10^{-3}$

Figure 18. The k_{eff} table for addition of moderator case

5. Recommendations on experiment operations

As shown in the normal and abnormal evaluation section, regardless of the configuration the maximum amount of hemishells that can be allowed within the experiment is a total of 40 hemishells distributed evenly in both top and bottom. One thing to keep in mind for the experiment is that symmetry should be guaranteed for the experiment. Additionally, in the storage area, containers can only shelter 40 hemishells if the plutonium sphere is also included. The configuration is such that in replacement of these 4 inner hemishells rubber stoppers will be mounted to maintain alignment of the setting in both experimental and storage locations.

Also, based on the result from our previous section on effect of amount of U-235, the amount of U-235 should not be a concern. Even with the maximum possible value of 0.7%, k_{eff} value does not become critical.

In conclusion, there must be a maximum of 40 hemishells with a symmetrical configuration for the experiment to guarantee subcriticality.

6. MCNP Input File

The following MCNP file calculates keff for the complete configuration of the 48 hemishells with a 0.7% of uranium 235:

```
Evaluation
c Cell cards
200 1   -19.84          -200                                         imp:n=1  $ Pu sphere
1   0                  200 -1 72                                     imp:n=1 $ 48 Hemishells
2   0                  1 -2 7 2                                      imp:n=1
3   2   -19.05         2 -3 72                                       imp:n=1
4   2   -19.05         3 -4 72                                       imp:n=1
5   2   -19.05         4 -5 72                                       imp:n=1
6   2   -19.05         5 -6 72                                       imp:n=1
7   2   -19.05         6 -7 72                                       imp:n=1
8   2   -19.05         7 -8 72                                       imp:n=1
9   2   -19.05         8 -9 72                                       imp:n=1
10  2   -19.05         9 -10 72                                      imp:n=1
11  2   -19.05         10 -11 72                                     imp:n=1
12  2   -19.05         11 -12 72                                     imp:n=1
13  2   -19.05         12 -13 72                                     imp:n=1
14  2   -19.05         13 -14 72                                     imp:n=1
15  2   -19.05         14 -15 72                                     imp:n=1
16  2   -19.05         15 -16 72                                     imp:n=1
17  2   -19.05         16 -17 72                                     imp:n=1
18  2   -19.05         17 -18 72                                     imp:n=1
19  2   -19.05         18 -19 72                                     imp:n=1
20  2   -19.05         19 -20 72                                     imp:n=1
21  2   -19.05         20 -21 72                                     imp:n=1
22  2   -19.05         21 -22 72                                     imp:n=1
23  2   -19.05         22 -23 72                                     imp:n=1
24  2   -19.05         23 -24 72                                     imp:n=1
25  0                 200 -1 -73                                     imp:n=1
26  0                  1 -2 -73                                      imp:n=1
27  2   -19.05         2 -3 -73                                      imp:n=1
28  2   -19.05         3 -4 -73                                      imp:n=1
29  2   -19.05         4 -5 -73                                      imp:n=1
30  2   -19.05         5 -6 -73                                      imp:n=1
31  2   -19.05         6 -7 -73                                      imp:n=1
32  2   -19.05         7 -8 -73                                      imp:n=1
33  2   -19.05         8 -9 -73                                      imp:n=1
34  2   -19.05         9 -10 -73                                     imp:n=1
35  2   -19.05         10 -11 -73                                    imp:n=1
36  2   -19.05         11 -12 -73                                    imp:n=1
37  2   -19.05         12 -13 -73                                    imp:n=1
38  2   -19.05         13 -14 -73                                    imp:n=1
39  2   -19.05         14 -15 -73                                    imp:n=1
40  2   -19.05         15 -16 -73                                    imp:n=1
41  2   -19.05         16 -17 -73                                    imp:n=1
42  2   -19.05         17 -18 -73                                    imp:n=1
43  2   -19.05         18 -19 -73                                    imp:n=1
44  2   -19.05         19 -20 -73                                    imp:n=1
45  2   -19.05         20 -21 -73                                    imp:n=1
46  2   -19.05         21 -22 -73                                    imp:n=1
47  2   -19.05         22 -23 -73                                    imp:n=1
48  2   -19.05         23 -24 -73                                    imp:n=1
50  3   -2.7           -50 -52 53                                    imp:n=1  $ Aluminum cylinder
60  4   -8.0          60 -61 -62 63 -64 65                           imp:n=1  $ Stainless steel Table
70  4   -8.0         70 -71 -72 73                                   imp:n=1  $ Platform
100 0                 200 -70 -72 73                                  imp:n=1 $ void platform
71  4   -8.0            -74 76 -77                                   imp:n=1  $ Right leg
72  4   -8.0             -75 78 -79                                  imp:n=1  $ Left leg
99  0             24 (50:52:-53) (-60:61:62:-63:64:-65) (-70:71:72:-73) (74:-76:77) (75:-78:79) imp:n=0
```

```
c  Surface cards
200  so     3.918   $ Plutonium radius
1    so     5.19
2    so     6.46
3    so     7.743
4    so     9.00
5    so     10.27
6    so     11.54
7    so     12.81
8    so     14.08
9    so     15.35
10   so     16.62
11   so     17.89
12   so     19.16
13   so     20.43
14   so     21.70
15   so     22.97
16   so     24.24
17   so     25.51
18   so     26.78
19   so     28.05
20   so     29.32
21   so     30.59
22   so     31.86
23   so     33.13
24   so     34.40
25   so     35.67
c Aluminum cylinder
50    cz      17.20
52    pz      -35.67
53    pz      -66.00
c Stationary platform
70    cz      3.918
71    cz      35.67
72    pz       0.019
73    pz      -0.019
c legs of stationary platform
74    c/z    0 35.68 1.0
75    c/z    0 -35.68 1.0
76    pz     -66.00
77    pz     -0.02
78    pz     -66.00
79    pz     -0.02
c Table
60    pz     -66.35
61    pz     -66.04
62    px      60.96
63    px     -60.96
64    py      91.44
65    py     -91.44

c Materials
c  Fuel: Pu
m1     94239.80c  0.95 94240.80c  0.05
c  Uranium
m2     92238.80c 0.993 92235.80c 0.007
c Aluminum
m3     13027.80c 1
c Stainless steel
m4     26056 0.61 6012 0.08 24052 0.20 28059 0.11
c --- Calculation options
kcode   10000 1 50 250 $multiplication factor of the system
ksrc    0. 0. -1.
mode n
```

The following MCNP file calculates keff for the abnormal event of water or isopropanol on the table and surrounding the outer hemishells:

```
Evaluation
c Cell cards
200 1   -19.84          -200                                   imp:n=1  $ Pu sphere
1   2   -19.05         200 -1 72                                     imp:n=1  $ 48 Hemishells
2   2   -19.05         1 -2 72                                   imp:n=1
3   2   -19.05         2 -3 72                                  imp:n=1
4   2   -19.05         3 -4 72                                 imp:n=1
5   2   -19.05         4 -5 72                                 imp:n=1
6   2   -19.05         5 -6 72                                 imp:n=1
7   2   -19.05         6 -7 72                                 imp:n=1
8   2   -19.05         7 -8 72                                 imp:n=1
9   2   -19.05         8 -9 72                                 imp:n=1
10  2   -19.05         9 -10 72                                imp:n=1
11  2   -19.05         10 -11 72                               imp:n=1
12  2   -19.05         11 -12 72                               imp:n=1
13  2   -19.05         12 -13 72                               imp:n=1
14  2   -19.05         13 -14 72                               imp:n=1
15  2   -19.05         14 -15 72                               imp:n=1
16  2   -19.05         15 -16 72                               imp:n=1
17  2   -19.05         16 -17 72                               imp:n=1
18  2   -19.05         17 -18 72                               imp:n=1
19  2   -19.05         18 -19 72                               imp:n=1
20  2   -19.05         19 -20 72                               imp:n=1
21  2   -19.05         20 -21 72                               imp:n=1
22  2   -19.05         21 -22 72                               imp:n=1
23  2   -19.05         22 -23 72                               imp:n=1
24  2   -19.05         23 -24 72                               imp:n=1
25  2   -19.05         200 -1 -73                              imp:n=1
26  2   -19.05         1 -2 -73                                imp:n=1
27  2   -19.05         2 -3 -73                                imp:n=1
28  2   -19.05         3 -4 -73                                imp:n=1
29  2   -19.05         4 -5 -73                                imp:n=1
30  2   -19.05         5 -6 -73                                imp:n=1
31  2   -19.05         6 -7 -73                                imp:n=1
32  2   -19.05         7 -8 -73                                imp:n=1
33  2   -19.05         8 -9 -73                                imp:n=1
34  2   -19.05         9 -10 -73                               imp:n=1
35  2   -19.05         10 -11 -73                              imp:n=1
36  2   -19.05         11 -12 -73                              imp:n=1
37  2   -19.05         12 -13 -73                              imp:n=1
38  2   -19.05         13 -14 -73                              imp:n=1
39  2   -19.05         14 -15 -73                              imp:n=1
40  2   -19.05         15 -16 -73                              imp:n=1
41  2   -19.05         16 -17 -73                              imp:n=1
42  2   -19.05         17 -18 -73                              imp:n=1
43  2   -19.05         18 -19 -73                              imp:n=1
44  2   -19.05         19 -20 -73                              imp:n=1
45  2   -19.05         20 -21 -73                              imp:n=1
46  2   -19.05         21 -22 -73                              imp:n=1
47  2   -19.05         22 -23 -73                              imp:n=1
48  2   -19.05         23 -24 -73                              imp:n=1
50  3   -2.7           -50 -52 53                              imp:n=1  $ Aluminum cylinder
60  4   -8.0          60 -61 -62 63 -64 65                     imp:n=1  $ Stainless steel Table
70  4   -8.0         70 -71 -72 73                             imp:n=1  $ Platform
100 0                 200 -70 -72 73                           imp:n=1  $ void platform
71  4   -8.0            -74 76 -77                             imp:n=1  $ Right leg
72  4   -8.0             -75 78 -79                            imp:n=1  $ Left leg
74  5   -0.786          24 -25                                     imp:n=1 $ Water or Isopropanol
99  0 25 (50:52:-53) (-60:61:62:-63:64:-65) (-70:71:72:-73) (74:-76:77) (75:-78:79) imp:n=0
```

```
c  Surface cards
200  so     3.918   $ Plutonium radius
1    so     5.19
2    so     6.46
3    so     7.743
4    so     9.00
5    so     10.27
6    so     11.54
7    so     12.81
8    so     14.08
9    so     15.35
10   so     16.62
11   so     17.89
12   so     19.16
13   so     20.43
14   so     21.70
15   so     22.97
16   so     24.24
17   so     25.51
18   so     26.78
19   so     28.05
20   so     29.32
21   so     30.59
22   so     31.86
23   so     33.13
24   so     34.40
25   so     35.67
c Aluminum cylinder
50    cz      17.20
52    pz      -35.67
53    pz      -65.6082
c Stationary platform
70    cz      3.918
71    cz      35.67
72    pz       0.019
73    pz      -0.019
c legs of stationary platform
74    c/z    0 35.68 1.0
75    c/z    0 -35.68 1.0
76    pz     -66.00
77    pz     -0.02
78    pz     -66.00
79    pz     -0.02
c Table
60    pz     -66.35
61    pz     -66.04
62    px      60.96
63    px     -60.96
64    py      91.44
65    py     -91.44

c Materials
c  Fuel: Pu
m1     94239.80c  0.95 94240.80c  0.05
c  Uranium
m2     92238.80c 0.993 92235.80c 0.007
c Aluminum
m3     13027.80c 1
c Stainless steel
m4     26056 0.61 6012 0.08 24052 0.20 28059 0.11
c Isopropanol
m5          1001  8  8016  1  6012 3
c Water
m6     1001  2 8016  1
c
c --- Calculation options
kcode   10000 1 50 250 $multiplication factor of the system
ksrc    0. 0. 0.
mode n
```

The following MCNP file calculates keff for the abnormal event of dropping an outer hemishell on the top:

```
Evaluation
c Cell cards
200 1   -19.84          -200                                   imp:n=1  $ Pu sphere
1   0                  200 -1 72                               imp:n=1  $ 48 Hemishells
2   0                  1 -2 72                                 imp:n=1
3   2   -19.05         2 -3 72                                  imp:n=1
4   2   -19.05         3 -4 72                                 imp:n=1
5   2   -19.05         4 -5 72                                 imp:n=1
6   2   -19.05         5 -6 72                                 imp:n=1
7   2   -19.05         6 -7 72                                 imp:n=1
8   2   -19.05         7 -8 72                                 imp:n=1
9   2   -19.05         8 -9 72                                 imp:n=1
10  2   -19.05         9 -10 72                                imp:n=1
11  2   -19.05         10 -11 72                               imp:n=1
12  2   -19.05         11 -12 72                               imp:n=1
13  2   -19.05         12 -13 72                               imp:n=1
14  2   -19.05         13 -14 72                               imp:n=1
15  2   -19.05         14 -15 72                               imp:n=1
16  2   -19.05         15 -16 72                               imp:n=1
17  2   -19.05         16 -17 72                               imp:n=1
18  2   -19.05         17 -18 72                               imp:n=1
19  2   -19.05         18 -19 72                               imp:n=1
20  2   -19.05         19 -20 72                               imp:n=1
21  2   -19.05         20 -21 72                               imp:n=1
22  2   -19.05         21 -22 72                               imp:n=1
23  2   -19.05         22 -23 72                               imp:n=1
24  2   -19.05         23 -24 72                               imp:n=1
25  0                  200 -1 -73                              imp:n=1
26  0                  1 -2 -73                                imp:n=1
27  2   -19.05         2 -3 -73                                imp:n=1
28  2   -19.05         3 -4 -73                                imp:n=1
29  2   -19.05         4 -5 -73                                imp:n=1
30  2   -19.05         5 -6 -73                                imp:n=1
31  2   -19.05         6 -7 -73                                imp:n=1
32  2   -19.05         7 -8 -73                                imp:n=1
33  2   -19.05         8 -9 -73                                imp:n=1
34  2   -19.05         9 -10 -73                               imp:n=1
35  2   -19.05         10 -11 -73                              imp:n=1
36  2   -19.05         11 -12 -73                              imp:n=1
37  2   -19.05         12 -13 -73                              imp:n=1
38  2   -19.05         13 -14 -73                              imp:n=1
39  2   -19.05         14 -15 -73                              imp:n=1
40  2   -19.05         15 -16 -73                              imp:n=1
41  2   -19.05         16 -17 -73                              imp:n=1
42  2   -19.05         17 -18 -73                              imp:n=1
43  2   -19.05         18 -19 -73                              imp:n=1
44  2   -19.05         19 -20 -73                              imp:n=1
45  2   -19.05         20 -21 -73                              imp:n=1
46  2   -19.05         21 -22 -73                              imp:n=1
47  2   -19.05         22 -23 -73                              imp:n=1
48  2   -19.05         23 -24 -73                              imp:n=1
201 2   -19.05        205 -206 -207                            imp:n=1  $ dropped shell
50  3   -2.7           -50 -52 53                              imp:n=1  $ Aluminum cylinder
60  4   -8.0          60 -61 -62 63 -64 65                     imp:n=1  $ Stainless steel Table
70  4   -8.0         70 -71 -72 73                             imp:n=1  $ Platform
100 0                 200 -70 -72 73                            imp:n=1  $ void platform
71  4   -8.0            -74 76 -77                             imp:n=1  $ Right leg
72  4   -8.0             -75 78 -79                            imp:n=1  $ Left leg
99  0    24 (50:52:-53) (-60:61:62:-63:64:-65) (-70:71:72:-73) (74:-76:77) (75:-78:79) (-205:206:207) imp:n=0
```

```
c  Surface cards
200  so     3.918   $ Plutonium radius
1    so     5.19
2    so     6.46
3    so     7.743
4    so     9.00
5    so     10.27
6    so     11.54
7    so     12.81
8    so     14.08
9    so     15.35
10   so     16.62
11   so     17.89
12   so     19.16
13   so     20.43
14   so     21.70
15   so     22.97
16   so     24.24
17   so     25.51
18   so     26.78
19   so     28.05
20   so     29.32
21   so     30.59
22   so     31.86
23   so     33.13
24   so     34.40
25   so     35.67
205   s     0 74.24 -31.64 33.13
206   s     0 74.24 -31.64 34.40
c Aluminum cylinder
50    cz      17.20
52    pz      -35.67
53    pz      -66.00
c Stationary platform
70    cz      3.91844
71    cz      35.67
72    pz       0.019
73    pz      -0.019
c legs of stationary platform
74    c/z    0 35.68 1.0
75    c/z    0 -35.68 1.0
76    pz     -66.00
77    pz     -0.02
78    pz     -66.00
79    pz     -0.02
c Table
60    pz     -66.35
61    pz     -66.04
62    px      60.96
63    px     -60.96
64    py      91.44
65    py     -91.44
c Dropped shell
207    pz      -31.64

c Materials
c  Fuel: Pu
m1     94239.80c  0.95 94240.80c  0.05
c  Uranium
m2     92238.80c 0.993 92235.80c 0.007
c Aluminum
m3     13027.80c 1
c Stainless steel
m4     26056 0.61 6012 0.08 24052 0.20 28059 0.11
c
c --- Calculation options
kcode   10000 1 50 250 $multiplication factor of the system
ksrc    0. 0. 0.
mode n
```

The following MCNP file calculates keff for the abnormal event of dripping water from the sprinklers over the storage area:

```
Evaluation
c Cell cards
1   1   -19.84          -200                                  imp:n=1  $ Pu sphere
2   0                  200 -23                                imp:n=1  $ Void between sphere and DU
3   2   -19.05         23 -24                                 imp:n=1  $ 48 Hemishells
4   0                24 -101 102 -103 104 -105 106            imp:n=1  $ air
99  0                   101:-102:103:-104:105:-106            imp:n=0

c  Surface cards
200  so     3.918   $ Plutonium radius
23   so     6.46
24   so     34.40
c Room
101    px      100
102    px     -100
103    py      100
104    py     -100
105    pz      100
106    pz     -34.40

c Materials
c  Fuel: Pu
m1     94239.80c  0.95 94240.80c  0.05
c  Uranium
m2     92238.80c 0.993 92235.80c 0.007
c --- Calculation options
kcode   1000  1  20  120 $multiplication factor of the system
ksrc    0. 0. -1.
mode n
print
c --- end of input
```