# REVISED RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

**APR1400 Design Certification**

**Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD**

**Docket No. 52-046**

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|---|---|
| **RAI No.:** | **179-8190** |
| **SRP Section:** | **09.01.01 - Criticality Safety of Fresh and Spent Fuel Storage and Handling** |
| **Application Section:** | **DCD Tier 2, Section 9.1.1, Criticality Analysis TeR Sections 2.4 and 2.5** |
| **Date of RAI Issue:** | **09/01/2015** |

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## Question No. 09.01.01-23

Question 9.1.1-6: Calculation of sensitivities to new fuel rack tolerances and variations

REQUIREMENTS AND GUIDANCE

In 10 CFR Part 50 Appendix A, General Design Criterion (GDC) 62 requires the prevention of criticality in fuel storage and handling. 10 CFR 50.68(b) sets specific requirements for the demonstration of nuclear criticality prevention in new fuel storage. NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” Section 9.1.1 guides the reviewer, in part, to verify the conservatism of normal-conditions models and the appropriateness of assumptions and approximations made therein. Sensitivity studies are one way to support normal-conditions model development.

ISSUE

For the new fuel rack criticality analysis, the applicant calculates sensitivities to design tolerances and variations on a model of an infinite-array of rack cells moderated by full-density water. The staff notes that this calculation model neglects the neutronic effects of storage pit concrete and does not address sensitivities under the potentially more limiting accident conditions of optimum moderation by low-density water.

INFORMATION NEEDED

The applicant should describe in its response and in the DCD or its incorporated references additional sensitivity calculations on an analysis model that addresses the neutronic effects of storage pit concrete as well as the respective conditions of optimum moderation by low-density water and moderation by full- density water. The results of the supplemental

sensitivity studies should be applied as necessary to the neutron multiplication factors computed for the respective moderation accident conditions.

## Response – (Rev. 2)

Sensitivity calculations on a finite array model describing the new fuel racks with storage pit concrete in optimum moderation and full-density water conditions have been performed to obtain uncertainties due to design tolerances. The criticality analysis TeR will be revised to include the sensitivity calculation results.

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### Impact on DCD

There is no impact on the DCD.

### Impact on PRA

There is no impact on the PRA.

### Impact on Technical Specifications

There is no impact on the Technical Specifications.

### Impact on Technical/Topical/Environmental Reports

Sections 2.4.2 and 2.5, Tables 2.4-3, 2.4-4, and 2.5-1, Figures 2.4-2, 2.4-3, and 2.5-1 in the criticality analysis TeR will be revised as indicated in the attachment.

Table 2.1-1 Design Input Data of Fuel Assembly and New Fuel Storage Rack

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[ ]TS

[ ]TS

## 2.4 Criticality Analysis for New Fuel Storage Rack

### 2.4.1 Criticality Calculation

The criticality analyses for the NFR consider waters with an optimum moderation condition and the maximum densities, therefore criticality calculations are performed for water densities ranged from 0.01 g/cm$^3$ to 1.0 g/cm$^3$ to determine the maximum $k_{eff}$ for an optimum moderation condition. The criticality calculation model including NFSP is shown in Figure 2.4-1.

The calculation results are presented in Table 2.4-1 as the calculated nominal $k_{eff}$ with corresponding water densities. The nominal $k_{eff}$ values in the Table 2.4-1 do not contain any bias or uncertainties.

### 2.4.2 Bias and Uncertainty

The bias and uncertainties by the calculation methods and variations of design parameters are estimated from the following items:

a. Bias and bias uncertainty of a criticality calculation method,

b. Statistical uncertainty of the Monte Carlo calculation, and

c. Uncertainty due to tolerances or variations in the design parameters.

The basis of bias and uncertainty items and their corresponding values considered for the criticality analysis of the NFR are described in below.

(1) Bias and bias uncertainty of a criticality calculation method

Bias and bias uncertainty are evaluated to validate the criticality analysis methodology through the benchmark calculations based on the criticality experiments (Reference 7).

a. Bias: [ ]$^{TS}$

b. Bias uncertainty: [

(2) Statistical uncertainty of the Monte Carlo calculation

~~Statistical uncertainty (2σ) of the criticality calculation for full density water model (reference model) is [ ]$^{TS}$ as shown in Table 2.4-2.~~

a. Optimum moderation (2σ) : [ ]$^{TS}$

b. Moderation by full density water (2σ) : [ ]$^{TS}$

Statistical uncertainties of the criticality calculation for the optimum moderation condition and fully flooded condition are provided in Tables 2.4-3 and 2.4-4, respectively.

(3) Uncertainty due to tolerances or variations in the design parameters

These items should be replaced with page 3 of Attachment.

To evaluate uncertainties due to the tolerances in the mechanical and material specifications of the fuel and rack structures, sensitivity analyses are performed for the fuel rack cell in various conditions including the dimensional and material tolerances of the structure. Items in the sensitivity analysis for the criticality uncertainty evaluation are as follows:

a. $UO_2$ pellet stack density: [ ]$^{TS}$,

b. $UO_2$ pellet diameter: [ ]$^{TS}$,

c. Fuel rod pitch: [ ]$^{TS}$,

d. Fuel clad outer diameter: [ ]$^{TS}$,

e. Fuel assembly position in fuel rack cell: [ ]$^{TS}$,

f. NFR cell pitch: [ ]$^{TS}$, and

a. U-235 enrichment: [ ]$^{TS}$

b. $UO_2$ pellet stack density: [ ]$^{TS}$,

c. $UO_2$ pellet diameter: [ ]$^{TS}$,

d. Fuel rod pitch: [ ]$^{TS}$,

e. Fuel clad outer diameter: [ ]$^{TS}$,

f. Guide tube outer diameter: [ ]$^{TS}$

g. Fuel assembly position in fuel rack cell: [ ]$^{TS}$,

h. NFR cell pitch: [ ]$^{TS}$, and

i. NFR cell thickness: [ ] TS.

g. NFR cell thickness: [ ] TS.

The uncertainty analyses are performed for the unit cell model of the NFR as shown in Figure 2.4-2. The calculation results for the uncertainty analysis due to the tolerances or variations in the design parameters are summarized in Table 2.4-2. To determine the reactivity difference ($\Delta k_i$) associated with a specific manufacturing tolerance, the $k_{eff}$ calculated for the reference model is compared to that for the model with an individual tolerance. The $\Delta k_i$ due to a tolerance is then calculated as follows:

The uncertainty analyses are performed for the finite array model including NFSP as shown in Figure 2.4-1.

$$\Delta k_i = k_i - k_R + 1.645\sqrt{\sigma_i^2 + \sigma_R^2}$$

Tables 2.4-3 and 2.4-4.

where:

$k_i$ = $k_{eff}$ with the tolerance,

$k_R$ = $k_{eff}$ for the reference model,

$\sigma_i$ = Monte Carlo standard deviation for the case with tolerance,

$\sigma_R$ = Monte Carlo standard deviation for the reference model, and

1.645 = One-sided 95/95 confidence interval factor.

for optimum moderation and fully flooded conditions, which include

Tables 2.4-3 and 2.4-4.

The resultant uncertainty due to tolerances or variations in the design parameters which is calculated as square root of the sum of the squares of individual $\Delta k_i$ is presented in the last row of Table 2.4-2.

The evaluated total bias and uncertainty ($\Delta k_{NFR}$), which includes bias for the criticality analysis of the NFR is determined as follows:

[ ] TS

This equation should be replaced with page 5 of Attachment.

For conservatism, a total uncertainty of 0.01665 will be applied to obtain final criticality analysis results for new fuel rack storage system.

[ ]TS

[ ]TS

Table 2.4-3 Tolerance Uncertainty for Optimum Moderation Condition

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This table should be added.

Table 2.4-4 Tolerance Uncertainty for Fully Flooded Condition

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This table should be added.

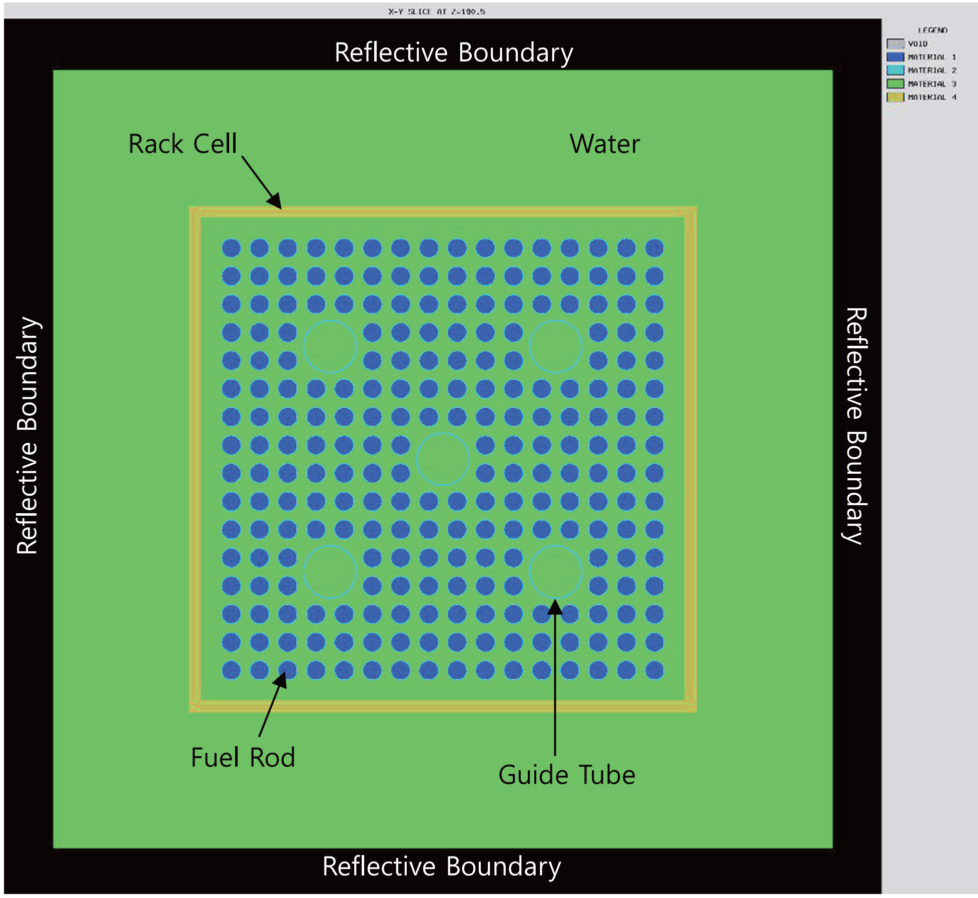


Figure 2.4-2 Unit Cell Model for Uncertainty Analysis

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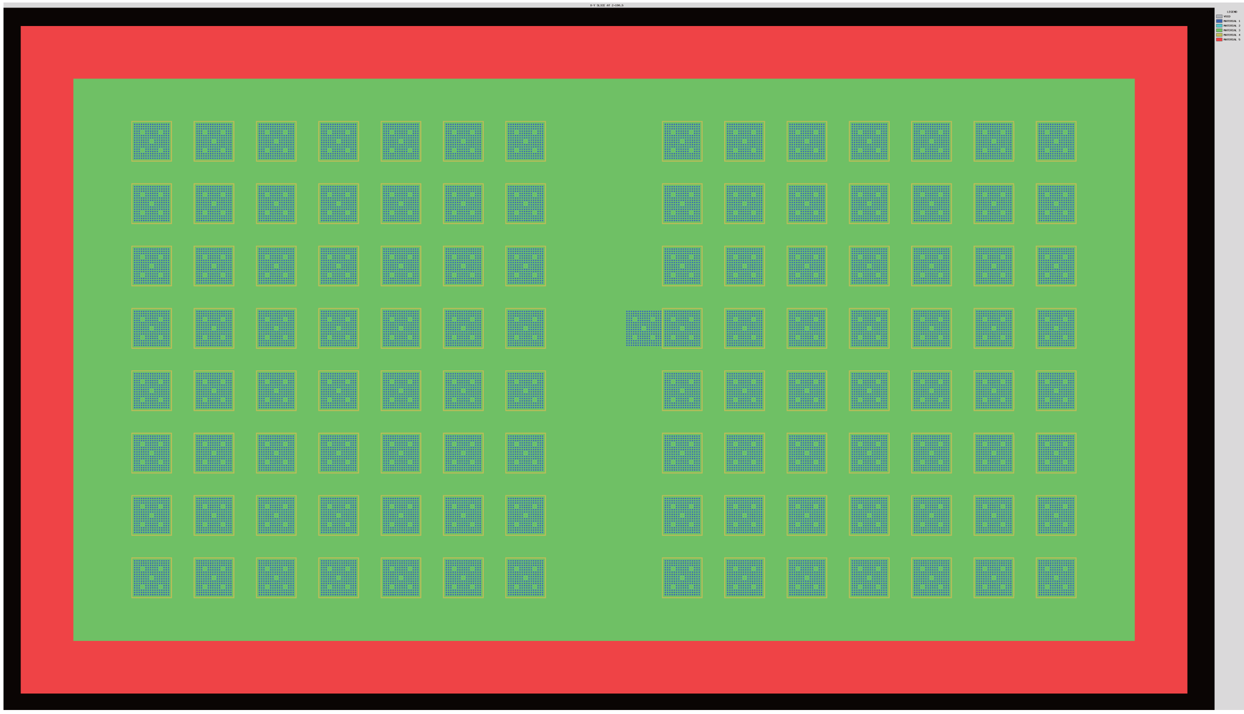

Figure 2.4-2 Criticality Calculation Model for a Dropped Fuel Assembly Accident (Contact)

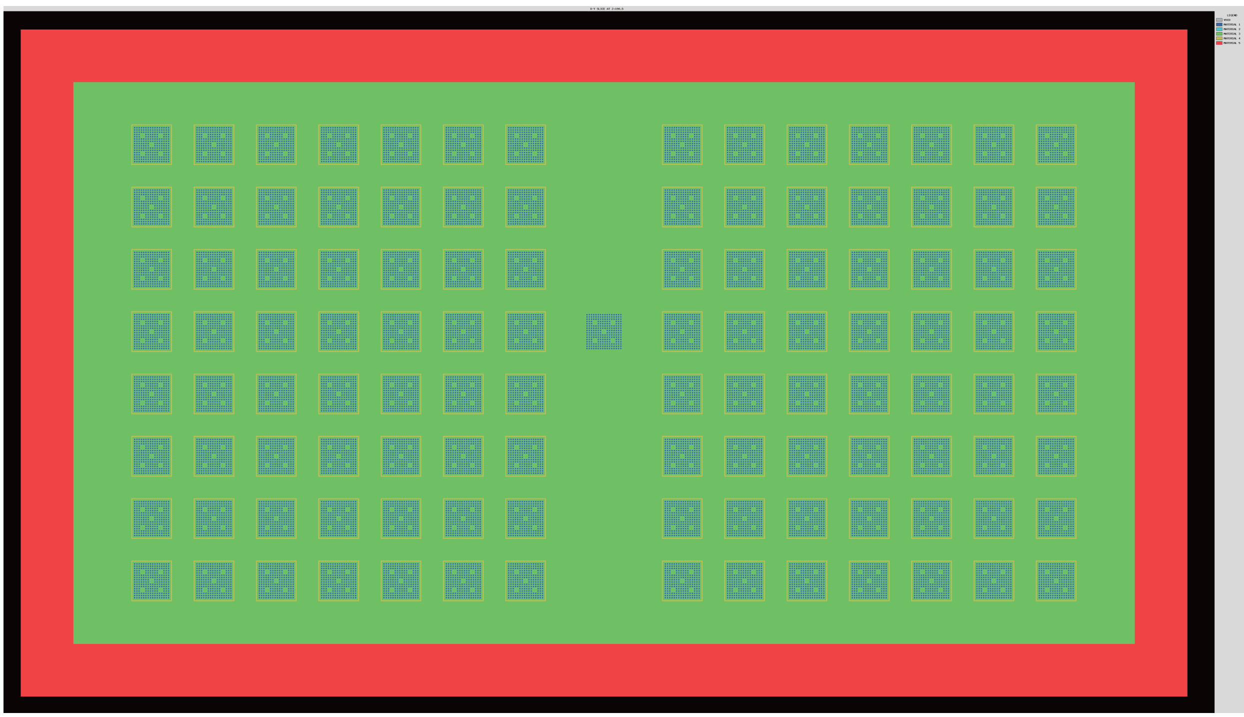

Figure 2.4-3 Criticality Calculation Model for a Dropped Fuel Assembly Accident (Centered)

This figure should be added.

Table 2.5-2 shows the evaluated $k_{eff}$ for postulated accident cases of a dropped fuel assembly in the space between fuel racks.

## 2.5 Results

The criticality analysis for the NFR with 5.0 wt% enrichment of the PLUS7 fuel is performed by using SCALE 6.1.2 code. Table 2.5-1 and Figure 2.5-1 show the evaluated effective neutron multiplication factors according to various water densities. The evaluated results for the criticality analysis include the evaluated total bias and uncertainty ($\Delta k_{NFR}$). An optimum moderation condition occurs at water density of 0.14 g/cm$^3$.

The evaluated effective neutron multiplication factors for the NFR have the additional margin due to the conservative assumptions for the criticality analysis as follows:

- The design maximum enrichment of 5.0 wt% is applied to all the $UO_2$ fuel rods in the NFR,
- Miscellaneous structures such as grid, spring, end caps, etc., are not included in the calculation model,
- Burnable absorber rods in fuel assembly or axial blankets in fuel rod are not considered in the calculation model, and
- Zoning to alleviate the power peak in the fuel assembly is not considered and all fuel rods are assumed to have the same maximum enrichment.

As a conclusion, the evaluated effective neutron multiplication factors for the NFR satisfy the acceptance criteria as follows:

| Description | $k_{eff}$ | Acceptance criteria |
|---|---|---|
| $k_{eff}$ for flooded by pure water | 0.91257 | ≤ 0.95 |
| $k_{eff}$ for optimum moderation | 0.93298 | ≤ 0.98 |

This table should be replaced with table on page 12 of Attachment.

| Description | $k_{eff}$ | Acceptance criteria |
|---|---|---|
| $k_{eff}$ for flooded by pure water | 0.91393 | ≤ 0.95 |
| $k_{eff}$ for optimum moderation | 0.93439 | ≤ 0.98 |

Table 2.5-1 Effective Multiplication Factors for the NFR

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This table should be replaced with page 14 of Attachment.

Table 2.5-1 Evaluation Results of $k_{eff}$ for Various Water Densities

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Figure 2.5-1 Effective Multiplication Factors for the NFR according to Water Density Changes

This figure should be replaced with page 16 of Attachment.

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Figure 2.5-1 Effective Multiplication Factors of NFR according to Water Density Changes

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| **Date of RAI Issue:** | **09/01/2015** |

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## Question No. 09.01.01-25

RAI 9.1.1-24: Dimensional tolerances for the new fuel storage racks

REQUIREMENTS AND GUIDANCE

In 10 CFR Part 50 Appendix A, General Design Criterion (GDC) 62 requires the prevention of criticality in fuel storage and handling. 10 CFR 50.68(b) sets specific requirements for the demonstration of nuclear criticality prevention in fuel storage and handling. NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition” (SRP), Section 9.1.1 guides the reviewer, in part, to verify that normal and abnormal conditions are modeled correctly and that all modeling approximations and assumptions are appropriate. This includes appropriate handling of dimensional and material tolerances and uncertainties. The SRP Acceptance Criteria for Section 9.1.1 refer to ANSI/ANS-57.3, which provides in Subsection 6.2.4.1.5 a list of parameters that should be evaluated in the determination of the most reactive fuel assembly, including maximum fissile fuel loading, fuel rod pitch, and fuel rod cladding thickness.

ISSUE

Table 2.4-2 of the criticality technical report provides a list of the mechanical tolerances or variations for the input parameters to the new fuel storage rack model used in a sensitivity analysis for the new fuel storage rack criticality uncertainty evaluation. It is not clear to the staff why the tolerances in this table are not consistent with those for the region I spent fuel storage rack criticality uncertainty evaluations in that the new fuel tolerances do not consider uncertainty in uranium enrichment and both positive and negative tolerances in dimensions such as fuel rod pitch, fuel clad diameter, and rack cell thickness.

INFORMATION NEEDED

In its response and in the DCD or its incorporated reference, the applicant should either (1) provide justification for not including the uncertainty in uranium enrichment and both positive and negative dimensional variations or (2) update the sensitivity analysis for the new fuel storage racks to include these tolerances and apply the revised results to the new fuel storage rack criticality analysis accordingly.

## Response – (Rev. 2)

Sensitivity analysis for the new fuel storage rack criticality uncertainty evaluation has been performed to include additional items such as uranium enrichment and both positive and negative tolerances in dimensions such as fuel rod pitch, fuel clad diameter, and rack cell thickness. Criticality analysis TeR will be revised to include the additional sensitivity calculation results.

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### Impact on DCD

There is no impact on the DCD.

### Impact on PRA

There is no impact on the PRA.

### Impact on Technical Specifications

There is no impact on the Technical Specifications.

### Impact on Technical/Topical/Environmental Reports

Sections 2.4.2 and 2.5, Tables 2.4-3, 2.4-4, and 2.5-1, Figures 2.4-2, 2.4-3, and 2.5-1 in the criticality TeR will be revised as indicated in the attachment.

Table 2.1-1 Design Input Data of Fuel Assembly and New Fuel Storage Rack

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[ ]TS

[ ]TS

### 2.4 Criticality Analysis for New Fuel Storage Rack

#### 2.4.1 Criticality Calculation

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c. Uncertainty due to tolerances or variations in the design parameters.

The basis of bias and uncertainty items and their corresponding values considered for the criticality analysis of the NFR are described in below.

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e. Fuel assembly position in fuel rack cell: [ ]TS,

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where:

for optimum moderation and fully flooded conditions, which include

$k_i$ = $k_{eff}$ with the tolerance,

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Table 2.4-3 Tolerance Uncertainty for Optimum Moderation Condition

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Table 2.4-4 Tolerance Uncertainty for Fully Flooded Condition

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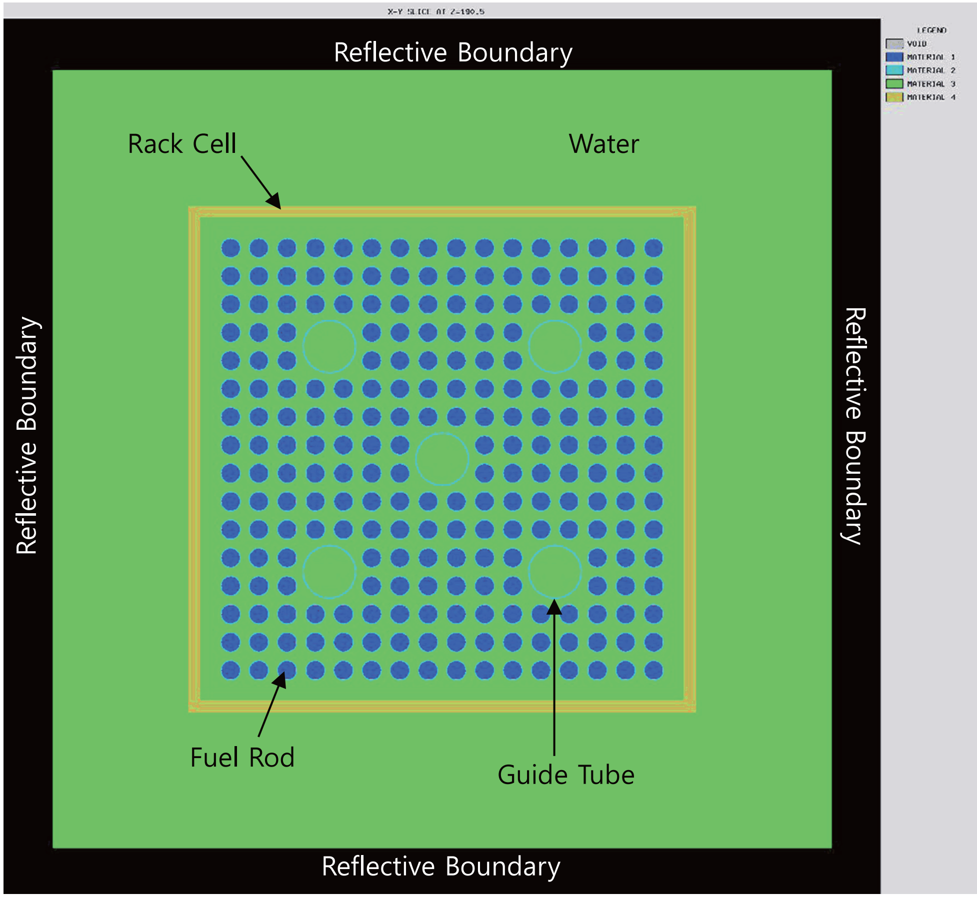


Figure 2.4-2 Unit Cell Model for Uncertainty Analysis

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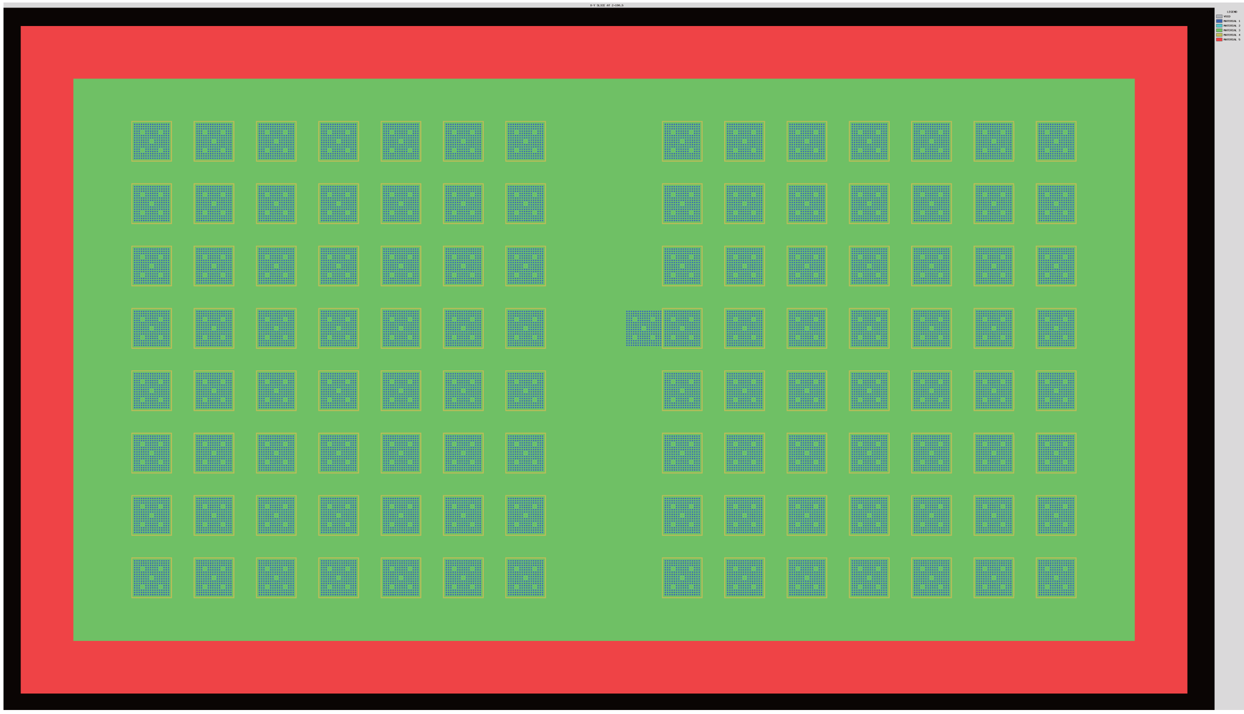

Figure 2.4-2 Criticality Calculation Model for a Dropped Fuel Assembly Accident (Contact)

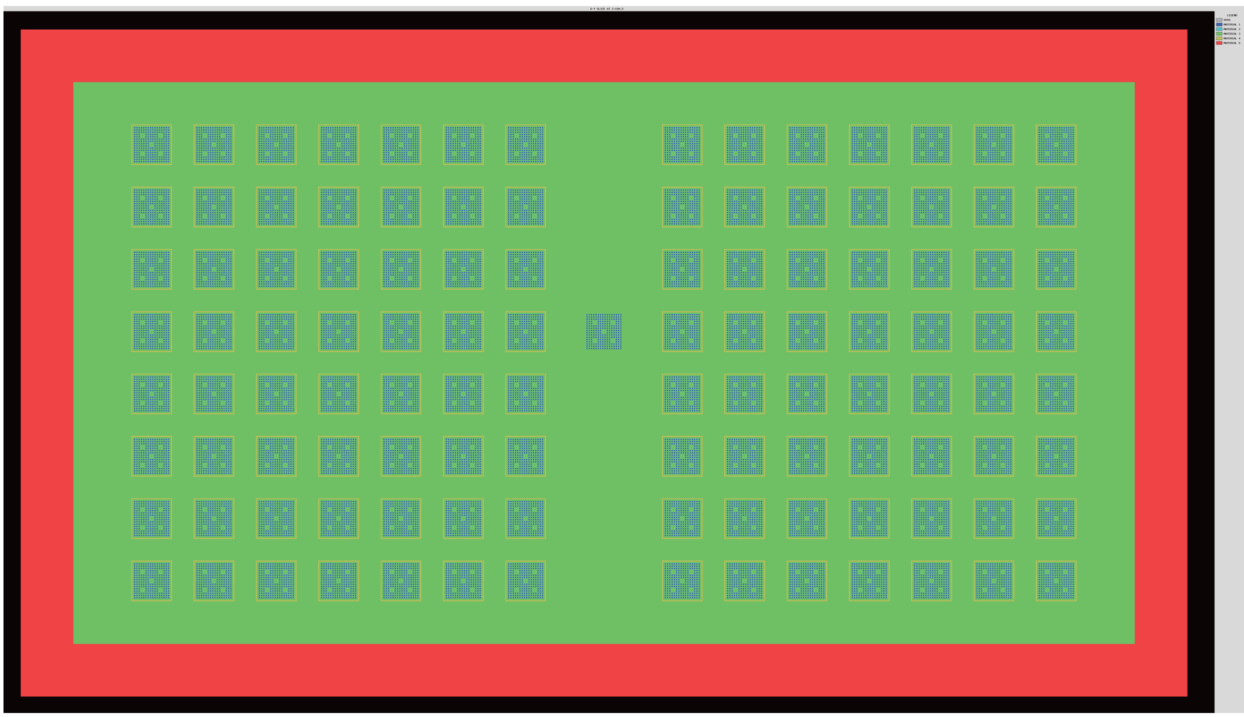

Figure 2.4-3 Criticality Calculation Model for a Dropped Fuel Assembly Accident (Centered)

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## 2.5 Results

Table 2.5-2 shows the evaluated $k_{eff}$ for postulated accident cases of a dropped fuel assembly in the space between fuel racks.

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Table 2.5-1 Evaluation Results of $k_{eff}$ for Various Water Densities

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Figure 2.5-1 Effective Multiplication Factors for the NFR according to Water Density Changes

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