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Criticality Safety Analysis of Fresh Fuel Storage of Barakah Nuclear Power Plant (APR1400)

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INTRODUCTION

- In order to keep the nuclear energy system safe, sub-criticality should be ensured at all times and at all locations where fresh fuel and spent fuel are stored or handled during normal, abnormal and accident conditions.
- Different Nuclear power plants include different types for storage of new and spent fuel assemblies.

CASE STUDY

- A criticality safety analysis was performed in this study for the fresh fuel storage racks of Barakah Nuclear Power Plant.
- MCNP6.1 and RMC were used to assess the (K_{eff}) in the racks under Normal and abnormal conditions, manufacturing tolerances.
- Optimum moderation condition study has been also performed, and will be reported in another paper.

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REQULATORY REQUIREMENT

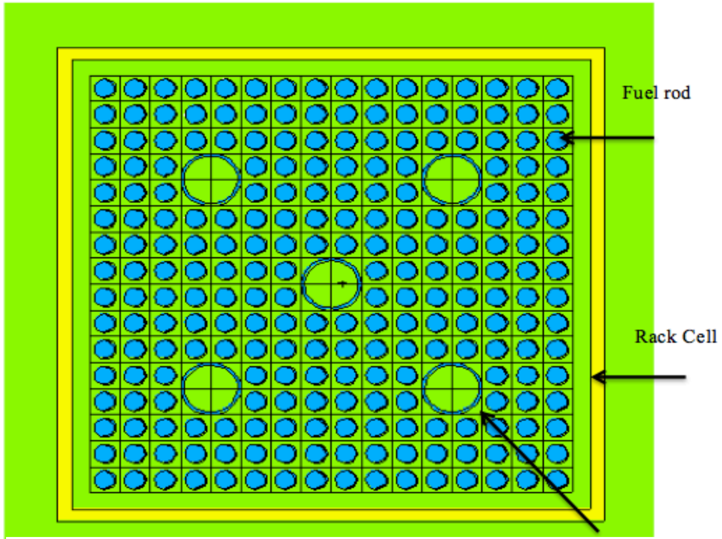
- The acceptance criteria of the new fuel storage racks is that (K_{eff}), including all the biases and uncertainties does not exceed **0.95** with flooded by un-borated water at 95 percent probability and 95 percent confidence level

CRITICALITY CALCULATIONS

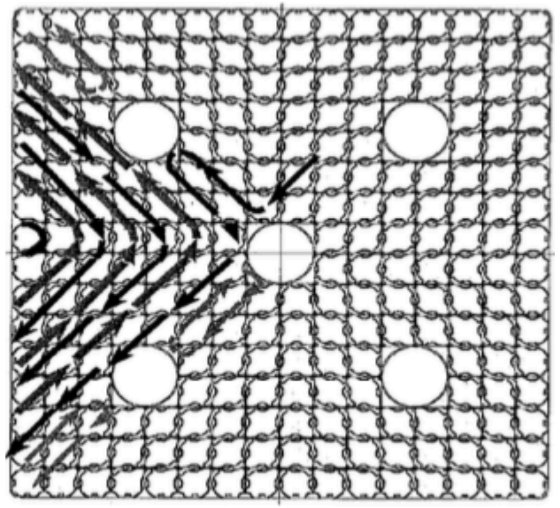
- PLUS7 fuel
  - 16x16 array
  - Maximum enrichment of 5.0w/o U-235
  - ZIRLO cladding material.

Modeled Fuel Assembly Parameters

Assembly geometry	16 x 16
No. of rods per assembly:	
Fueled (UO_2)	236
Unfueled	5
Assembly length	452.8 cm
Assembly width	20.7 cm
Fuel outer diameter	0.95 cm
Pellet length	0.983 cm
Pellet outside diameter	0.8192 cm
Cladding material	ZIRLO
Clad thickness	0.0572
Fuel rod inner diameter	0.8356 cm
Fuel rod length	409.4 cm
Guide tube thickness	0.07 cm (assumed)
Guide tube diameter	2.6334 cm (assumed)



Modeled fuel assembly by MCNP


2PLUS7 Design

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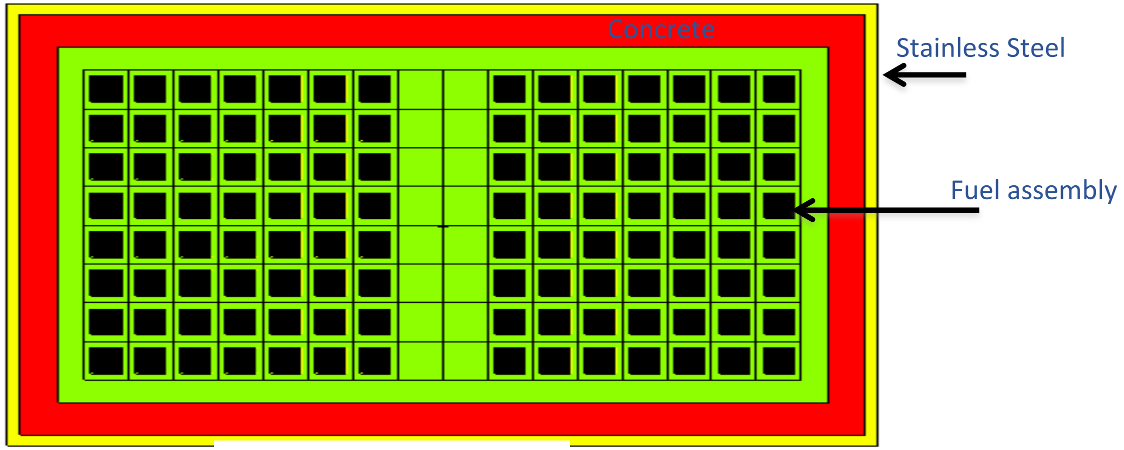
CRITICALITY CALCULATIONS

- Dry Racks
  - Consist of two racks
  - Each rack is 7x8 cells array, (can store total of 112 new fuel assemblies)
  - Surrounded by concrete walls.



Fresh Fuel Stor

Fresh Fuel Storage Rack Design Parameters

Racks geometry	2 x 7 x 8
Storage Capacity	112 Fuel Assemblies
Rack Cell Thickness	0.6 cm (assumed)
Depth	5.18 m
Racks Material	Stainless steel
Storage Material	Concrete
Concrete thickness	30 cm

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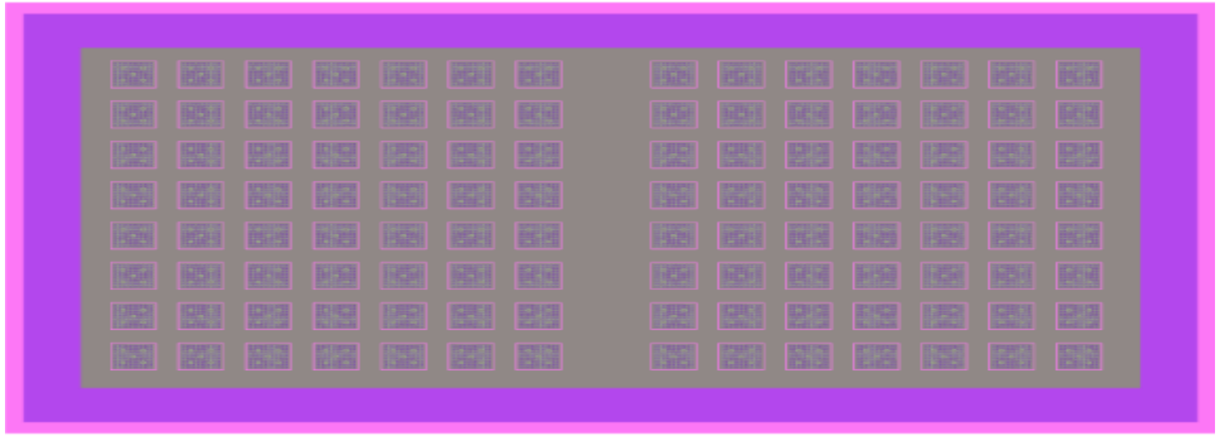
CRITICALITY CALCULATIONS

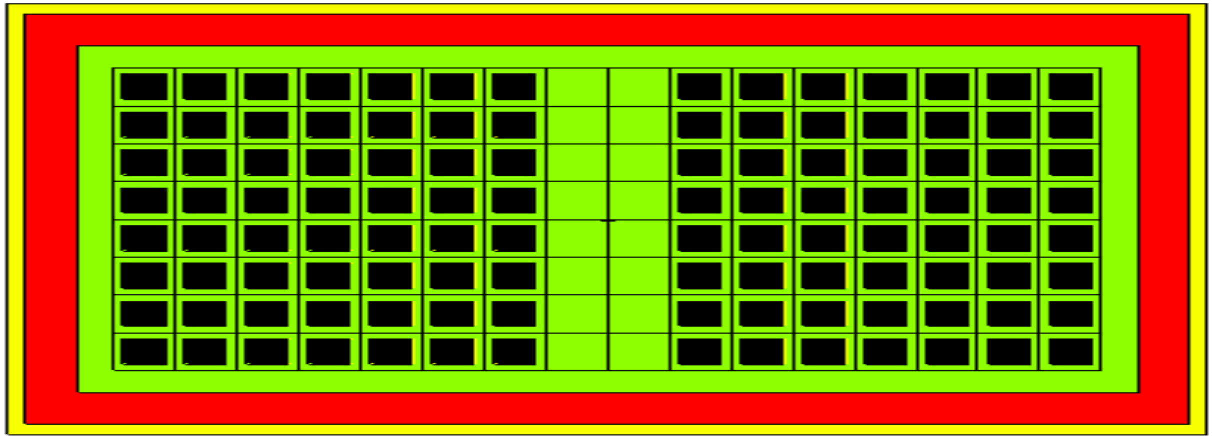
The criticality study was implemented using the following conservative assumptions:

- Maximum enrichment for the UO_2 is 5.0wt%.
- No burnable rods and No axial blankets in the fuel rod.
- All of the structural materials were ignored.
- The temperature of the fuel assembly, and rack structure, were assumed as room temperature.
- Abnormal conditions represent the temperature variation of water filling the storage rack (0^oC, 20^oC, and 100^oC).

CRITICALITY CALCULATIONS

- A 3D storage rack has been modeled using MCNP, while a more conservative 2D storage rack was modeled using RMC.





Fresh fuel rack base model using MCNP and RMC

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CRITICALITY CALCULATIONS

The bias and uncertainties of the calculation methods and variations of design parameters were estimated with the following items:

- Bias and bias uncertainty of a criticality calculation method.
- Statistical uncertainty of Monte Carlo calculation.
- Uncertainty due to tolerances and variation in the design parameters.

CRITICALITY CALCULATIONS

Fuel Assembly and Storage Rack Tolerances

Tolerances	Nominal Value	Tolerance
1) UO_2 enrichment	5%	0
2) UO_2 pellet stack density	10.431 g/cm^3	1.5%
3) Pellet diameter	0.8192cm	0.0012 cm
4) Fuel rod pitch	1.3167cm	0.00556 cm
5) Clad outer diameter	0.95 cm	0.0045 cm
6) Guide Tube Radius	1.3167cm	0.005 cm
7) Rack cell pitch	35.5cm	1 cm 2 cm
8) Fuel assembly position in fuel rack cell	Move all the assemblies to the corners. Move all the assemblies to the right.	
9) Rack cell thickness	0.6 cm	1% 2% 3% 4% 5%

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CRITICALITY CALCULATIONS

- The calculation of the maximum K_{eff} included an added uncertainty, which accounts for the effects on reactivity of fuel assembly tolerances.

- In order to calculate the reactivity difference associated with a specific manufacturing tolerance, (Δk_i) is calculated as:

$$\Delta k_{Ti} = k_i - k_R + 1.645\sqrt{\sigma^2{}_i + \sigma^2{}_R}$$

- In addition, for abnormal conditions, this equation was used: $\Delta_{ki}=k_i - k_R$ where k_i is k_{eff} with the abnormal condition with uncertainty as:

$$\sigma_{\Delta k_i} = 2 * \sqrt{\sigma^2{}_i + \sigma^2{}_R}.$$

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CRITICALITY CALCULATIONS

- The total uncertainty was calculated using the following equation

$$\Delta k_{\text{Uncertainty}} = \sqrt{(2 * \sigma_R)^2 + \sum_{i=1}^{5} \sigma_{\Delta k_i}^2}$$

- Taking into consideration bias and uncertainties, the maximum keff was evaluated by the following equations:

$$K_{eff}^{max} = K(calc) + \Delta K(bias) + \Delta K\ (tolerances) + \Delta K\ (uncertainty)$$

RESULTS

- In order to compare MCNP and RMC results, bias calculations were performed to find a 3D K_{eff} of RMC results comparable to MCNP results.
- This calculation includes code-to-code comparison; RMC and MCNP 2D model, and 2D to 3D comparison of MCNP.

RESULTS

- The analysis performed in this study was compared with an analysis performed by KEPCO in which SCALE 6.1.2 was used to calculate the neutron multiplication factor. As a result, it’s stated that both codes are meeting the intended requirements and the corrected base model for the studied cases with an error of 1.5% between MCNP and SCALE and 2% between MCNP and RMC.

Results Summary

Description	K_{eff}			Acceptance criteria	Relative Error (%)
	MCNP	RMC	KEPCO SCALE		
Normal Dry Condition	0.526± 0.00018	0.571± 0.00021 (2D model)	-		8.6
Flooded by pure water	0.915 ± 0.00029 (including bias)	0.933 ± 0.00085(2D model) 0.921 (Comparable 3D Model)	-	$\leq$ 0.95	2.0
	0.927 ± 0.00029 (including bias and tolerances)	-	0.913		1.5

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CONCLUSIONS

The objective of this study was to calculate the neutron multiplication factor under normal and flooded by pure water conditions. The calculations of criticality demonstrated that FANR and NRC acceptance criteria is met for BNPP for the storage with a maximum initial average enrichment of 5wt% of U-235.

In comparison, MCNP results shows a very close results to KEPCO SCALE results, also to compare between RMC and MCNP, 3-dimentional model has been done using MCNP while 2-dimentional model using RMC, so in order to compare between the two models, an RMC K value comparable to 3D results of MCNP was calculated using bias calculations, and the results shows that both models gave a very close results as well.