Criticality Analysis of High Density Storage Rack for Fresh Fuel Assemblies

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1. Introduction

A new suspension-type High Density Storage Rack (HDSR) is developed by KONES and KNF to increase the storage density of fresh fuel assemblies in the pit. In comparison with the existing old rack, a so-called neutron absorber material, which is borated stainless steel (BSS, ASTM A887 Type B6) with a minimum boron content of 1.5 wt% boron, is applied in HDSR. This paper presents the results of the criticality analysis for HDSR.

2. HDSR Design Features

The storage pit consists of 12 self-standing HDSR modules (eight 4x17, two 4x16, one 4x14, one 4x13) and 4 visual inspection stands are further used without any change. Fig. 1 shows the overall configuration of modules in the storage pit. Four different types of fuel assemblies (WH14x14, 16ACE7, 17ACE7, PLUS7) are allowed to be stored in the racks. Any fuel except above four types of fuel will require analysis before being placed in the racks. The pellet densities used for PWR fuel designs have been increasing. Therefore, in order to cover future designs a maximum 97% of the theoretical density of UO_2 was assumed in all the analysis. This density is the stack density. Since pellets are generally dished and chamfered, the actual theoretical density of the pellet allowed by this analysis is over 98%. Any lower stack density is covered by this analysis. The important rack dimensions for criticality evaluations are given in Table 1.

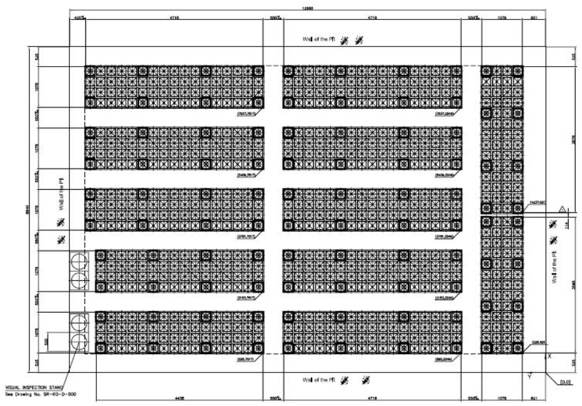

Fig. 1 Configuration of HDSR modules in the storage pit

Table 1: Rack dimensions

Item	Size [mm]	Tolerance [mm]
Cell wall thickness	4	+0.4/-0
Cell inside Diameter	230	+0.3/-0
Cell pitch	280	+1.0/-0
Separation between modules	550	+0/-4

3. Relevant Codes and Reference Model

The relevant codes and standards [1, 2, 3] specifies that a criticality event cannot occur in the HDSR under normal and accident conditions. The objective of this paper is to show that the maximum calculated reactivity under full flood and optimum moderation conditions do not exceed the regulatory limits.

- Full flood conditions : 0.95 with a 95% probability at a 95% confidence level
- Optimum moderation conditions : 0.98 with a 95% probability at a 95% confidence level

As shown in Fig.1 the racks are separated by 55 cm of water under full flood conditions. This distance is enough that they do not interact neutronically. The longest rack is 17 boxes long. This is long enough that it is assumed essentially to be infinite. These observations allow for a simplified model of the pit with the HDSR. The simplified model (Reference Model) consists of two boxes and one half of the rack separation. Each box is surrounded by half the flux trap (the 42 mm between the boxes). On the outside of this reflective boundary conditions are assumed. The nominal dimensions in Table 1 are adopted for the wall thickness, pitch and inside diameter of the racks. Axially, the active fuel region is modeled with a reflector above and below the fuel. Fig. 2 shows the reference model.

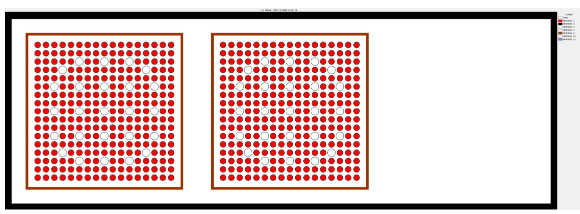

Fig. 2 Reference model

3. Validation of Computer Codes and USL

All analyses are performed using the CSAS25 module of SCALE5.1 and the 44 group of ENDF/B-V library. The validation of the code package was done by comparison to 132 critical experiments. Trends in the data, however, were sought on 10 different parameters. The statistical analysis was performed to determine an Upper Subcriticality Limit (USL) for analysis of k_{eff} [4]. USL contains the bias and uncertainty from the analysis of the critical experiments as well as 0.05 safety margin. Any calculated k (after adjustment for the uncertainty in that calculation) that is lower than USL assures that the analyzed configuration will be 5% subcritical with a 95/95 confidence. Table 2 shows the results of USL determinations for the trends analyzed. As can be seen on Table 2 the minimum USL is 0.9412. Calculated configurations with a k_{eff} plus 2 sigma of less than 0.9412 will be subcritical configurations.

Table 2: Minimum USLs for trending parameters

Trending Parameter	Min. USL	Range in Criticals
Enrichment	0.9417	2.35-5.74
Fuel Pin Pitch	***0.9412***	1.2-2.5
AEG	0.9430	29.9-36.6
AEF	0.9430	0.082-1.402
Water to Fuel Ratio	0.9430	.383-5.067
H/X Ratio	0.9430	45-504
Dancoff Factor	0.9430	.039-.615
Areal Boron Density	0.9430	.0003-.083
Assembly Separation	0.9418	0-15.87
Boron Content	0.9430	.0001-.0135

4. Evaluations and Results

Table 3 shows the results of the reference model analyses and the sensitivity runs for the full flood conditions. The maximum reactivity of HDSR is less than 0.9412(USL), therefore HDSR of KNF is evaluated to maintain subcriticality. As a result of the sensitivity runs, the increased cell inner diameter, the increased pellet OD and the decreased clad OD show a small positive effect. The difference is close to the uncertainty for the analysis, so each of the items will be used for the final analysis.

Table 3: Reference model and sensitivity results

Case	k-eff	Sigma	Δk
Reference model	**0.93052**	**0.00007**	**Base**
Modeling Condition			
- Rack separation from 55 to 45 cm	0.93048	0.00008	-0.0001
- Connecting Plates	0.93122	0.00008	0.0007
Reflector Study			
- 99% water 1% SS	0.93051	0.00046	-0.0001
- 70% water 30% SS	0.93088	0.00042	0.0004
- 30% water 70% SS	0.93079	0.00043	0.0003
- 1% water 99% SS	0.93096	0.00043	0.0004
Rack Tolerance			
- the Box wall thickness 4->4.4 mm	0.92614	0.00041	-0.0044
- the Box inner diameter 230->230.3 mm	0.93062	0.00008	0.0001
Fuel Tolerance			
- the Pellet OD from 8.192 to 8.204 mm	0.93076	0.00009	0.0003
- the clad OD from 9.50 to 9.40 mm	0.93257	0.00008	0.0030

To analyze optimum moderation conditions for HDSR reactivity calculations of the model are performed with variable water density. Fig. 3 shows the results graphically. Note that although there is a low density peak in reactivity, the k_{eff} for that peak is much less than that for full density water.

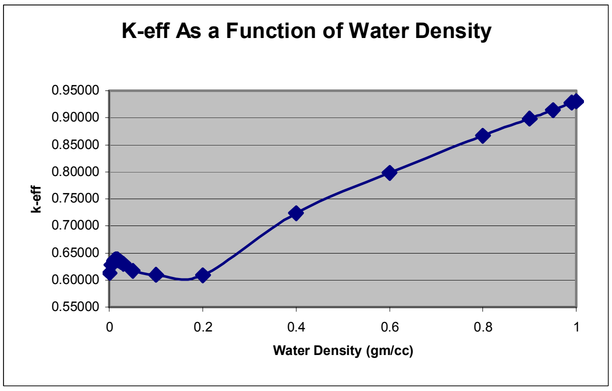

Fig. 3 k_{eff} as a function of water density

5. Conclusions

With the model tested and the most limiting conditions determined, a case was analyzed using all the most limiting conditions. All of the sensitivity analyses were done with the 17ACE7 fuel. A limiting case using the model with connecting plates and using the maximum pellet OD, minimum clad OD, clad all the way to the pellet, and eccentric positioning of the fuel was run to put everything together before comparing to USL. Table 3 shows the results. As can be seen from Table 4 the resulting k_{eff} of the limiting case is less than USL, therefore the system is safe in criticality.

Table 4: Final analysis and comparison with USL

Case Description	**17ACE7 Fuel, 5 wt%U-235, 97% TD stack density, Pellet OD= 8.204 mm, Clad OD=9.46 mm, Eccentric Fuel Positioning, and Connecting Plates, Run ID=sal3**
k-eff	**0.93589**
2*Sigma	**0.00040**
Total	**0.93629**
USL	**0.94120**

REFERENCES

[1] Title 10 of the Code of Federal Regulations Part 70 (10 CFR Part 70), DOMESTIC LICENSING OF SPECIAL NUCLEAR MATERIAL, US NRC April 1996.
[2] American National Standard Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, ANSI/ANS-8.1-1998 (R2007), American Nuclear Society, La Grange, Illinois.
[3] American National Standard Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors, ANSI/ANS-8.17-2004, American Nuclear Society, La Grange, Illinois.
[4] KONES & Lancaster, D. B., "Calculation of the Upper Subcritical Limits for the HDSR by Use of Critical Experiments," Document ID: NuC/CTR/KONES/HDSR – 1, KONES & CTR Technical Services, July 2008.