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Criticality Analysis of SFP Region I under Dry Air Condition

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1. Introduction

Criticality safety analyses are performed to show that a proposed fuel storage or transport configuration meets the applicable requirements and that it includes calculations to demonstrate that the proposed configuration will meet the maximum effective neutron multiplication factor (keff) limits specified in the applicable requirements and guidance. This paper is to provide a result of the criticality evaluation under the condition that new fuel assemblies for initial fuel loading are storing in Region 1 of SFP in the dry air. The objective of this analysis is to ensure the effective neutron multiplication factor(keff) of SFP is less than 0.95 under that condition.

2. Modeling Approach and Assumption

SCALE(**S**tandardized **C**omputer **A**nalyses for **L**icensing **E**valuation) is used for the criticality analysis. The SCALE computer software system developed at Oak Ridge National Laboratory is widely used and accepted around the world for criticality safety analyses[1]. The well-known KENO-VI three-dimensional Monte Carlo criticality computer code is one of the primary criticality safety analysis tools in SCALE. Scale was originally created under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC), and it continues to be supported by the NRC, as well as the U.S. Department of Energy (DOE)

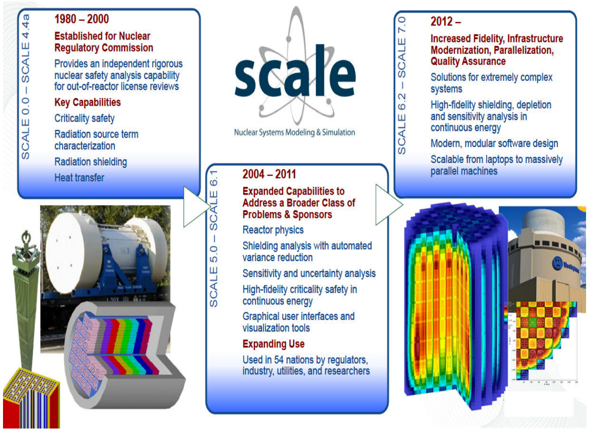

Figure 2-1. History of SCALE Code

2.1 Modeling Approach

Within the life cycle of the SCALE system, the CSAS5 program has superseded earlier programs that contained criticality safety analysis sequences. Embedded within the CSAS5 program are numerous sequences that enable automated cross-section processing and criticality analyses with and without the search option. All the criticality analysis sequences (sometimes referred to as modules) within SCALE are contained within the CSAS5 program.

Criticality Safety Analysis Sequence with KENO V.a (CSAS5) was developed to provide a search capability for three-dimensional (3-D) configurations in the SCALE system. Because it encompassed all the options and functional modules available in earlier SCALE criticality sequences, the program was initially called by the same name as its search sequence CSAS4. In order to distinguish the program from the numerous sequences that it contained (including CSAS4). The program name was later generalized to CSAS5, and then even later to CSAS5 to indicate its association with version V.a of KENO.

The standardized automated procedures can process SCALE cross sections using the Bondarenko method (via BONAMI) and either the Nordheim integral method (via NITAWL) or collapsing of pointwise continuous cross sections using a problem dependent pointwise continuous flux (via WORKER, CENTRM and PMC) to provide a resonance-corrected cross-section library based on the physical characteristics of the problem being analyzed. This cross-section library can be utilized by KENO V.a, a 3-D multigroup Monte Carlo criticality program, or XSDRNPM, a one-dimensional (1-D) discreteordinates code for transport analysis. Instead of this problem dependent cross section processing, a KENO continuous energy library can be specified, and processing goes directly from CSAS5 to KENO V.a. The search capability utilizes KENO V.a and is performed by starting the first line of the problem with CSAS5S. The type of search is defined by the input data. When CSAS5S is specified a parameter search is performed on *keff* (effective multiplication factor) as a function of dimensions or densities. The two basic search options offered are (1) an optimum search seeking a maximum or minimum value of *keff* and (2) a critical search seeking a fixed value of *keff*.

All the control sequences in the CSAS5 control module are listed in Table 2-1 with the modules they invoke. The first four sequences are subsets of the CSAS5 sequence. Although the sequence name varies, the program is the same. The sequence name is used to determine the execution path. The sequence names were changed in SCALE 6 to more accurately reflect their purpose. Old sequence names from previous versions of SCALE are still recognized by the code[2] [3].

Control sequence	Function	Functional modules executed by the control sequence (for multigroup libraries)			
CSASI[a]	Macroscopic cross sections	CRAWDAD/ BONAMI	CENTRM/PMC/WORKER[b]	ICE	
CSAS-MG[a*]	Microscopic cross sections	CRAWDAD/ BONAMI	CENTRM/PMC/WORKER[b]		
CSAS1[a]	k_{eff} (1-D)	CRAWDAD/ BONAMI	CENTRM/PMC/WORKER[b]		
CSAS5	k_{eff} (3-D)	CRAWDAD/ BONAMI	CENTRM/PMC/WORKER[b]	KENO V.a[c]	
CSAS5S[a]	k_{eff} (3-D) search	CRAWDAD/ BONAMI	CENTRM/PMC/WORKER[b]	KENO V.a[c]	MODIFY[c, d]

[a]XSDRNPM is only called if unit cells have been specified as being cell-weighted or XSDRNPM parameters are specified in the optional MORE DATA block. These multigroup sequences only.
[b]NITAWL is used if PARM=NITAWL is specified. CENTRM is default.
[c]KENO V.a and MODIFY are used for both multigroup and continuous energy problems.
MODIFY is a control module.
*Previously known as CSASN.

Table 2-1 CSAS5 Sequences for Criticality Safety

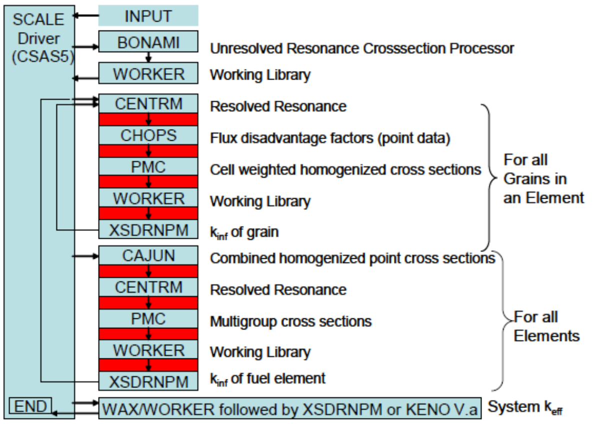

Figure 2-1. Diagram of Criticality Safety Sequence

2.2 Assumption

The geometric mechanical models for Barakah spent fuel rack and 16x16 PLUS7 fuel rod were constructed for the criticality analysis. Calculations are performed to determine the k_{eff} at the fully flooded moderator density and the dry air density. Calculations were performed for the Region I rack fully loaded with 5.0 wt% fuel at the circumstance temperature of 20℃[4]. Region I SCALE model consists of a single rack cell (rack cell wall, neutron absorber Metamic^{TM}, sheathing and water gap) with reflective boundary conditions through the centerline of the water gaps, thus simulating an infinite array of Region 1 storage racks

Parameters	Value
Storage cell	
Material	SS-304
Thickness	2.5 mm (±0.1)
Cell pitch	275 mm (±1)
Inner dimension	220 mm x 220 mm
Neutron absorber	
Material	METAMIC^{TM} (Al-B_4C)
Boron concentration (minimum)	0.0220 g B-10/cm^2
Thickness (maximum)	2.5 mm
Width (minimum)	180 mm
Length (minimum)	3850 mm

Table 2-2. Specifications of Storage Cell and Neutron Absorber

Parameter	Value
Fuel Assembly Type	16x16
Rods per Assembly	236
Guide Tubes per Assembly	5
Fuel Pellet Density	10.4394 g/cc
Fuel Pellet OD	0.3225 inches
Fuel Rod Cladding OD	0.374 inches
Fuel Rod Cladding ID	0.329 inches
Fuel Rod Pitch	0.506 inches
Fuel Rod Active Length	150 inches
Distance from Bottom of Assembly to Start of Active Length	5.122 inches
Instrument/Guide Tube OD	0.980 inches
Instrument/Guide ID thickness	0.036 inches
Maximum Fuel Rod Growth	2.0%[7]

Table 2-3 SCALE 6.1 Design Data of PLUS7

3. Analysis Result

The analysis is performed to determine the k_{eff} with respect to the various water densities from the pool flooded with un-borated water to the dry air for the normal condition without any uncertainty and bias calculation.

3.1 Code Verification

SCALE is used for the criticality analysis. HOLTEC used MCNP for licensing report for BNPP 1, 2, 3 & 4. The Scale code system developed at Oak Ridge National Laboratory provides a comprehensive, verified and validated, user-friendly tool set for criticality safety, reactor physics, radiation shielding, and sensitivity and uncertainty analysis. For more than 30 years, regulators, licensees, and research institutions around the world have used Scale for safety analysis and design. Scale provides a "plug-and-play" framework with 89 computational modules, including three deterministic and three Monte Carlo radiation transport solvers that are selected based on the desired solution. The cross-section data provided with Scale include comprehensive continuous-energy neutron and multi-group neutron and coupled neutron-gamma data based on ENDF/B-VI.8 and ENDF/B-VII.0. In order to verify the accuracy of SCALE, we performed the comparison of SCALE and MCNP results for fresh fuel in the Region I racks with an enrichment of 5.0 wt% U-235 with the moderator temperature 4℃, density 1g/cc and no S(α,β).

Case (1g/cc)	MCNP 5[6]		SCALE 6.1		Difference (SCALE/MCNP-1)
	k_{calc}	σ	k_{calc}	σ	
1wr15 04s	0.9053	0.0004	0.9051	0.0003	-0.028

Table 3-1. Verification between MCNP 5 and SCALE 6.1

The above table shows that there is a good agreement between MCNP and SCALE for the criticality analysis of SFP.

3.2 Calculation

Calculations are performed to determine the k_{eff} at the fully flooded moderator density and the dry air density. The Region 1 rack calculations were performed for the Region I rack fully loaded with 5.0 wt% fuel at the circumstance temperature of 20 ℃. The Region I SCALE model consists of a single rack cell (rack cell wall, neutron absorber Metamic^{TM}, sheathing and water gap) with reflective boundary conditions through the centerline of the water gaps, thus simulating an infinite array of Region 1 storage racks[5].

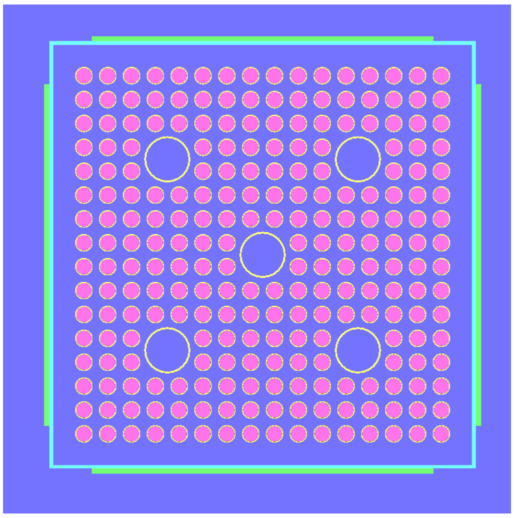

Figure 3-1. Scale 6.1 Design Basis Model

The below graph shows the k_{eff} with respect to the various water densities from the pool flooded with un-borated water to the dry air for the normal condition. The k_{eff} in Region I of SFP under the condition of the dry air is 0.5865.

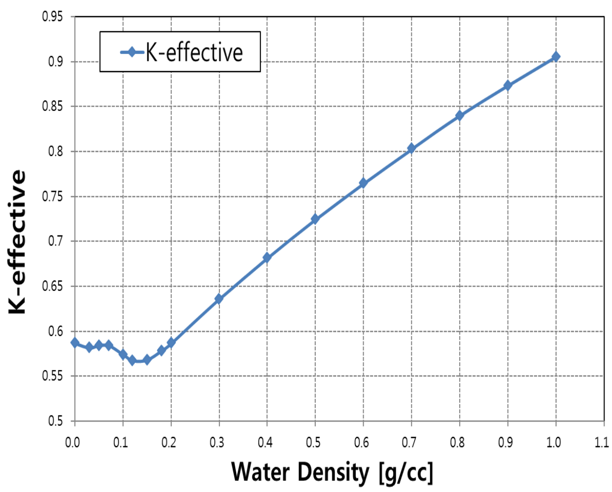

Figure 3-2. Keff with respect to the various water densities

3.3 Accident Analysis in Region 1

The k_{calc} of the Region 1 after the mislocated fuel assembly accident is increased from 0.9107 to 0.9551 according to HOLTEC's Region 1 rack MCNP5 model with 5.0wt% fuel assembly at the fully flooded moderator density (1g/cc) [6].

Case	Reference (k_{calc})	Mislocated Accident (k_{calc})	Increased k_{calc}
5.0wt%, 1g/cc, 0ppm	0.9107	0.9551	0.0444

Table 3-2. The k_{calc} of the Region 1 after the mislocated fuel assembly accident

4. Conclusions

This analysis ensured the effective neutron multiplication factor(k_{eff}) of Region 1 of SFP is less than 0.95 under the condition in the air. The k_{eff} in Region I of SFP under the condition of the dry air is 0.5865. The increased k_{calc} of the Region 1 after the mislocated fuel assembly accident is 0.0444 at the pool flooded with un-borated water.

Although this analysis did not perform the accident calculation in the dry air, such as fuel assembly mislocated and fuel assembly drop, we can conclude that there is very sufficient margin of k_{eff} to the regulatory limit 0.95 in Region 1 under the any accident condition in the dry air.

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[6] Licensing Report for Barakah Spent Fuel and New Fuel Storage Racks, N224-DR-Go1-01 issued by Holtec, 2014