Bounding Fuel Type for Criticality Analysis of Dry Storage Cask

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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 (k_{eff}) limits specified in the applicable requirements and guidance. The objective of the evaluation is to determine the fuel type that has the maximum effective neutron multiplication factor (k_{eff}) among domestic fuel types in dry storage cask. According to the regulatory limit, the effective neutron multiplication factor (k_{eff}) should be less than 0.95 excluding the subcritical margin 0.5.

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)

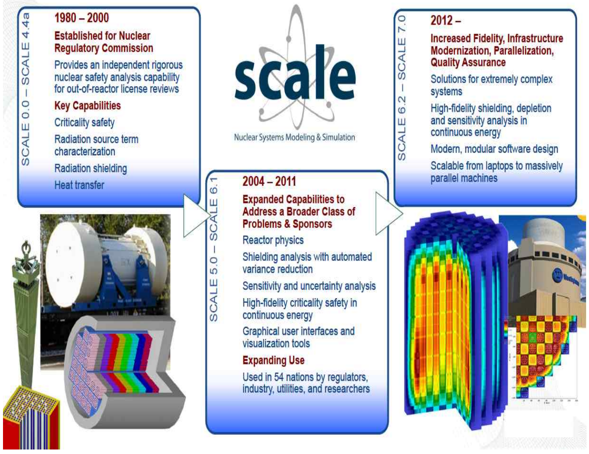

Figure 1-1. History of SCALE Code

2.1 Modeling Approach

Scale is a comprehensive modeling and simulation code for nuclear safety analysis and design that is developed, maintained, tested, and managed by the Reactor and Nuclear Systems Division (RNSD) of Oak Ridge National Laboratory (ORNL). Scale provides a comprehensive, verified and validated, user-friendly tool set for criticality safety, reactor physics, radiation shielding, radioactive source term characterization, and sensitivity and uncertainty analysis. 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. All the control sequences in the CSAS5 control module are listed in Table 2-1 and figure 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

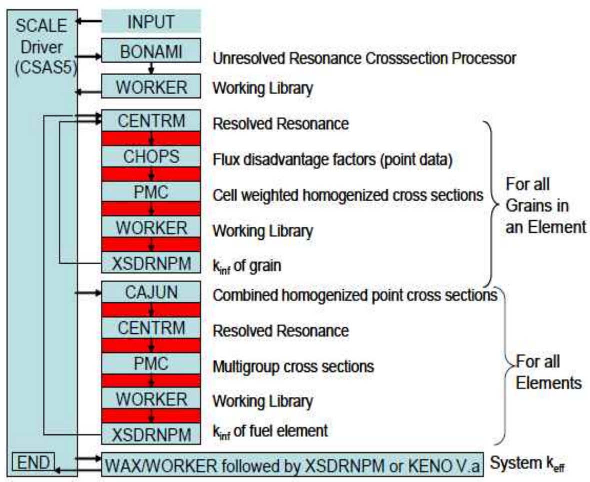

Figure 2-1. Diagram of Criticality Safety Sequence

2.2 Assumption

The geometric mechanical models for dry storage cask with concrete shielding were constructed for the criticality analysis. This paper considers the domestic WH fuel types like STD, OFA, KOFA, V5H, RFA(ACE7) with 17x17 array. CE Fuel types like Standard, Guardian, PLUS7 are not excluded in this paper because they is less conservative than WH fuel types. RFA and ACE7 is same in dimension and UO_2 weight. Calculations are performed to determine the k_{eff} at the fully flooded moderator and at the temperature of 20℃. New fuel assembly with enrichment 5.0wt% is assumed because it has the maximum effective neutron multiplication factor (k_{eff}) in criticality analysis. Dry storage cask consists of 24 rack cells (rack cell wall, neutron absorber Metamic, sheathing and water gap), stainless canister and concrete shielding.

3. Analysis Result

The objective of the evaluation is to determine the fuel type that has the maximum effective neutron multiplication factor (k_{eff}) among domestic fuel types. So the analysis is performed to calculate the effective neutron multiplication factor (k_{eff}) according to the types of fuel assemblies in the same dry storage cask.

3.1 Code Validation

Evaluations for nuclear criticality safety must assure that the effective neutron multiplication factor (k_{eff}) should be less than 0.95 excluding the subcritical margin 0.5. Such evaluations typically rely upon computational techniques that are capable of modeling complex three-dimensional systems. An upper safety limit (USL) must be established through the statistical evaluation of the calculational bias.

Table 3-1 shows the USL including bias and uncertainty of SCALE 6.1.2. Reference Model for the analysis is dry storage cask (24 FA) with 17V5H fuel. It is analyzed according to procedures(NUREG-6698) by which nuclear fuel cycle facility licensees may perform the validation activity, including determination of calculational bias, bias uncertainty, and an USL[4][5].

Parameter	K_{eff}
O Regulatory Limit	1
O Subcritical margin(ΔKsm)	0.05
O Bias of Criticality Calculation(ΔKsb)	0.00661
O Total Uncertainty(ΔKsc)	0.01079
O Upper Safety Limit(USL)	**0.9326**
* USL= 1 - ΔKsm - ΔKsb - ΔKsc	

Table 3-1. Upper Safety Limit (USL) of Reference Model

3.2 Calculation

Calculations are performed to determine the fuel type that has the maximum effective neutron multiplication factor (k_{eff}) among domestic fuel types because safety analysis should consider the most conservative fuel type. The specifications of dry storage cask and neutron absorber lists in Table 3-2 and design data according to fuel types lists in Table 3-3.

Description		Material	Dimension	Used in Analysis
○ Neutron Absorber				
• Thickness(㎜)		B_4C + Aluminum	4.6 +0.13/-0.1	4.6
• Width(㎜)			190.5 ±1.6	190.5
• B-10 Areal Density (g/㎠)	MMCs		0.0558399 -10%	Min. 0.050256
○ Receptacle Box				
• Wall Thickness(㎜)		SS-304	5 ±0.16	5
• Inner Width(㎜)			220 ±1.0	220
○ Canister				
• Lid Thickness(㎜)		SS-304	10	10
• Body Thickness(㎜)			10	10
• Bottom Plate Thickness(㎜)			10	10
• Inner Diameter(㎜)			1,680	1,680
○ Cask				
• Inner Diameter(㎜)		Concrete	1,740	1,740
• Body Thickness(㎜)			798	798

Table 3-2. Specifications of Dry Storage Cask and Neutron Absorber

Parameter	Value				
Fuel Assembly Type	17STD	17OFA	17KOFA	17V5H	17RFA(ACE7)
Rods per Assembly	264	264	264	264	264
Fuel Pellet OD(mm)	8.192	7.84	8.05	8.192	8.192
Cladding OD(mm)	9.5	9.14	9.5	9.5	9.5
Cladding Thick.(mm)	0.57	0.57	0.64	0.57	0.57
Guide Tube OD(mm)	12.24	12.04	12.24	12.04	12.24
Guide Tube Thick.(mm)	0.405	0.405	0.42	0.405	0.505

Table 3-3 SCALE 6.1.2 Design Data According to the Fuel Types

Figure 3-1 shows the top half view of dry storage cask that consists of 24 fuel assemblies, stainless canister, neutron absorber (Metamic), and concrete shielding. Figure 3-2 shows the Axial half view of dry storage cask. These figures are SCALE code models using KENO3D

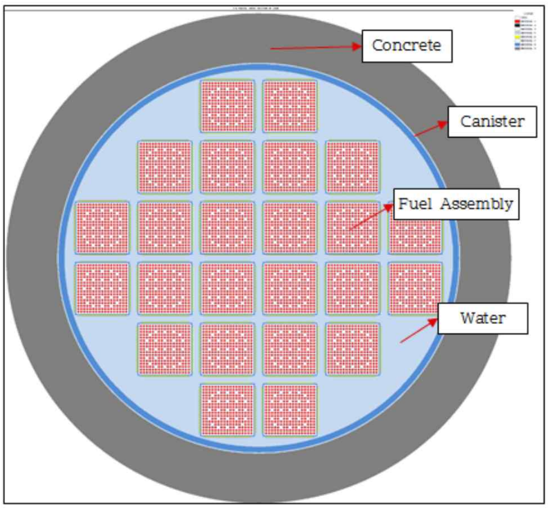

Figure 3-1. Top Half View of Dry Storage Cask (24 FA)

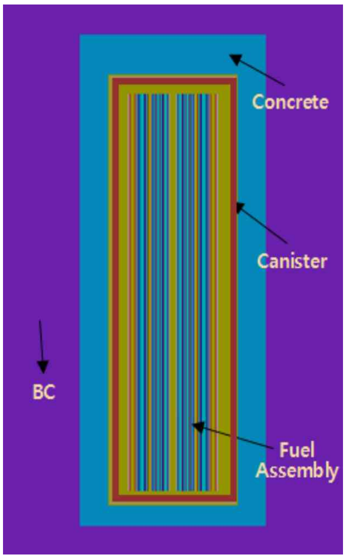

Figure 3-2. Axial Half View of Dry Storage Cask (24 FA)

Table 3-4 shows the fuel type that has the maximum effective neutron multiplication factor (k_{eff}) among domestic fuel types. As the result, 17OFA has the maximum effective neutron multiplication factor (k_{eff}) and 17RFA has the minimum value. That is why dry storage cask with 17OFA has the greatest water inventory even though UO_2 weight in 17OFA is largest. Water is generally the moderate material of neutrons.

Fuel Type	Best Estimate k_{eff}	USL
17STD	0.92213 ± 0.00042	0.9326
17OFA	0.93375 ± 0.00043	
17KOFA	0.91913 ± 0.00039	
17V5H	0.92334 ± 0.00042	
17RFA(17ACE7)	0.92077 ± 0.00045	

Table 3-4. Best Estimate k_{eff} According to the Fuel Types

4. Conclusions

The objective of the evaluation is to determine the fuel type that has the maximum effective neutron multiplication factor (k_{eff}) among domestic fuel types in dry storage cask. This paper ensured that 17OFA has the maximum effective neutron multiplication factor (k_{eff}) among domestic fuel types because dry storage cask with 17OFA has the greatest water inventory even though UO_2 weight in 17OFA is largest. Water is generally the moderate material of neutrons. Finally, bounding fuel for criticality analysis in dry storage cask is 17OFA.

REFERENCES

[1] A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design. ORNL/TM-2005/39 Version 6.1.

[2] A Primer for Criticality Calculations with SCALE/KENO-VI Using GeeWiz. ORNL/TM-2008/069.

[3] Guidance for Performing Criticality Analyses of Fuel Storage at Light-Water reactor Power Plants, NEI 12-16, Revision 1, ML14112A516, April 2014.

[4] Guide for Validation of Nuclear Criticality Safety Calculational Methodology, NUREG/CR-6698, US. NRC, December 2000.

[5] Benchmarks for Quantifying Fuel Reactivity Depletion Uncertainty, EPRI, Palo Alto, CA: 1022909, 2011.