INL/CON-21-61390-Revision-0

Structural, Criticality, and Radiation Dose Calculations to Support SNF Loading into a DOE Standard Canister

February 2022

Changing the World's Energy Future

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Idaho National Laboratory

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Structural, Criticality, and Radiation Dose Calculations to Support SNF Loading into a DOE Standard Canister – 21113

WM2021 Symposia

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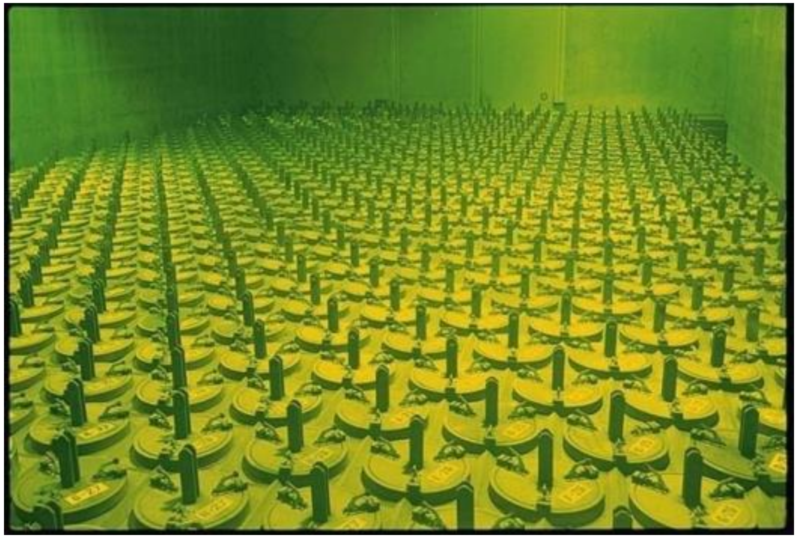
Overview

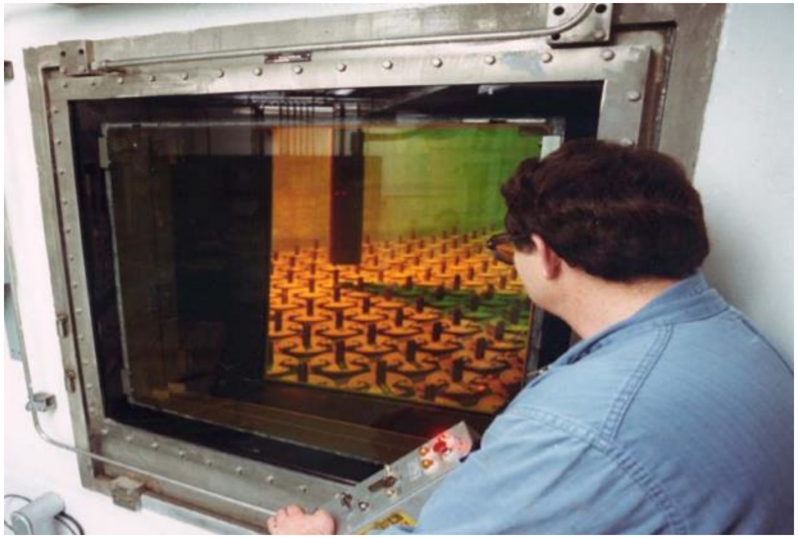
- **Introduction** – U.S. Department of Energy (DOE) spent nuclear fuel (SNF) stored at Idaho National Laboratory (INL)
- **Background** – The DOE Standard Canister Demonstration Project
- **Internal Support Structure (ISS) design**
- **Structural Evaluations**
- **Criticality Safety Analysis**
- **Radiation Dose Calculations**

Introduction

- A significant amount of DOE SNF is in dry storage at INL's CPP-603 facility
- Includes assemblies from:
  - Training, Research, Isotope, General Atomics (TRIGA), ~ 4,330
  - Advanced Test Reactor (ATR), ~ 2,600
  - Fort St. Vrain (FSV), ~790
  - Peach Bottom 1 Core II (PB2), ~ 740
- In canisters in CPP-603 fuel storage area
- Multi-year effort: Transfer SNF to new dry storage system → **DOE Standard Canister**



CPP-603 Fuel Storage Area[1]



Look into CPP-603's Fuel Storage Area[3]

The DOE Standard Canister and Demonstration Project

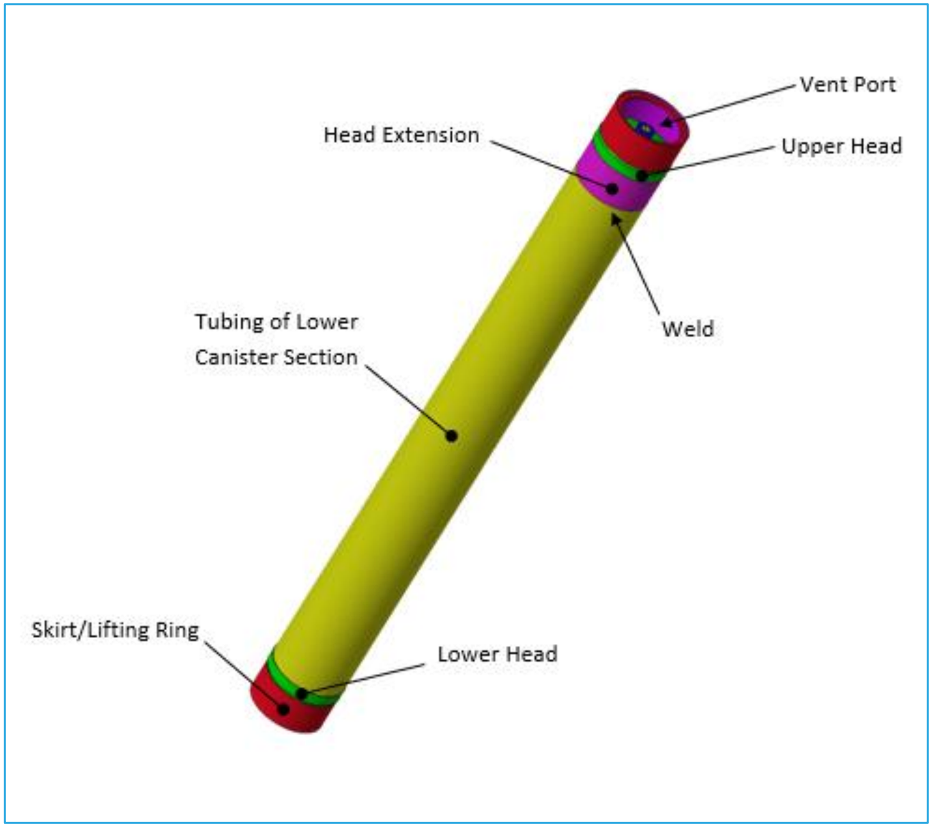
DOE Standard Canister:

- Standardized system to store DOE SNF
- Length L = 3 to 4.6 m
- Outer diameter D = 46 to 61 cm
- Wall thickness t = 0.95 to 1.27 cm
- 316L stainless steel
- Different baskets for different fuel types

DOE Standard Canister Demonstration Project:

- Demonstrate loading of one or more canisters with CPP-603 SNF
- Canister(s) will be placed into dry storage overpack

→ DOE Standard Canister ISS needed



DOE Standard Canister

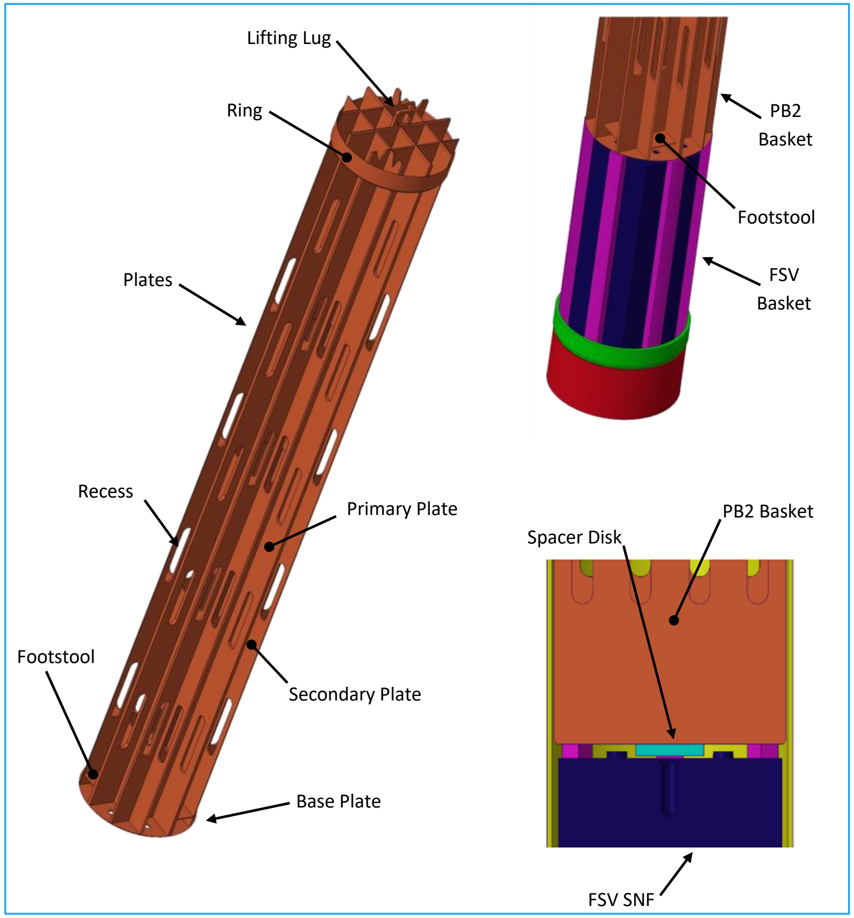
Internal Support Structure Design

Overview:

- Design of an ISS to support loading of SNF into DOE Standard Canister
- Fits into DOE Standard Canister with D = 46 cm (18 in) and L = 4.6 m (15 ft)
- Made of 316L stainless steel (SS)

Parts:

- Basket for twelve PB2 rods with recesses to improve air circulation
- Basket for one FSV element, welded to the inner canister wall
- Aluminum spacer disk
- After placing of FSV element, PB2 basket is placed on top of FSV basket



ISS Design

Structural Evaluations

Structural evaluations to support smooth canisters-loading operations:

- Note – Criticality safety margins tolerate ISS and SNF failure, including reconfiguration
- Evaluations according to ASME BPVC.III.3
- Definition of credible load cases (LCs)
- Relative placement of PB2 Basket on FSV Basket (LC_{3a} to LC_{3d})
- Two scenarios to analyze PB2 Basket wedging in canister (LC_{5a} and LC_{5b})

LC	Loading Type	Service Limits	Loading Situation
LC_1	Design	Design Load	Empty PB2 Basket Sitting Outside Canister
LC_2	Normal	Level A	Empty PB2 Basket Lifted
LC_{3a}	Normal	Level A	Full PB2 Basket Sitting Inside Canister
LC_{3b}	Normal	Level A	Full PB2 Basket Sitting Inside Canister
LC_{3c}	Normal	Level A	Full PB2 Basket Sitting Inside Canister
LC_{3d}	Normal	Level A	Full PB2 Basket Sitting Inside Canister
LC_4	Off-Normal	Level C	Full PB2 Basket Lifted
LC_{5a}	Off-Normal	Level C	Full PB2 Basket and Wedged Canister Lifted
LC_{5b}	Off-Normal	Level C	Full PB2 Basket and Wedged Canister Lifted

Structural Evaluations, Continued

Finite element (FE) simulations of PB2 basket:

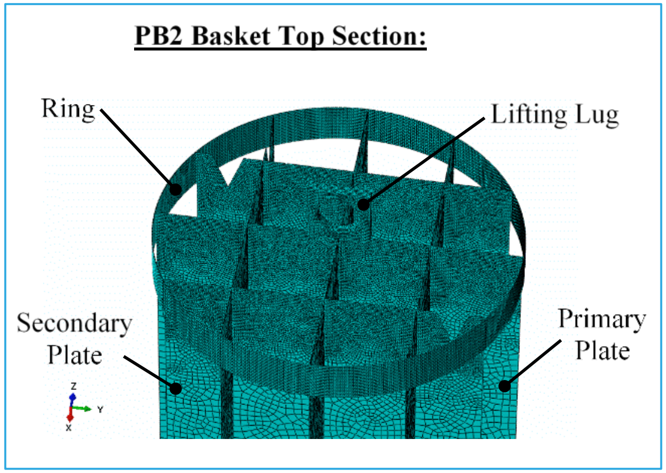
- Nonlinear
- Static, assuming up to 2 g to consider shocks
- Shell (S4R) and solid (C3D8R) elements
- Evaluation of the peak stress intensity:

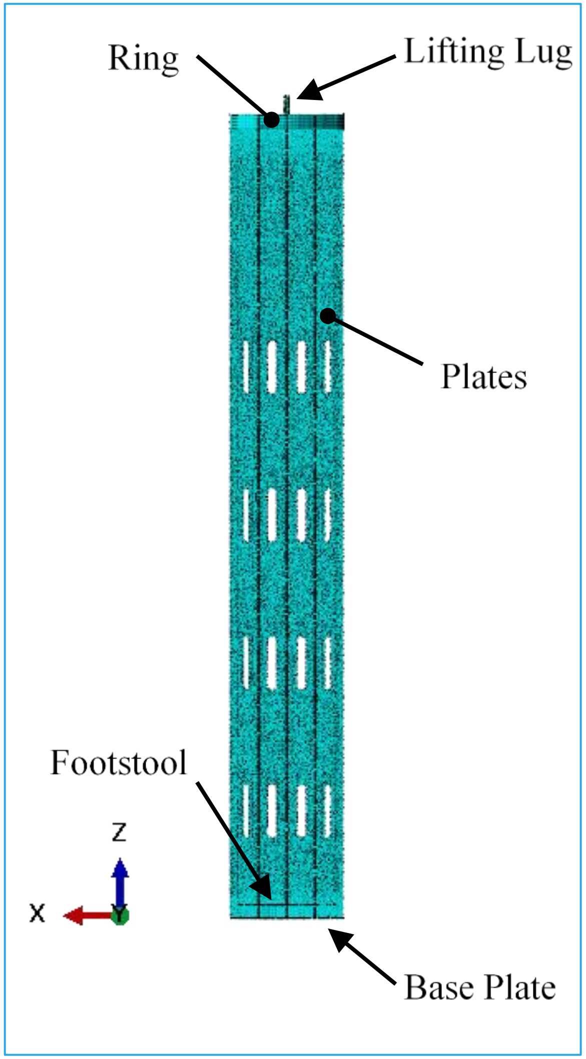
$$S_{max} = \max(|\sigma_1 - \sigma_2|, |\sigma_2 - \sigma_3|, |\sigma_3 - \sigma_1|)$$

- Buckling analyses
- ABAQUS 6.14 CAE

Hand calculations:

- FSV basket
- Welds
- Bolts
- Acceptable deformations





PB2 Basket FE Model

Structural Evaluations – Evaluation of FE Simulation Results

1. **Comparison with the General Membrane Stress Intensity Limit:**

LC	Peak Stress Intensity S_{max} [MPa]						General Membrane Stress Intensity Limit [MPa]
	Lifting Lug	Ring	Main Plates	Secondary Plates	Footstools	Base Plate	
LC_1	0	0	4	0	1	3	115
LC_2	51	1	25	2	0	0	115
LC_{3a}	0	0	69	104	12	49	115
LC_{3b}	0	0	28	80	20	**216**	115
LC_{3c}	0	0	69	**137**	11	49	115
LC_{3d}	0	0	31	113	23	**216**	115
LC_4	104	1	52	12	22	13	173
LC_{5a}	169	71	92	14	22	13	173
LC_{5b}	169	110	89	**296**	22	13	173

2. **Closer investigations at locations of exceedance (values in red):**
   - Contributions of membrane and bending stress to stress intensity
   - Improved (more realistic) modeling of boundary conditions
   - Acceptance of stress concentrations and local deformations (off-normal loading)

→ Peak stress intensities decrease to acceptable levels

→ Applicable ASME BPVC.III.3 limits are met

Structural Evaluations – Results

Buckling analyses:

- Linear FE
- Secondary basket plate, off-normal condition (LC_{5b})

→ Basket/Canister wedged

- First Eigenmode at Eigenvalue of 18.97

→ No structural instability is expected

FSV basket analyses:

- Hand calculations

→ Meets ASME stress limits

→ No structural instability is expected

→ Meets ASME exceptions for cyclic loading

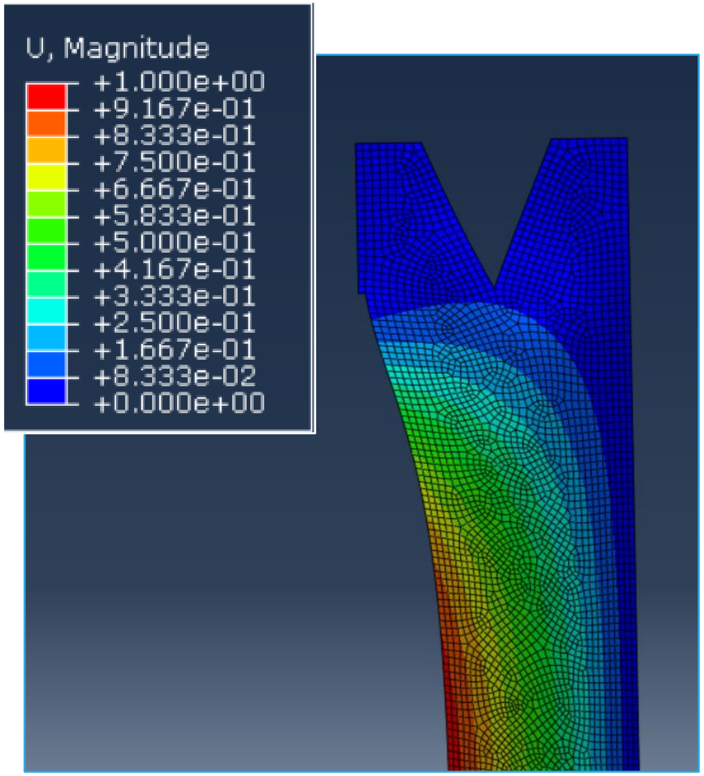
Weld analyses:

- Category A/C, Type I/III full-penetration welds
- Full weld examination → Full load transfer

Bolts analyses:

- ASME B18.3-2012 Size 4 bolts

→ Meets ASME stress limits



First Eigenmode

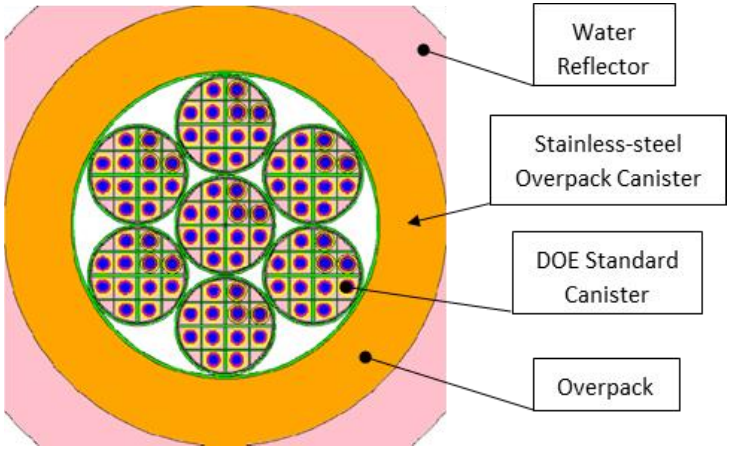
Criticality Safety Analyses

Generic overpacks and waste packages:

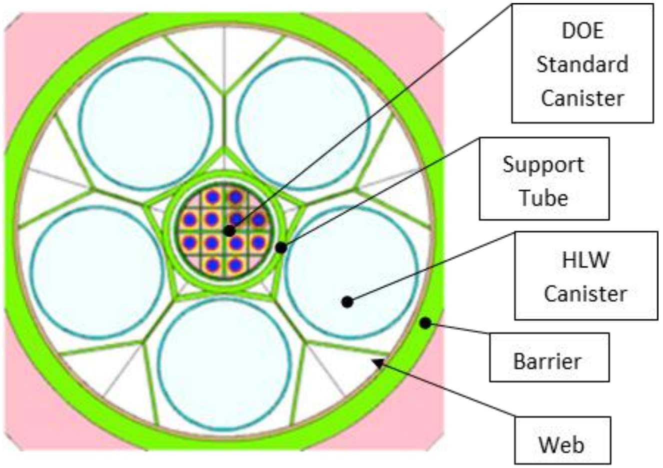
- Single DOE Standard Canister in a concrete overpack (t = 30.5 cm)
- Multi-canister concrete overpack:
  - Seven DOE Standard Canisters
  - Twelve DOE Standard Canisters
- Codisposal waste package with vitrified SRS glass in five Hanford HLW canister

Evaluated conditions:

- Wet/dry canister(s) and/or overpack
- Variations of water densities
- Effect of SS overpack canister (t = 1.27 cm)
- Intact/degraded package contents
- 30-cm water reflector
- PB2 rod relocation within basket



Multicanister Overpack



Codisposal Waste Package

Criticality Safety Analyses, Continued

Evaluated parameter:

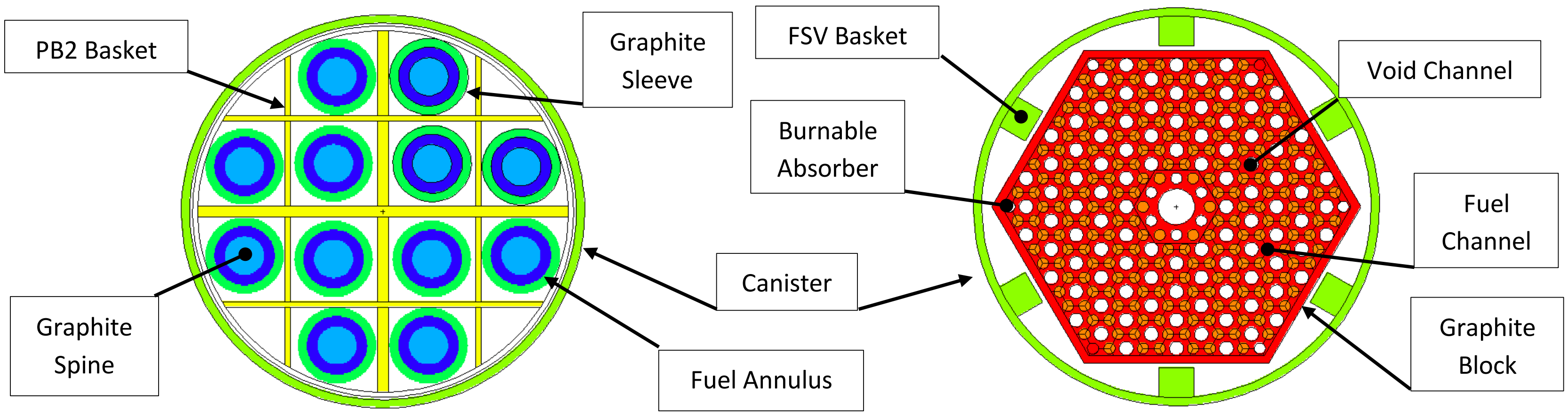
- Maximum effective neutron multiplication factor k_{eff}
- Safety limit: $k_{eff} < 0.93$ (critical system at $k_{eff} = 1.0$)

Software:

- Monte Carlo N-Particle (MCNP) Transportation Software Version 6.2
- ENDF/B-V continuous-energy cross section libraries

Modelling assumptions:

- Void replaces air
- Burnable absorbers not credited



Model Cross-Section – PB2 Region

Model Cross-Section – FSV Region

Criticality Safety Analyses, Continued

Modeled active fuel compositions

Element/Isotope	Mass [g]	
	Single PB2 SNF Rod	Single FSV SNF Element
Th-232	1310	10789.97
U-233	35.2	0
U-234	0	0
U-235	232.5	1485
U-236	0	0
U-238	17.01	0
Pu-239	0.27	2.59
Pu-240	0.09	0
Pu-241	0.15	0
Pu-242	0.07	0

PB2 SNF:

- Maximum documented end-of-life (EOL) U-233 concentration
- Beginning-of-life (BOL) U-235 concentration
- Average EOL Pu concentrations
- U-234 and U-236 disregarded

FSV SNF: BOL U-235 concentration

Criticality Safety Analyses – Results

Maximum effective neutron multiplication factor k_{eff}

Configuration	Condition	k_{eff}
Single canister	Intact, dry	0.134
	Fully flooded canister, dry overpack, saturated SNF	0.8512
Multicanister	Seven Canisters, fully flooded canisters, dry overpack, saturated SNF, SS overpack canister	0.8989
Codisposal waste package	Intact but flooded DOE Standard Canister, degraded HLW canisters, dry codisposal package	**0.9072**

- Negligible effect of PB2 rod relocation within basket, or aluminum spacer items
- Rubblized PB2 SNF increases reactivity in dry condition (wet not credible)
- Package reactivity increases with increasing water density

→ Maximum k_{eff} < 0.93

→ Safety limit met

Radiation Dose Calculations

Radiation levels at different DOE Standard Canister locations/distances:

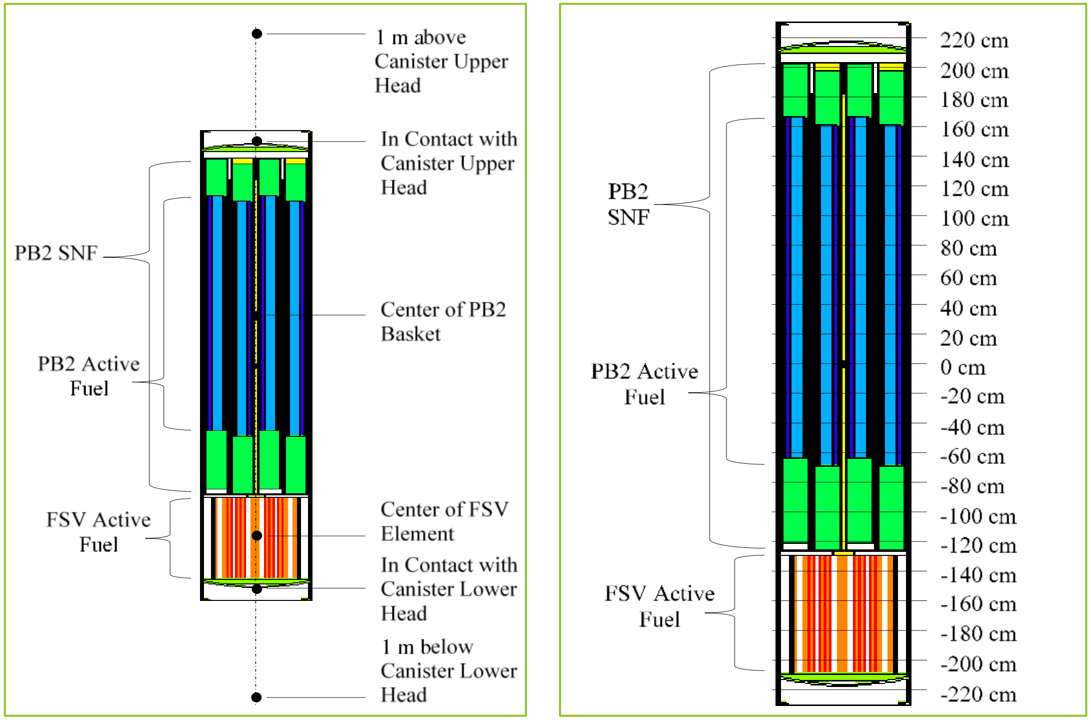
- At 1-m below lower/above upper canister head
- At lower/upper head
- In 20-cm vertical increments at canister surface
- At 1-m radial distance

ORIGEN decay correction:

- Source term from DOE Spent Fuel Database[3]
- 1974/1980 PB2/FSV discharge
- Canister loading in 2022

MCNP simulations:

- 19/27-group photon/neutron spectrum
- f5 point detector and ring tallies
- ANSI/ANS-6.1.1-1977 flux-to-dose conversion factors



Locations of Dose Rate Calculations

Radiation Dose Calculation – Results

Selected compounded dose-equivalent rates:

Approximate DOE Standard Canister Axial Plane	Total Dose-Equivalent Rate [rem/hr]		
	Centerline	Canister Surface	1-m Radial Distance
1 m below Lower Canister Head/-320 cm	3.01	-	-
In Contact with Lower Canister Head/-220 cm	57.6	9.29	9.61
-200 cm	-	448	44.7
Center of FSV Element/-160 cm	**3,820**	591	58.2
Center of PB2 Basket/40 cm	**3,920**	1,150	150
200 cm	-	16.5	65.3
In Contact with Upper Canister Head/220 cm	2.40	-	49.4
1 m above Upper Canister Head/320 cm	0.15	-	-

- Peak rates of 3,820 rem/hr and 3,920 rem/hr at SNF element center
- Variations in rates in circumferential canister direction due to radiation streaming paths and areas of maximum source attenuation
- Peak dose is 1,369 rem/hr at canister surface at PB2 basket center
- Peak dose is 710 rem/hr at canister surface at FSV element center
- Convergence of flux tallies and a relative error below 5%

Conclusions and Future Work

Conclusions:

- Structurally sound system → Will support safe and smooth loading of SNF in DOE Standard Canister
- Meets stipulated minimum criticality safety requirements for storage and disposal
- Dose-equivalent rate data provide confidence that sufficient canister shielding is technically achievable with common transportation and overpack designs

Future work:

- Computations are of preliminary nature
- ISS design should be optimized (mass, geometry, structural integrity)
- Reevaluations needs to be completed under consideration of the final design and SNF configuration
- Manufacturing and demonstration

Acknowledgements

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Questions?

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