

## **Criticality Analysis of Fort St. Vrain Spent Nuclear Fuel** in the DOE Standard Canister

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hanging the World's Energy Future

Benjamin Luis Estrada, Evans Damenortey Kitcher, Daniel Albert Thomas, Kristy Diane Yancey Spencer



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Idaho National Laboratory Idaho Falls, Idaho 83415

http://www.inl.gov

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**Benjamin Estrada** 

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Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy



## **DOE** manages a broad array of SNF

- Over 300+ types of DOE-managed SNF across the DOE complex
  - Fuels (oxides, metals, carbides, etc.)
  - Different enrichments, geometries, and sizes



ATR Fuel Element



**Fuels from Research Reactors** 



Shippingport Fuel Element

# **DOE-managed SNF can be packaged in standardized canisters**

- The National Spent Nuclear Fuel Program designed the DOE Standard Canister in the 1990s.
  - Minimizes dependence on fuel type and characterization
  - Based on the reliability of systems, structures, and components
  - Can be used to transport and store SNF



# **DOE** is funding a packaging demonstration at INL

• The goal is to load 4 or 5 FSV fuel elements into the DOE Standard Canister.



**FSV Fuel Element** 



Cross-Sectional 3-D Model of the DOE Standard Canister

# **Criticality Analysis**

- The neutron multiplication factor (k<sub>eff</sub>) is found via Monte Carlo N-Particle Transport (MCNP) 6.2.
- Upper subcritical limits (USLs) are calculated using Whisper 1.1.
- One, seven, or nine canisters are loaded into a concrete overpack.
- The cases are derived from credible abnormal conditions.
  - Moderator ingress
  - Geometry changes
  - Concentration
  - Reflection



 $k_{calc} + 2\sigma < \mathsf{USL}$ 

USL = 1

- + (Bias)
- (Bias Uncertainty)
- (Margin of Subcriticality)

## **Normal Conditions**

- Dry fuel, canister, and overpack
- The fuel is assumed fresh and intact
- Full water reflection



Single-, Seven-, and Nine-Canister Arrangements



### Four vs. Five FSV Fuel Assemblies Loaded

### **Transport Scenarios**

- USL of 0.92171 for transport
- Scenario 1: degraded fuel collects at the bottom of a canister



**Two Different Orientations** 

Configuration		$k_{eff} + 2\sigma$			
		1 SC	7 SCs	9 SCs	
4 FSV	Dry overpack	0.12827	0.38794	0.31711	
assemblies	Flooded overpack	0.18078	0.38071	0.24284	
5 FSV	Dry overpack	0.12852	0.36116	0.29969	
assemblies	Flooded overpack	0.18046	0.35565	0.22289	

### **Transport Scenarios**

• Scenario 2: nine-canister drop event



Configurat	$k_{eff} + 2\sigma$	
4 FSV assemblies	Dry overpack	0.3252
	Wet overpack	0.26418
5 ECV as a subling	Dry overpack	0.3296
5 FSV assemblies	Wet overpack	0.26438

# **Storage Scenarios**

- USL of 0.95171 for storage
- Moderator ingress through fuel saturation, canister flooding, and overpack flooding

	$k_{eff} + 2\sigma$		
		Unsaturated	Saturated
	Dry canister in a dry overpack	0.34092	0.93005
4 FSV	Dry canister in a fully flooded overpack	0.33145	0.80986
assemblies	Fully flooded canister in a dry overpack	0.83726	0.94594
	Fully flooded canister in a fully flooded overpack	0.78439	0.91848
	Dry canister in a dry overpack	0.34233	0.93036
5 FSV	Dry canister in a fully flooded overpack	0.33244	0.8108
assemblies	Fully flooded canister in a dry overpack	0.83726	0.94626
	Fully flooded canister in a fully flooded overpack	0.7845	0.91794

### Seven-Canister Overpack

## **Storage Scenarios**

### Nine-Canister Overpack

	$k_{eff} + 2\sigma$		
		Unsaturated	Saturated
4 FSV assemblies	Dry canister in a dry overpack	0.27689	0.88459
	Dry canister in a fully flooded overpack	0.20416	0.68488
	Fully flooded canister in a dry overpack	0.82348	0.93884
	Fully flooded canister in a fully flooded overpack	0.72593	0.88651
5 FSV assemblies	Dry canister in a dry overpack	0.28441	0.88774
	Dry canister in a fully flooded overpack	0.20445	0.68504
	Fully flooded canister in a dry overpack	0.82387	0.93907
	Fully flooded canister in a fully flooded overpack	0.72591	0.8866

## **Disposal Scenarios**

- USL of 0.95171 for disposal
- Formation of a water-uranium slurry



Configuration		$k_{eff} + 2\sigma$			
		1 SC	7 SCs	9 SCs	
	Fully flooded canister in a dry	0.90397	0.94989	0.94281	
4 FSV	overpack				
assemblies	Fully flooded canister in a fully	0 80331	0 02315	0 8021	
	flooded overpack	0.07551	0.72313	0.0921	
	Fully flooded canister in a dry	0 00/02 0 0/088 0 0/		0 04280	
5 FSV	overpack	0.90403	0.94900	0.94209	
assemblies	Fully flooded canister in a fully	0 80224 0 022 0 8		0 80202	
	flooded overpack	0.09524	07524 0.725	0.09202	

# **Disposal Scenarios**

### • Degradation of stainless steel into hematite or goethite

	Configuration		$k_{eff} + 2\sigma$			
			1 SC	7 SCs	9 SCs	
Degradation into hematite	4 FSV assemblies	Fully flooded canister in a dry overpack	0.89984	0.95033	0.94249	
		Fully flooded canister in a fully flooded overpack	0.89016	0.92212	0.88926	
	5 FSV assemblies	Fully flooded canister in a dry overpack	0.90009	0.95026	0.94233	
		Fully flooded canister in a fully flooded overpack	0.88965	0.92268	0.8898	
		Configuration		$k_{eff} + 2\sigma$		
			1 SC	7 SCs	9 SCs	
Degradation into goothite	4 FSV assemblies	Fully flooded canister in a dry overpack	0.88937	0.93593	0.92923	
Degradation into goethite		Fully flooded canister in a fully flooded overpack	0.88414	0.91419	0.88655	
	5 FSV assemblies	Fully flooded canister in a dry overpack	0.88894	0.93682	0.92905	
		Fully flooded canister in a fully flooded overpack	0.88504	0.91464	0.88651	

# **Summary of Results**

- No scenario exceeded the application-specific USL (i.e., 0.92171 for transport; 0.95171 for storage/disposal).
- The highest k<sub>eff</sub> (i.e., 0.95033) stemmed from stainless steel degradation into hematite.
- Saturated fuel, flooded canister, and dry overpack were the most reactive conditions.
- k<sub>eff</sub> showed minimal variation when comparing four vs five fuel elements.

### **Questions?**

# Idaho National Laboratory

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