DOE/NRC Criticality Benchmark Safety Support for HALEU (DNCSH)

01/25/24

Energy Act of 2020; Sec. 2001 “Advanced Nuclear Fuel Availability” (42 U.S.C. 16281; PL-116)
Section (A) and (C)(ii)

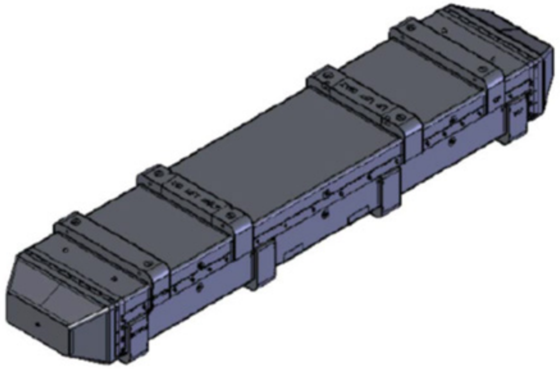
Don Algama (DOE Fed. Manager); Andrew Barto (NRC PM); William Wieselquist (NTD)

Authorities

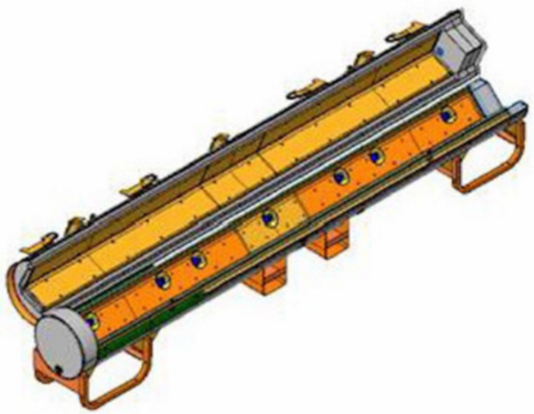
- The Energy Act of 2020 directs the DOE and NRC to collaborate to develop **criticality safety data**.
- Inflation Reduction Act in 2022 provided $700M, of which **$60M** is currently allocated for this project.
- **HALEU fuel cycle** except reactor operation is the primary scope.
- **NRC** is primary customer.

Existing HALEU Packages

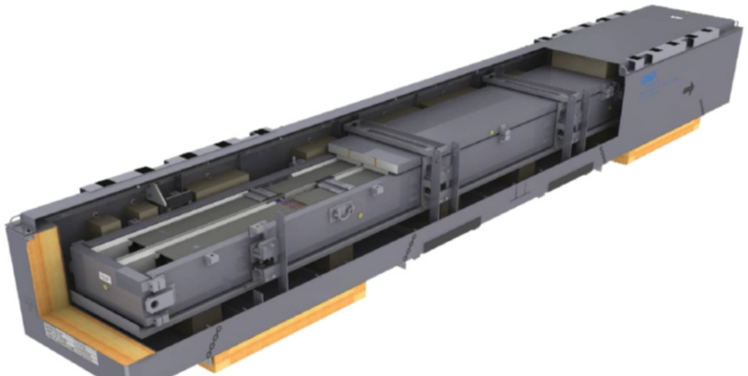
LWR Fresh Fuel:



MAP 12 and MAP 13 (71-9319)



Traveller (71-9380)



GNF RAJ-II (71-9309)

- **Certified to LEU+ range – up to 8.0% enrichment**
- **No issues with code validation**
  - Many applicable low enriched UO_2 experiments
  - Regulations require consideration of moderation by water – thermal uranium systems generally fairly easy to validate

The critical benchmarks performed at SNL with 7% enriched fuel were instrumental in making these approvals easy.

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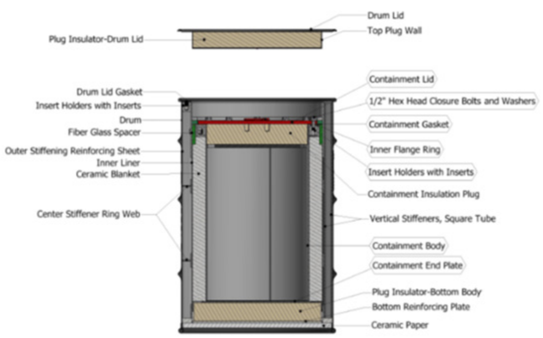
HALEU Packages for non-LWRs (not for commercial-scale)

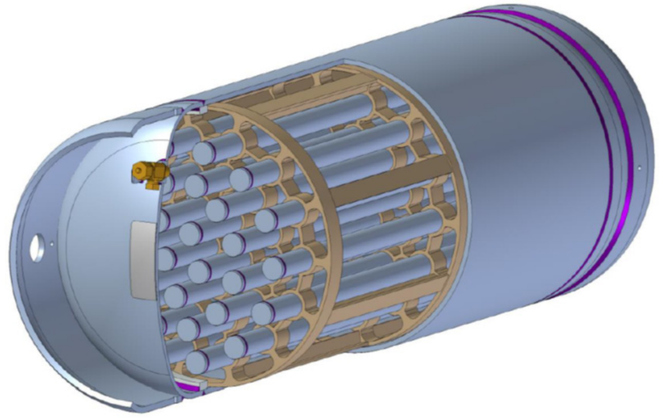


Versa Pac (71-9342)

- Varied uranium contents enriched up to 100%
- TRISO allowed – treated as uranium/water mixture
- Low mass limit - <1 kg ^{235}U
- Large margin from not crediting graphite in pebbles/compacts (no benchmark data)

Optimus-L (71-9390)

- Up to 68 kg of 20% enriched TRISO compacts
- Currently under review
- Large margin due to validation limitations



DN30-X (71-9388)

- UF_6 cylinder with internal criticality control system in overpack
- Up to 10% enriched UF_6 in 30B-10 cylinder; 20% enriched in 30B-20
- Up to 1,460 kg UF_6 in 30B-10, 1,271 kg in 30B-20 (standard 30B is 2,277 kg)
- CSI = 0.0

DNCSH Goals

- **Coordinate new high-quality benchmark experiments in ICSBEP and other tangential supporting data applicable to wide range of HALEU systems where current data is lacking**
- **Allow applicants and licensees to the NRC more options for optimizing HALEU fuel cycle and transportation systems, with potentially:**
  - Higher throughput fuel cycle processes
  - Higher capacity transportation package designs
  - Fewer iterations with NRC related to code validation
- **Obligate 60M of funding by end of FY26**

Backup

BACKGROUND

- **Office of Nuclear Material Safety and Safeguards Division of Fuel Management (NMSS/DFM) within NRC is responsible for regulation of:**
  - Fuel cycle facilities under 10 CFR Part 70
  - Radioactive material (including fissile material, e.g., HALEU) transportation package designs under 10 CFR Part 71
- **Regulations include requirements to maintain criticality safety under all conditions**

REGULATIONS

- **10 CFR 70.61 – Subcritical under normal and credible abnormal conditions**
- **10 CFR 70.64 – Double contingency principle**
- **10 CFR 70.24 – Criticality monitoring**
- **10 CFR 71.55 - Single packages.**
  - 10 CFR 71.55(b): subcritical considering water in-leakage
  - 10 CFR 71.55(d): subcritical under normal conditions of transport (NCT)
  - 10 CFR 71.55(e): subcritical under hypothetical accident conditions (HAC)
- **10 CFR 71.59 – Package arrays.**
  - Subcritical under NCT and HAC
  - Limiting number of packages under NCT or HAC used to determine Criticality Safety Index (CSI) to control package accumulation on conveyance

CODE VALIDATION

ANS 8.1 - *Nuclear Criticality Safety In Operations With Fissionable Materials Outside Reactors*:

- **Validation shall be performed by comparison to critical experiments, and the area of applicability for the validation should be established from this comparison**
- **Establish:**
  - Applicability of experiments
  - Code bias and bias uncertainty
  - Trending analysis

CODE VALIDATION

- **ANS 8.24 - *Validation of Neutron Transport Methods for Nuclear Criticality Safety Calculations***
- **NUREG/CR-6698 - *Guide for Validation of Nuclear Criticality Safety Calculational Methodology***
- **NUREG/CR-5661 - *Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages***
- **NUREG/CR-6361 - *Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages***
- **International Criticality Safety Benchmark Evaluation Project (ICSBEP):**
  - Descriptions of over 5,000 laboratory critical experiments
  - Grouped by fissile media, physical form, and neutron energy where most fissions occur
  - Many experiments representative of <5% enriched UO_2 LWR fuel; less for enrichment range of 5-20%; much less for key systems of interest (e.g., TRISO, low moderation UF_6)

Critical Benchmarks in ICSBEP

- International Criticality Safety Benchmark Evaluation Project (ICSBEP) contains over 5000 benchmarks
- Includes ~430 critical experiments with HALEU
- Only ~19 appear relevant for non-LWRs
  - 11 before 1980

benchmark	moderator	year	form	u235 wt%
IEU-COMP-THERM-010-001	Graphite	2000	Uranium Oxide	17%
IEU-MET-FAST-011-007	Graphite	1967	Uranium Metal	6%
MIX-MET-FAST-011-001	None	1990	Plutonium Metal, Uranium Metal	18%
IEU-MET-FAST-010-001	None	1981	Uranium Metal	9%
IEU-MET-FAST-007-001	None	1980	Uranium Metal	10%
IEU-MET-FAST-014-001	None	1964	Uranium Metal	16%
IEU-MET-FAST-013-001	None	1964	Uranium Metal	12%
IEU-MET-FAST-012-001	None	1962	Uranium Metal	17%
IEU-MET-FAST-016-001	None	1958	Uranium Metal	12%
IEU-MET-FAST-002-001	None	1956	Uranium Metal	16%
LEU-SOL-THERM-013-001	None	2001	Uranyl Nitrate (U235)	10%
IEU-COMP-INTER-005-001	Sodium	1970	Uranium Metal, Uranium Oxide	16%
IEU-COMP-INTER-005-001a	Sodium	1970	Uranium Metal, Uranium Oxide	16%
IEU-COMP-INTER-005-001b	Sodium	1970	Uranium Metal, Uranium Oxide	16%
LEU-COMP-THERM-103-002b	Water (Light Water)	2016	Uranium Molybdenum	20%
LEU-COMP-THERM-103-003b	Water (Light Water)	2016	Uranium Molybdenum	20%
IEU-COMP-THERM-013-001	Water (Light Water)	2010	Uranium Hydride	20%
IEU-COMP-THERM-003-001	Water (Light Water)	1991	Uranium Hydride	20%
IEU-COMP-THERM-003-002	Water (Light Water)	1991	Uranium Hydride	20%

Data gathered using OECD/NEA DICE tool for filtering benchmarks

Lack of benchmarks means smaller amounts of HALEU per conveyance, which increases cost. For example, **TRISO fuel pebbles can currently be shipped** in Versa-Pac 55 gallon drums (~350 pebbles per drum). The hypothetical accident condition (HAC) k_{eff} =0.6. A 400 MWth pebble bed needs ~700 fresh pebbles per day.

DNCSH Model Development

- Use an FOA Process to collect proposals and award $30M in benchmarks
  - 3 FOAs, 2 in FY24, 1 in FY25
  - Each FOA awards $10M
  - Each FOA will target a different type of system
  - **Each FOA will occur after a public workshop present SCALE transportation and facility models for HALEU-based fuel cycles to use in assessing benchmark applicability**
- Measurement FOA #1 in early March 2024 with $10M in awards
  - Focus on TRISO and graphite moderated systems
  - Following Feb. 29 Workshop
- Measurement FOA #2 in FY24 Q3
  - Focus on micro reactors
  - Workshop date TBD

ORNL assessment model for commercial-scale Transportation of Fresh Fuel Pebbles