

New Developments in Shipping Packages Related to Criticality Safety – Panel Session

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Opening Remarks

- Purpose of the panel session

Over the last decade(s) there have been many new Type A and Type B shipping package designs and new allowed fissile contents. Both ANSI/ANS Standards and the Code of Federal Regulations require an evaluation of criticality safety for each combination of shipping package configuration and content. The purpose of this session is to provide a discussion of the unique challenges and requirements for criticality safety during both transport and storage of shipping packages.

- Panelists

- Doug Bowen, Oak Ridge National Laboratory
 - **Presentation:** Summary of HALEU Validation Issues for Packaging and Transportation
- Lon Paulson, Global Nuclear Fuels
 - **Presentation:** Model 30B UF6 Cylinder Transport in Support of LEU+: Technical and Regulatory Challenges
- Marcus Harris, Savannah River Site
 - **Presentation:** Criticality Differences in Methodology Between SRS Onsite Transportation and Offsite Transportation of Packages
- Steven Nathan, Savannah River Site
 - **Presentation:** Criticality Safety Analyses for Revision 5 of the 9977 SARP

Summary of HALEU Validation Issues for Packaging and Transportation

Doug Bowen
Oak Ridge National Laboratory



Introduction

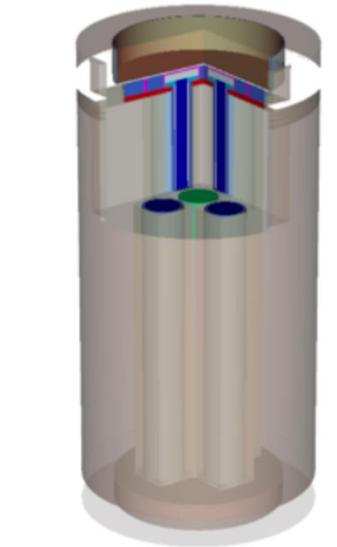
- This presentation is a summary of several ORNL publications
 - ***Initial Investigations of the Criticality Safety Validation Basis for HA-LEU Transportation***, Rearden, Marshall, Clarity, Holcomb, Bostelmann, & Scaglione, (2019)
 - ***HALEU Transportation Preliminary Criticality and Shielding Evaluation***, R. A. Hall (ORNL), B. D. Brickner (ORNL), B. J. Marshall (ORNL) (2020)
 - ***Assessment of Critical Experiment Benchmark Applicability to a Large-Capacity HALEU Transportation Package Concept***, R. A. Hall (ORNL), B.J. Marshall (ORNL), E. Eidelpes (INL), B. M. Hom (PNNL) (2020)
- Two other topics that are also mentioned for community awareness
 - NUREG/CR-7239, Review of Exemptions and General Licenses for Fissile Material in 10 CFR 71, D. G. Bowen & C. V. Parks (2018)
 - Safety Analysis Review for Packaging Analyst Training, Oak Ridge National Laboratory (2020)

Initial Investigations of the Criticality Safety Validation Basis for HA-LEU Transportation, Rearden, et. al.

- Concern – validation of computational methods with sparse critical benchmarks at High Assay LEU enrichments (<20 wt. % U-235)
- Advanced reactor concepts are being explored by the nuclear industry
 - Salt-fueled fast reactors
 - Integral molten salt thermal reactor
 - Liquid fluoride thorium thermal reactor
 - Liquid fluoride cooled thermal reactor
 - Other concepts
- These reactor concepts involve enrichments from ~15-20 wt. % U-235 or involve systems with minimal or zero critical benchmarks
- Most benchmarks tend to cover the range of interest with PWR, BWR enrichments (2-5 wt. % U-235)

Initial Investigations of the Criticality Safety Validation Basis for HA-LEU Transportation, Rearden, et. al.

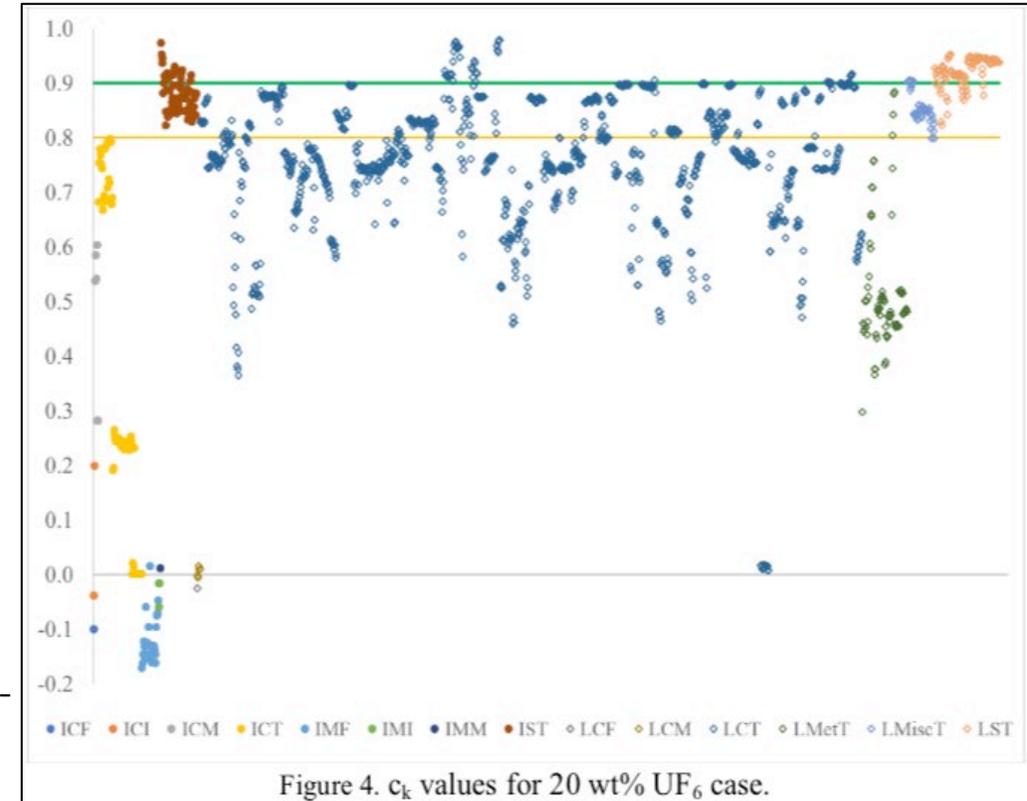
- A criticality validation example was performed for this reference using the ES-4100 package for 20% enriched UF₆
 - Package designed at Y-12; currently designed to ship fresh research reactor fuel and has four separate containment vessels
 - Each vessel has a 5-in inner diameter with an inside height of 58-in; overall package is 34-in in diameter with an inside height of 58-in.; a cast ceramic absorber containing boron carbide (neutron poison) and Kaolite insulation is included in the package model
 - Selected as being a potentially representative container for shipping HA-LEU UF₆ (no plans to currently certify the container for this purpose)
 - Model details
 - 20 wt. % enriched UF₆ homogeneously mixed with water and polyethylene in the containment vessel
 - Similar approach as is presented in the current SARP criticality analysis
 - An individual package is modeled with the maximum U-235 mass allowed in each containment vessel per the certificate (1 kg per cylinder or 4 kg per package)



Initial Investigations of the Criticality Safety Validation Basis for HA-LEU Transportation, Rearden, et. al.

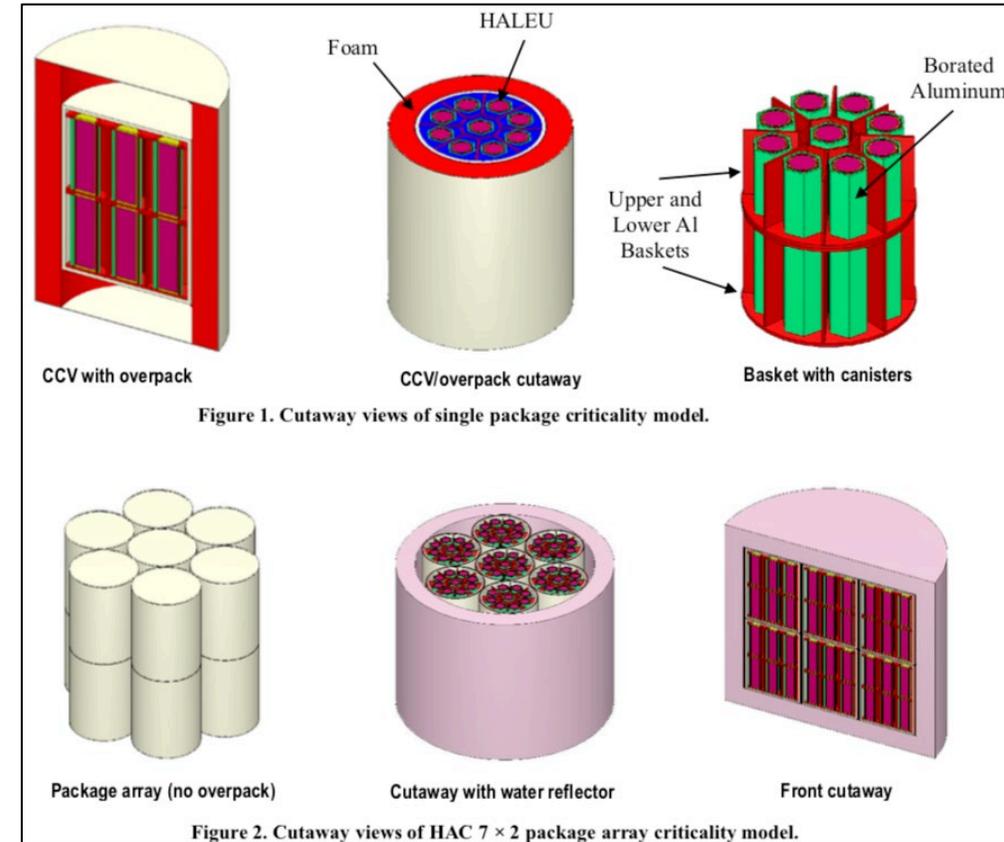
- Results

- Study examines nuclear data/cross section changes between ENDF/B-VI.1 to ENDF/B-VIII.0
 - Authors show how some of the cross sections have new evaluations incorporated into the ENDF/B-VIII library – significant changes are noted for some isotopes of interest
 - TSUNAMI was used to generate sensitivity data for the ES-4100 configuration
 - 1,584 critical experiments from the VALID database of benchmarks at ORNL with available sensitivity data was used to identify applicable critical experiments to validate the k_{eff} computational method for this HA-LEU configuration
- Results indicate applicability of existing critical experiments for HA-LEU transportation – 698 experiments have a c_k value of at least 0.8 and 173 of these have c_k of 0.9 or higher
 - Experiments for IEU, LEU solutions had the highest c_k values
 - Other highly applicable experiments include low enriched U compound (LEU-COMP-THERM or LCT) systems
 - Indicate the c_k values are not a strong function of enrichment



HALEU Transportation Preliminary Criticality and Shielding Evaluation, Hall, et. al.

- NAC International OPTIMUS-L cask design as a representative transportation package
 - A two-section inner aluminum basket is used to hold 18 stainless-steel canisters containing HALEU in 9 aluminum storage tubes
 - Hexagonal borated aluminum tubes, which are integral to the basket surrounding the storage tubes, provide neutron absorption for criticality control
- Calculations for normal conditions of transport (NCT) and Hypothetical Accident Conditions (HAC) are performed to derive a criticality safety index per 10 CFR 71 requirements
 - NCT – Single package; infinite array – subcritical
 - HAC – 7x2 array results in a subcritical system with 85% water in the canisters that contain 15% UO_2
- TSUNAMI calculations were performed to calculate c_k
 - 614 experiments were identified (out of 1584 with a c_k greater than 0.8) for the single package model
 - 855 experiments were identified for the normal NCT infinite array model and 1,097 for the HAC array model



HALEU Transportation Preliminary Criticality and Shielding Evaluation, Hall, et. al.

- The TSUNAMI analysis indicates there are many applicable benchmark critical experiments available to support the validation effort for this analysis (determination of the k_{eff} bias and bias uncertainty)
- This preliminary study indicates that a similar package design with the proposed contents could meet the package certification requirements related to subcriticality

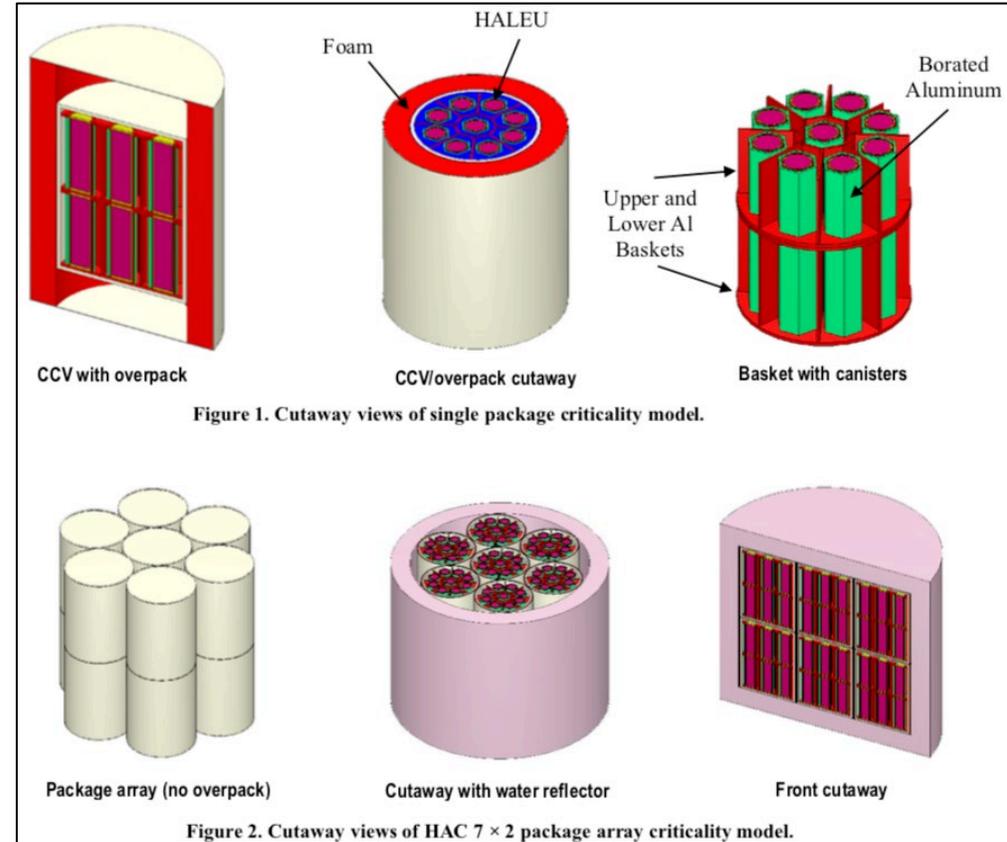
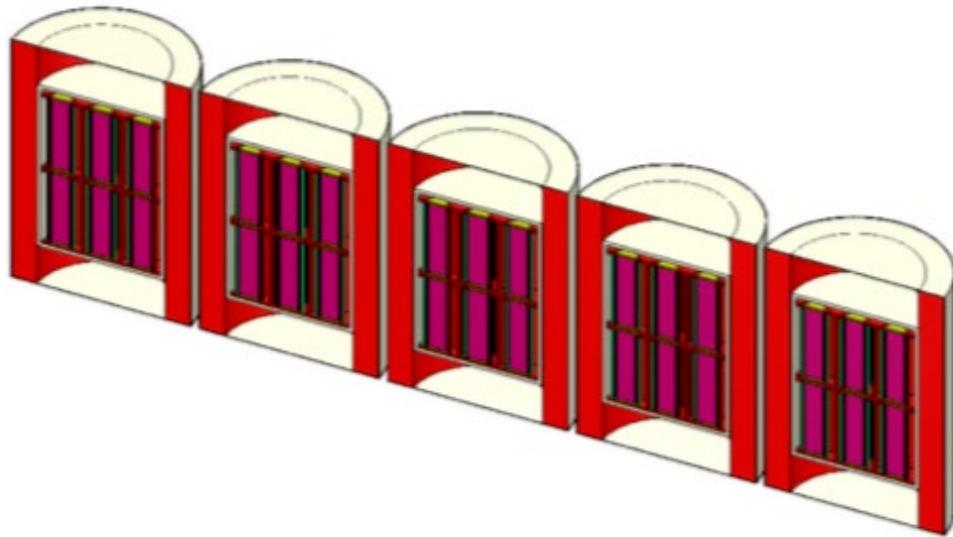
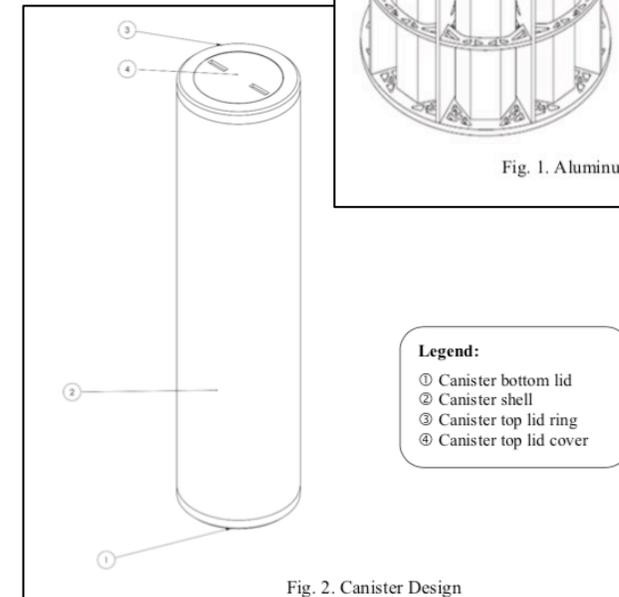
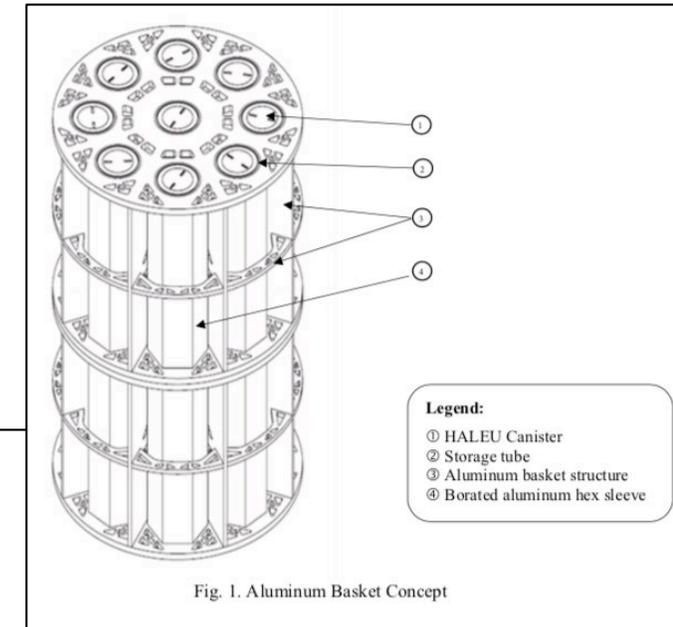


Figure 1. Cutaway views of single package criticality model.

Figure 2. Cutaway views of HAC 7 x 2 package array criticality model.

Assessment of Critical Experiment Benchmark Applicability to a Large-Capacity HALEU Transportation Package Concept, Hall, et. al.

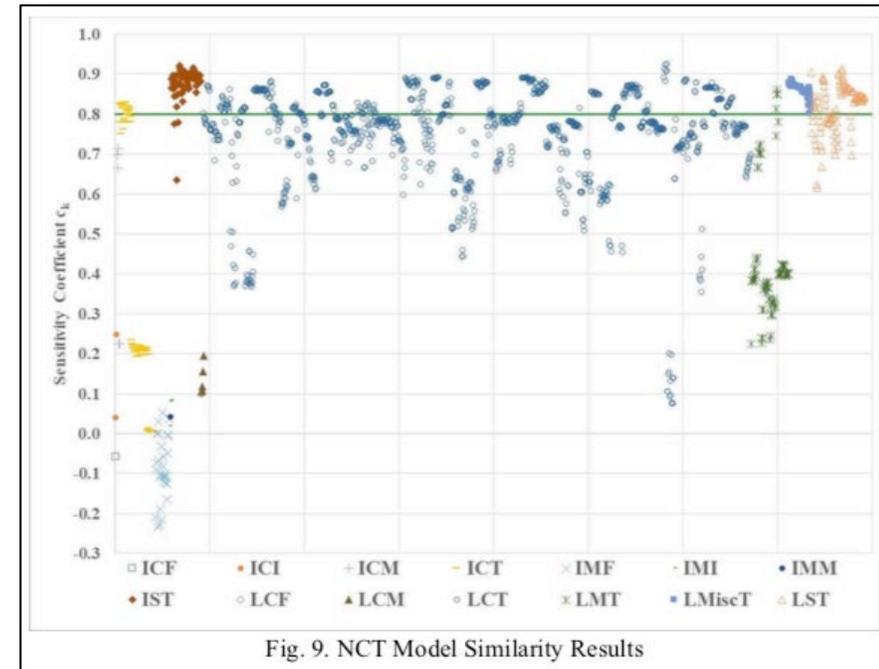
- A similar study (10 CFR 71) was performed for a large volume shipping package containing UO_2 enriched to 20 wt. % U-235 to determine if
 - additional critical experiments would be needed with HALEU fuels and materials of interest to support the validation of the computation method for k_{eff} calculations
 - Adapting an existing package design to add HALEU to the contents of an already-approved and certified shipping package rather than a new redesign effort
- Nuclear Assurance Company (NAC) International Optimal Modular Universal Shipping for Low-Activity Contents (OPTIMUS-L) cask was chosen as a representative package for its payload capacity and relative ease of handling
- Payload consists of 18 stainless steel HALEU canisters in fixed positions that contain 14-28 kg of UO_2 powder, depending on the oxide density ($2\text{-}4\text{ g/cm}^3$)



Assessment of Critical Experiment Benchmark Applicability to a Large-Capacity HALEU Transportation Package Concept, Hall, et. al.

- Results

- NCT model – infinite array of undamaged packages subcritical
 - TSUNAMI similarity assessment
 - 10 LEU experiments and 76 IEU experiments with a c_k value ≥ 0.9 (similar)
 - 590 LEU experiments and 76 IEU experiments with a c_k value ≥ 0.8 (marginally similar)
- HAC model – a 7x2 array of damaged packages subcritical
 - TSUNAMI similarity assessment
 - 55 LEU experiments and 76 IEU experiments with a c_k value ≥ 0.9 (similar)
 - 1,044 LEU experiments and 60 IEU experiments with a c_k value ≥ 0.8 (marginally similar)
- For transportation packages like the concept analyzed, a large set of applicable existing experiments was identified, increasing confidence that new experiments or large criticality conservatism will not be required.



Conclusions

- Results for the three referenced studies indicate that there are enough benchmark critical experiments to support the validation of computational methods for the shipping package criticality safety analysis
 - Bias and bias uncertainties will be sufficiently low to support projected HALEU contents for the representative package
- No additional critical experiments seem to be needed to support these efforts