Spent Nuclear Fuel Management Alternatives at the Savannah River Site

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Office of Nuclear Materials

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Overview

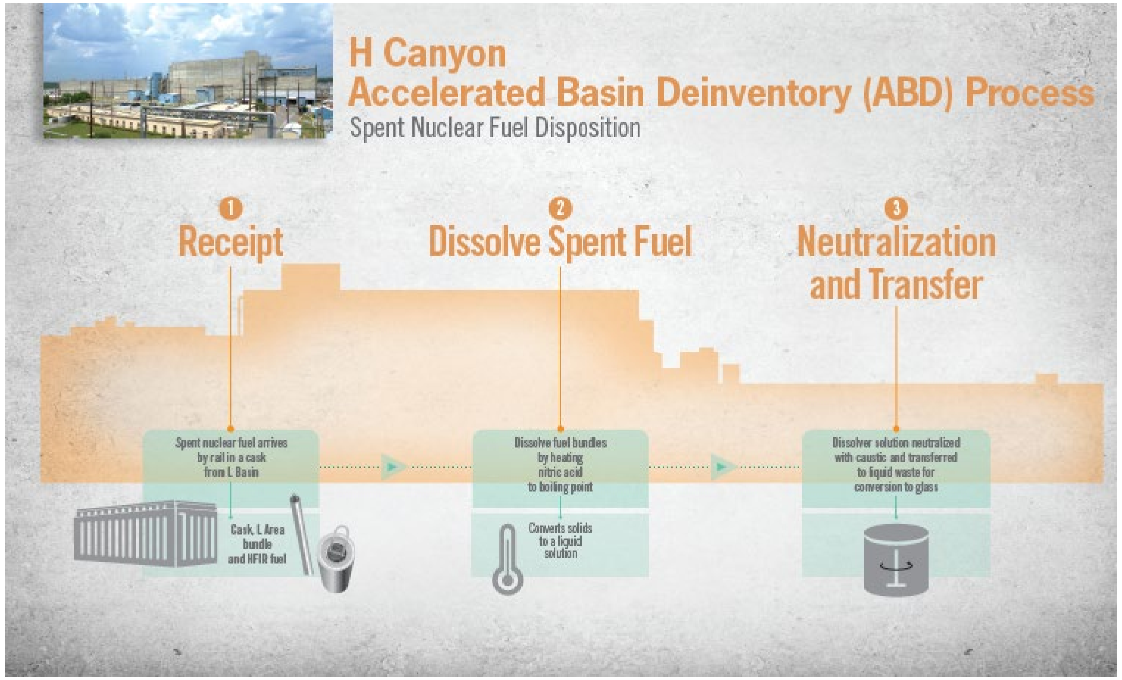
- Current and future options for managing spent nuclear fuel post accelerated basin de-inventory (ABD) mission
  - Current Storage Capabilities
  - Post ABD SNF Sources
  - Alternatives
  - Future Considerations

Current Storage in L-Basin

- Continues to provide a crucial solution for the management of spent nuclear fuel.
  - Current inventory as well potential future receipts
  - Adequate storage thru the projected life
- Ensures safe storage while future solutions are developed
  - Additional capabilities needed for repository disposal
  - Processing and/or drying and road ready packaging

Post ABD SNF Sources

- Any SNF not processed during ABD
  - ABD Mission progress
  - Non-Aluminum Spent Nuclear Fuel (NASNF)
- Foreign Research Reactor Returns
- Domestic Research Reactor Returns
  - US High Performance Research Reactors
    - Massachusetts Institute of Technology Reactor
    - Missouri University Research Reactor
    - The National Bureau of Standards Reactor at the National Institute of Standards and Technology,
    - High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory



Post ABD SNF Sources cont.

- 2023 SNF Future Receipts Working Group Initial Assessment of DOE Capabilities to Manage Future SNF*
  - Key observations
    - Adequate interim storage capacity to manage the existing and projected SNF inventories for the next 25 to 30 years.
      - However, programmatic policies and enforceable State agreements constrain the efficient use of those facilities and prevent the ability to manage this future inventory.
    - Aging existing interim storage infrastructure
    - Resources to conduct focused research and development of appropriate technologies for management of challenging SNF
- Recommendations
  - Determine a path forward for addressing near-term storage needs destined for SRS post ABD mission
  - Support identified technology development requirements and funding
  - Establish a schedule for staged implementation of appropriate new SNF management infrastructure at SRS for future operations
  - Develop a long-term infrastructure management plan and further develop an SNF integrated strategy, including any NEPA updates

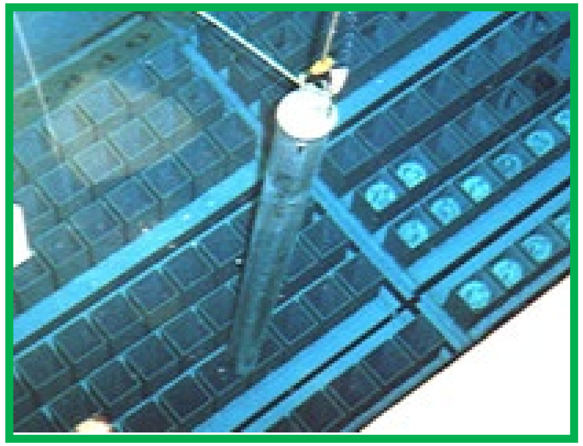
This assessment regarding management of future spent nuclear fuel receipts at multiple U.S. Department of Energy (DOE) sites was an analytical exercise based on facts and assumptions that may not be consistent with DOE commitments and legal requirements and does not represent final decisions.

Alternatives

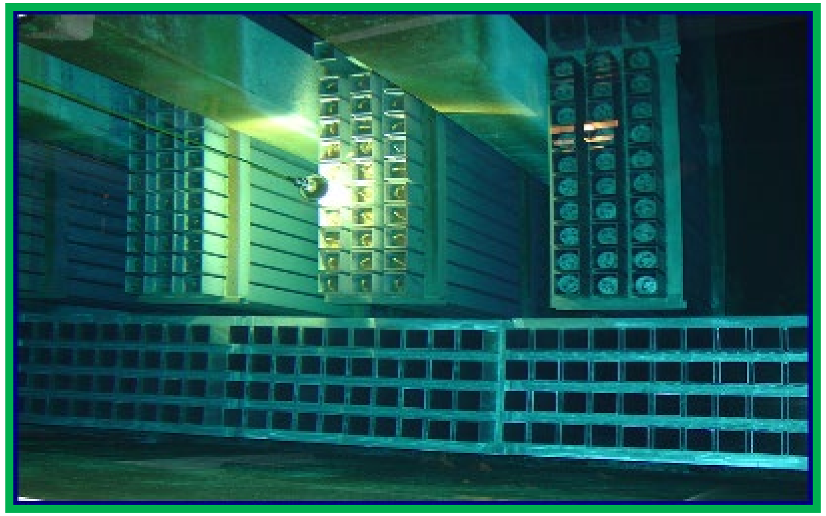
- H-canyon 2019 AOA that led to ABD decision
  - All options from analysis resulted in materials that will have to be addressed by next generation nuclear material processing capability including dry storage and/or treatment, which does not currently exist
  - Processing needs, preferred technologies, and scale will be driven by alternative implemented for H-canyon (quality and types of materials dispositioned) and the resulting remaining inventories of SNF/NM across the DOE complex
- Technological challenges with NASNF processing
- Management of SNF/NM will continue to be needed and represents programmatic challenges for multiple DOE program offices
  - Facility age
  - Eventually replacement will be necessary
    - Opportunity to optimize a multi program nuclear material processing capability to manage nuclear materials.

Alternatives (cont.)

- Both past and current options are being considered
- Plans for a feasibility assessment on using melt/dilute technology to disposition NASNF
  - considering past (L-Area Experimental Facility (LEF)) and
  - current (Modular Melt and Dilute (e.g., MMC)) capabilities
- Continued Storage in L-Basin
- Dry Storage



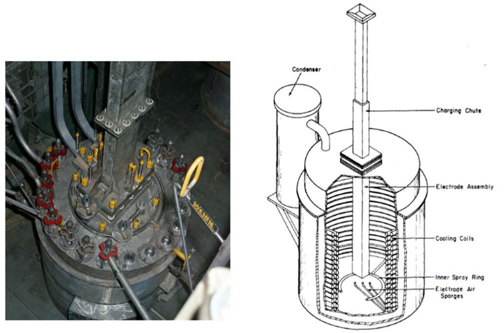
Suspended Fuel Bundle



Alternatives (cont.)

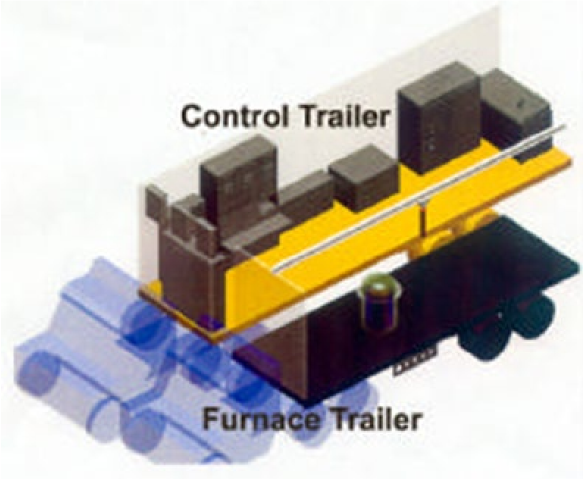
- Mobile Melt and Consolidate
- Electrolytic Dissolver
- Chop/Leach Module
- Cold Crucible Induction Melter (CCIM)
- Drying and Packaging Capability

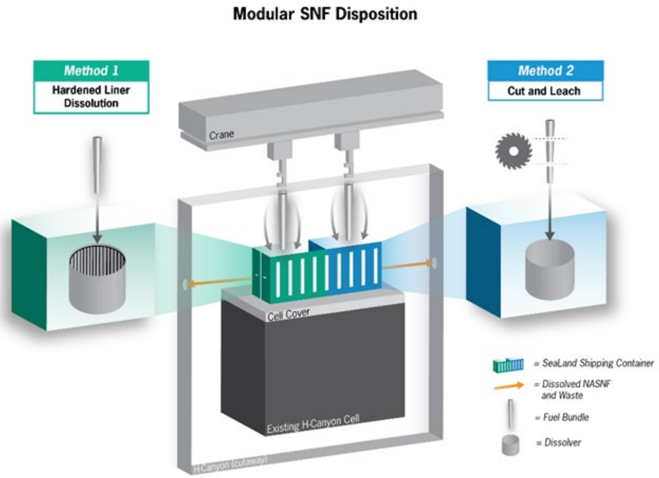
MMC Treatment Modules



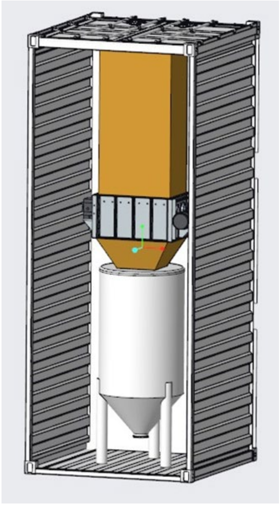
Existing ED installed in H-Canyon

Concept for modular Melt and Dilute system for processing SNF





***Left:** Concept of integrated Chop/Leach modules that could be deployed within H-Canyon.*
***Right:** Concept of standalone external module*



Paths Forward

- Opportunity to conduct a pilot scale demonstration
  - Potential to leverage the current SRS infrastructure
  - Modular processing capability could address one or more of the NM/SNF inventory groups that are likely to remain post-ABD.

- Opportunity to evaluate prioritization of inventory groups that may remain and alternatives to best suit those priorities
  - Development of a Roadmap
  - Potential to eliminate more of the NM and SNF inventory in addition to ABD mission
  - Selection criteria to prioritize NM/SNF types and applicability to evolving DOE program mission needs
  - The technology demonstrated will be based on the target NM/SNF inventories

Near-Term

- Past efforts will be used as the starting point to accelerate the identification and evaluation of options in roadmap development.
- There are likely other technologies that will be identified and evaluated for viability regarding small scale modularization.

- Develop Scope
  - Use tailored Roadmap approach to prepare an initial assessment of pilot scale capabilities based on EM needs
  - Determine viable processing technologies that are readily modularized for integration with H-Canyon infrastructure
  - Assess feasibility of implementing a pilot scale demonstration
  - Identify National Environmental Policy Act (NEPA) analysis required for implementation
  - Provide recommended initial pilot demonstration with estimated implementation cost and schedule

Follow-On Actions

- Depending on results of the pilot study, develop a formal Mission Need Statement (MNS) that is focused on broader scope of EM needs, and specifically full completion of the ABD scope.

- MNS should consider potential strategies to address needs
  - Suite of modular technologies that can address all remaining SNF and NMs in H-Canyon and L-Basin
  - Potential new build of focused Nuclear Material Processing Facility

- Consider needs of other DOE Programs (Office of Science, Office of Nuclear Energy) and capability for potential future expansion

- Identify NEPA compliance strategy for full scope effort

Infrastructure Strategy

- Planning for the future infrastructure needs to support any ongoing and expanded storage and processing capabilities.
- Ensures readiness for handling spent fuel efficiently and safely.
- Investment in infrastructure improvements and potential new facilities.
- Strategic planning to accommodate evolving technologies and regulatory requirements.
- Ongoing planning with specific milestones for infrastructure development
- DOE EM SNF Strategic Framework (internal) to evaluate dry storage and packaging needed for Road-Ready Dry Storage (RRDS)
  - Material is packaged in a form that can readily be placed into a configuration that would applicable transportation requirements, and applicable disposal requirements without the need to re-open and/or repackage, for as long as may be needed until transportation for final disposition.

Future Considerations

- Anticipated needs for future technology and infrastructure development
- Verification and Validation of technology development research
  - Essential steps to verify and validate new capabilities and ensure the safe and reliable storage
  - Continuous monitoring and assessment throughout the development and implementation phases.
- To maintain and enhance the safety and efficiency of spent fuel management.
- Implementing capabilities and technologies at INL and SRNL for long-term storage solutions
- Specific focus on Aluminum SNF Drying pilot using HFIR (High Flux Isotope Reactor) SNF
- DOE Standard Canister packaging and storage implementation

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ASNF Dry Storage Pilot

Anna d'Entremont, Nathan Morgan, Lisa Ward, Chris Verst, Bob Sindelar

Nuclear Waste Technical Review Board Public Meeting

Aug. 29, 2024

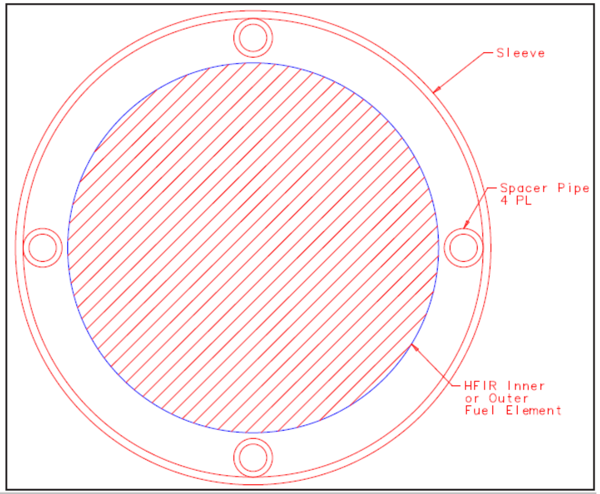
Motivations for ASNF Dry Storage Pilot

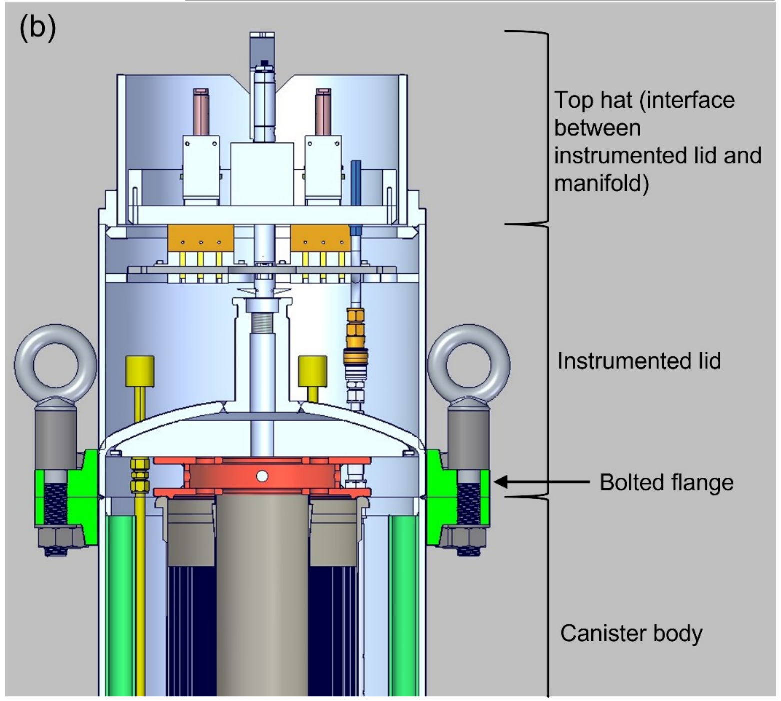
- Technical basis for aluminum-clad spent nuclear fuel (ASNF) dry storage
  - Dry storage in multipurpose DOE standard canisters (DSCs) provides an alternative path for interim storage and potentially direct disposition
  - Key challenge is chemically bound water in aluminum (oxy)hydroxides (AlOOH or $Al(OH)_3$) with potential for radiolysis producing H_2 gas
  - SRNL and INL have developed technical basis based on experiments and modeling
  - Results to date point to extended dry storage being viable
- **Next step: Full-scale, monitored pilot canister for verification and validation**
  - **Demonstrate canister loading, handling, and drying processes**
  - **Monitor internal conditions (temperature and gas composition) to validate models**

ASNF Dry Storage Pilot concept

- Two 18-in OD x 10 ft DOE Standard Canisters (DSC)
  - Actual ASNF: 3 HFIR inner fuel elements per DSC
  - Prototypic basket (no neutron absorber)
  - “Instrumented lid” to monitor internal conditions
  - Bolted-flange lid for SNF retrieval after pilot
- Dry-to-dry transfer from transport cask
- Two commercial drying processes: vacuum drying and forced-helium dehydration (FHD)
- 1-5 years of monitoring: temperature and gas composition
- SRS L Area siting

Basket design (top view)





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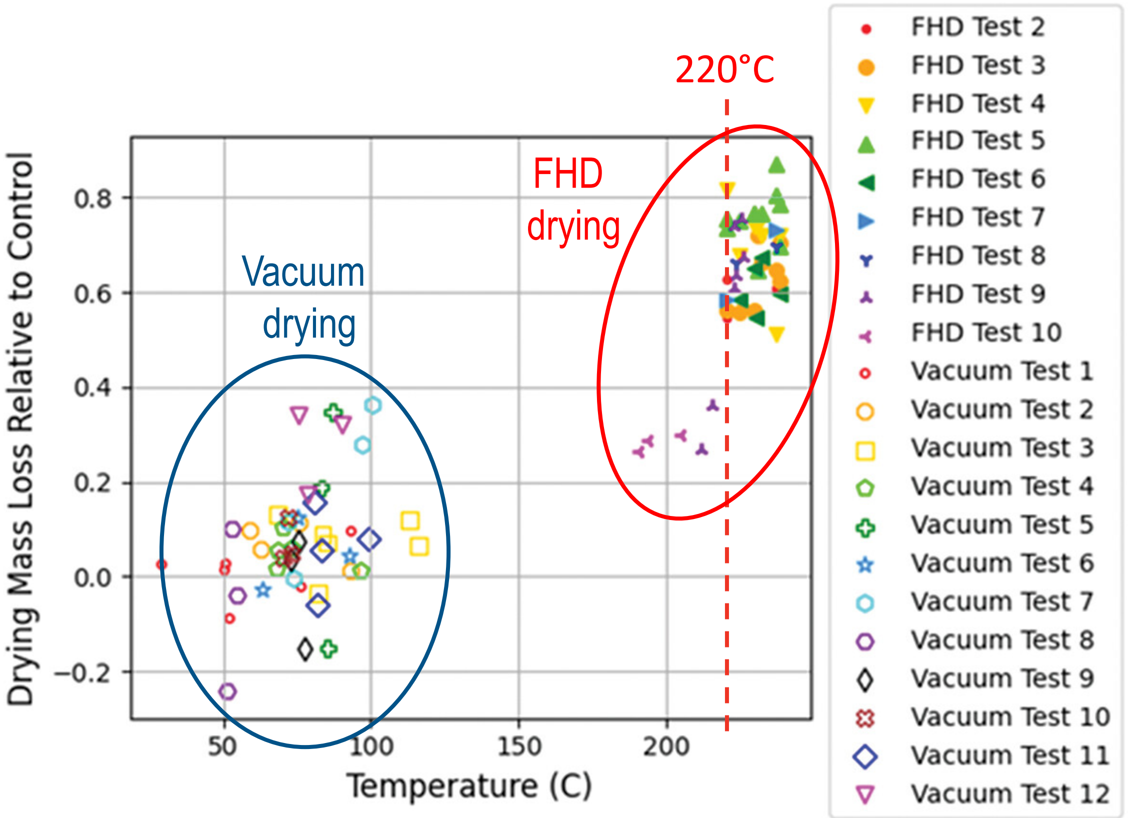
Drying tests

- Lab-scale tests showed dehydration of bayerite starting at ~220°C
- Engineering-scale tests of vacuum drying and FHD on 1/3-height canister mockup
  - Both methods removed free water
  - FHD could bring mockup SNF to 220°C (vacuum drying did not)
  - Sharp increase in drying mass loss at 220°C threshold



- Estimated residual water in pilot:
  - **~35 mol in undried (oxy)hydroxide, reduced to ~20 mol if dried to AlOOH**
  - Other H_2O <0.1 mol

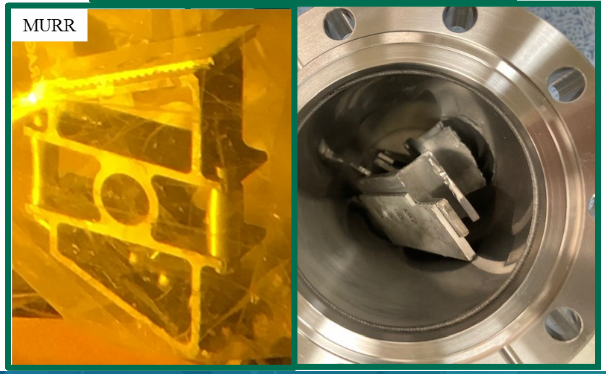
Lab-scale precursor: Mini-canister radiolysis testing

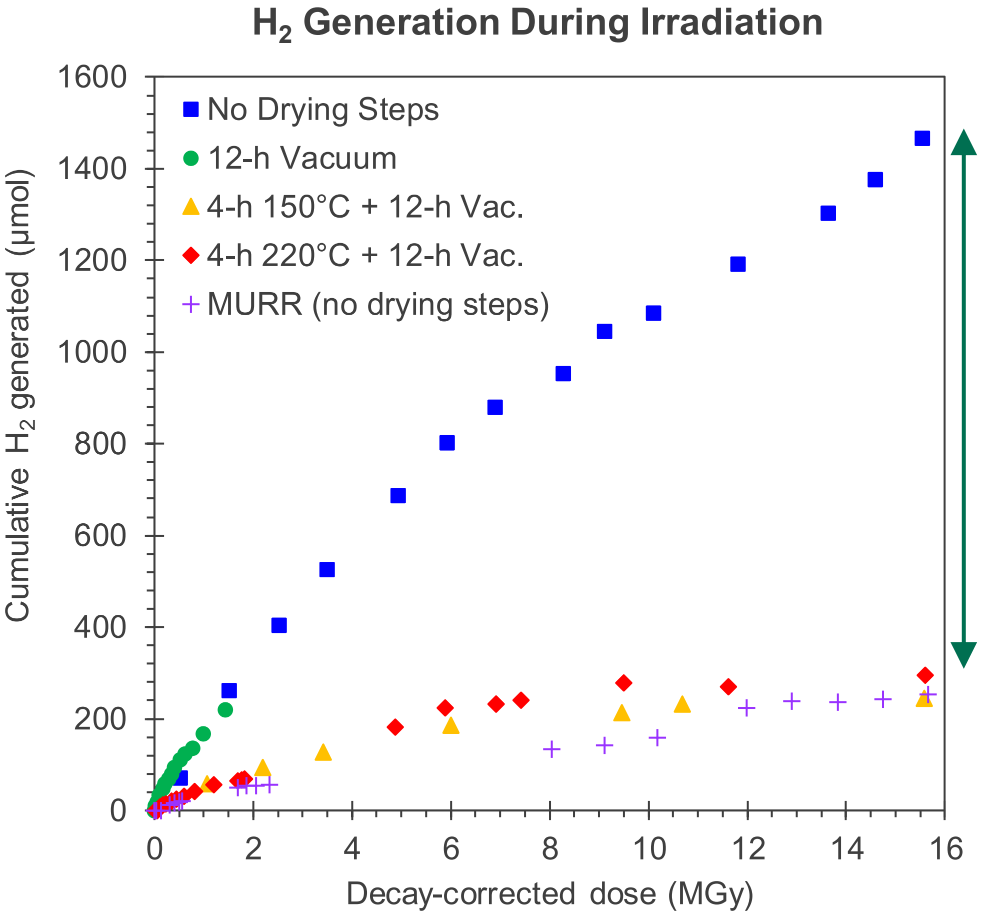
Sampling line through lid

Small commercially available steel vacuum vessels

Aluminum surrogate assemblies with bayerite

MURR cropping from actual ASNF



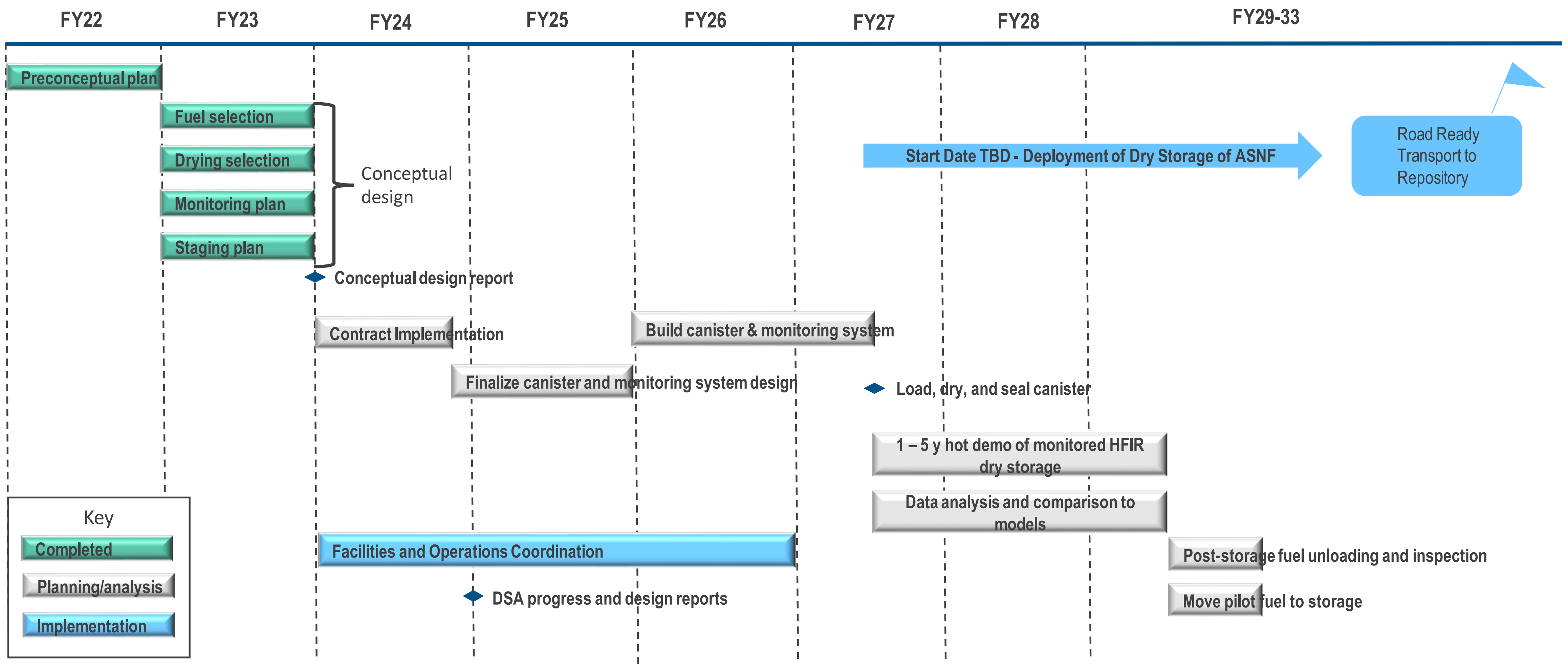


Large impact from heated drying

Implementation details

- Safety planning and documentation in development
  - Evaluations of flammability, dose rate/shielding, etc.
  - Planning for emergency retrieval, drying procedure, etc.
- Component designs to be finalized with commercial vendor
  - Dry-to-dry transfer system
  - Overpack
  - DSC modifications (bolted flange and instrumented lid)
  - Spacers
- Pre- and post-storage visual examination
- Horizontal storage configuration
  - Access to both ends of canister
  - Stability for safety purposes
- Two sets of dry runs with dummy fuel to verify equipment function and train SRS personnel

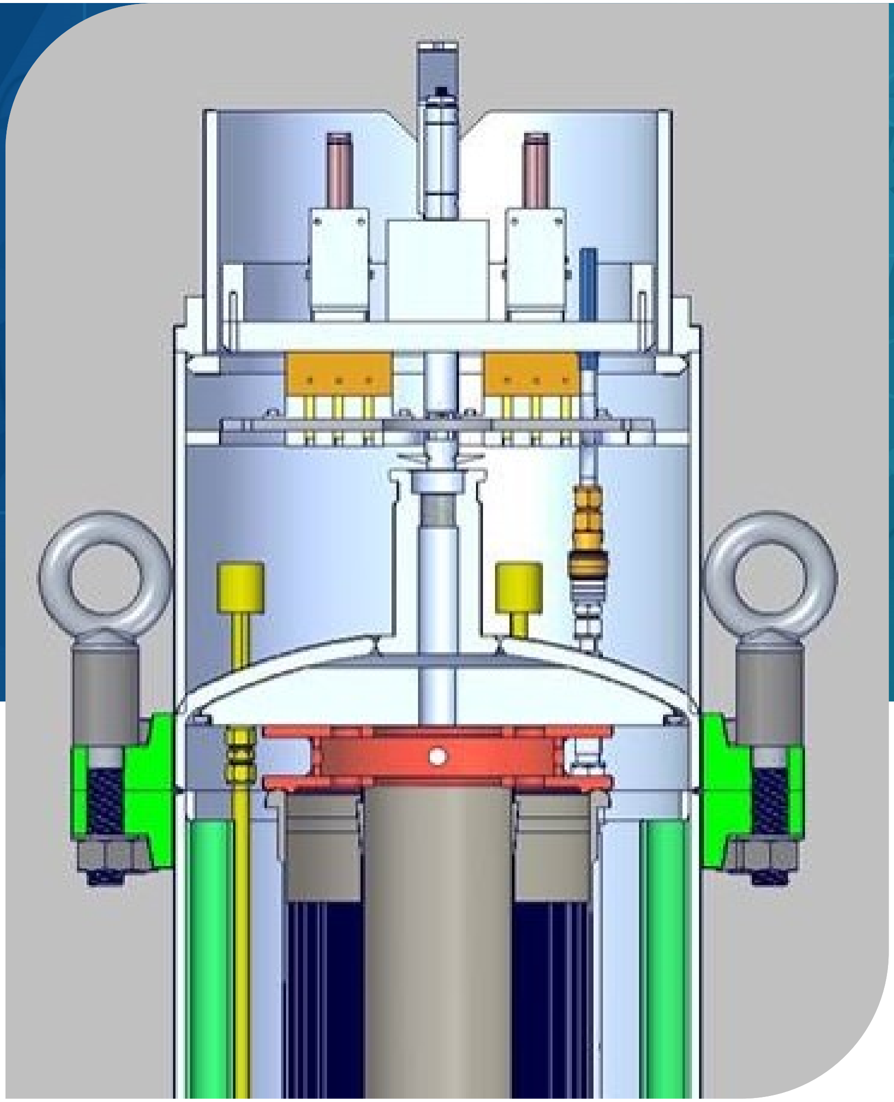
Roadmap for ASNF Dry Storage Pilot



Conclusions

- Dry storage is a potential path for future ASNF receipts and/or SNF remaining in L Basin after H Canyon closure
- Pilot will provide verification and validation of drying and dry storage performance and of models developed using lab-scale data for ASNF
- Pilot will establish SRS capability in
  - Dry-to-dry transfers (potentially applicable to future SNF receipts)
  - Use of vacuum drying and FHD processes, applicable to wet-stored SNF or SNF directly from transport casks

Questions?



Extra slides

Residual water estimates

- Estimated surface areas
  - HFIR inner core: ~19 m^2 each
  - Basket (stainless steel): ~9 m^2
  - Canister interior: ~3.8 m^2
  - Spacers currently undetermined
- Gas volume in canister: <0.323 m^3
- Drying expected to remove:
  - Free water (except <3 Torr vapor)
  - Some physisorbed
  - Some (oxy)hydroxide (FHD only)

- Estimated water
  - (Oxy)hydroxide on 3 HFIR cores
    - **For 17 µm of 50%-50% bayerite/boehmite: 35 mol H_2O**
    - **Fully dried to boehmite: 20 mol H_2O**
  - Physisorbed
    - Depends on material, humidity, microscopic surface area → # of monolayers of water
    - Canister and basket: 0.21 mmol/monolayer H_2O
    - 3 HFIR cores: 0.93 mmol/monolayer H_2O
  - <3 Torr water vapor: ≤53 mmol.

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Flaw Tolerance of DOE SNF Storage Canisters

SRNL-STI-2024-00339

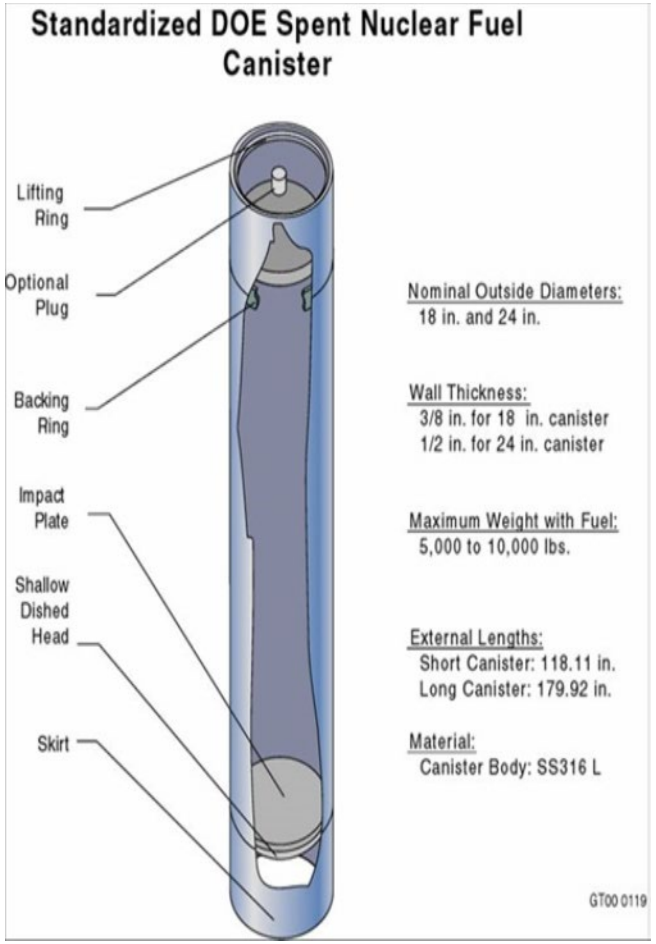
Xian-Kui Zhu, Principal Engineer, Savannah River National Laboratory

U.S. Nuclear Waste Technical Review Board, Summer 2024 Board Meeting; August 29, 2024

DOE Standard SNF Storage Canisters – Structural Integrity

- DOE Standard SNF Storage Canisters
  - DOE designed standard spent nuclear fuel (SNF) storage canisters for storage of wide range of DOE SNFs in different designs, conditions.
  - DOE canisters are significantly different from commercial Multi-Purpose Canisters (MPC) in size:
    - MPC canisters are large with OD = 68”, WT = 0.5”, and height = 15.8 ft.
    - DOE canisters are small with OD = 18” / 24”, WT = 0.375” (for OD = 18”) / 0.5” (for OD = 24”), and length = 10’ / 15’, leading to four standard designs.

- Structural Evaluation of DOE versus MPC Canisters
  - Structural evaluations, including flaw tolerance, have been performed for MPC canisters.
    - MPC canister: 4 axial welds, 1 center girth weld, and 2 closing welds, susceptible to chloride-induced stress corrosion cracking (CISCC).
    - Flaw stability analysis and results were published.
  - Structural evaluation was also performed for DOE standard canisters.
    - DOE has sponsored structural integrity studies to evaluate weld integrity using drop tests and FEA simulations.
    - Most of these studies were done at Idaho National Lab (INL).
  - DOE canister: 1 axial weld and 2 closing girth welds (TBD).
    - There are no rigorous flaw tolerance analysis of the DOE standard canisters.
    - The flaw tolerance analysis will ensure robust DOE standard canister for handling, storage, disposal of SNFs as waste form.



Schematic of DOE standard canister, and DOE canister at INL.

Proposed Technology, Scope, and Benefits to DOE

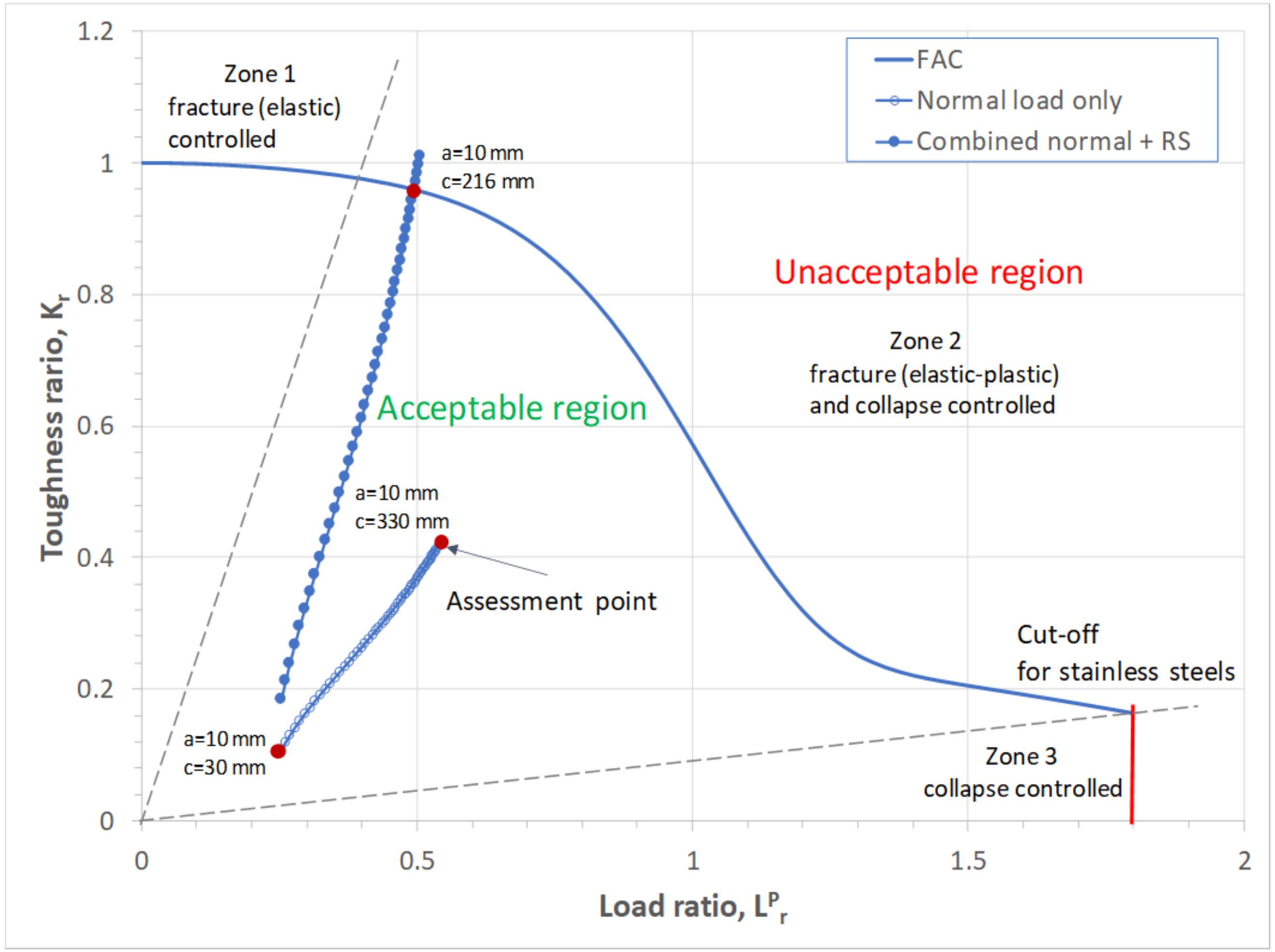
- Proposed Fracture Mechanics Technology
  - Adopt API 579 approach to estimate residual stress distributions for longitudinal and circumferential welds.
  - Using API 579 FAD (failure assessment diagram) approach to determine the flaw acceptance criteria and the critical flaw sizes at flaw instability.
  - The FAD assessment approaches are similar for both MPC commercial and DOE standard canisters.

- Scope: Literature Study and Technology Development
  - Develop fracture mechanics method to evaluate flaw tolerance of DOE canisters.
  - Develop FAD framework and flaw acceptance criteria for FY24.
  - Evaluate crack opening displacement (COD) of a postulated crack in DOE canisters for safety and risk evaluations (radiological source term release) in FY25.

- Benefits to DOE
  - Provide advanced technologies for reducing risk of DOE standard SNF storage.
  - Provide advanced models for evaluating structural integrity of DOE standard canisters.

FAD Assessment Method and Example

- FAD Fracture Mechanics Method
  - API 579 – 2016 version
  - 3 zones: elastic, elastic-plastic, collapse controlled
  - Acceptable flaw: inside of failure assessment curve (FAC)
  - Unacceptable flaw: outside of FAC
- FAD Assessment Example
  - An axial, outside surface crack lies in the axial weld with hoop residual stress (RS)
  - An initial crack sizes a=10 mm (80%t), c=30 mm
  - The crack grows due to SCC under RS and applied loadings (p= 50 psi + canister weight/handling force)
  - Flaw acceptance conditions are:
    - Normal loading: no failure
    - Combined normal + RS: critical a=10 mm, & c=216 mm
    - This may indicate the flaw is stable and acceptable



Thank You for Your Attention !