HALEU TRANSPORTATION AND FUEL CYCLE LICENSING AND THE DNCSH PROJECT

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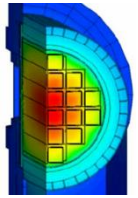
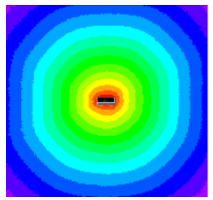
OVERVIEW

- Regulations and Guidance
- Licensing and Certification Status
- Anticipated data gaps for future licensing
- DNCSH Project

Regulations



Decay Heat



Shielding and Radiation Protection

Neutron Multiplication and Criticality

NRC Regulations limit radiation dose under all phases of the fuel cycle:

- Direct radiation dose
- Radioactive material releases
- Inadvertent criticality

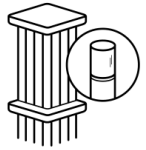
Computer codes used to determine:

- Irradiated fuel composition for nuclides that contribute to:
  - Direct radiation dose and dose from radioactive material releases
  - Decay heat
  - Determination of criticality safety (k_{eff})
- Radiation dose and k_{eff}

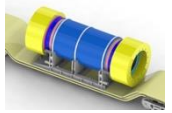
Codes must be validated against measured irradiated fuel data

10 CFR 20 – Radiation Protection

10 CFR 50/52 – Power Plants



10 CFR 70 – Fuel Cycle Facilities



10 CFR 71 – Transportation

10 CFR 72 – SNF Storage

Regulations and Guidance

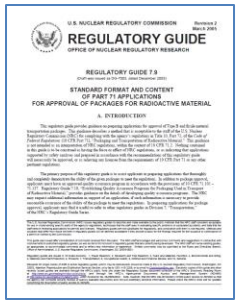
Transportation

- Criticality
  - 10 CFR 71.55 - General requirements for fissile material packages
  - 10 CFR 71.59 - Standards for arrays of fissile material packages
- Radiation Dose
  - 10 CFR 71.47 - External radiation standards for all packages
  - 10 CFR 71.51 - Additional requirements for Type B packages
    - (a)(2) HAC External Dose Rate

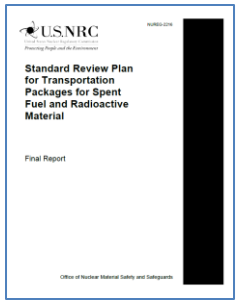
Fuel Cycle Facilities

- Criticality
  - 10 CFR 70.24 – Criticality accident requirements
  - 10 CFR 70.61 – Performance requirements
- Radiation Dose
  - 10 CFR 70.61 – Performance requirements
  - 10 CFR 20 – Standards for protection against radiation

Guidance:

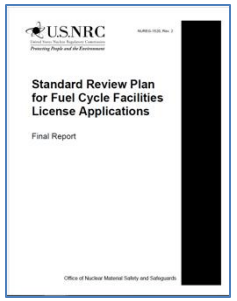


RG 7.9



NUREG-2216

RG 3.71

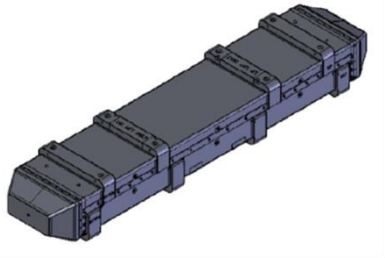


NUREG-1520

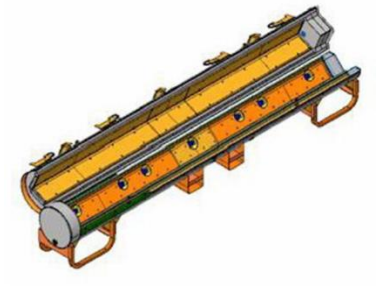
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

HALEU Licensing and Certification

LWR LEU+ Fresh Fuel Assembly Transportation Packages:

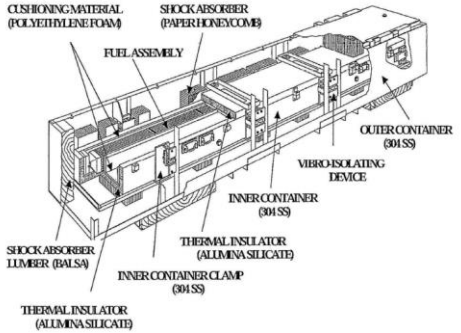


MAP 12 & MAP 13 (71-9319)



Traveller (71-9380)

GNF RAJ-II (71-9309)



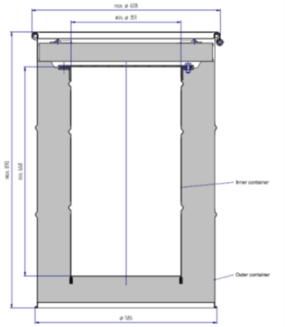
TN-B1 (71-9372)

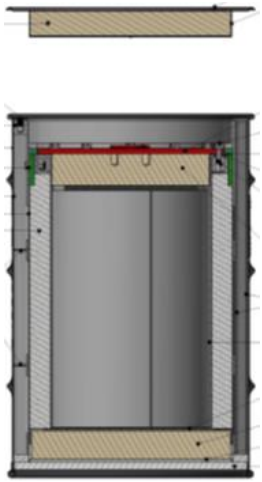
- Certified to LEU+ range – up to 8.0% enrichment
- No significant issues with code validation
  - Many applicable low enriched UO_2 experiments
  - Regulations require consideration of moderation by water – thermal uranium systems generally easy to validate

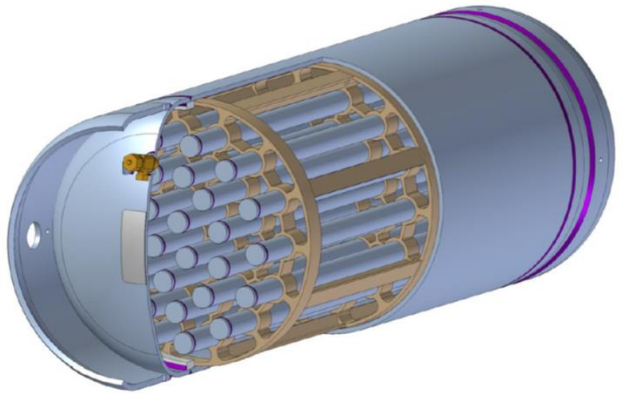
The critical benchmarks performed at SNL with 7% enriched fuel were instrumental in limiting validation RAIs for these reviews.

HALEU Licensing and Certification

Other Transportation Packages:







UO_2 Powder and Pellets

- BU-D (71-3037)

TRISO Compacts

- Optimus-L (71-9390)

Uranium Compounds

- Versa Pac (71-9342)

UF_6

- DN30-X (71-9388)

HALEU Licensing and Certification

Facilities:

- Urenco
  - License amendment for production and possession up to 10 wt.%, except for recycling and support systems
  - License amendment for recycling and support systems currently under NRC review
- American Centrifuge (ACO / ACP)
  - License authorization to produce HALEU as part of HALEU Demonstration Program (19.75 wt.%)
- Global Nuclear Fuels (GNF-A)
  - License amendment granted for possession and processing of 8 wt.%
- Framatome
  - License amendment for Specialty Fuels Building (10 wt.%) currently under NRC review
  - License amendment for site-wide 6.5 wt.% currently under NRC review
- TRISO-X
  - New fuel facility license application currently under NRC review

Potential Validation Gaps for Future Licensing

Critical Benchmarks in ICSBEP

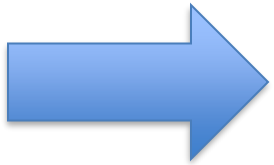
- International Criticality Safety Benchmark Evaluation Project (ICSBEP) contains over 5000 benchmarks
- Includes ~430 critical experiments with HALEU
- Only ~19 appear relevant for non-LWRs
  - 11 before 1980

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%

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.

Potential Nuclear Data Gaps for Future Licensing

Many Non-LWR fuel designs incorporate materials that are significantly different from materials in standard LWR fuel designs. Such materials may have sparse nuclear data available for use in nuclear codes.



Example: TSL data for advanced moderators

Material	Available TSL ENDF Files	Differential Measurement	Integral Measurements	Benchmark* Experiments.
Graphite	Yes	Yes	Yes	Yes
$ZrH_{1.6}$ & ZrH_2	Yes	Yes	Yes	Yes
YH_2	Yes	Yes	Yes	No
Be metal	Yes	Yes	Yes	No
BeO	Yes	No	Yes	No
MgO	No**	No	Yes	No
Be_2C	Yes	No	No	No
FLiBe	Yes	No	No	No
SiC	Yes	No	No	No
Zr_3Si_2	No	No	No	No

* These experiments involve fuel compositions ranging from 5 to 19.75 wt% enrichment with ^{235}U and exhibit a neutron flux of < 0.625 eV

** The MgO TSL sub-library has been submitted to the Cross Section Evaluation Working Group (CSEWG) for approval and inclusion in the ENDF database; at this writing, approval is pending.

Congressional mandate

(A) shall develop, in consultation with the Commission, **criticality benchmark data** to assist the Commission in—

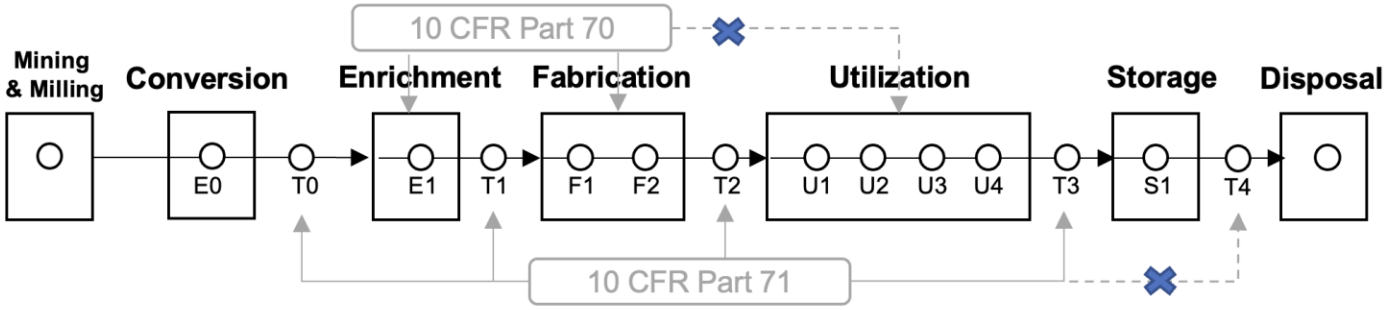
i. the licensing and regulation of special nuclear material fuel fabrication and enrichment facilities under **part 70** of title 10, Code of Federal Regulations; and

ii. certification of transportation packages under **part 71** of title 10, Code of Federal Regulations;

(C) Shall, to the extent practicable—

i. by January 1, 2024, support commercial entity submission of such transportation package designs to the Commission for certification by the Commission under part 71 of title 10, Code of Federal Regulations; and

ii. encourage the Commission to have such transportation package designs so certified by the Commission within 24 months after receipt of an application;



E0 – Conversion U3O8 to UF6
T0 – transportation of UF6 to enrichment facility
E1 – UF6 enrichment (<5w/o) and deconversion
T1 – transportation of UF6 to fuel fabrication facility
F1 – fabrication of UO2 fuel pellets
F2 – fabrication of LWR fuel assemblies
T2 – transportation of fresh fuel assemblies to the plant
U1 – fresh fuel staging and loading
U2 – power production
U3 – spent fuel pool/shuffle operations
U4 – on-site dry cask storage
T3 – transportation of spent fuel to off-site storage
S1 – off-site storage
T4 – transportation to disposition

DNCSH Mission

DOE/NRC collaboration for Criticality Safety support for commercial-scale HALEU fuel cycles and transportation (DNCSH)

DNCSH Charter: <ML25041A072>

Enable new data sources and methods such that the NRC, and applicants, can use to assess performance of HALEU-based systems in the fuel cycle stages: enrichment, fabrication, transport, staging, and storage

Primary customer:
US NRC

Authority
Energy Act of 2020 &
Inflation Reduction Act (IRA)

Timeline
Initiated in late FY23 / All commitments must be made by end of FY26 / work finalized in FY28

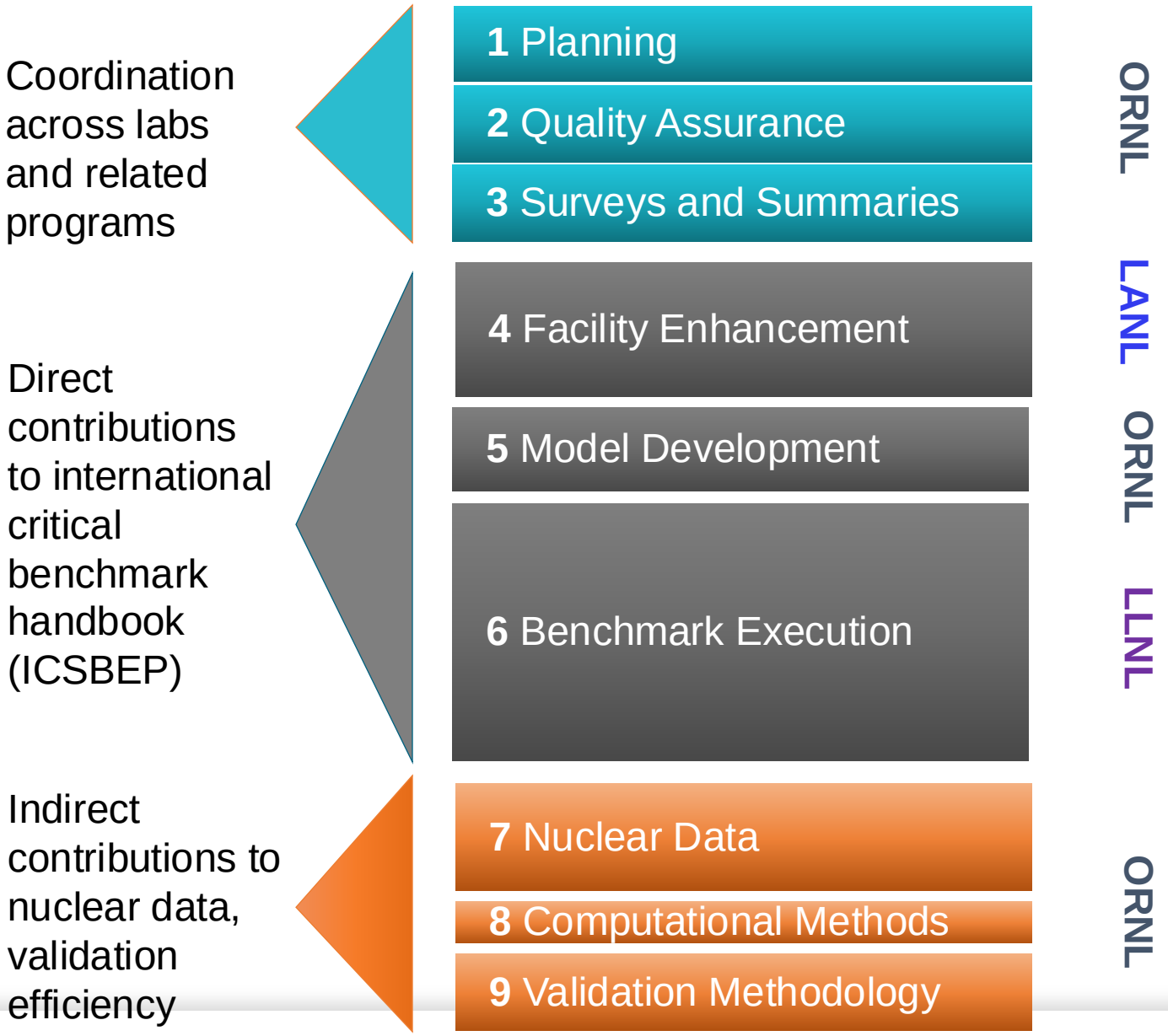
Project Areas

Activities distributed over 9 areas supporting development of criticality-related benchmarks with

Key program element
Benchmark Execution

Highlights:

- Call #1, completed in FY24, funded $17M in new benchmarks
- Call #2, pending focused on facility conditions.
- Additionally, intend to enhance the only two US facilities producing benchmarks
  - SPRF/CX SNL facility with 19.75% UO2 fuel rods
  - NCERC LANL facility with 19.75% TRISO-fueled compacts



FY23 Strategy

The main goals for FY23 (project ramp up), were to establish the project scope, framework, boundaries, and collect information on the current state of the art. This resulted in funding the following tasks by area:

- Area 1: Initial PMP
- Area 2: Building out collaborations
- Area 3: Survey of status and state of the art in HALEU-based fuel cycle models
- Area 4: Briefing on current benchmark capacity and near-term options
- Area 5: Prototype set-up for a model repository

- NOTE: It became apparent that to address the congressional mandate, it may be necessary to increase the throughput/capacity for critical benchmarks. During this FY, feasibility of current facilities are being assessed, as well as a new facility to provide additional bandwidth or prioritization of existing facilities for these efforts, with the backlog to be offset by a new facility. Another goal of this FY was to establish points of contact in various areas that can make suggestions for activities.

DOE OS/NP

DOE NCSP

FY24 Strategy

The main strategy elements for FY24 were as follows.

- Area 1: Assemble the core team, make subcontracts as needed to fill gaps in experience within the project, look for existing benchmarks which could have modifications/extensions for extra relevance for us, and continue to look for opportunities for cross-project collaboration.
- Area 2: Document the initial landscape for critical benchmarks, assess gaps, and present this data at the Call #1 for Experiment and Analysis Work packages (EAW).
- Area 3: Work with NCSP, SNL SPRF/CX, and LANL NCERC to develop a plan to increase capacity for benchmarks relevant to HALEU system gaps.
- Area 4: Continue to significantly expand the model repository with internal and external contributions.
- Area 5: Allocate funding for new benchmarks resulting from Call #1.
- Area 6: Initiate nuclear data measurements to improve thermal moderators' experimental basis and data improvements related to uncertainty in thermal scattering law.
- Area 7: Initiate code improvement activities related to uncertainty and sensitivity data processing, calculation, and benchmark model improvement.
- Area 8: Initiate research on alternative benchmark prioritization approaches.

Call 1:

- Public workshop held on 02/29/24.
  - Reference Info: ML24066A083 / ML24106A195 / ML24107A030.
- Call 1 received 30 proposals totaling $28M across 5 topic areas.
- 16 Proposals funded for ~$17M.

Area 1	Area 2	Area 3	Area 4	Area 5
UF6 Transportation with Moderator Exclusion	10-20% Enrichment Gap	Non-Fissile Material Validation	Fissile Salts	Graphite and Advanced Moderator Nuclear Data

FY25 Strategy

Expand key members in the project to include Principle Investigators (PIs), ownership of areas, and a significant amount of in-progress work. The main strategy elements for FY25 are as follows.

- Begin execution of the Work Packages (WPs) from Call #1. By end of FY25, many of the PIs will be approximately half-way to a published benchmark. Calls #2 and #3 will be planned with refined topic areas with a facilities/fabrication focus for Call #2 and a microreactor focus for Call #3.
- Calls #2 and #3 will both utilize application models from the public model repository, https://code.ornl.gov/dncsh/applications. The models will include transportation packages, facilities, and front-end for a diverse set of reactor systems utilizing HALEU.
    - All models will have pedigree* and available in a public repository.
    - The validation basis for application models will have been assessed.
    - Application models will be used as one input to identify scenarios having a validation basis that can be improved.
    - A public report will describe these scenarios and all interested parties (industry, NRC, etc.) will have a chance to review before the Calls #2 and #3 workshops.
    - The workshops will collect feedback which will be used to create the laboratory led calls for proposals.
- Fuel procurement activities for SPRF/CX and NCERC will be pursued, and dependent on cost/schedule, arrive in early FY26 at facilities for experiments.
- The horizontal split table (HST) critical facility will be pursued at INL, with an initial scoping study leading to a go/no-go starting in Q3 FY25.

*Models will be of sufficient QA to support this work. Users of these models must QA according to their own needs and QA environment.

FY26 - 28 Strategy

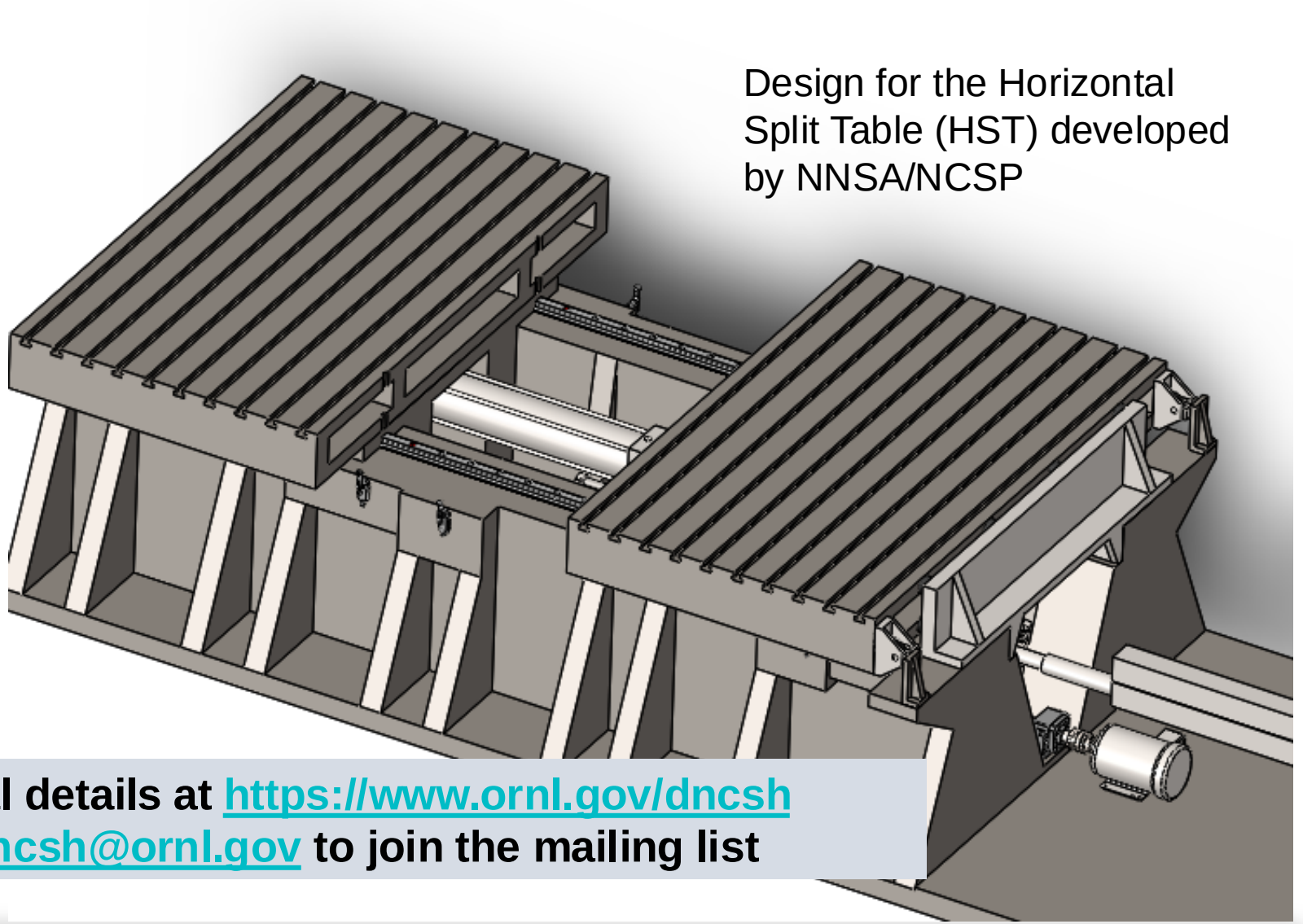
In FY26, the project will continue to focus primarily on benchmark execution and evaluation, with a ramp-down of any non-benchmark activities.

- Remaining funds will be committed.
- Benchmarks should start to become available in the ICSBEP* handbook later in the FY.
- The final set of WPs based on Calls #2 and #3 will be established as PICS:NE** work packages. These benchmarks will proceed through FY27.
- Depending on new fuel procurement success, new experiments may be under design with this new fuel.
- Depending on the HST moving forward, new experiments may be under design with the HST.
- In FY27/28, remaining benchmark execution and evaluation activities for which funding was obligated in FY26 will move toward completion. No new activities will be funded.

* International Criticality Safety Benchmark Evaluation Project
** Program Information Collection System: Nuclear Energy

Summary

- 16 new benchmark activities started.
- Working to procure fuel for NCERC and SPRF/CX.
- Developing gap analyses for call #2 targeting micro reactor transport and facility operations
- Developing gap analyses for call #3 targeting back end/spent fuel
- Developing a strategy document for a horizontal split table (HST) at INL to give the US a 3rd complimentary facility for benchmarks



Design for the Horizontal Split Table (HST) developed by NNSA/NCSP

Additional details at https://www.ornl.gov/dncsh
Email dncsh@ornl.gov to join the mailing list