Challenges in the Deployment of HALEU and Novel Moderators for Advanced Reactors Closeout
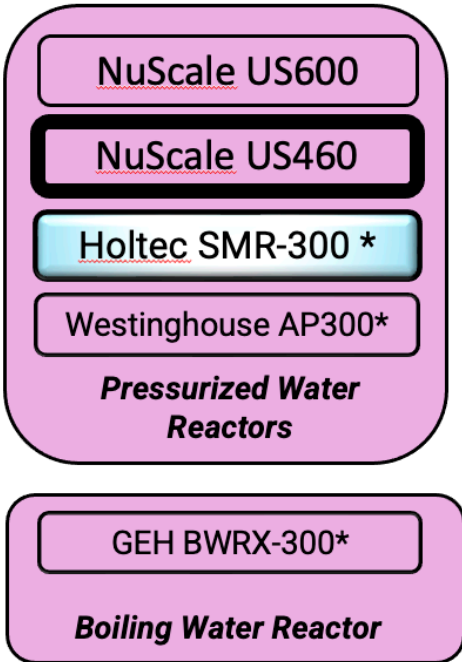
WANDA 2025

Theresa Cutler, Javier Ortensi
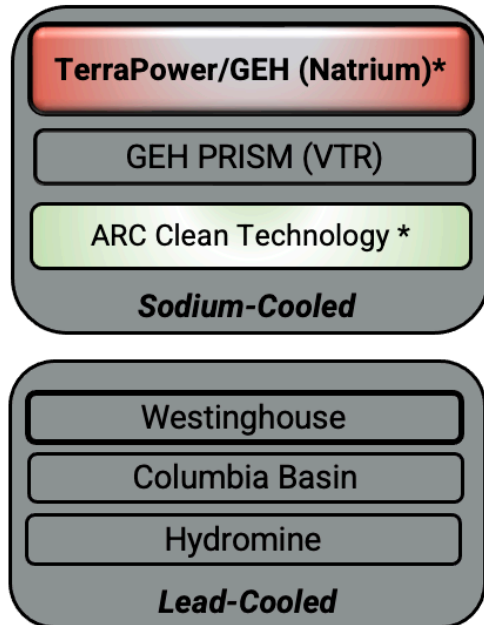
LA-UR-25-21499
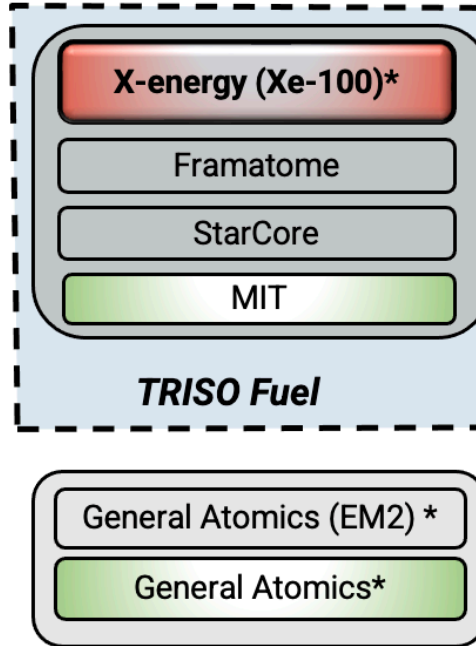
Advanced Reactor Landscape

U.S. NRC Slides from 4/3/24 ACRS meeting
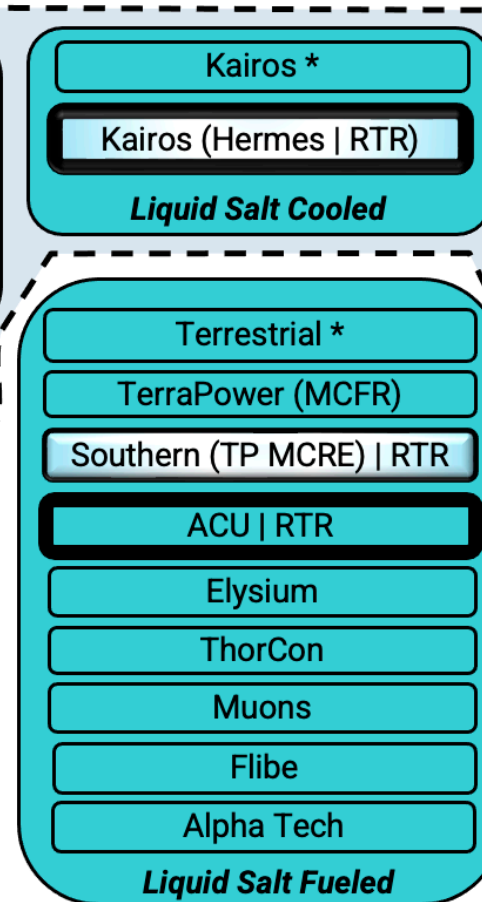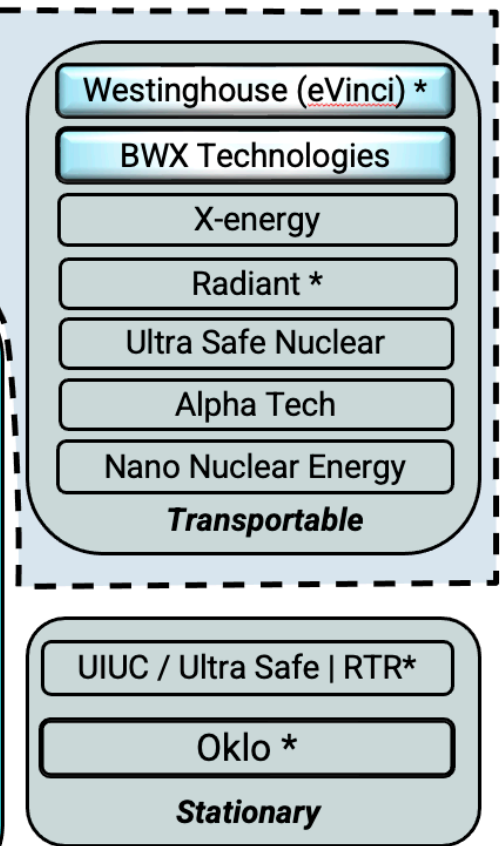
Sessions

- **Customer Perspective**
- **Fuel Procurement and Experiment Needs**
- **Thermal Scattering Law Updates**
- **Safeguards**

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Customers

- NRC

- Kairos

- Westinghouse

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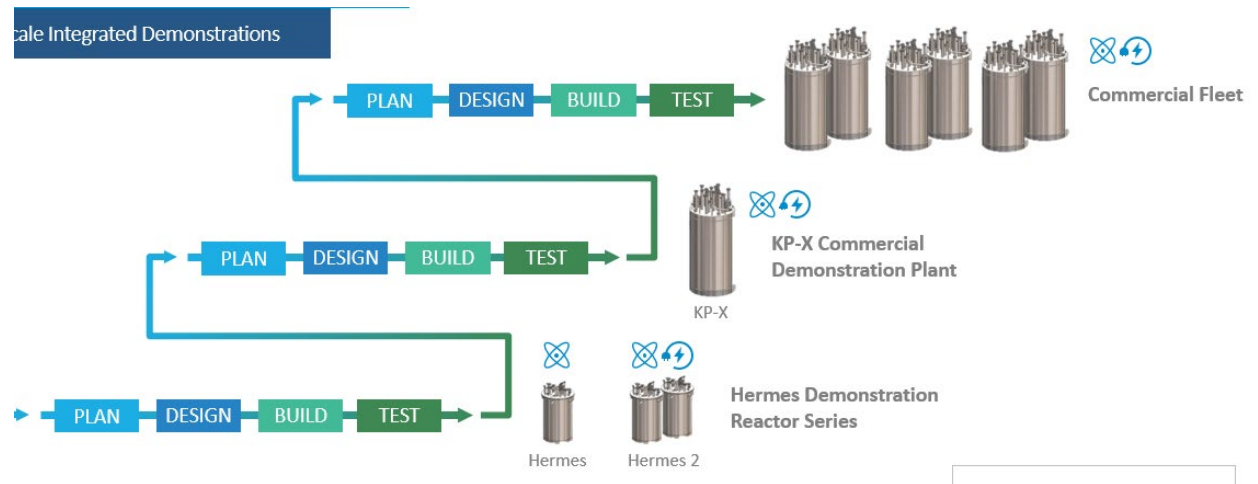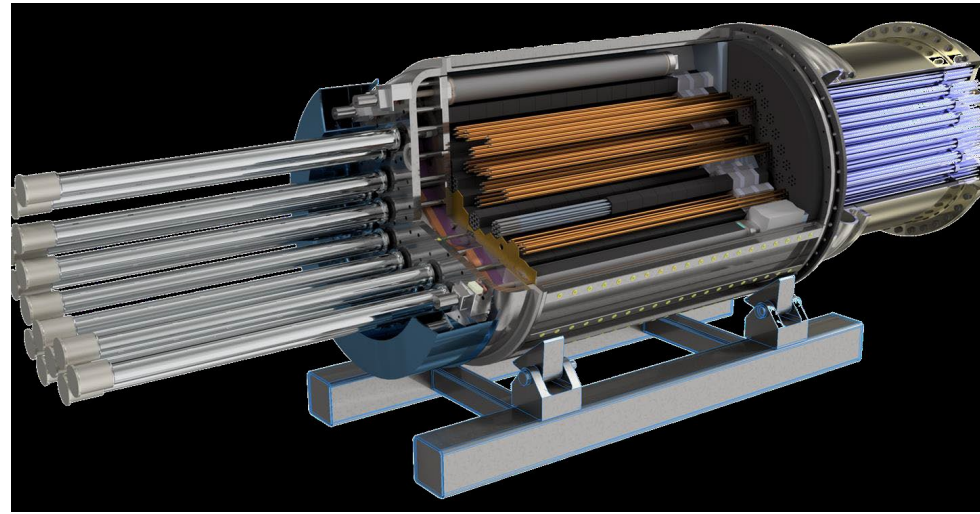
Fuel Procurement and Experiment Needs

- **Two Primary Facilities**
  - NCERC and SCRF/CX
- **Deimos Testbed**
- **New HALEU Fuel for both facilities**

SPR Facility

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Thermal Scattering Law Updates

- ## Status of Current TSLs in ENDF

- ## TSLs needed for Advanced Reactors

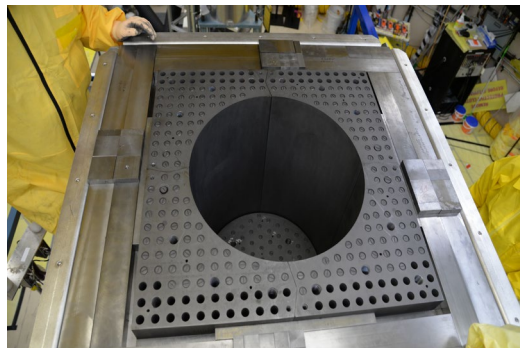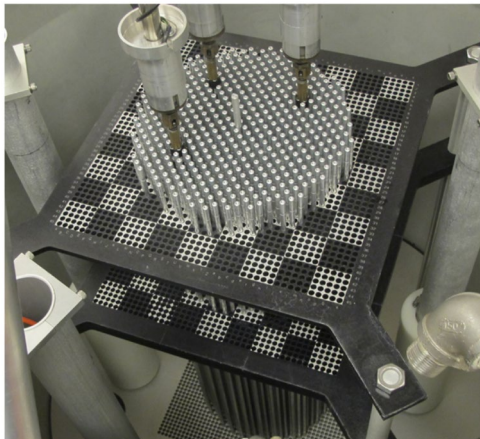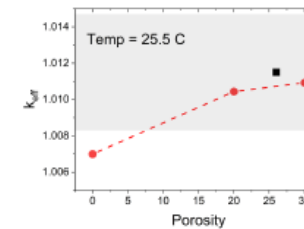| Material	Available TSL ENDF Files	Differential XS Meas.	Integral XS Meas.	Benchmark* Experiments
Graphite	Yes	Yes	Yes	Yes
$ZrH_{1.6}$ & ZrH_2	Yes	Yes	Yes	Yes
YH_2	Yes	Yes	Yes	No
Be metal	Yes	Yes	Yes	No
BeO	Yes	No	Yes	No
MgO	Yes	Yes	Yes	No
Be_2C	Yes	No	No	No
FLiBe	Yes	No	No	No
SiC	Yes	Yes	Yes	No
Zr_3Si_2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

Reactor Graphite Validation

Temp = 25.5 C

Density = 1.67 g/cm³
Porosity ≈ 30%

VHTRC-GCR-EXP-001

$$Porosity(\%) = \left(1 - \frac{\rho_{component}}{\rho_{ideal}}\right) \times 100\%$$
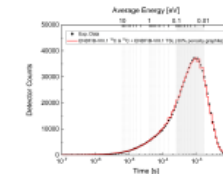
Cross Sections	Mean Absolute Deviation (%)
ENDF/B-VIII.0 + Cry	4.14%
ENDF/B-VIII.1 + Cry	4.09%
ENDF/B-VIII.1+S_α	5.01%
ENDF/B-VIII.1+30%	1.68%

Density = 1.66 g/cm³
Porosity ≈ 30%

FUND-ORELA-ACC-GRAPH-PNSDT-001
(Nuclear Graphite)
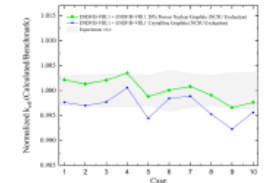
Case	Crystalline	20% Nuclear
1	235	204
2	303	137
3	230	188
4	57	322
5	707	146
6	258	12
7	83	91
8	344	95
9	782	385
10	529	247

C-E (pcm)

Density = 1.7 g/cm³
Porosity ≈ 20-30%

PROTEUS-GCR-EXP-001 to -004
(Nuclear Graphite)

Safeguards

Fresh fuel receipt/storage — Reactor containment — Spent fuel pool
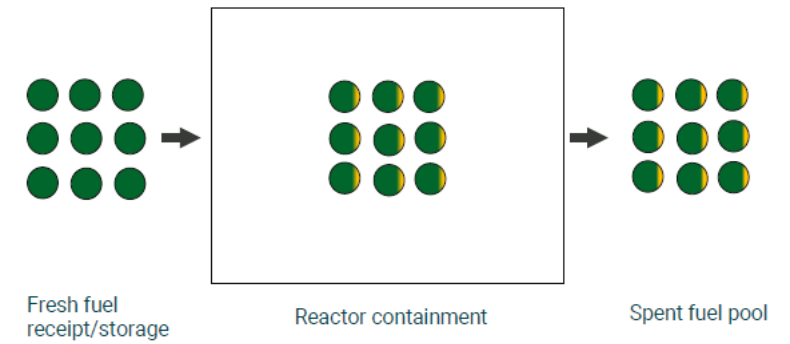
- **Data Needs for NMC&A for HALEU Fuel Cycle**

- **Multi-physics code predictions for HALEU Fuel Cycle**

HEU limit

Current Capability 3.2% RSD (ITV)

0.5% RSD

19.75% enrichment
Error bars plotted at 95% CI
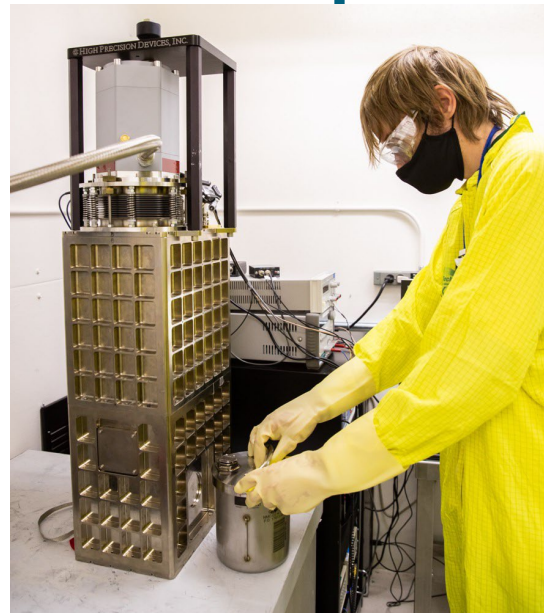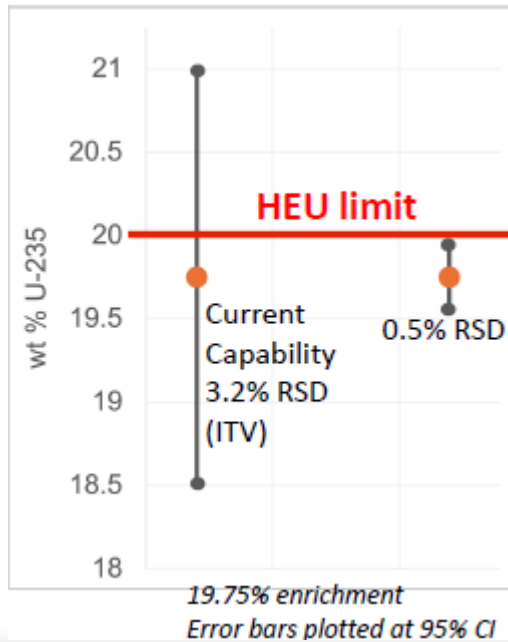
Material	Domestic Safeguards[1]	International Safeguards[2]
Total U	whole g (for enriched U) whole kg (for depleted U) ^{235}U isotope wt%	g (for U enriched in ^{235}U or ^{233}U) kg (for natural U, depleted U)
^{235}U	whole g	g
^{233}U	whole g	g
^{233}U + ^{235}U	-	g
Total Pu	whole g ^{240}Pu isotope wt%	g
^{238}Pu	g to tenth	g
^{239}Pu	-	g
^{240}Pu	-	g
^{241}Pu	-	g
^{242}Pu	whole g	g
^{239}Pu + ^{241}Pu	whole g	g
Thorium	whole kg	kg

Connections to Other Tracks

- **Deterrence: ^{235}U(n,n') differential measurements**
- **NMC&A: (α,n) benchmarks**
- **Fusion: (n,α) reactions**
- **Data Preservation: benchmarks**
- **Data Preservation: compiled data**

Key Takeaways

- **DNCSH collaboration highlights the need by industry and support from NRC to license new designs**

- **Industry is moving forward with test facilities, using <u>large margins</u> to account for ND uncertainties**

- **Immediate need to update ND libraries and data calibration for design optimization/safety analysis**
  - competitive power designs
  - safe designs that can build confidence in these technologies

- **Many TSLs have been added (might need improvements)**

- **Safeguards needs**
  - benchmarks to reduce uncertainty in fundamental physics/ detector response
  - new safeguards methods are needed which have yet-to-be-defined ND needs

Specific Needs (High Priority)

- **Differential measurements**
  - $^9Be(n,\alpha)$ cross section
  - $^{19}F(n,n')$ cross section
  - $^7Li(n,\gamma)$ cross sections

- **Integral measurements and TSL validation**
  - FLiBe
  - YH_x
  - Large graphite moderators
  - HALEU TRISO with varied packing fractions
  - Reactivity coefficients
  - Elevated temperatures

Specific Needs

- **NDA/NMC&A Benchmarks for Detector Response (High Priority)**
  - Fundamental physics in ICSBEP
  - Full uncertainty quantification to reduce measurement uncertainty
  - Measurements application to all parts of the fuel cycle

- **Intentional R&D to quantify NMC&A inventory for each class of reactor (U/Pu, Th, salt-based, thermal/ fast spectrum) (Low Priority)**

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General Needs (High Priority)

- **Immediate needs to update ND libraries and data calibration for design optimization/safety analysis**

- **Larger integral experiment designs to better match vendor needs**
    - Built-in flexibility (horizontal split table)
    - Using **<u>prototypic fuel forms</u>** planned for current vendor designs
    - Emphasis on modeling/ simulation to validate the experiments
    - HALEU TRISO benchmarks at varied packing fractions (realistic)
    - HALEU 10-20 wt% ^{235}U standard fuel benchmarks
    - HALEU benchmarks with a variety of moderators

General Needs (Lower Priority)

- **TSLs for novel moderators**

- **TSL covariance data**

- **Differential measurements at extreme temperatures (cryogenic and high ranges)**

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