# Integrated Fuel Cycle Solutions Update

July 2022

Michael Anthony Norato, Michele H Oliveira

Changing the World's Energy Future

**Idaho National Laboratory**

# Integrated Fuel Cycle Solutions Update

Michael Anthony Norato, Michele H Oliveira

July 2022

**Idaho National Laboratory**
**Idaho Falls, Idaho 83415**

**http://www.inl.gov**

# Integrated Fuel Cycle Solutions Update

Battelle Energy Alliance, Board of Managers, Science and Technology Committee Meeting
Idaho Falls, ID

Idaho National Laboratory

# Innovation for the clean energy future
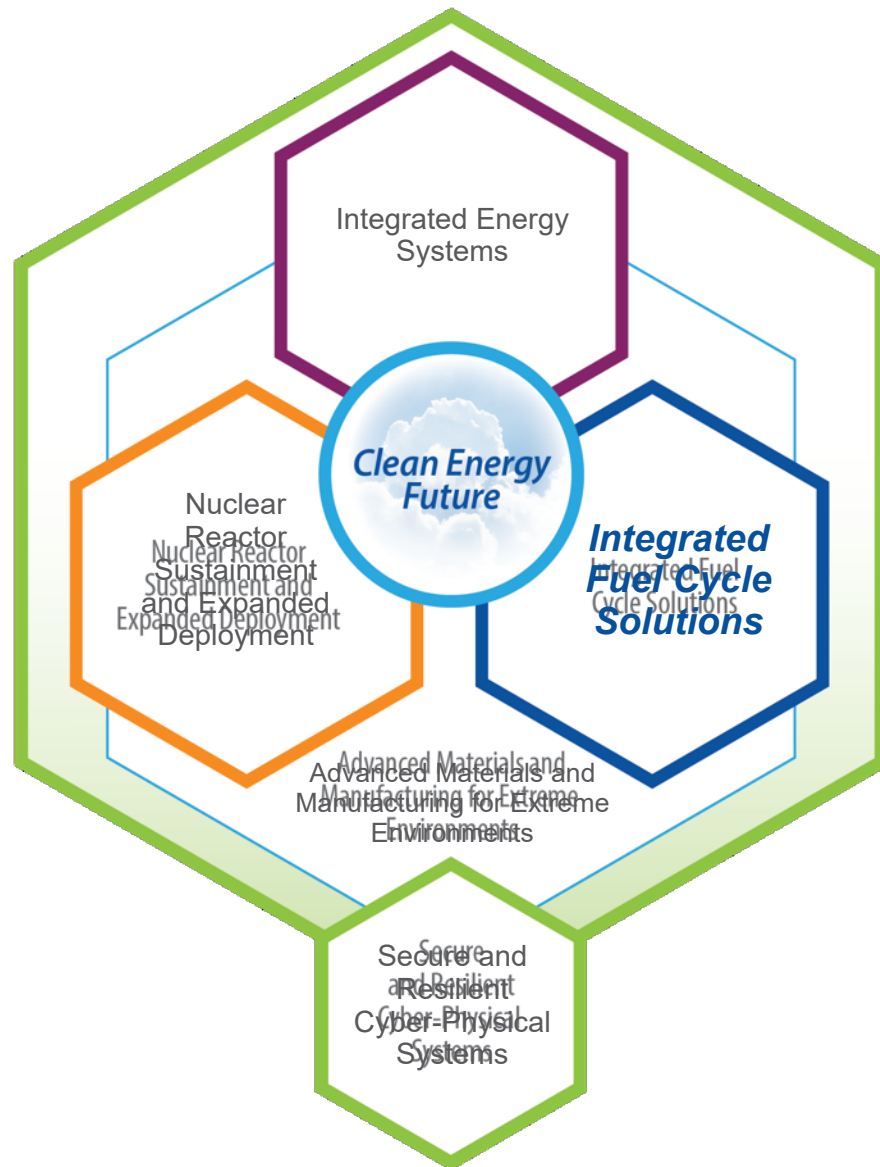


INL strategic S&T initiatives support transforming the world's energy future and securing our critical infrastructure

# Integrated Fuel Cycle Solutions

*Supports the safe, secure, and economic management of nuclear materials from inception to final disposition*

- Ensuring availability of special nuclear materials and strategic isotopes

- Reducing proliferation risk

- Managing radiological waste materials and used nuclear fuels

- Developing RD&D test beds

# Availability of SNM
*Increased urgency as imports from Russia are no longer viable*

**INL advances investment risk reduction strategies by:**

- Identifying high-fidelity markets
- Determining initial enrichment capability for a private-public partnership
- Recognizing the need for co-location of enrichment and de-conversion
- Addressing the need for a working inventory to support projected market peaks/valleys

**INL provides HALEU from recovered stocks for near-term needs**

- Initiated higher processing rate of EBR-II driver fuel, 600 kg per year transitioning to 1MT annually
- Increase polishing capability ($UO_2$) to support TRISO testing and other advanced reactor deployments.
- Determine synergistic processing alternatives with SRS
- Evaluate other feedstock options, ATR and materials in the vault
- Identify alternative uses for recovered HALEU as required by the Idaho Settlement Agreement (ISA) by 2035

*INL works with DOE and Industry to ensure the availably of HALEU.*



Low dose rate, small size HALEU metal regulus
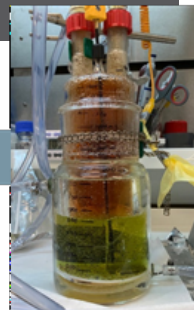
U metal dissolution

U purification

Uranyl Peroxide

Uranium Oxide

Uranium Trioxide

IDAHO NATIONAL LABORATORY

# Deploying nuclear energy systems with confidence
## *Reducing proliferation risk through the implementation of safeguards by design*



**Existing infrastructures and workforce expertise are not adequate.**

**Capabilities for the nuclear fuel cycle must evolve to add keep pace with emerging technologies**

- Higher Enrichments
- Bulk Reactors
- Fuel Type and Form
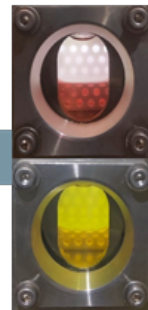- Fuel Reprocessing
- Nonaqueous Coolants
- Size, Modularity and Transportability
- Neutron Spectra
- Longer Cycles

**Through NNSA Nonproliferation Stewardship Program, INL is developing:**

- Expertise in chemistry, physics and engineering key to
  - Establishing and identifying new signatures and observables
  - Developing and demonstrating new instrumentation and safeguards tools and methodologies
  - Understanding technology misuse

- New tools to advance safeguard approaches, physical security, and proliferation detection methods
  - Digital twins to autonomously increase proliferation detection
  - Modern cohesive tools that merge integrated and connected data, sensors and instrumentation, artificial intelligence, and online monitoring

IDAHO NATIONAL LABORATORY

# Waste management solutions
*Addressing the past, enabling the future*



***Addressing newly generated waste streams enables INL's long-tern R&D mission.***

## Management of SNF and radiological waste materials

- Modeling and simulation tools to support advanced reactor spent fuel disposition

- Supports proliferation risk reduction of attractive SNF and radiological wastes

- Predictive capabilities to support future repository programs

- S&T breakthroughs needed to eliminate/decrease radioactive liquid waste from R&D programs

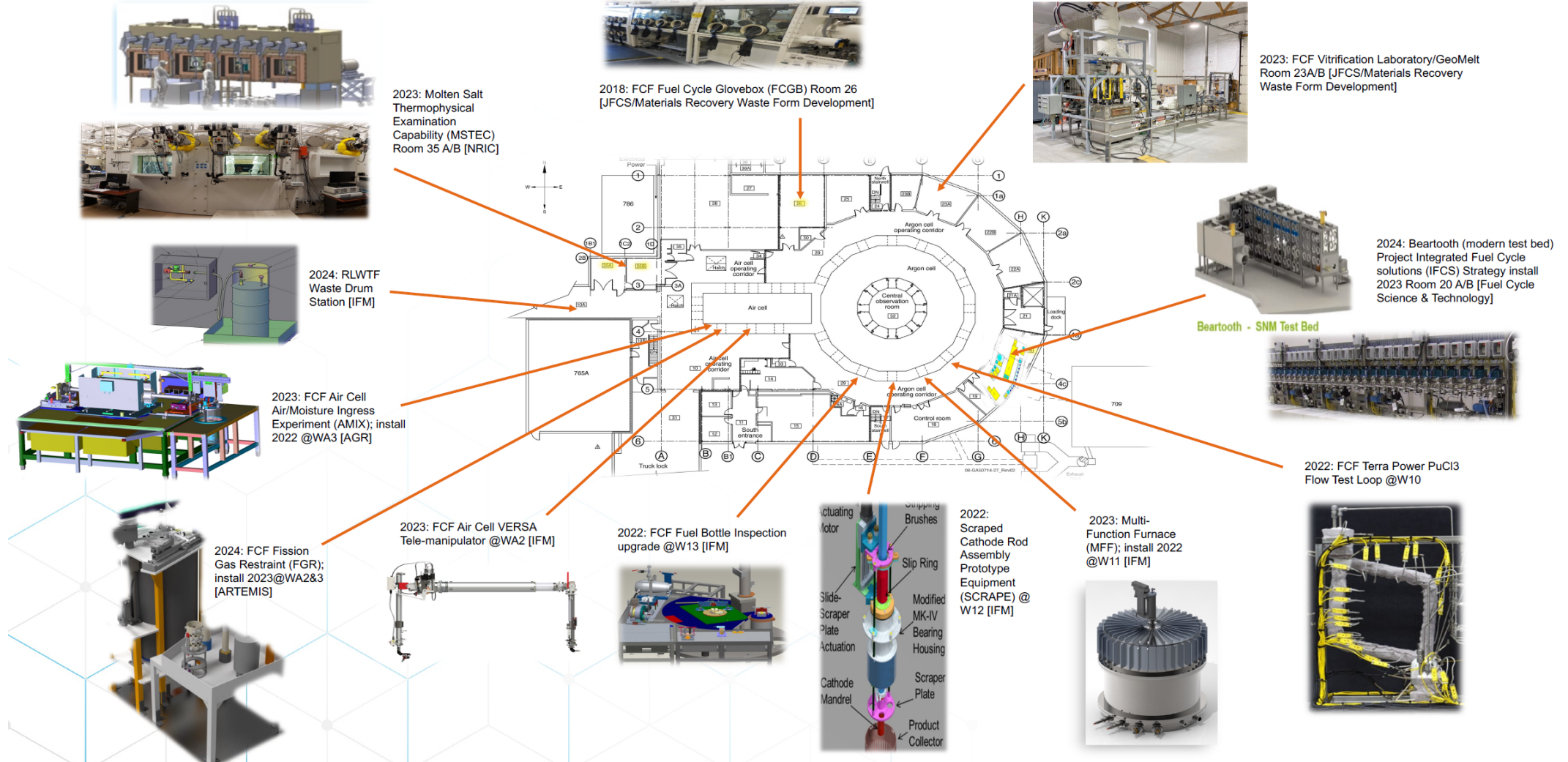- Economic management and disposition of legacy SNF and radiological waste

## Reducing INL's environmental liabilities

- RD&D of technologies required to support preparations for off site disposition and/or safe storage

- Strategic onsite core treatment capabilities

- Leveraging commercial offsite capabilities

IDAHO NATIONAL LABORATORY

# New and upcoming fuel cycle test bed capabilities at MFC-FCF
## *Strategic investments support development of new expertise and capabilities*



2023: Molten Salt Thermophysical Examination Capability (MSTEC) Room 35 A/B [NRIC]

2018: FCF Fuel Cycle Glovebox (FCGB) Room 26 [JFCS/Materials Recovery Waste Form Development]

2023: FCF Vitrification Laboratory/GeoMelt Room 23A/B [JFCS/Materials Recovery Waste Form Development]

2024: RLWTF Waste Drum Station [IFM]

2024: Beartooth (modern test bed) Project Integrated Fuel Cycle solutions (IFCS) Strategy install 2023 Room 20 A/B [Fuel Cycle Science & Technology]

Beartooth - SNM Test Bed

2023: FCF Air Cell Air/Moisture Ingress Experiment (AMIX); install 2022 @WA3 [AGR]

2024: FCF Fission Gas Restraint (FGR); install 2023@WA2&3 [ARTEMIS]

2023: FCF Air Cell VERSA Tele-manipulator @WA2 [IFM]

2022: FCF Fuel Bottle Inspection upgrade @W13 [IFM]

2022: Scraped Cathode Rod Assembly Prototype Equipment (SCRAPE) @ W12 [IFM]

2023: Multi-Function Furnace (MFF); install 2022 @W11 [IFM]

2022: FCF Terra Power PuCl3 Flow Test Loop @W10

# Upcoming test beds available at MFC starting 2023
*Modern facilities to engage and train the next generation of fuel cycle experts*

**All new fuel cycle test beds are designed with the ability to demonstrate innovative safeguards and security concepts applicable to advanced reactors and their fuel cycles in support of national security objectives.**
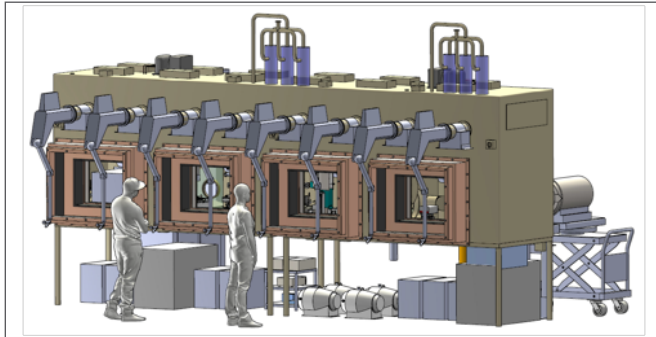


**Molten Salt Thermophysical Examination Capability (MSTEC)**
Platform to design, demonstrate, license, and operate MSRs
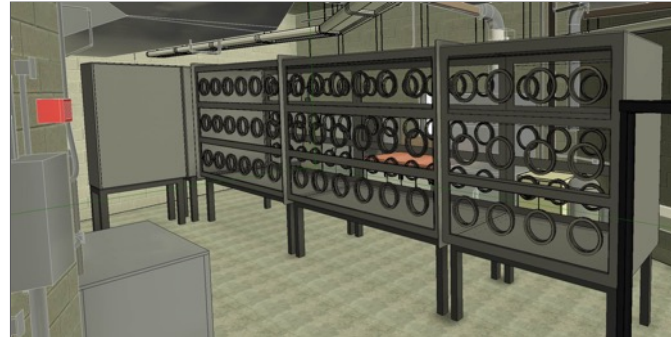


**Beartooth - SNM Test Bed**
Aqueous processing platform for demonstrating new safeguards and security concepts applicable to advanced fuel cycle operations
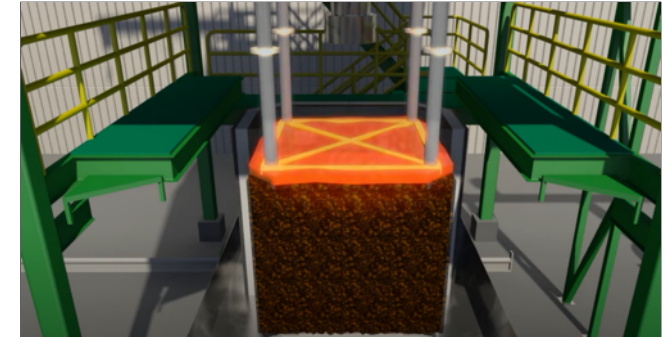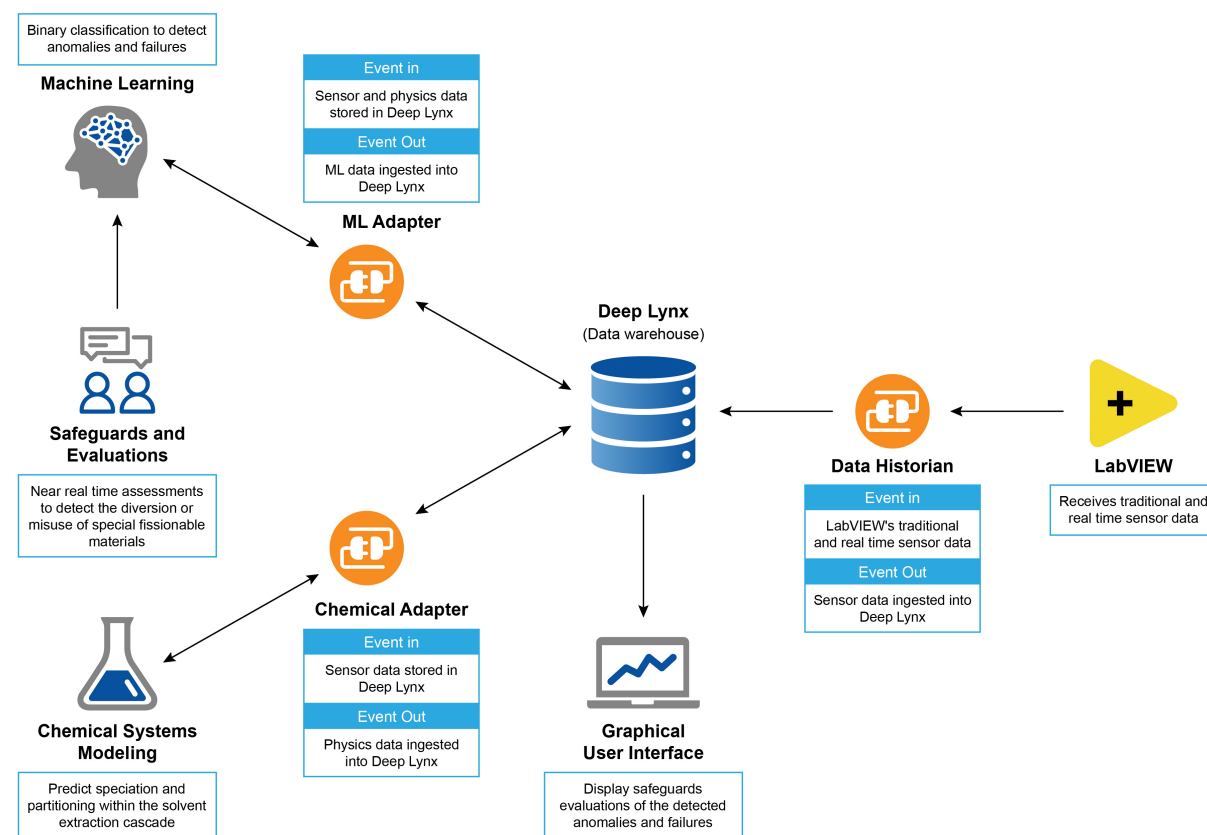


**Sustainability – WM Test Bed**
Platform to develop better more stable waste forms for final disposition in support of advanced reactor development and to address DOE legacy waste issues.

# Reinvigorating material accountancy
*Material tracking – bulk facilities*

- **Utilizing process specific intrinsic signals**
  - Instrumentation/advanced sensors
- **New methodology that reduces accountancy errors**
  - Application of data science, AI/ML, digital twins
- **Integration of process data to develop knowledge of facility status in near real time**
  - Monitoring data, security data, and other information, including cyber



**Machine Learning**
Binary classification to detect anomalies and failures

**ML Adapter**
| Event in |
| --- |
| Sensor and physics data stored in Deep Lynx |
| Event Out |
| ML data ingested into Deep Lynx |

**Safeguards and Evaluations**
Near real time assessments to detect the diversion or misuse of special fissionable materials

**Chemical Systems Modeling**
Predict speciation and partitioning within the solvent extraction cascade

**Chemical Adapter**
| Event in |
| --- |
| Sensor data stored in Deep Lynx |
| Event Out |
| Physics data ingested into Deep Lynx |

**Deep Lynx** (Data warehouse)

**Graphical User Interface**
Display safeguards evaluations of the detected anomalies and failures

**Data Historian**
| Event in |
| --- |
| LabVIEW's traditional and real time sensor data |
| Event Out |
| Sensor data ingested into Deep Lynx |

**LabVIEW**
Receives traditional and real time sensor data

# Investments
*Support development of new expertise and capabilities*

## LDRD INVESTMENTS

- **Proliferation risk reduction -** The use of AI, and ML and deep learning (DL), to detect and characterize chemical process operations

- **Management of spent fuel -** Modeling and simulation tools to support advanced reactor spent fuel disposition and predictive capabilities for future repository programs
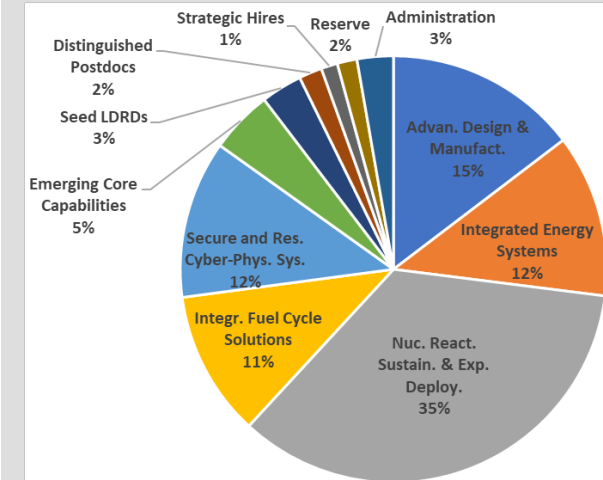
## IPL INVESTMENTS

- **Beartooth Test Bed –** Aqueous reprocessing platform for demonstrating new safeguards and security concepts applicable to advanced fuel cycle operations

- **Sustainability Test Bed -** Waste management capabilities to address legacy and newly generated advanced reactor waste
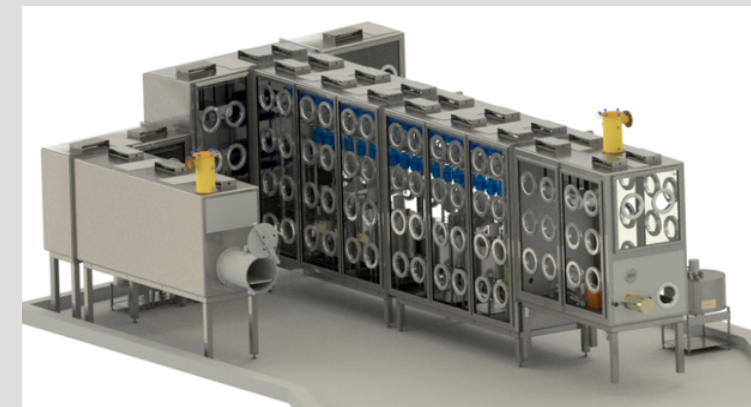
*Critical Skills:* Non-proliferation: Control system cyber security, instrumentation, digital twin and AI/ML

*Emerging Core Capabilities:* Chemical and Molecular Science: Multi-component/phase systems to address HLW/SNM processing, supporting advanced liquid reactors and HLW/SNF repository behavior

## Supporting INL's S&T Strategy



Pie chart segments:
- Strategic Hires 1%
- Reserve 2%
- Administration 3%
- Distinguished Postdocs 2%
- Seed LDRDs 3%
- Emerging Core Capabilities 5%
- Advan. Design & Manufact. 15%
- Integrated Energy Systems 12%
- Secure and Res. Cyber-Phys. Sys. 12%
- Integr. Fuel Cycle Solutions 11%
- Nuc. React. Sustain. & Exp. Deploy. 35%

*LDRD FY22 budget $40M*



*IPL investment $15M over 3 years*

IDAHO NATIONAL LABORATORY

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

WWW.INL.GOV