ADVANCED REACTOR SAFEGUARDS & SECURITY

Nuclear Material Control and Holdup Considerations in Circulating Liquid-Fueled MSRs

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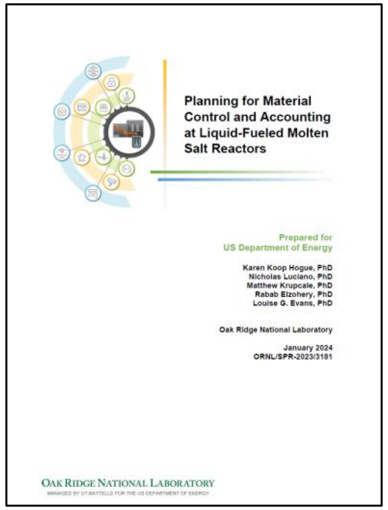
Background

- The NRC will require submission and review of an MC&A plan or detailed program description for liquid-fueled MSRs
- No specific NRC guidance or MC&A plan template currently exists for liquid-fueled MSRs
- *Planning for Material Control and Accounting at Liquid-Fueled Molten Salt Reactors* (Jan 2024) provides recommendations to liquid-fueled MSR developers to develop an MC&A plan


Planning for Material Control and Accounting at Liquid-Fueled Molten Salt Reactors

Prepared for
US Department of Energy

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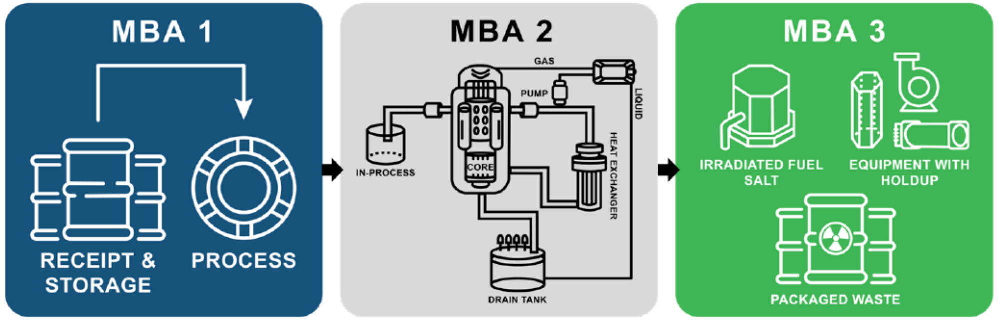


Periodic inventories performed, IDs and SEIDs calculated (follows Part 74 requirements)

Monitoring performed in specific locations to detect diversion

Periodic inventories performed, IDs and SEIDs calculated (follows Part 74 requirements)

NRC Engagement on MC&A

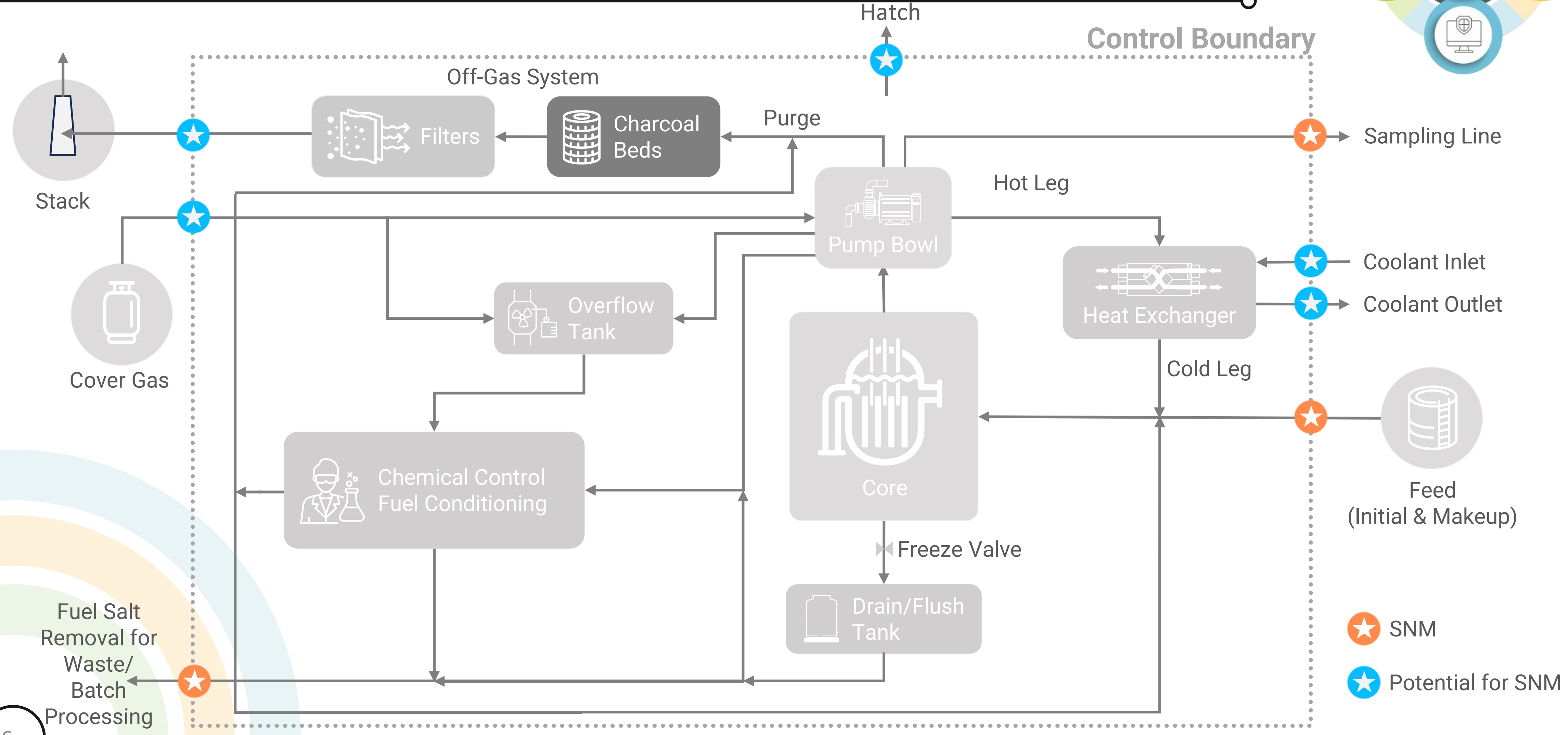
- Recurring engagement with the NRC MC&A group
- Topics discussed include:
  - Risk-informed, performance-based MC&A approach
  - Diversion path analysis to identify MC&A elements and justify requested exemptions from 10 CFR Part 74
  - Considerations for reporting inventories into the Nuclear Material Management and Safeguards System (NMMSS)

Technical Focus Area:
Material Control in Reactor Confinement

Material Control in Reactor Confinement

- MC&A plans approved by the NRC have typically relied heavily on accounting of SNM
- MC&A of SNM in reactors could rely on control
  - Consistent with MC&A in NRC-licensed LWRs
- Tamper-safing (e.g., seals or other tamper indicating devices) would likely be needed to detect access into confinement
- Surveillance (e.g., cameras) would likely be needed to monitor that planned access was consistent with anticipated operations
- Extended surveillance or monitoring elements (e.g., flow measurement) may be needed to monitor for theft of SNM from identified pathways

Material Control: Locations of Interest



Technical Focus Area:
SNM Holdup

Holdup

- U.S. NRC defines residual holdup as the inventory component remaining in and about process equipment and handling areas after those collection areas have been prepared for inventory[1][2].
- Holdup is difficult to quantify and a challenge to MC&A
  - ➢ A small fraction of facility throughput (0.1 to 0.2% after destructive cleaning)
  - ➢ The initial holdup in a new facility can be from 1 to 10%
- U.S. NRC has proposed design considerations to minimize holdup [4,5,6]

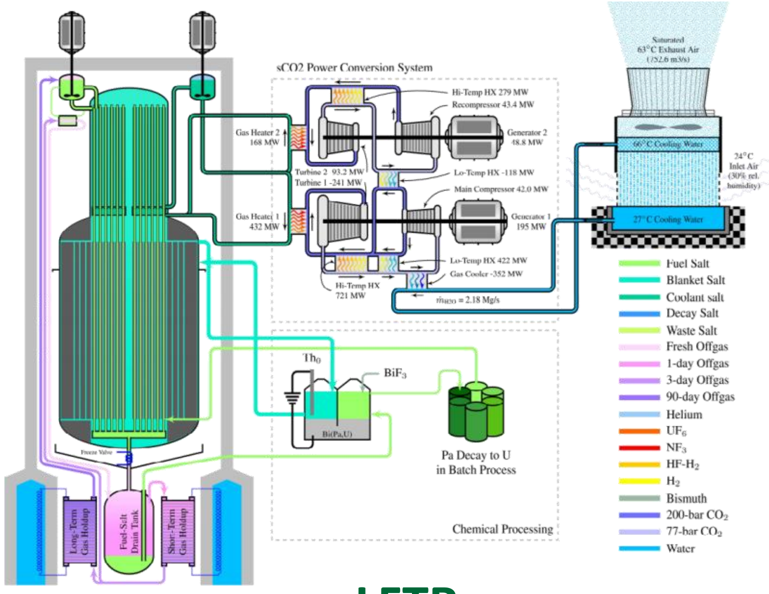
Typical magnitudes of holdup in facility equipment [3]	
Glovebox prefilters	2 to 100 g
Final filters	10 to 100 g
Equipment interiors (after routine cleaning)	10 to 50 g/m^2
Pipes (after destructive cleaning)	0.3 g/m
Ducts (no cleaning)	1 to 100 g/m
Annular tanks	1 to 10 g
Furnaces	50 to 500 g

Circulating Liquid-Fueled MSRs

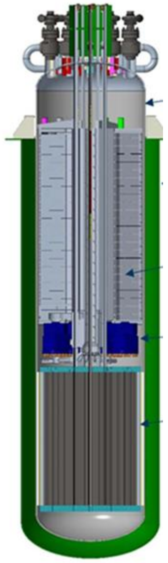
- Fuel salt is circulating in and out of the core as well as flowing through a heat exchanger
- Holdup can be significant with the amount of nuclear material circulating in the primary system
    - ➢ Can affect safety, security, and safeguards
    - ➢ Can amount to many kilograms of nuclear material in a circulating liquid-fueled MSR
    - ➢ Theft of nuclear material may go undetected due to the unquantified holdup
    - ➢ Quantifying holdup is difficult due to inaccessibility to areas and lack of knowledge about the deposition profile
- Numerous designs of this type are under development, warranting assessment

Categorizing Circulating Liquid-Fueled MSRs for Holdup

- **<u>Group 1:</u>** Makeup fuel salt with online fuel conditioning or processing: e.g., Molten Chloride Fast Reactor (TerraPower, USA), Lithium Fluoride Thorium Reactor (FLiBe Energy, USA)
- **<u>Group 2:</u>** Makeup fuel salt (potentially in batches) but without online conditioning or processing: e.g., IMSR (Terrestrial Energy – USA and Canada)
- **<u>Group 3:</u>** No makeup fuel salt or online refueling: e.g., Compact Molten Salt Reactor-CMSR (Seaborg Technologies, Denmark)



LFTR

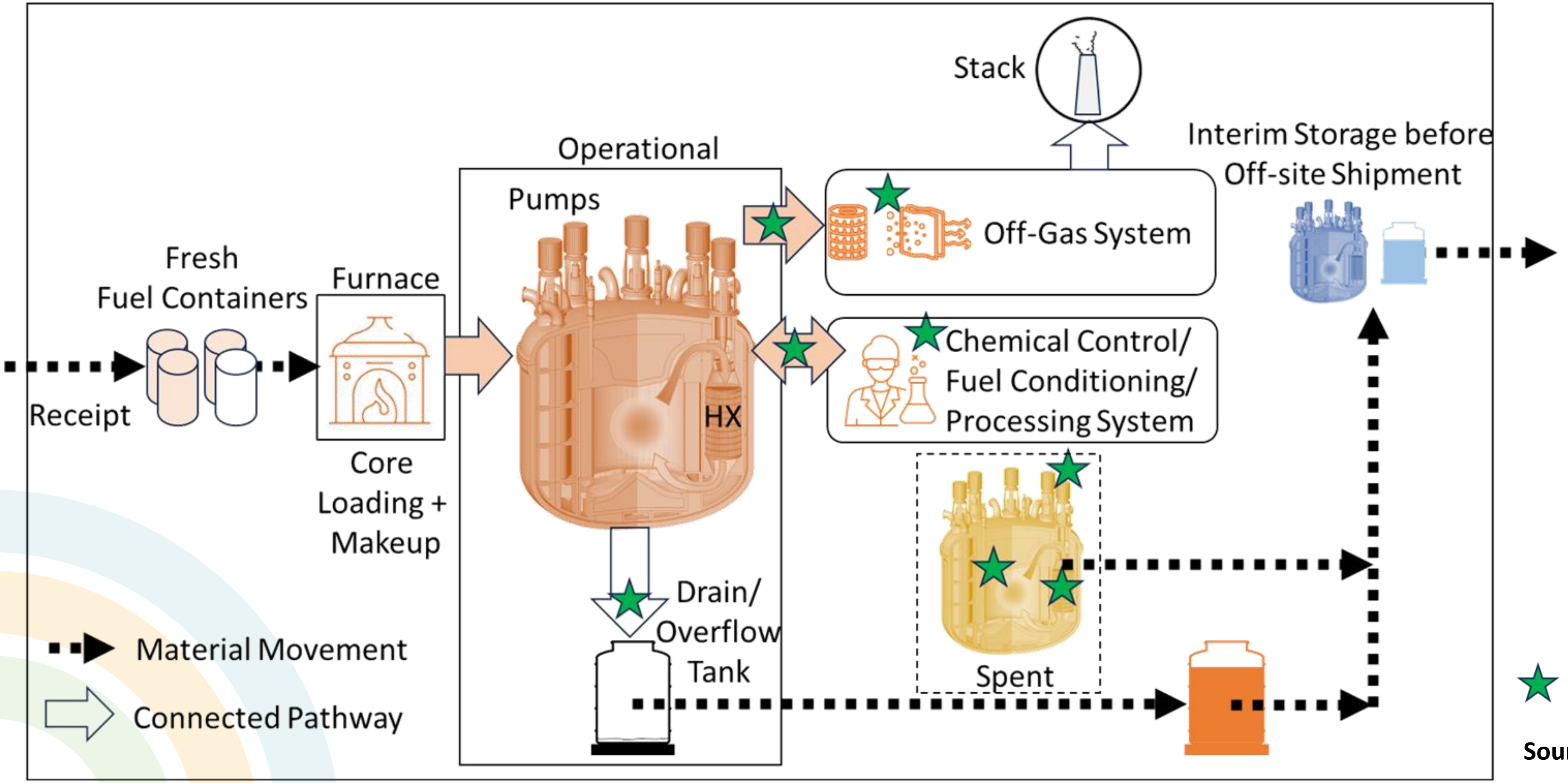


IMSR-400

CMSR

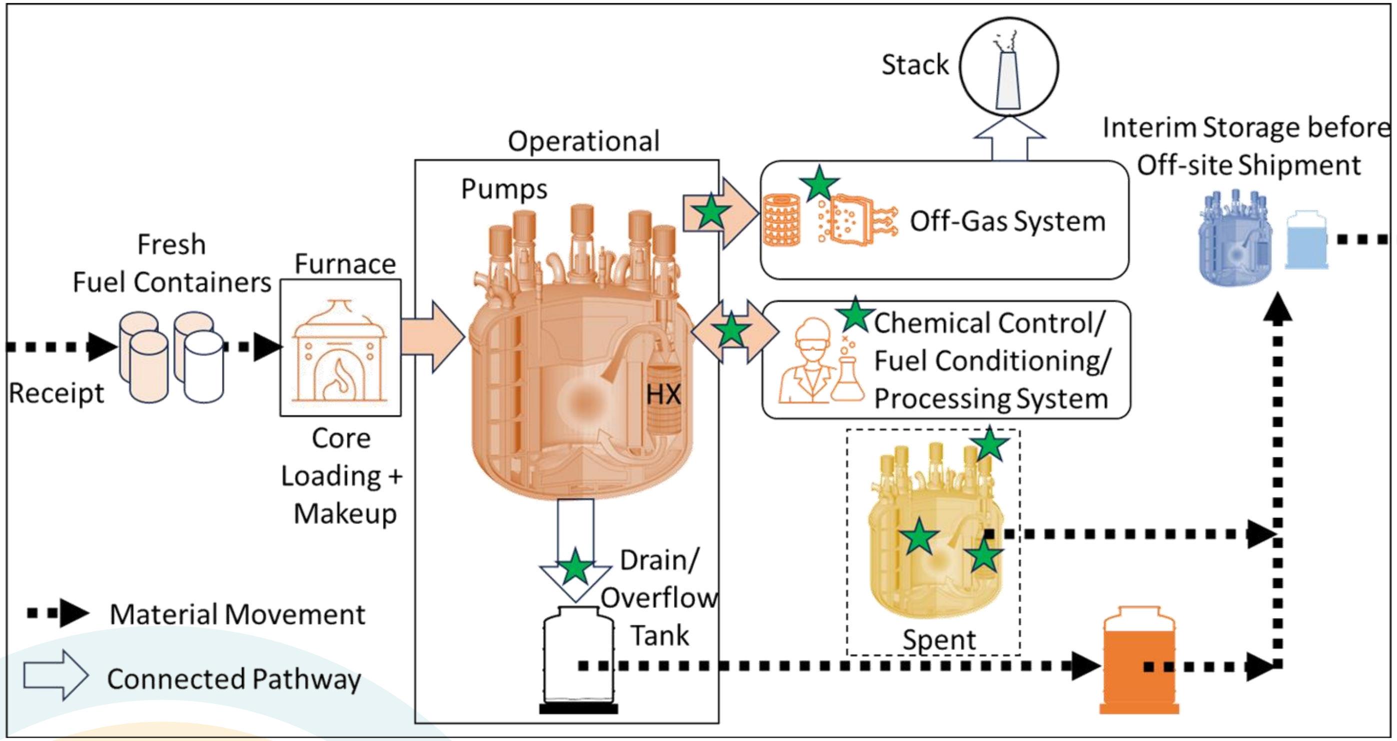
Source: **Reference [7]**

Group 1: Potential Holdup Areas

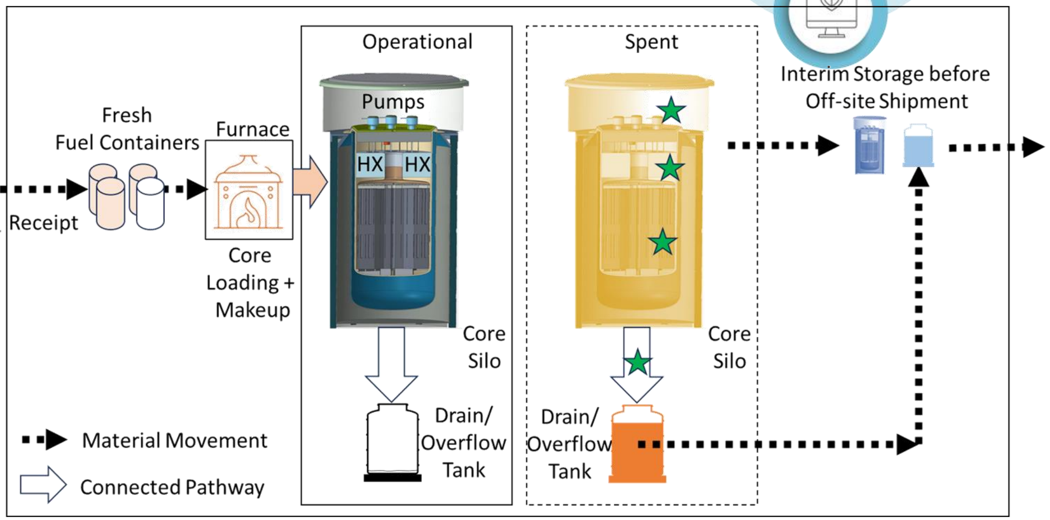


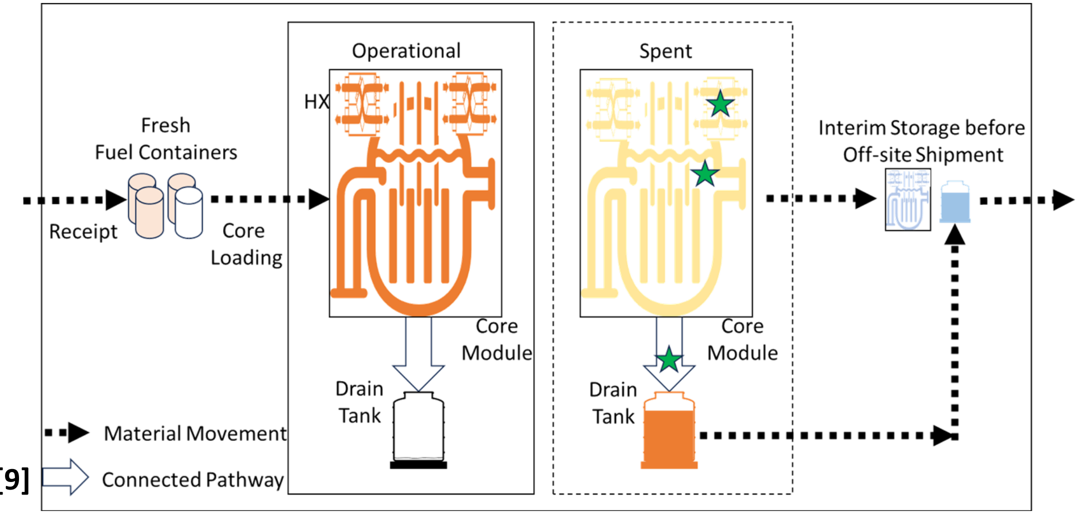
Source: Reference [8]

Group 1-3: Potential Holdup Areas



Potential Holdup Areas





Source: References [7]-[9]

Group 1: Holdup Characterization

Holdup Area	Measurement Environment	Measurement Frequency
Chemical Control System	Very high radiation area	During maintenance or component replacement
Fuel conditioning or processing system	Very high radiation area	During maintenance or component replacement
Off-Gas System	Very high radiation area	During maintenance or component replacement
Pipes (e.g., connections between various systems/ components)	Very high radiation area	During maintenance or component replacement
Reactor Primary System		
Core	Very high radiation area	After its design life
Graphite	Very high radiation area	After its design life
HXs (fuel–side)	Very high radiation area	After its design life
Pumps and associated connections	Very high radiation area	After its design life
Reactor core	Very high radiation area	After its design life

➢ Similar characterizations were made for other two groups.

Conclusions & Future Work

- Material control and holdup quantification are important aspects for accurate accounting of SNM and relevant to safety, security, and safeguards (3S)
  - Important to build into the technical considerations for 3S
- Assess the existing measures of tamper safing and surveillance of nuclear material
  - Measures depend on nuclear material crossing a boundary either continuously or in batches
- Characterize each of the identified holdup areas in detail for each system
  - Identify specific components in each system that would be of a major holdup concern
- Leverage characterization results to develop holdup measurement strategies for high radiation environment
  - Developers need to know **NOW** whether to plan for equipment inside reactor confinement to quantify SNM holdup
  - MC&A plan to NRC should include methods for quantifying SNM in holdup

References

[1] NRC Regulatory Guide 5.37, “In-situ Assay of Enriched Uranium Residual Holdup,” Rev. 1, October 1983.

[2] D. Reilly, “Nondestructive Assay of Holdup,” Los Alamos Report LA-UR-07-5149, Passive Nondestructive Assay of Nuclear Materials, Addendum, 2007.

[3] D. Reilly, N. Ensslin, H. Smith, Jr., and S. Kreiner, “Passive Nondestructive Assay of Nuclear Materials,” United States Nuclear Regulatory Commission, NUREG/CR-5550, LA-UR-90-732, 1991.

[4] NRC Regulatory Guide 5.8, “Design Considerations for Minimizing Residual Holdup of Special Nuclear Material in Drying and Fluidized Bed Operations,” May 1974.

[5] NRC Regulatory Guide 5.25, “Design Considerations for Minimizing Residual Holdup of Special Nuclear Material in Equipment for Wet Process Operations,” June 1974.

[6] NRC Regulatory Guide 5.42, “Design Considerations for Minimizing Residual Holdup of Special Nuclear Material in Equipment for Dry Process Operations,” January 1975.

[7] IAEA, “Advances in Small Modular Reactor Technology Developments, A Supplement to: IAEA Advanced Reactors Information System (ARIS),” 2022. https://aris.iaea.org/Publications/SMR_booklet_2022.pdf

[8] J. Walter “Overview of TerraPower’s Molten Chloride Fast Reactor (MCFR) Program,” 2023 Page 438 msrworkshop.ornl.gov/wp-content/uploads/2023/12/MSR-Workshop-2023-Agenda-and-Presentations.pdf.

[9] IAEA, “Status Update – IMSR-400,” 2016. https://aris.iaea.org/PDF/IMSR400.pdf.

Q&A

Group 2: Holdup Characterization

Holdup Area	Measurement Environment	Measurement Frequency
Chemical Control System	Very high radiation area	5-10 years, during core module switchover
Core Module		
Graphite	Very high radiation area	5-10 years, during core module switchover
HXs (fuel–side)	Very high radiation area	5-10 years, during core module switchover
Pumps and associated connections	Very high radiation area	5-10 years, during core module switchover
Reactor core	Very high radiation area	5-10 years, during core module switchover
Off-Gas System	Very high radiation area	5-10 years, during core module switchover
Pipes (e.g., connections between various systems/ components)	Very high radiation area	During switchover of pipes (at the end of its life span)

Group 3: Holdup Characterization

Holdup Area	Measurement Environment	Measurement Frequency
Chemical Control System	Very high radiation area	5-10 years, during core module switchover
Core Module		
Graphite channels (fuel–side)	Very high radiation area	5-10 years, during core module switchover
HXs (fuel–side)	Very high radiation area	5-10 years, during core module switchover
Pumps and associated connections	Very high radiation area	5-10 years, during core module switchover
Reactor core	Very high radiation area	5-10 years, during core module switchover
Off-Gas System	Very high radiation area	5-10 years, during core module switchover
Piping – Connecting Core and Drain Tank	Very high radiation area	During piping connection switchover (at the end of its life span)