MSR International & Safety Activities

MSR Annual Campaign Review Meeting – April 22-23

Pacific Northwest National Laboratory

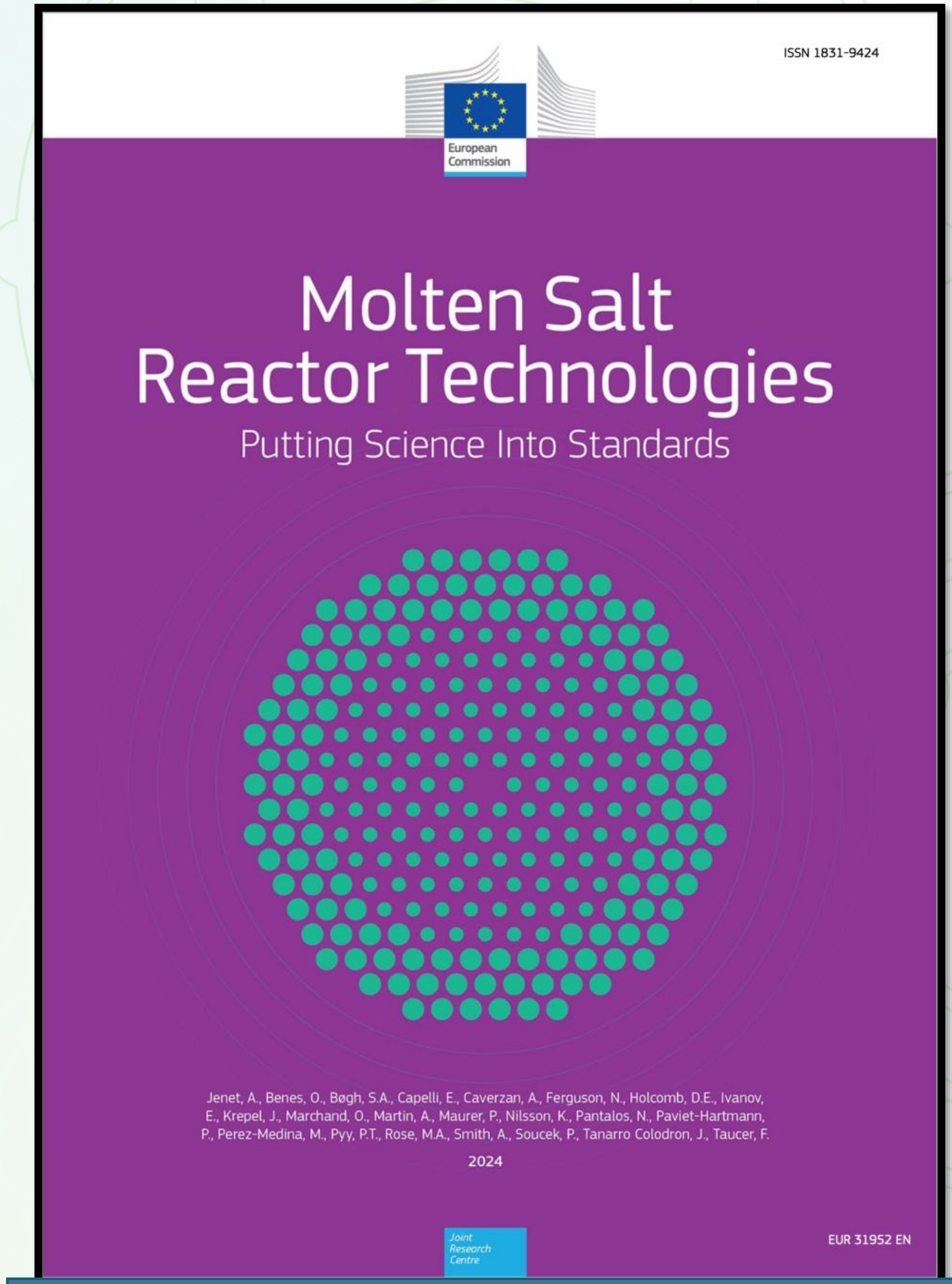
David Holcomb

Generation IV International Forum MSR Provisional System Steering Committee

- Primary vehicle to learn activities of other members
  - Minimize overlap of salt property measurements and improve measurement techniques
  - Understand plans and progress of members including entities with little public presence
- Ensure that U.S. views on proliferation resistance and physical protection are represented in consensus documents
- Develop consensus MSR safety assessment methods
  - Ensure that U.S. vendors are not disadvantaged in safety adequacy assessment process

European Union

- Cooperating on Safety Standards
  - Molten Salt Reactor Technologies – Putting Science into Standards
- Discussing harmonization of supply chain and component technologies
- Joint publication submitted to Nuclear Engineering and Design Special Issue on MSRs
  - Advancing Molten Salt Reactor Technologies: Prioritizing Standardisation Needs and Bridging Gaps



…aiming to accelerate the market adoption of MSR technology by leveraging the expertise of the European research and innovation community using standardization.

Campaign Cooperation with IAEA is Focused on Safety

- Updating safety guidance documents
  - Technical Meeting (October 2024) on Severe Accident Analysis and Management for Non-Water-Cooled Reactors
- Ongoing effort to develop appropriate MSR safety guidance
  - Next technical meeting June-July 2025 in Vienna
- Updating Primary Safety Guidance (SSR-2/1)
  - Currently includes embedded surrogates such as core damage and core coolability
  - Ensuring evolving U.S. process – 10 CFR Part 53 is not disadvantaged
  - Next technical meeting June-July 2025 in Vienna (different meeting during same week)

Technology-Neutral, Accident Containment-Based Path to Reduce Nuclear Power Costs

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Abstract

Cost remains a substantial impediment to nuclear power plant (NPP) deployment. The origin of the multifold cost difference between NPPs and other industrial facilities is in their unique potential for societally disruptive accidents. Consequently, one means to substantially reduce NPP costs would be to provide a transparent means of demonstrating that a plant's potential for land-contamination accidents is so remote to amount to a practical certainty that no significant quantity of radionuclides would ever reach the public. The necessary confidence can be developed through employing a containment capable of withstanding both a complete internal energy release accident along with credible external events with ample margin. This paper provides an overview of a path forward to develop a technology-neutral, containment-based safety-adequacy demonstration method.

Alternate Safety Methodology Paper Presented at IAEA Technical Meeting
https://doi.org/10.2172/2519019 (OSTI not currently updating)

Molten Salt Reactor PROGRAM

U.S. DEPARTMENT of ENERGY
Office of Nuclear Energy

Bi-Lateral Cooperation - France

- Safety leading topic
- Held initial virtual organizing meeting August
  - Multiple national laboratory participants
- In-person discussions held at CEA-Saclay in November
  - Looking at common safety experiments and tool validation methods
  - Lead recommendation was to develop modern, non-proprietary evaluation models
    - Fast and thermal spectrum systems
    - Allows assessment of impact of modern configurations—security requirements, proliferation vulnerability, waste forms and streams, accident performance, fuel requirements, siting issues

GIF MSR pSSC Safety Collaboration

- MSRs only GenIV system not to have completed safety assessment white paper
  - pSSC – RSWG collaboration meeting scheduled for May 15th
  - Extension to next pSSC meeting (virtual)
- Limited to exchange of open/fundamental information
- Focus of collaboration is on developing and exchanging information suitable for providing technical basis for safety adequacy assessment
  - Multiple alternative methods for safety adequacy assessment are possible
- Technical basis derives from fundamental data
  - Fuel salt thermophysical and thermochemical properties
  - Safety system, structures, and component (SSC) performance
  - Accident progression experiments and simulations
- Accident progression demonstrations have not yet been at sufficient scale to necessitate collaborative activities

Generation and Validation of Fundamental Data is a Key Element of GIF MSR Cooperation

- Fuel salt thermochemical and thermophysical properties are central to understanding potential source term and accident progression
  - Multiple independent measurements decrease property uncertainty
  - Fundamental scientific data is published openly
- Multiple GIF participants independently contribute related information to safety-related topics
  - United States demonstrating laser induced breakdown spectroscopy for monitoring aerosolized species and gases in headspace
  - European Union (EU) recently published thermodynamic evaluation of release kinetics of CsI into headspace
  - Canada has been experimentally evaluating fission product releases from halide salts

Cascade Impactor - Measuring aerosol sizes over halide salts

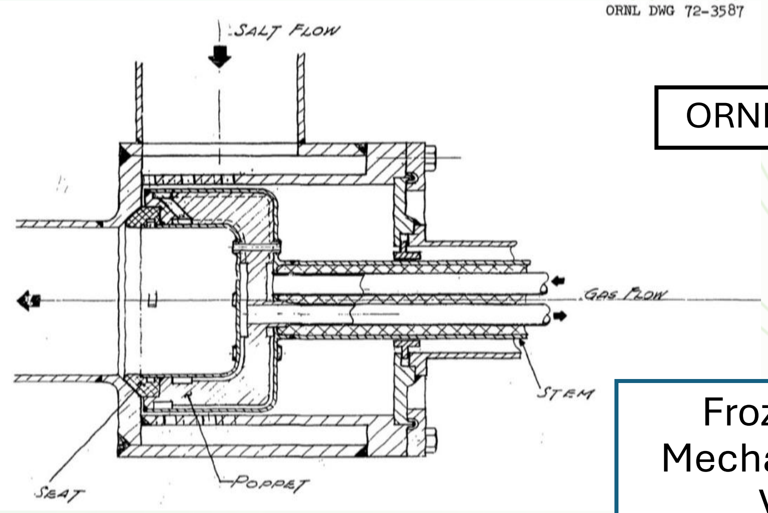
Supporting Safety Assessment for Modern Designs

- MSR technology is evolving more rapidly than at any time in the past half century
  - Half-century of accumulated technology advances
- Modern designs build from historic concepts
  - Significant, disruptive technologies are emerging
  - Creating processes that ensure safety of or develop technical data for historic concepts is of less value
- Need to understand where industry/technology is heading
  - Begin building modern evaluation models

Example – Historic designs employed full flow path freeze valves

- Proved to be technically difficult
- Multiple modern alternatives

1. Frozen seat valves
2. Don't drain
3. Pneumatic fuel salt position control
4. Open drain with parallel pumped refill



ORNL-TM-3832

Frozen Seal Mechanical Salt Valve

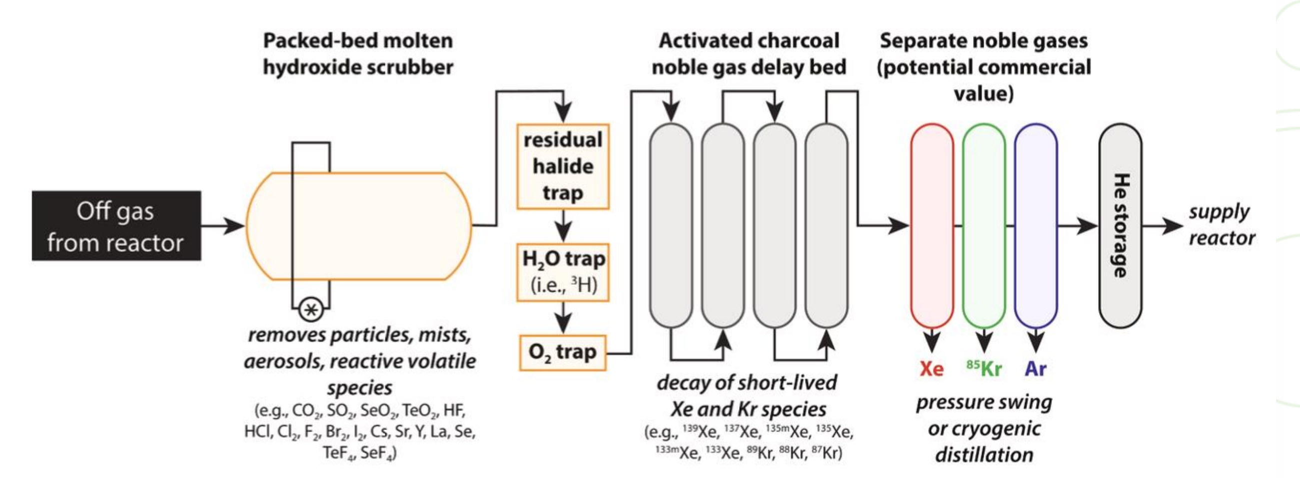
Reliance on legacy designs identified as a key vulnerability in EPRI advanced reactor roadmap

Off-Gas System Configuration is a Residual of Historic Materials Issues & Design Objectives

- Graphite only potential fuel salt contacting material with substantial surface connected porosity
  - Sparging only required to strip ^{135}Xe in designs where fission gases are retained in core
    - Noble gas solubility in fuel salt is very small
  - Could not see ^{135}Xe feedback with metal fuel salt tubes at Aircraft Reactor Experiment
- Most labile radionuclides are in off-gas
- Current commercial design proposals either
  - Don't strip fission gases from fuel salt and accept ^{135}Xe reactivity penalty
  - Employ non-graphite fuel salt containers (e.g., metal tubes)

Activated Carbon Beds Likely to Be Replaced by Engineered Zeolites

- Materials – Waste Stream – example
  - Activated carbon beds key element of off-gas system
    - Only combustible material in containment
    - Substantial potential heat load
      - Submerged in water
      - Phase-change pressurization hazard



Riley et al., doi:10.1016/j.nucengdes.2019.02.002

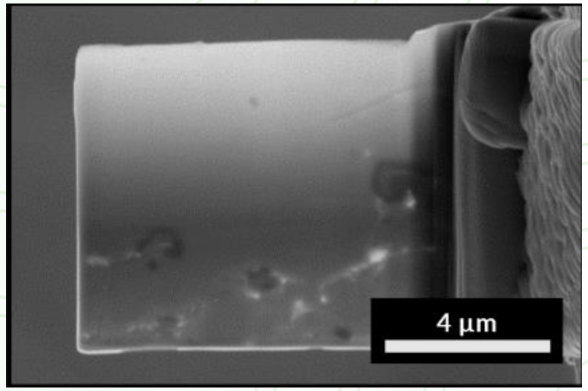
Advanced Radioactive Material Removal System by Silver Zeolite (7) Evaluation of Noble Gas Adsorption Characteristics

Yoshihiro Ishikawa, Koji Endo, Tadashi Narabayashi, Yasuhiro Kawahara, Yuta Nakasaka

Published November 2024

Modern Materials Technologies May Have Substantial Impact on Tritium Management

- Beryllium Carbide is highly vulnerable to hydrolysis
  - $Be_2C + 4H_2O \rightarrow 2Be(OH)_2 + CH_4$
  - One of the major issues with use of beryllium carbide ceramics as moderator material – Quirk 1953 (doi:10.2172/4384109)
  - Reaction kinetics and redox dependency largely unknown
- Beryllium oxide layer will natively exist on surface of Be_2C
- Tritium can react with the BeO layer on surface layer
- Methane will release from barren fuel salt as a gas
  - Beryllium carbide is not compatible with uranium bearing fluoride salts
- Tritium management has substantial impact on thermal spectrum MSR designs



No observed amorphization of 30 dpa sample

Muzquiz et al., 2024

Long-Term Storage of Used Fuel Salt Has Significant Potential Safety Impacts

- MSRE fuel salt left to cool in drain tanks for decades without removing actinides
  - Below 150 °C radiolysis becomes significant
- Significant uranium deposits found in carbon beds in off-gas system in 1990s
  - Gaseous UF_6 formed – enhanced by heating and cooling cycles
  - Information on MSRE carbon bed became OUO until uranium removed
- Actinide co-separation (thorium, uranium, plutonium, and transuranics) avoids creation of proliferation vulnerable material as part of waste process
  - Al-Be alloy based process
  - High burn-up actinide stream

MSR Waste Forms Journal Article submitted to Nuclear Engineering and Design special issue – Holcomb and Riley

MSR Characteristics Substantially Impact the Development of Technology Independent Rules

- Core coolability and core damage frequency are traditional safety surrogates
  - Embedded in both national and international requirements
- Reactor vessel failure likely results in catastrophic impacts in large LWRs
  - ASME Boiler and Pressure Vessel Code (BPVC) incorporated due conservatism
  - 10 CFR 50.55a requires LWR compliance with (BPVC)
  - MSRs may consider run-to-failure
- LWR shutdown involves inserting absorbers into core
  - MSRs may remove fuel from core for shutdown
- Concept of ‘cold’ shutdown substantially different for MSRs
  - Freezing fuel salt in vessel may result in permanent damage

Thank you

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