Understanding the Possible Molten Salt Reactor Safeguards Issues
Technical Meeting on the Status of Molten Salt Reactor Technology
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Meeting Room: VIC M Bldg M7

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Key Objective

• Illuminate safeguards issues unique to Molten Salt Reactors (MSRs) that need attention now for future design and deployment
Overview

• Bases and Purpose of IAEA Safeguards
• Significance of IAEA Safeguards for range of MSR Designs
• Safeguards By Design (SBD) for future facilities
• MSR specific issues for discussion in this forum
Information circulars (INFCIRCs) contain the legal instruments that establish IAEA safeguards objectives and practices.

**IAEA Founded**

- **1957**: IAEA Founded
- **INFCIRC/66**: Pre-NPT Safeguards Model
- **1965**: NPT requires NNWS to accept full-scope safeguards and to conclude a CSA with the IAEA
- **INFCIRC/153**: Comprehensive Safeguards Agreement (CSA) Model
- **1970**: Comprehensive Safeguards Agreement (CSA) Model
- **1972**: Additional Protocol (AP) Model
- **INFCIRC/540**: Additional Protocol (AP) Model
- **1997**: Additional Protocol (AP) Model

**Non-Proliferation Treaty (NPT)**

- **INFCIRC/140**: The NPT requires NNWS to accept full-scope safeguards and to conclude a CSA with the IAEA
IAEA Safeguards Overview

• IAEA determination that all nuclear material remains in peaceful activities is based on the IAEA finding of no indications of the diversion of declared nuclear material and no indications of undeclared nuclear material or activities in the State as a whole.

• State-level safeguards objectives common to all States with Comprehensive Safeguards Agreements (CSAs):
  – Detect any diversion of declared nuclear material in declared facilities or LOFs.
  – Detect any undeclared production or processing of nuclear material in declared facilities or Locations Outside Facilities (LOFs).
  – Detect any undeclared nuclear material or activities in the State as a whole.
Comprehensive Safeguards Agreement (INFCIRC/153 Corr.)

- INFCIRC/153 Para. 2 states that all safeguards are applied on all source or special fissionable material in all peaceful nuclear activities within the territory of the State.
- INFCIRC/153 Para. 28 established the technical objective of safeguards: timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities... and deterrence of such diversion by the risk of early detection.

Verify State's Declarations  
Nuclear Materials Accountancy  
C/S and Monitoring  
Independent Inspection and Conclusion
Comprehensive Safeguards Agreement – Key Points

• Safeguards on all source and special fissionable material in a State allows the IAEA to provide credible assurance safeguards objective is met
• Cornerstone of IAEA safeguards is nuclear materials accountancy
  – complemented by Containment and Surveillance (C/S) - Continuity of Knowledge (CoK)
• Inspection regimes verify continuing effectiveness of safeguards measures
  – Provide bases for IAEA conclusions regarding State compliance and absence of diversion
Design of a Safeguards Approach

- Safeguards approaches developed by the IAEA for each type of nuclear facility consist of a system of nuclear material accountancy, containment, surveillance, and other measures to meet detection goals.
- Technical Objectives (TOs) serve as guidelines for development of safeguards approaches and detailed procedures for inspection activities including quantity and timely detection goals.
- Model safeguards approaches are adapted to specific facilities, with detailed inspection goals, procedures, and measures specified in subsidiary arrangements and facility attachments.
IAEA Safeguards Needs

- Nuclear material accountancy is basis for deriving a conclusion on non-diversion of declared nuclear material from declared facilities
- To comply with its verification obligations, at facility level the IAEA will/may need to use a full range of tools and measures available to it
- Molten Salt Reactors will have unique safeguards issues especially in light of the range of novel designs being presented and possible deployment modes
MSR Types

• Molten Salt Reactors with fuel dissolved in the coolant as fuel salt
  – Th, U and Pu all form suitable fluoride salts dissolvable in LiF-BeF2 (FLiBe) mix
  – Thorium and uranium easily separated from one another in fluoride form
  – Online reprocessing possibility

• Molten Salt Reactors with molten salt coolant
  – Solid fuels using with TRISO fuels
  – Pebbles or graphite block fuel structures
Perspective: Generic Safeguards Approach: Type I Large Scale Commercial LWR

Typical Type I Light Water Reactor Layout

LWR Type I have the spent fuel (SF) pool within the reactor containment building – many SMRs will use this concept to save space – could have stacked spent fuel racks

MSR there is can be a totally different concept – bulk material vs. item

Molten salt as coolant to solid fuels has similarity to LWRs and CANDU types under safeguards

From IAEA Technical Report Series 392, Design Measures to Facilitate Implementation of Safeguards at Future Water Cooled Nuclear Power Plants
Perspective: Pebble-Bed Fluoride-Salt-Cooled High-Temperature Reactor as a Prototype

Pebble-Bed Fluoride-Salt-Cooled High-Temperature Reactor (PB-FHR) As reference design

MSR has solid fuel core with a static pebble bed composed of fuel from HTR-PM program - Fuel can be added on-line to compensate for burn-up - Thorium based fuel can be added in later cores

Fresh Fuel
Pebble fuels in matrix vs. oxide LEU fuels (both are items)

Spent Fuel
Pebble matrices that can be refueled on-line vs. item oxide fuels with Pu and fission products removed during scheduled refueling (12-24 mon cycles)

From Current U.S. & World Status of Fluoride Salt-Cooled High-Temperature Reactors - David Holcomb - NEAC Meeting 10 December 2014 – Crystal City, VA USA
Perspective: Pebble-Bed Fluoride-Salt-Cooled High-Temperature Reactor as a Prototype

Pebble-Bed Fluoride-Salt-Cooled High-Temperature Reactor (PB-FHR) As reference design

MSR is between item and bulk facility

Fresh Fuel
Pebble fuels vs. oxide LEU fuels

Spent Fuel
Pebbles that circulate in through the core and removed when spent vs. item oxide fuels with Pu and fission products removed during scheduled refueling (12-24 mon cycles)

Perspective: The Molten-Salt Reactor Experiment (MSRE) as a Prototype

Molten-Salt Reactor Experiment (MSRE)
As reference design

MSR is bulk material reactor not item facility

Fresh Fuel
Flouride salts vs. Oxide LEU (U-235)
Salts have potential to include U-235, Th, U-233, Pu as fuels

Spent Fuel
Flourides containing Pu and U-233 (Pa-233) with fission products – cycled out of core and processed and new salts replace them vs. oxide fuels with Pu and fission products

From NUCLEAR APPLICATIONS & TECHNOLOGY VOL. 8 FEB 1970, Experience with the Molten-salt Reactor Experiment – Haubenreich and Engel (ORNL)
Safeguards By Design (SBD)

• SBD definition:
  – integration of features to support IAEA safeguards into the design process for a new nuclear facility from the initial planning through design, construction, operation, and decommissioning

• SBD Objectives
  – Avoid costly and time-consuming redesign work or retrofits of new nuclear facilities to implement IAEA safeguards approach
  – Improve effectiveness and efficiency of IAEA safeguards

• Challenges
  – Lack of IAEA safeguards design requirements or standards
  – IAEA Model Safeguards Approach for MSR may change over facility design life as experience with MSR design and operation accumulates – especially in light of various proposed MSR types
  – Note: Certain minimum requirements will apply
SBD Structure and Approach

- Anticipate general safeguards needs based upon current safeguards practices and IAEA guidance
- Incorporate safeguards “infrastructure” measures into plant design to accommodate a range of IAEA safeguards approaches
  - Safeguards approaches rely upon IAEA equipment that plant design needs to accommodate
  - SBD should offer flexibility for differing IAEA safeguards approaches over plant design life
  - SBD can be very useful for MSRs since unique features create new situations for safeguarding nuclear material
Impacts of Not Being Safeguards Friendly

- Example Issue - Gen 3+ LWR Design
  - Design made continuous surveillance of fuel transfer routes difficult
  - Modifications to improve camera coverage / continuity of knowledge required
  - Additional required penetrations / cable runs for safeguards instrumentation
  - Delays and additional costs for redesign / rework
Placing a Facility and Nuclear Material (NM) under IAEA Safeguards - Design Information

• Early provision of Design Information / Model A.P. Art 2.a.(ix)(b) equipment receipt

• State submits a completed Design Information Questionnaire (DIQ)
  – Used by the IAEA to develop a safeguards approach
  – Provision of preliminary design information – as soon as decision to construct
  – For new facilities, *completed* Agency DIQ must be submitted not later than 180 days prior to the start of construction
  – Continuing update and IAEA review during design / construction
Placing a Facility and NM under IAEA Safeguards

Verifying DIQ and Initial NM

- IAEA conducts Design Information Verification (DIV) of declared facility
- Facility Attachment documents safeguards measures and obligations of State and IAEA
- State provides a declaration of its initial nuclear material inventory
- IAEA/SSAC or RSAC/Operator – interactions and coordination
  - Create a dialogue for a more efficient implementation of IAEA safeguards
Comments

- Safeguards obligations for a totally item facility would be challenge
- MSRs that are not LWRs present new challenges for:
  - Viable safeguards approaches
  - Nondestructive Assay tools / techniques to verify salts as nuclear materials
  - Use of operator instruments / on-line sampling by DA
  - Materials – solid fuels vs. salts (item vs. bulk)
    - U with U-235
    - Th/U-233 cycle – Pa-233 issues
    - Pu salts mixed with U-235 or Th/U-233(Pa-233)
    - Recycling of salts and storage of wastes or salts for new fresh salt mixes