Pebble Bed Reactors (PBR) Material Control and Accounting (MC&A)

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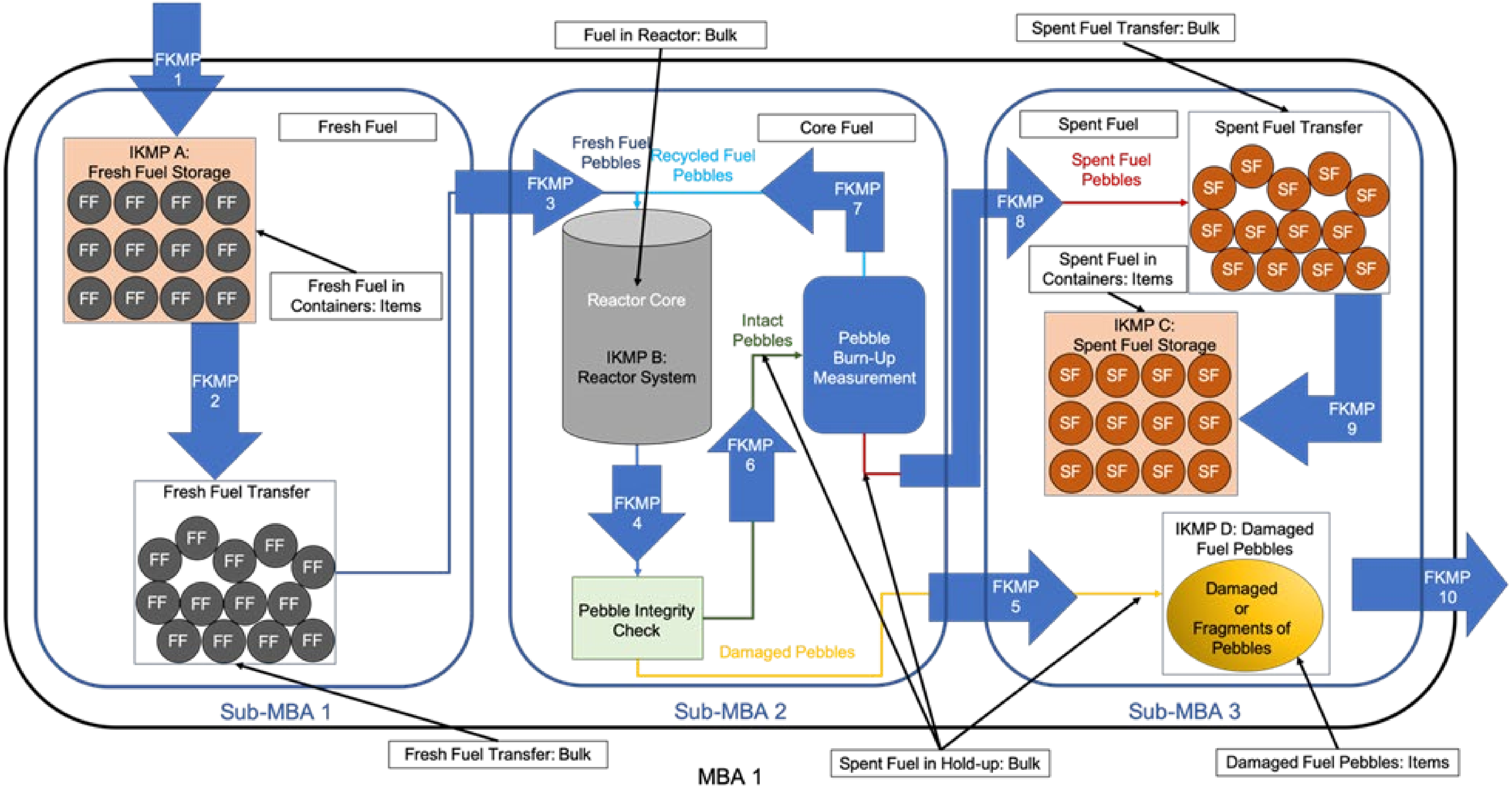
Motivation

Identify how to best adapt Material Control and Accounting (MC&A) requirements to the unique design aspects of this technology.

- Reactor Overview - Conceptual
- Facility Categorization Discussion
- Item Control - Containerization
- Inventory of Reactor Core
- Burnup Measurements
- Conclusions

Note: Focus is on domestic safeguards or Material Control and Accounting (MC&A)
10 CFR Part 74 - Material Control and Accounting of Special Nuclear Material

Reactor Process Overview



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Fundamental Nuclear Material Control Plan (FNMC) will be required

- NUREG-2159 provides guidance on format and content for projected facility category
- Material Control and Accounting system design should focus on performance objectives in 10 CFR Part 74
- FNMC covers reporting, shipments, receipts, measurements, physical inventory, etc.
- Concept of "<u>*item control program*</u>" will be prevalent
- Clearly describing concept of item, fuel component, and container will be important *(e.g., most designs considering not uniquely marking pebbles*)

Material Balance Area (MBA) Structure

- Likely to be one MBA for both MC&A and international safeguards
- MC&A (domestic safeguards) will make use of *Item Control Areas* to further subdivide reactor for material control
  - At least 3 likely (fresh, reactor, spent)
  - Could be more depending upon facility layout (e.g., multiple fresh or spent fuel storage areas)
  - Objective is to segregate process to support loss detection
- **Relevant to insider protection strategy which needs to be clear in both the physical security and FNMC (e.g.,) plans**
  - Integration point with physical security

What is the correct protection strategy of the facility?

Key factor is PBR Fuel’s Attractiveness for Theft or Diversion

Pebble Bed Reactors are Category II based on fuel enrichment (>10% < 20%) and quantities

Key Questions:

- Are Category II Safeguards and Security requirements the right approach for proposed designs?
- Or are aspects of Category II requirements overly conservative due to other mitigating design factors?
- How are these reactors the same or different from LWRs which have significant amounts of Pu in the spent fuel but are treated with less stringent MC&A requirements?

Light Water Reactor's Safeguards and Security is focused on sabotage versus theft

- LWR fuel size (e.g., not man portable) – non or less credible theft target

- AND/OR -

- Theft scenarios typically bounded by sabotage physical security measures

Historical Result: Light Water Reactors have been exempted from some MC&A requirements, specifically 10 CFR Part 74 Subpart D and E performance objectives that focus on theft / diversion

Questions:

1. Should PBRs be treated the same? (*Exempt from Subpart D and E)*
2. Or is theft/diversion a risk that should be addressed?

What's different for PBRs versus LWRs as a theft target

- Uses higher enrichments
- Fuel is man portable (*e.g., theft is more credible)*
- SNM is more dilute in the fuel *(e.g., large numbers of pebbles are required to obtain safeguard level goal quantities.)*
- A single stolen irradiated pebble does have potential for use in a RDD or RED (see definitions below).

Radiological Dispersal Device (RDD) is the combination of radioactive material and the means (whether active or passive) to disperse that material with malicious intent without a nuclear explosion.

Radiation Exposure Device (RED) is an object used to maliciously expose people, equipment, and/or the environment to ionizing radiation without dispersal of radioactive material.

Mitigating Factors for PBR Fuel

- For theft/diversion with respect to MC&A, SNM is dilute *(e.g., large numbers of pebbles are required to obtain safeguard level goal quantities. Abrupt theft likely not credible. Protracted theft?)*
- High radiation levels for reactor and spent fuel with appropriate facility designs likely to provide significant theft mitigation. (Reduces credible diversion paths or scenarios for even single pebbles)
- Once pebbles in spent fuel storage containers approaches likely analogous to those used for LWR or CANDU fuel (*e.g., theft not credible or bounded due to container bulk and radiation levels*)

Extensive use of containerization and containment/surveillance systems along with appropriate facility designs should be sufficient to bound or minimize most credible diversion scenarios, even protracted theft.

Item Control

Containers – Fresh and Spent Fuel

Item Areas – Fresh, Spent, and Damaged Pebbles

Investigate **packaging and handling approaches for fresh and spent PBR fuel** along with confirmation/measurement approaches.

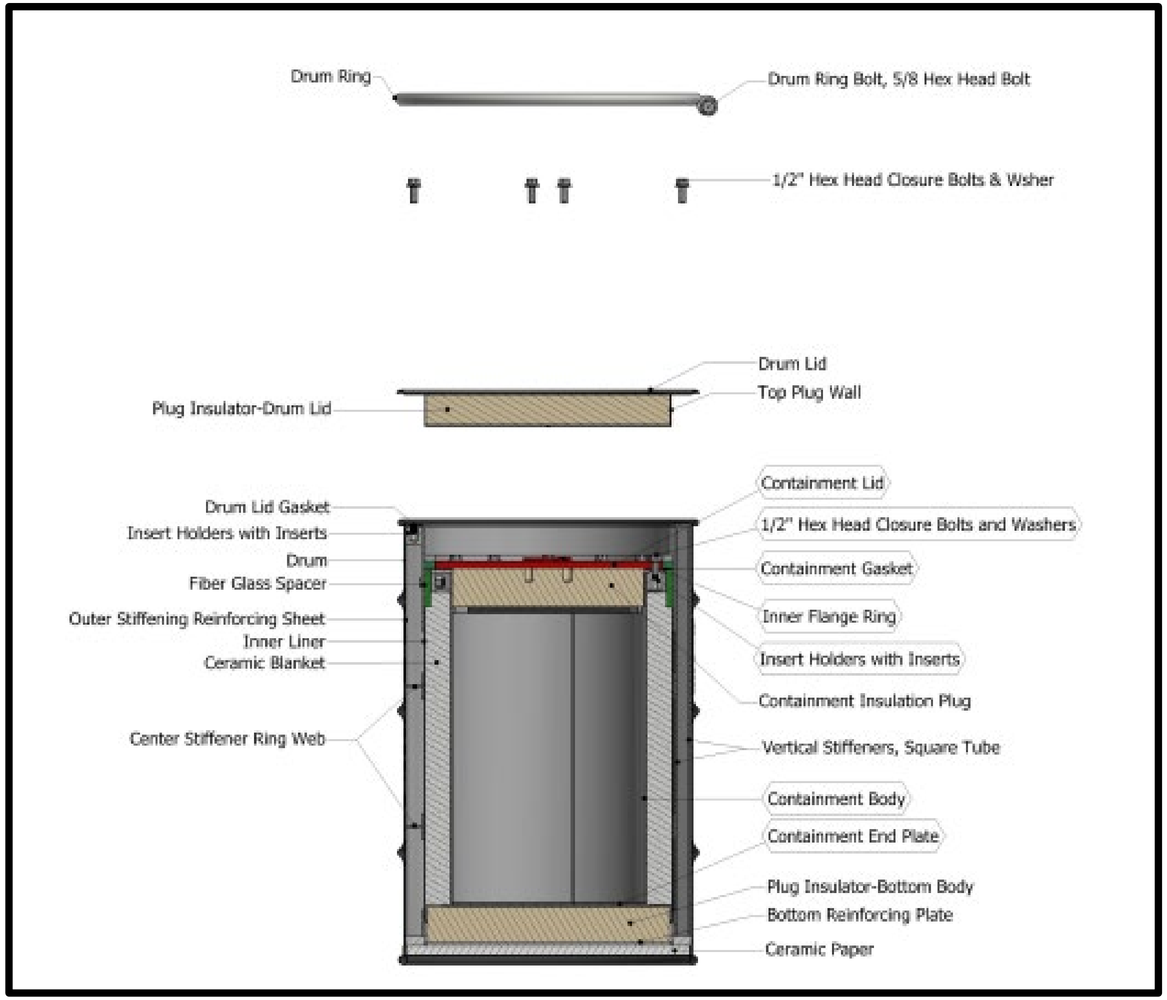
The implementation and effectiveness of the MC&A *item control program* will be affected by choices in container size and design.

Objective: identify approaches that balance MC&A, operational, and safety goals plus possible packaging design options.

- Extensive use of containerization and tamper-safing to manage large numbers of pebbles
- Be able to segregate or distinguish between non-SNM (graphite pebbles) and pebbles of differing enrichments
- Approaches would be analogous to concept of *fuel component container* (ANSI N15.8-2009)
- Damaged pebble not unlike concept of *damaged cladding* (ANSI N15.8-2009)

Versa-Pac (VP55) Candidate for Fresh Fuel Container

Container Exploded View

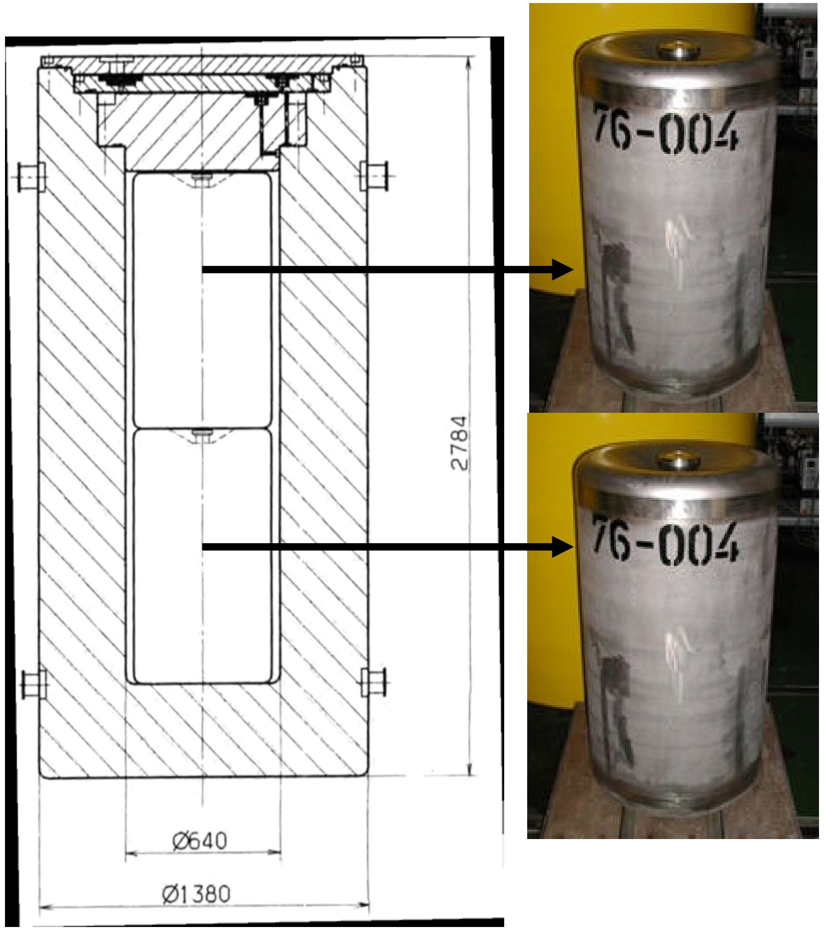


Inventory

- ~350 pebbles/VP55
- < 400 grams U235
- Total U approximately 3 kg

https://rampac.energy.gov/docs/default-source/certificates/1039342.pdf

Spent fuel containers designs under review



Example spent pebble container used for reprocessing HTGR Fuel

Note: Castor THTR/AVR (German design) was revalidated in 2017

Ref: Process Description for Processing of HTGR Pebble Fuel at SRS, SRNL-TR-2014-00209, October 2014

Reactor Core Inventory – pebble counting systems and core monitoring

Reactor and Recycle Loops

Investigate approaches for **physical inventory of the reactor vessel.**

- The ORNL NRC work from 2019/2020 report highlighted some of the challenges from both a technical and policy perspective for inventory of the reactor vessel.
- Objective: investigate approaches that fit within current policy guidelines and/or identify needed changes.

Reactor operating parameters will need to inform domestic safeguards conclusions (*e.g., provide indication no anomalies with declared inventory*)

- Process is analogous to a combination of a reactor and bulk process like an enrichment facility and considered <u>*Material in Process*</u>
- Key questions remaining:
  - How to use of reactor operating data to inform safeguards
  - Timing or when to recognize isotopic changes in fuel
  - Measurement data quality objectives for both safety and MC&A
  - Pebble counting system performance (accuracy)
  - Accounting for broken pebbles

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Burnup Measurement Systems (BUMS)

Implementation of BUMS for operations and MC&A

Investigate proposed approaches for **burnup measurements and/or calculations.**

- Magnitude of the impact of this uncertainty remains to be determined based on the final disposition path for spent pebbles (e.g., repository versus reprocessing), it will affect declared values for MC&A, safety, and waste disposition.
- Objective: review proposed approaches and measurement methods and identify areas where further work may be needed to manage or improve their use in providing nuclear material values.

Decision point for fuel to be removed from or reloaded to the core. Measurement uncertainty affecting decision remains to be determined. It will affect declared values for MC&A, safety, and operations.

- Understand the current state-of-the-art of the application of burnup measurements to PBRs (TRL)
- Understand needs for qualification of the method
  - Target measurement uncertainty
  - Evaluate: Possible to distinguish between passes and account for pebble (Pu mass) variability? Use of stream average?

Conclusions

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- PBR technology (fuel and reactor design) have intrinsic features that will contribute positively to MC&A and physical security
- There are differences that will require adaptation or re-interpretation of regulatory and licensing approaches for MC&A
- Regardless, existing MC&A concepts and approaches can reasonably be adapted
  - Extensive use of containerization and containment/surveillance systems along with appropriate facility designs should be sufficient to bound or minimize most credible diversion scenarios, even protracted theft
- Work remains on measurement system development and getting agreement on the physical inventory approach for the reactor core and recycle loops

References

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