A conceptual approach to MSR safeguards

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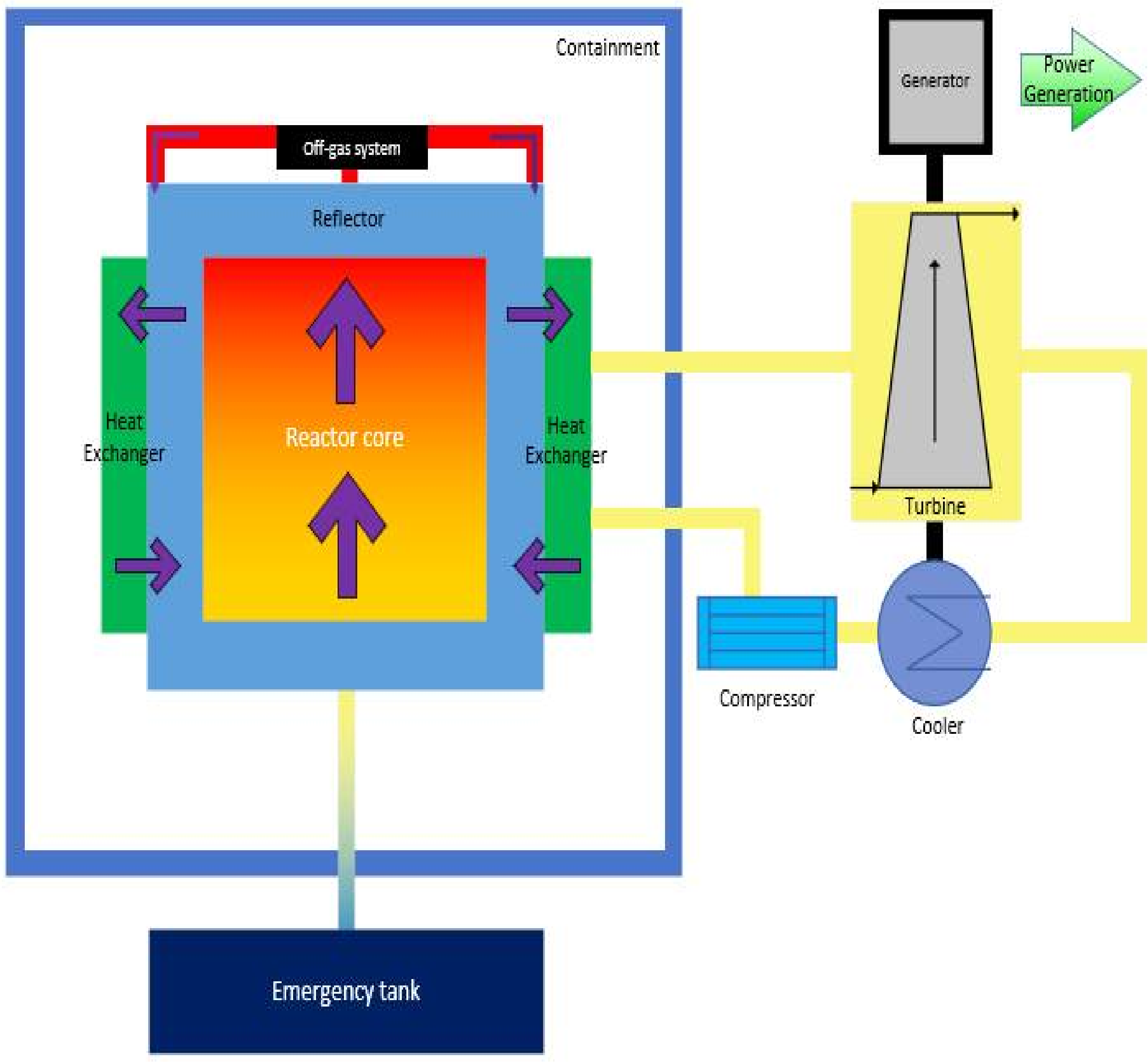
1. Introduction

- Nuclear power has increased interest for mitigating CO_2. One advanced NPP, the Molten Salt Reactor (MSR), is receiving considerable attention because its safety features are superior to existing light water reactors (LWRs). The MSR uses liquid fuel dissolved in molten salt. This feature allows the MSR to be operated at low pressure and refueled on-line. More importantly, since there is no separate coolant, it has the advantage of preventing core meltdown.
- Since the fuel is liquid, it is difficult to apply existing safeguards, which were designed for solid fuels. This poses a potential problem for MSR commercialization.
- This study will focus on one Korean MSR design and determine which safeguards by design applied at other nuclear facilities could potentially be applied.
- Burnup monitoring of the flowing fuel in terms of depletion and movement of fissile materials will be studied. Knowing the fuel composition and reactor power, implies normal operation. This can facilitate identifying off-normal operation and removal of fissile materials which can be checked by measuring burnup along with process monitoring.

2. Material flow in MSR



3. Safeguards challenges for MSR

- There are two types of MSRs. One uses molten salt as a coolant and the fuel is solid. In the second type, the fuel is dissolved in the molten salt. This study focuses on the second type of MSR which is under development in South Korea.

  The current IAEA safeguards inspection system uses item counting for nuclear reactors which cannot be applied to liquid fuel MSRs. The main safeguards challenges are as follows.

  - Continuously flowing material: The fuel is a homogeneous liquid mixture of fuel, coolant, FPs (fission products), and actinides. Unlike conventional NPPs, liquid fuel salts continue to move into and out of the core and this movement generates electricity.
  - Continuously changing material (salt and its contents): The salt is solid state before reactor loading and is liquid during normal reactor operations; it remains liquid when discharged but then becomes a solid again. In addition, fuel isotopics are continously changing due to the breeding of fissile material such as Pu-239.
  - Measurement environment: Radiation and temperature environment are much more severe than existing reactors because measurements need to be taken before sufficient decay can occur.
  - Accessibility: Both the reactor and the entire containment, will be contaminated, making both inaccessible. New access methods such as remote and unattended techniques are needed to allow for inspections and measurements.
- Considering these characteristics, MSRs require different approach from existing safeguards such as item accounting.

4. Ealrier studies about MSR safeguards

- **Multidimensional gamma-spectrometry**

  Using a dual-detector configuration, U-233 was identified in the MSR liquid fuel. In a thorium MSR, the intermediate reaction of Pa-233 to Pa-232 leads to the production of U-232. The resulting high energy gamma rays make NDA techniques challenging. It was also demonstrated that U-233 could be determined using four of its coincidence gamma-emissions (42.5 keV, 54.7 keV; 42.5 keV, 278.1 keV; 146.4 keV, 174.2 keV; 146.4 keV, 219 keV).
- **Process monitoring**

  One suggestion for MSR safeguards is to track the amount of reduced ANs by monitoring the overall process and isotopic changes due to depletion and decay. The research proposed a process model based on the Separations and Safeguards Performance Model (SSPM). This new model considers the blanket salt surrounding the core, the fuel salt circulating through the core, and the reactor subsystem in charge of the chemical process. In addition, a decay tank is also considered so that the fuel and blanket salt can produce a smooth reaction.

5. Proposed conceptual approach to MSR safeguards

- **For accounting of all materials**

  Since the MSR liquid fuel circulates through out the system, the flow rate (m^3/s) and total time ($\triangle t$) of flow can be used to determine the amount of nuclear materials loaded into the reactor and discharged out of the reactor.

  - Amount of nuclear materials loading into reactor = Amount of materials undergoing fission in reactor core + Amount of materials moving in total pipes outside the core
- **For accounting of special nuclear materials**

  - Burnup monitoring

    Along with the quantification of mass flow in and out of the reactor, this study proposes the use of burnup monitoring to determine fissile content in the flowing fuel salt at every key measurement point.

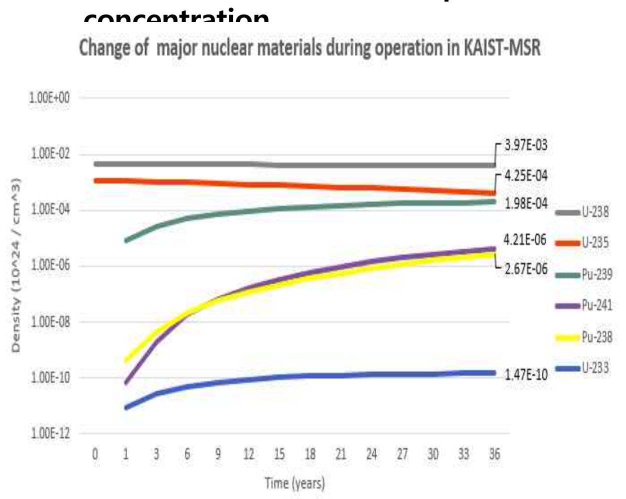
    In order to measure fuel burnup, counting the passive neutron emissions of specific elements was considered. Cm-242 and Cm-244 generated through neutron capture from Pu and beta decay were selected as cumulative burnup indicators. As the fresh fuel with zero burnup passes through the core, the burnup increases, and the passive neutron emissions from Cm-242 and Cm-244 begin to emerge. By counting the passive neutron emissions of Cm-242 and Cm-244 we can determine the cumulative burnup of the fuel.

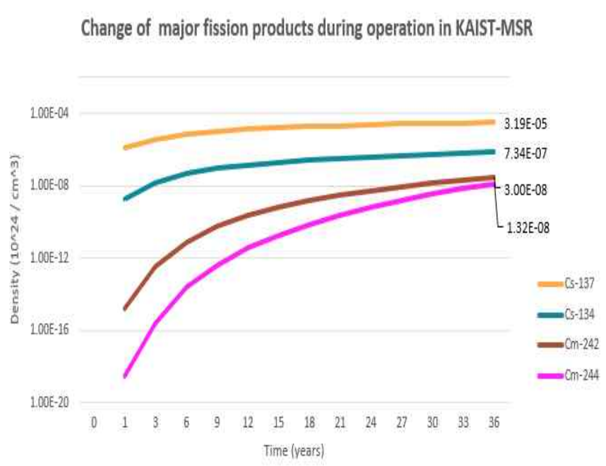
    If the estimated burnup values, based on measurements, are different from the expected burnup, off-normal operation can be suspected as part of the operation .

  - Hybrid K-edge densitometry (HKED)

    Measurement by HKED is a combination of x-ray fluorescence (XRF) and k-edge densitometry (KED). The XRF portion measures characteristic x-rays indicative of the element of interest. The KED measures the concentration of some elements by monitoring the transmission of gamma rays around the k-shell absorption edge.

    As a result of using HKED in the environment of pyroprocessing, the XRF response was clearly identified not only for Pu and U, but also for the peak of minor ANs such as Np and Am. The KED results showed a distinct k-edge drop in both U and Pu, but ANs other than Np and Am did not show a k-edge drop due to their low concentration





6. Conclusions

- This study proposes to use material flow monitoring along with burnup monitoring at key measurement points for MSR nuclear safeguards. Using flow rate and total time, it is possible to calculate the overall material flow circulated in the reactor, thereby satisfying the material accountancy for all nuclear materials.
- However, since it is limited to confirming changes in special nuclear materials, burnup monitoring is proposed to check only the concentration of specific nuclides. Cm generated during operation can be used as a cumulative burnup indicator by emitting passive neutrons, and off-normal operation can be suspected by counting passive neutrons.
- HKED complements the undetected portions of burnup monitoring and can increase the accuracy of nuclear safeguards by simultaneously measuring the presence and concentration of special nuclear materials.

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