Containment and Sodium-specific SFR Design Criteria in RG 1.232

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Regulatory Guide (RG) 1.232

Guidance For Developing Principal Design Criteria (PDC) For Non-light-water Reactors:

• RG 1.232 is the result from a joint DOE-NRC Initiative pursued in 2013 to establish DCs for non-LWRs similar to the LWR focused GDCs in 10 CFR 50 appendix A.

• RG 1.232 describes the NRC’s proposed guidance on how GDC in Appendix A of 10 CFR Part 50 may be adapted for non-LWR designs. This guidance may be used by non-LWR reactor designers to develop PDC for any non-LWR designs as required by applicable NRC regulations. The RG also describes NRC’s proposed guidance for two specific non-LWR design concepts: SFRs and MHTGRs.
SFR-DC 16: Containment Design

**SFR-DC Content:**

- A reactor containment consisting of a low-leakage, pressure-retaining structure surrounding the reactor and its primary cooling system shall be provided to control the release of radioactivity to the environment and to ensure that the reactor containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

- The containment leakage shall be restricted to be less than that needed to meet the acceptable onsite and offsite dose consequence limits, as specified in 10 CFR 50.34 for postulated accidents.
SFR-DC 16: Containment Design

NRC Rationale for Adaptations to GDC:

• The Commission approved the staff’s recommendation to restrict the leakage of the containment to be less than that needed to meet the acceptable onsite and offsite dose consequence limits in SECY 93-092, “Issues Pertaining to the Advanced (PRISM, MHTGR, and PIUS) and CANDU Designs and their Relationship to Current Regulatory Requirements.”

• Therefore, the Commission agreed that the containment leakage for advanced reactors, similar to and including PRISM, should not be required to meet the “essentially leak-tight” statement in GDC 16. [NUREG-1368, “PSER for the (PRISM) Liquid-Metal Reactor,” February 1994.]
SFR-DC 16: Containment Design

NRC Rationale for Adaptations to GDC:

• Furthermore, all past, and current, SFR designs use low-leakage, pressure-retaining containment concept, which aims to provide a barrier to contain the fission products and other substances and to control the release of radioactivity to the environment.

• Reactions of sodium with air or water, sodium fires, and hypothetical reactivity accidents caused by sodium voiding or boiling could release significant energy inside the reactor containment structure. Therefore, a low-leakage, pressure-retaining structure surrounding the reactor and its primary cooling system is required.
  — Note that a design could have a low containment design pressure.
SFR-DC 16: Containment Design

NRC Rationale for Adaptations to GDC:

• Several international reports support the need for a pressure-retaining structure surrounding SFRs.
  – NEA report, “Experimental Facilities for Sodium Fast Reactor Safety Studies, Task Group on Advanced Reactors Experimental Facilities (TAREF), indicates that it is necessary for structures to withstand the thermo-mechanical load caused by sodium fire to avoid fire propagation and dispersion of aerosols.
  – GIF report, “Safety Design Criteria for GEN IV Sodium-Cooled Fast Reactor Systems,” notes that the design basis for containment shall consider pressure increase and thermal loads due to sodium fire.
SFR-DC 16: Containment Design

Examples:

- **S-PRISM** containment consists of a lower volume, which is a leak-tight steel vessel that surrounds the reactor vessel, is welded to the reactor closure, and also serves as a guard vessel, and an upper volume, which is a low-leakage pressure-retaining steel-lined concrete room located directly above the reactor closure. It provides access to components located on the top of the reactor vessel.

- **FERMI 1** used a pressure retaining containment structure. Coolant flow blockage caused about 1% of the fuel to experience melting and subsequent release of radioactivity to the primary sodium coolant. But the accident was terminated and release of radioactivity to the environment was prevented. The incident served as a successful demonstration of the containment meeting SFR-DC 16.
SFR-DC 70: Intermediate Coolant System

**SFR-DC Content:**

- If an intermediate cooling system is provided, then the intermediate coolant system shall be designed with sufficient margin to assure that (1) the design conditions of the intermediate coolant boundary are not exceeded during normal operations, including anticipated occupational occurrences, and (2) the integrity of the primary coolant boundary is maintained during postulated accidents.
SFR-DC 71: Primary Coolant & Cover Gas Purity Control

SFR-DC Content:

• Systems shall be provided as necessary to maintain the purity of primary coolant sodium and cover gas within specified design limits. These limits shall be based on consideration of (1) chemical attack, (2) fouling and plugging of passages, (3) radionuclide concentrations, and (4) air or moisture ingress as a result of a leak of cover gas.
SFR-DC Content:

• Heating systems shall be provided for systems and components important to safety, which contain or could be required to contain sodium. These heating systems and their controls shall be appropriately designed to assure that the temperature distribution and rate of change of temperature in systems and components containing sodium are maintained within design limits assuming a single failure.

• If plugging of any cover gas line due to condensation or plate out of sodium aerosol or vapor could prevent accomplishing a safety function, the temperature control and the relevant corrective measures associated with that line shall be considered important to safety.
SFR-DC 73: Sodium Leakage Detection and Reaction Prevention and Mitigation

**SFR-DC Content:**

- Means to detect and identify sodium leakage as practical and to limit and control the extent of sodium-air and sodium-concrete reactions and to mitigate the effects of fires resulting from these sodium-air and sodium-concrete reactions shall be provided to ensure that the safety functions of structures, systems, and components important to safety are maintained. Systems from which sodium leakage constitutes a significant safety hazard shall include measures for protection, such as inerted enclosures or guard vessels.
SFR-DC 74: Sodium/Water Reaction Prevention/Mitigation

**SFR-DC Content:**

- SSCs containing sodium shall be designed and located to avoid contact between sodium and water, and to limit the adverse effects of chemical reactions between sodium and water on the capability of any structure, system, or component to perform any of its intended safety functions.

- If steam-water is used for energy conversion, to prevent loss of any plant safety function, the sodium-steam generator system shall be designed to detect and contain sodium-water reactions and limit the effects of the energy and reaction products released by such reactions, including mitigation of the effects of any resulting fire involving sodium.
SFR-DC 75: Quality of the Intermediate Coolant Boundary

**SFR-DC Content:**

- Components that are part of the intermediate coolant boundary shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed.
SFR-DC 76: Fracture Prevention of the Intermediate Coolant Boundary

**SFR-DC Content:**

- The intermediate coolant boundary shall be designed with sufficient margin to ensure that, when stressed under operating, maintenance, testing, and postulated accident conditions, (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized.
SFR-DC 77: Inspection of the Intermediate Coolant Boundary

**SFR-DC Content:**

- Components which are part of the intermediate coolant boundary shall be designed to permit (1) periodic inspection and functional testing of important areas and features to assess their structural and leaktight integrity commensurate with the system’s importance to safety, and (2) an appropriate material surveillance program for the intermediate coolant boundary.
SFR-DC 78: Primary Coolant System Interfaces

**SFR-DC Content:**

- When the primary coolant system interfaces with a structure, system, or component containing fluid that is chemically incompatible with the primary coolant, the interface location shall be designed to ensure that the primary coolant is separated from the chemically incompatible fluid by two redundant, passive barriers. When the primary coolant system interfaces with a structure, system, or component containing fluid that is chemically compatible with the primary coolant, then the interface location may be a single passive barrier provided that the following conditions are met:
  
  - (1) postulated leakage at the interface location does not result in failure of the intended safety functions of structures, systems or components important to safety or result in exceeding the fuel design limits
  
  - (2) the fluid contained in the structure, system, or component is maintained at a higher pressure than the primary coolant during normal operation, anticipated operational occurrences, shutdown, and accident conditions.
SFR-DC 79: Cover Gas Inventory Maintenance

SFR-DC Content:

• A system to maintain cover gas inventory shall be provided as necessary to ensure that the primary coolant sodium design limits are not exceeded as a result of cover gas loss due to leakage from the primary coolant boundary and rupture of small piping or other small components that are part of the primary coolant boundary.
Concluding Remarks

• During its development, RG 1.232 has gone through several rounds of internal and external review.
• The final version of RG 1.232 is scheduled to go out in the next couple of weeks.
• It has received generally positive feedback from our stakeholders.
• ANS Standard 54.1 for SFRs has incorporated all of the design criteria in RG 1.232
References

• NRC NUREG-1368, “PSER for the PRISM Liquid Metal Reactor,” 1994
• NRC NUREG-0968, “SER Related to Construction of CRBRP,” 1983
• SECY-93-092, “Issues Pertaining to Advanced Reactor (PRISM, MHTGR, PIUS, and CANDU 3) Designs and their Relationship to Current Regulatory Requirements,” 1993