IAEA Safety Standards for Fast Neutron Reactors and High Temperature Gas-cooled Reactors

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FR13, 4-7 Mar 2013, Paris

Background

IAEA organized in 2010 and 2011, a series of Consultancy Meetings to review the Safety Requirements for "Design of Nuclear Power Plants" (NS-R-1), replaced by the new Specific Safety Requirement No SSR 2/1 to interpret their applicability for fast reactor (FR) and high temperature gas-cooled reactor (HTGR) technologies.

Objectives of Consultancy Meetings

- **to review and discuss potential updates to the safety requirements for safety assessment and for design;**
- **to make proposals for necessary changes or additions to include new types of reactors;**
- **to suggest a roadmap for the implementation of these changes into the standards;**
- **to interpret the safety requirements in view of needs identified for FRs and HTGRs.**

The presentation deals with the main requirements that were found in need of the interpretation or possible modifications required specific for fast reactor (FR) and high temperature gas-cooled reactor (HTGR) technologies

1. Codes and Standards

The requirement stipulates that items important to safety shall be designed in accordance with the relevant national and international codes and standards. Therefore the establishment of codes and standards (mostly not available for FRs and HTGRs) might be needed. The acceptance of these codes and standards is made under the supervision of national regulatory authorities.

For LMRs, for e.g. generic codes for the design for aerosol deposition and minimisation of gas entrainment, cold trap, in-service inspection and repair, material corrosion and erosion in lead or lead-bismuth eutectic coolants, etc. are not available. Currently, some adhaoc rules are employed by the countries developing FRs.

2. Multi-unit and Co-located Facilities

- **Aspects related to multi-unit plants as well as to co-located facilities have also been considered. These are common for LWRs, FRs and HTGRs, and require special attention for small and modular designs and installations with process heat applications including hydrogen production.**

In case of SFRs, control room designs need take into account the sodium aerosol dispersion and acceptable limits for the operators, especially during design extension conditions. As for the lead-bismuth cooled reactors, specific risks might exist due to the production of toxic 210Po.

3. Corrosion

In lead and lead-bismuth cooled fast reactors

The ingress of water (from SG tube rupture) is an example of the generation of corrosive products that can enter the cooling system (and the reactor) or of the potential mechanism for the loss of a corrosion control in the coolant. At high temperature, flowing lead and lead-bismuth are corrosive to structural materials and can via physical chemical processes induce or accelerate material failure under static loading via reduction in ductility and strength or under time-dependent loading involving fatigue and creep. This requires operating LFRs at low temperature range and maintaining a controlled concentration of dissolved oxygen in the coolant, which has to be high enough to support the formation of a protective layer of magnetite (Fe_3O_4) on the surfaces of structures and, at the same time, low enough to prevent the formation of large amounts of PbO precipitation.

3. Corrosion .. Contd…

In SFRs

Purity of the coolant needs to be also monitored and controlled to limit the corrosion, even though the requirements on corrosion control are less stringent than for lead-cooled reactors.

In HTGRs

The pressure boundary (and thus the reactor cooling system boundary) must also limit the possibility of large amounts of air ingress and consequent corrosion of graphite in the HTGR. In particular the possibility of two breaks occurring (top and bottom) that can lead to a chimney effect must be minimized

4. Opacity

- Unlike LWRs and HTGRs and GCFRs, the coolant of LMRs is optically opaque, which makes maintenance, testing, repair, replacement, inspection, and monitoring difficult.
- Difficulties are also fuel handling operations. This has shown to be an important operational aspect, as demonstrated by the experience gathered from fuel handling incidents, which occurred in Fast Breeder Test Reactor (FBTR) in India as well as in JOYO

5. Core Geometry Changes

- **In FR core, any small geometrical variations (e.g., due to internal / external excitations) could introduce significant reactivity variations.**
- **In case of LMR, the fuel subassemblies and the supporting structures therefore need to be designed so that a geometry that allows for the insertion of control rods is not impeded.**
- **Core compaction and insertability of control rods into the channels in case of pebble bed reactors, are the issues to be addressed in graphite based HTGRs.**

6. Freezing of Coolant

- Unlike in LWRs and gas-cooled reactors, the coolant / aerosol freezing might impact the fulfilment of fundamental safety function with respect to reactivity control (impairing control rod functions) and heat removal (forming coolant blockages). Consequently, the coolant needs to be kept molten during normal operating conditions, including the shut-down situations, handling operations and emergency situations, such as a turbine trip.
- The issue is relevant for sodium (Tm = 98° C), lead-bismuth eutectic (Tm = 125° C), but of particular importance for lead (Tm = 327° C) cooled systems.

7. Boiling

- **Sodium boiling may result in voids which could introduce positive void coefficient in SFR. Hence, special provisions should be made in core design and appropriate safety criteria should be evolved to ensure the reactor safety.**

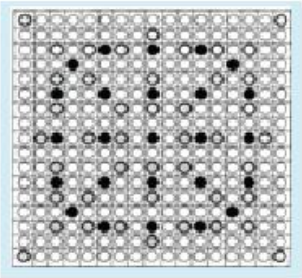
8. Operating Experience and Feedback

- In terms of reliability of items important to safety, with the absence of adequate long-term commercial operating experience (ca. 400 reactor·years for SFRs, specifically in France, UK, Germany, former Soviet Union and Russia, Japan, India, China, and USA, ca. 80 reactor·years for lead-bismuth cooled reactors in the former Soviet Union, and ca. 50 reactor·years for HTGRs in USA, Germany, UK, Japan, and China), key plant parameters such as temperatures and design life have to be chosen carefully. They have to be enhanced in a step by step manner with the accumulated experience and reliability demonstrated.
- There is no operating experience and feedback available on lead-cooled and gas-cooled fast reactors.

9. Fuel Design Differences

- **There is a need to homogenise the safety requirements of various kinds of fuels without linking them the specific design features.**
- **Terms such as fuel pins, fuel elements and subassemblies used in NS-R-1 and DS414 need to be either generalised or interpreted for specific reactor types**
- **Pebble bed reactors have an additional requirement that damaged fuel spheres (based on a specific criterion, e.g. on dimension for example) should be removed by the fuel handling system which may not be applicable to other designs. .**

LWR



HTR

SFR

10. Considerations on Fukushima Events

- In the review, in particular concerning risks and consequences related to the beyond design basis earthquake, beyond design basis flooding, and the total loss of the power and the ultimate heat sink were also considered.
- In case of LMR, the consequences of large EQ (core compaction and difficulty to shutdown) should be investigated.
- Specifically, in view of the large specific mass of lead, response of lead and lead-bismuth cooled reactors to earthquakes needs to be carefully considered.

10. Considerations on Fukushima…Contd..

- **In LMRs, the failure of primary coolant pressure boundary (main vessel in case of pool type designs) will not lead to a complete loss of decay heat removal capability due to presence of a safety vessel surrounding to the main vessel.**
- **In SFRs, another primary coolant pressure boundary is formed by primary pipes (“LIPOSO”). Rupture of one of the pipes is a design basis event (Category-IV) and it shall be demonstrated that the design safety limits are not exceeded under this event.**
- **In loop type reactors, the entire primary circuit has double envelope and in case of GCFRs, similar concept is adopted by the provision of the guard vessel. Hence, loss of integrity of primary coolant pressure boundary is less stringent for FRs.**
- **For SFRs, however, specific consideration must be given to consequences of possible multiple failures leading to sodium leakages and sodium fires or large sodium-air-water interactions, which might lead to damage of structures or components.**

10. Considerations on Fukushima…Contd..

- For LMRs, inherent characteristics related to coolants having high degree of thermal inertia and capability for natural convection provide increased robustness to the total loss of electric power supply and/or the heat sinks. As such decay heat removal function can be achieved either fully or at least partially passively. On the other hand GCFRs, have very low thermal inertia, which in the case of the depressurisation of the primary circuit requires that either forced circulation is maintained within the primary circuit or a minimum adequate pressure is kept to ensure that sufficient natural circulation is maintained.

10. Considerations on Fukushima…Contd..

- **For modular HTRs, the decay heat removal is performed by passive means through the natural phenomena of conduction, convection and radiation and thus don't rely on any active system or even the presence of the helium coolant. The building and surrounding earth can serve as the ultimate heat sink or this function can be fulfilled by the reactor cavity cooling system, which limits the temperatures of the concrete structures and which can be designed to operate in a passive mode. In modular HTRs which prescribe a very low power densities and large surface areas of a metal vessel to radiate heat, the so-called core meltdown is practically eliminated.**

10. Considerations on Fukushima…Contd..

- The ingress of water/steam to the sodium system needs to be practically excluded for SFRs in view of the abovementioned exothermic reaction of sodium with water, which consequences might be difficult to manage in LFRs.

- GCFRs, and HTRs are more tolerant to water ingress, but large water ingress needs to be also practically excluded as it might lead to positive reactivity insertions together with possible water chemistry effects.

Conclusions

- Most of the design requirements for the safety of nuclear plants are directly applicable to the evaluated FR and HTGR designs without the need of any modifications
- The specific requirements are also relatively easy adaptable and expandable to include FRs and HTGRs.
- Many of the requirements need specific interpretation or guidelines for the design specific aspects.
- As such, a technology neutral requirement will require designers to focus on the safety performance instead on existing, sometimes concept-specific solutions.
- Much more effort, consultations as well as involvement of other stakeholders, are required to develop a technology neutral reactor design safety requirements supported by safety guides for each types of a reactor.


THANK YOU