IMPROVED PRIMARY PIPE COOLANT DESIGN CONCEPTS FOR FUTURE FBRs

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Abstract

In this paper some design concepts are described that:
(i) Minimize the loss of coolant to core in case of pipe rupture;
(ii) Improve in-service inspection;
(iii) Eliminate double ended guillotine rupture (DEGR) from design basis event (DBE).

1. INTRODUCTION

The primary coolant pipes carry pressurized sodium (~ 0.8 MPa) from the pump header to the grid plate and thus, form a primary coolant pressure boundary. A rupture of the primary pipe is of great safety concern. Hence, structural reliability requirements are high for this component. In view of these considerations, a very ductile material, such as austenitic stainless steel type 316 LN, is selected and the pipe is designed as per Class 1 rules of RCC-MR [1].

High quality construction and very stringent pre-service inspection procedures are adopted. The layout, wall thickness, and junction profile are all optimized to achieve low stress field. Detailed structural mechanics analyses are carried out to comply with the RCC-MR, considering all possible loadings. Hence, failure of these pipes in the form of Double Ended Guillotine Rupture (DEGR) is a low probability event that can be considered a Beyond Design basis Event (BDBE). Accordingly, such an event does not need to be analyzed to predict the consequences.

However, to comply with the current safety philosophy that is followed in pressurized water reactors, the rupture of one of the pipes is considered, based on single failure criteria, and analyzed for its thermo-mechanical (temperature rise in fuel, cladding and coolant) and structural (mechanical interaction of failed pipe with adjacent pipes) consequences.

These analyses call for very complex 3-D modelling and solution techniques, since, in a simplified 1-D analysis, particularly in the design with a smaller number of pipes, it is difficult to demonstrate that temperature limits are respected with comfortable margins. Hence, it is worth considering alternative approaches, such as an increased number of smaller pipes, or provision for In Service Inspection (ISI), ensuring that even a small leak can be detected with confidence and that DEGR can be prevented. In this paper, some approaches are highlighted for the consideration of future FBR.

1.1. Concept 1: Increased number of smaller pipes

A greater number of pipes with reduced diameters have definite advantages. For the smaller diameter pipes, a lesser wall thickness can be chosen without increase of stress. As a result of this, the pipe become relatively flexible, which can accommodate higher thermal expansions.

Besides, in the case of DEGR of a pipe, the net loss of core flow is minimal. Consequently, the temperature rise in the fuel, cladding and coolant is reduced. It is also possible to consider seamless pipes with reduced thickness, by which the structural reliability can be improved significantly.

Figure 1 shows possible layouts with an increased number of pipes.

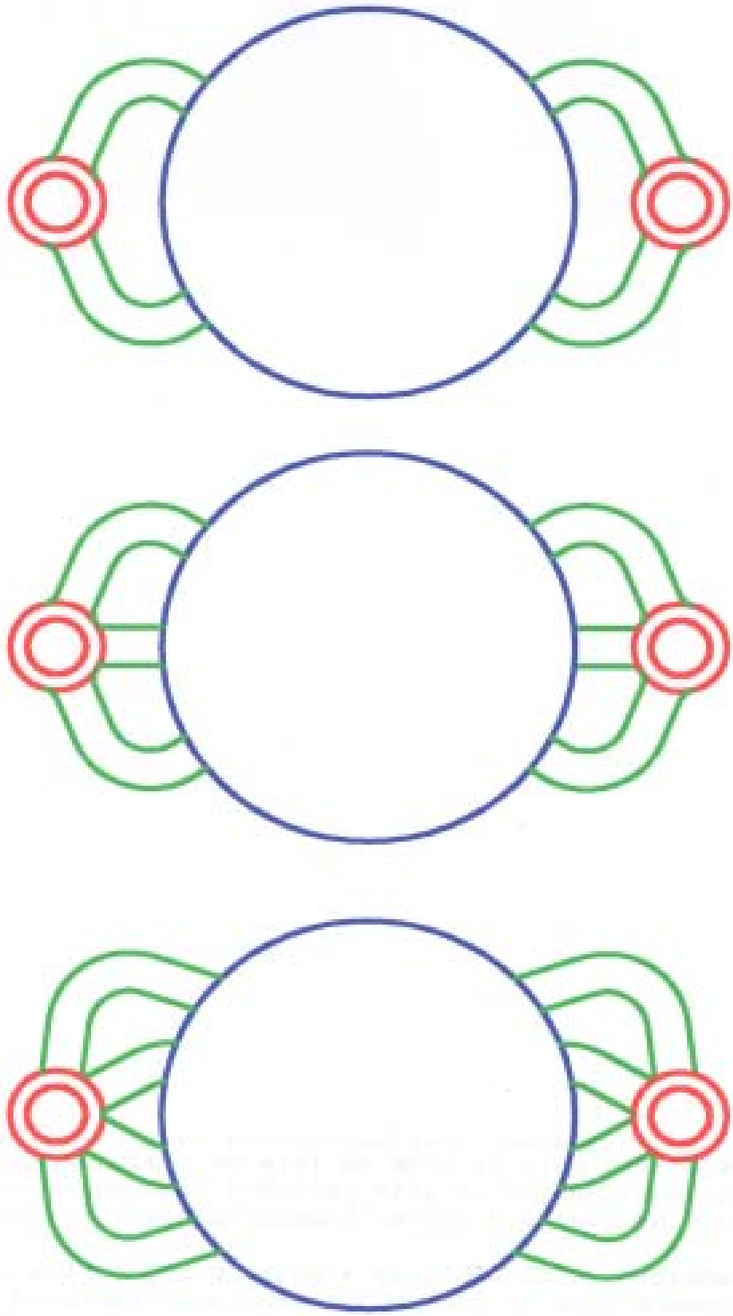

FIG. 1. Layout of primary pipes.

Table 1 provides an idea about the diameter and flow velocities with the increased number of pipes, for a typical 500 MWe FBR (PFBR) which has four pipes in the reference design with two primary pumps.

TABLE 1. PIPE DIAMETERS

No. of pipes	Velocity		
	7.5 m/s	10 m/s	15 m/s
4	600	520	420
6	480	420	340
8	420	360	300

However, there is a disadvantage in that an increased number of pipes may decrease the structural reliability due to an increase of pipe lengths.

1.2. Concept 2: Incorporation of a check valve

A check valve may be devised to be inserted into the grid plate end of the pipe, allowing free flow from pipe to the grid plate preventing coolant to flow from the grid plate to the pipe. This device could be a passive non-return valve that works on fluid drag principle. With such a device, the coolant bypass from the grid plate to the cold pool can be significantly reduced and thereby a flow increased of about 20 to 30% through core can be ensured. While designing such a device, its effectiveness during other design basis events, especially due to one primary pump trip should be investigated. Engineering development of this check valve needs to be carefully done. It should also be ensured that small parts of the flow diode device do not get separated and block the subassembly flow passage.

1.3. Concept 3: Demonstration of LBB by leak detection

A guard pipe filled with sodium can be provided that surrounds the primary pipe. The inter-space between the primary pipe and the guard pipe may be connected to a higher temperature location in the primary circuit, such as near the outer surface of the upper shell of the inner vessel in the PFBR by means of a small tube. When there is no leak in the primary pipe, the temperature of the sodium in this tube near its top end would be around 780 K, which is close to the hot pool sodium temperature. When the primary pipe starts leaking, cold sodium flows into this tube, and the temperature of the sodium near its top end reduces rapidly. Thus, the reduction in the temperature of sodium in this tube would give an indication of a leak in the primary pipe.

Alternatively, the approach followed in BN 600 can be adopted. In this concept, the outer wall is not leak tight and a tube is incorporated through which sodium can flow from the inter-space to the relatively hotter sodium in the space between inner vessel and the thermal baffle.

During no-leak condition, the temperature of the sodium in the tube is the same as its surrounding. Any sodium leak in the primary pipe can cause flow in the tube, the temperature of which will be reduced. Thereby a leak can be detected.

1.4. Concept 4: Demonstration of structural reliability

In order to eliminate DEGR, the structural integrity can be demonstrated by determining the structural reliability based on probabilistic methods in conjunction with studying the consequences for a maximum leak through a design basis crack opening area. The maximum leak area can be 1 cm^2, which is in fact the area considered for the secondary sodium pipe lines in estimating the design basis sodium leak event for the consideration of sodium fire. The approach followed by Japan is that the leakage area is equal to DT/4, i.e., $1/4^{th}$ of area for the rectangular slit having length equal to diameter and width equal to thickness.

1.5. Concept 5: Design with ISI

Low stress coupled with ISI could validate the rupture of pipe as BDBE. Accordingly, the present design of single wall piping could be retained with additional ISI features to ascertain the position and the size of the cracks in the pipes. In addition, the stress level could be kept low in the piping.

2. CONCLUSION

In this paper various design concepts, to minimize the loss of coolant to core in case of pipe rupture, to improve ISI and, to eliminate DEGR from DBE are highlighted. While the safety implications of incorporating more number of pipes require careful considerations of all aspects, the idea of improved ISI, particularly the concept used in BN 600, is worth considering for the future FBR design.

REFERENCE

[1] RCC-MR subsection NB for class 1 components, “Design and construction rules for Mechanical Components of FBR Nuclear Islands (RCC-MR)”, Association Française pour les règles de Conception et de Construction des matériels des chaudières Electro-Nucléaires (AFCEN), Paris, France (1993).