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Vibration of core subassemblies due to large sodium–water reaction in the steam generator of a Liquid Metal Fast Breeder Reactor

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ABSTRACT

In a Liquid Metal cooled Fast Breeder Reactor (LMFBR), liquid sodium is used as the reactor coolant to extract the heat energy from the core of the reactor. Liquid sodium has a chemical characteristic that makes it to violently react with water or steam. When large sodium-water reaction occurs due to defect, leakage or breakage in the steam generator tubes, high pressure waves will be generated and get transmitted throughout the secondary sodium circuit and interact with the components like sodium headers on top/bottom of steam generator, surge tank, intermediate heat exchanger etc., which also affects the safety of primary sodium circuit and core subassemblies. In LMFBR, sodium water reactions are included in the Design Basis Events. This dynamic event needs to be analyzed from the perspective of integrity of core subassemblies considering the phenomenon of fluid structure interaction. To evaluate the integrity of core subassemblies, the behavior of high pressure waves at intermediate heat exchanger is considered and the response of the subassemblies to the dynamic pressure load has been studied. The dynamic analysis of the reactor model is carried out using a three-dimensional finite element analysis in CAST3M computer code. In the code, the fluid elements are represented by volume elements and the coupling between fluid and structure by surface elements. Fluid damping is considered in the simulation. Validation of the code has been carried out using an experimental setup. Analysis results shows the maximum displacement of the primary circuit components viz., IHX, Inner vessel and subassemblies are 5.0 mm, 2.0 mm and 0.07 mm respectively for a design basis sodium water reaction event. Due to this displacement there is negligible change in the reactivity of the core.

1. Introduction

In a Liquid Metal cooled Fast Breeder Reactor (LMFBR), the fission heat generated in the reactor core is removed by liquid sodium in the primary circuit, which is transferred to the secondary sodium in the Intermediate heat exchanger (IHX). Further, heat from IHX is removed with water/steam circuit in steam generator unit to generate power. The overall heat transport with temperature flow diagram of a typical LMFBR is shown in Fig. 1 (Padmakumar et al., 2013).

The reactor assembly consists of Main vessel, Inner vessel and primary circuit which comprise the core, sodium pumps and IHX. Main vessel and Inner vessel contain the radioactive primary sodium and subassemblies are supported through the Grid plate. Further the Grid plate is supported by core support structure. The schematic of reactor assembly is shown in Fig. 2. The secondary sodium circuit consists of IHX, steam generator, surge tank and secondary sodium pump (Chetal et al., 2011). An analytical model for the response of Intermediate heat transport system due to sodium water reaction in an LMFBR has been carried out by Shin et al. (1988). It explains the dynamics of sodium water reaction coupled to the intermediate heat transport system. FSI studies with hydrodynamic mass effect, added damping in very closely spaced reactor internals and sloshing of the free surface of liquid sodium in fast breeder reactors have been studied by Fujita (1990). The pressure transients resulting due to sodium water reaction are detailed in Rajput (1983); Selvaraj et al. (1990). Consequences of sodium water reaction in the secondary sodium circuit for a typical pool type reactor considering the phenomenon of FSI in pipelines and the pressure propagation to IHX and surge tank has been presented (Selvaraj et al., 1996). In (Aizawa, 1998), the importance of safety study of sodium water reactions, examples of safety studies in fast reactors which lists the fluid structure coupled vibration due to water leakage has been discussed. Mechanical excitations of reactor assembly components due to primary sodium pump vibration have been studied by Chellapandi et al. (2003). Various structural dynamic studies for a typical pool type

Abbreviations: LMFBR, Liquid Metal Fast Breeder Reactor; FSI, Fluid Structure Interaction; FEM, Finite Element Method; IHX, Intermediate heat exchanger; DBE, Design basis event; DEG, Double Ended Guillotine

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Nomenclature

P	Pressure
C	Sound velocity
ρ_f	Fluid density
ρ_s	Structure density
μ	Poisson's ratio
u	Displacement
g	Acceleration due to gravity
Z	Fluid level
K	Stiffness matrix
M	Mass matrix
ω	Natural frequency
F	Surface force

fast breeder reactor including the response of intermediate heat transport system components due to sodium water reaction have been studied (Bhoje, 2003). Sodium water reaction in an LMFBR has been studied extensively by various countries having/had active fast breeder reactor programme. Both numerical as well as experimental studies have been carried out. Computer codes have been developed to predict the pressure wave propagation in the secondary sodium circuit due to a large sodium water reaction in the Steam Generator. These codes have been validated using experimental results. A computer code called SWEPT was developed at IGCAR (Indira Gandhi Centre for Atomic Research), to analyze the transient wave propagation in an LMFBR piping network with fluid structure interaction due to the incidents like sodium water reaction, sudden guillotine rupture of tubes, valve closure, pump shutdown etc. Research and development strategies in sodium cooled fast reactors across the world and the challenges faced were summarized (Aoto et al., 2014). Evaluation of temperature rise in the subassemblies due to steam generator tubes break event caused by sodium water reaction for prototype generation IV sodium cooled fast

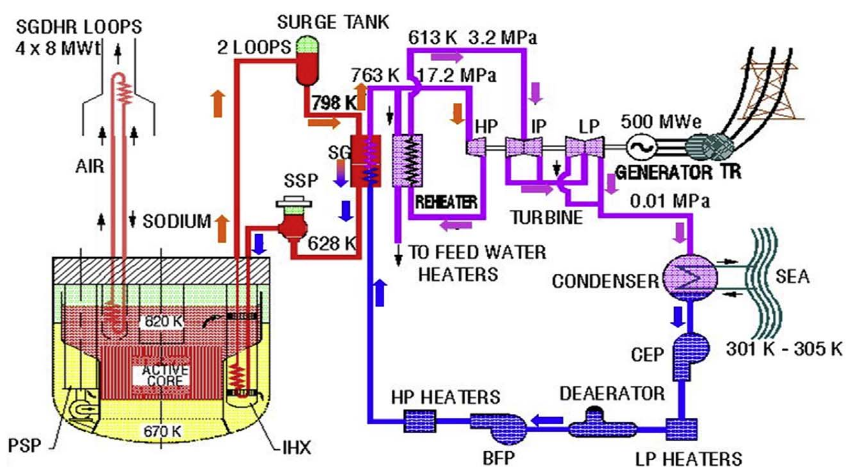

Fig. 1. Schematic of an LMFBR

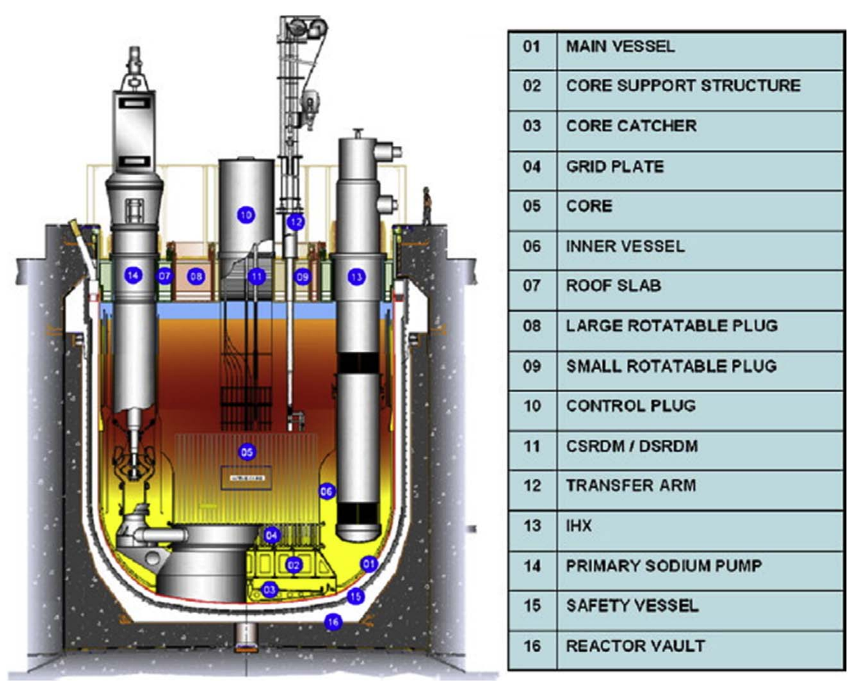

Fig. 2. Schematic of reactor assembly.