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Evaluation of post accident molten material relocation time to the core catcher in a fast breeder reactor

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ABSTRACT

Core Disruptive Accident (CDA) is categorized as a Beyond Design Basis Event in a Fast Breeder Reactor (FBR) because of highly reliable, redundant and diverse plant protection systems. Nonetheless, it is analysed with a view to assess its consequences and take remedial measures to mitigate its consequences. In the present paper, core-melt relocation studies have been carried out to assess the time taken for molten core material to get relocated to core catcher, by melting through various structures beneath the active core. Unprotected Loss of Flow Accident (ULOFA) and Protected Loss of Heat Sink (PLOHS) accident are the bounding events arising from different accident initiators. These are considered with the objective of estimating minimum and maximum time for core-melt relocation to the core catcher for the future Indian FBRs. Numerical heat transfer analysis has been carried out for both the postulated accident scenarios with conservative boundary conditions. In the case of ULOFA where the core-melt is envisaged to reach the grid plate within a few seconds, grid plate melt-through occurs in 300 s for constant molten fuel attack. On the other hand, for a PLOHS scenario, molten core relocation from core mid-plane to core catcher takes place in about 5.5 h with very conservative input conditions.

1. Introduction

In general, molten material relocation to the core catcher following a severe accident in a FBR is a matter of safety concern which needs to be analysed systematically for various possible accident scenarios to define the initial thermal load on the core catcher which is a decreasing function of time (Niwa, 1994). The core catcher is an engineered safety device placed at the bottom of the main vessel to protect it from the thermal attack due to time dependent decay heat contained within the core debris. The core-melt relocation time is defined as the time taken by the molten core materials to reach the core catcher, following a core melt down. For future Indian FBRs, the core catcher is proposed to be designed to withstand the consequences of even beyond design basis events such as a whole core melt-down. Therefore deterministic analysis of core-melt relocation time for various severe accident sequences becomes essential in order to define the initial thermal load on the core catcher.

In literature, it is found that safety analysis related to such molten material relocation has been carried out for FBRs like SUPERPHENIX and BN 800. For SUPERPHENIX the core-melt relocation time is estimated to be around 3000 s (Le Rigoleur and Kayser, 1982; Gluekler et al., 1982) and its core catcher is originally designed for handling the melting of seven subassemblies. For the BN 800 reactor, slow melting away of the structures underneath the core is postulated and the time estimate for relocation is estimated to lie between 3.5 h and 5.5 h depending upon the initial axioms set forth for the accident sequence (Voronov et al., 1994; Vlasichev et al., 1994). In case of UK reactors such as PFR and CDFR, the core-melt relocation time is estimated to lie between 1200 s and 3 h (Broadley et al., 1982). The wide range of time estimates seen from the literature reveals that the core-melt relocation time is very sensitive to the defined accident sequence, the imposed boundary conditions and specific to the fuel properties and geometry of the reactor.

In the present work, core-melt relocation time is estimated through heat transfer analysis for the future medium sized (500 MWe) pool type MOX fuelled Indian fast reactors assuming a core melt-down accident and a constant high temperature core-melt attack on the underlying structures. The vertical section of the reactor assembly following a melt-down accident is depicted in Fig. 1. The accidents investigated are ULOFA and PLOHS and in

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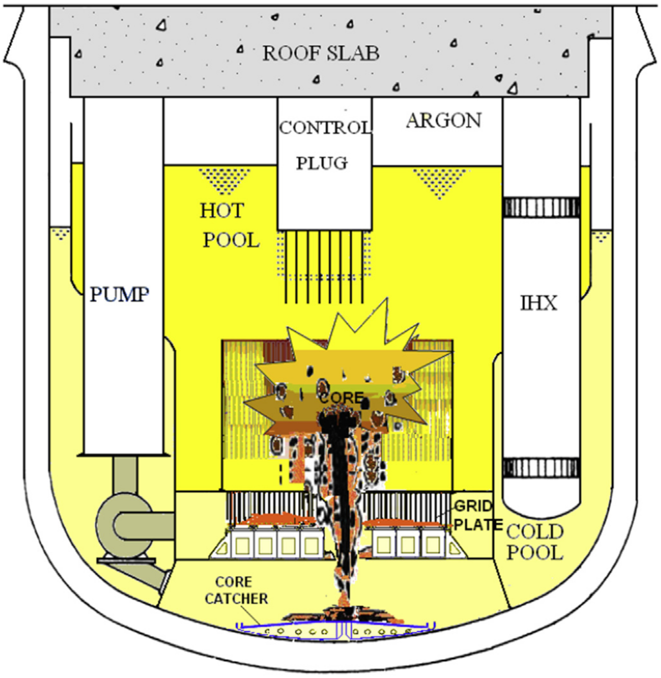

Fig. 1. Degraded reactor core following a core melt down.

both the cases, it is conservatively assumed that the core material gets relocated in the downward direction only and the structures are exposed to constant high temperature core-melt attack. Since the main objective is to obtain core-melt relocation time, analysis is restricted to the axial direction. In an earlier work by the authors (Sudha and Velusamy, 2013), grid plate melt-through time has been estimated, considering the time decreasing decay heat content of core debris as the heat source on the grid plate for ULOFA accident. This best estimate analysis revealed that grid plate melt-through can happen between 800 s–1000 s. The present study aims at obtaining conservative estimates for ULOFA by postulating that the grid plate is exposed to constant temperature (3020 K) core-melt attack. Moreover, PLOHS accident which is an equally severe accident, posing safety threat to the structural integrity of core components and hence the main vessel, is also analysed to evaluate the core-melt relocation time.

In the case of ULOFA, the molten fuel which is termed core-melt reaches the grid plate which serves as the sodium inlet plenum, within a few seconds after the accident and the lower plate of the grid plate is a solid obstacle for the molten corium to melt through, before settling on the in-vessel core catcher. This process of 'grid plate melt-through' for some possible core-melt configurations and boundary conditions is addressed as part of the investigation of ULOFA scenario using in-house developed HEATRAN-1 code.

Subsequently, PLOHS event is analysed using a commercial CFD code to determine melt relocation time. Core-melt progression takes place slowly starting from the bottom axial blanket region, moving through the fission gas plenum, tail piece, discriminator and grid plate top plate as shown Fig. 2. Porous body formulation is adopted and effective thermophysical properties are defined for each region which is made up of different components such as uranium oxide, sodium, stainless steel cladding etc. For this analysis, it is assumed that boiling fuel is in constant touch with the underlying regions, similar to the analysis done for BN 800 reactor (Voronov et al., 1994).

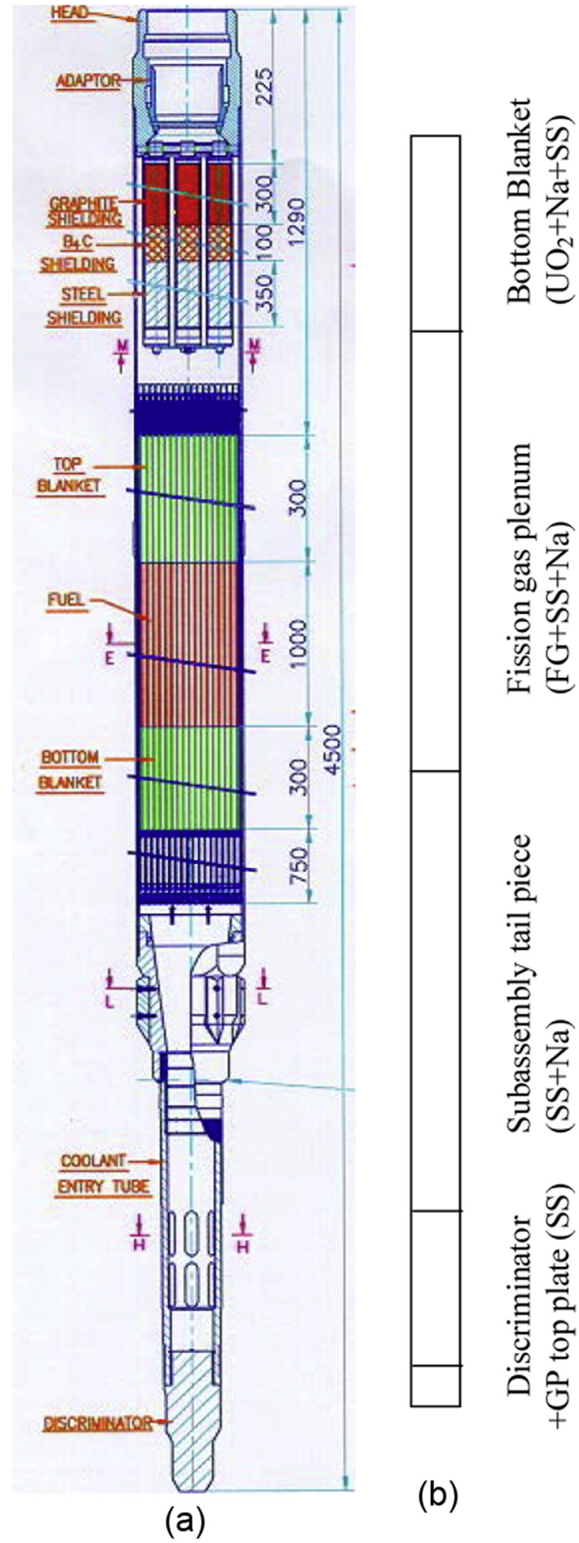

Fig. 2. Schematic of (a) FBR fuel subassembly and (b) computational domain for PLOHS.

2. Accident scenario

2.1. ULOFA scenario

An ULOFA can occur when both the primary pumps are tripped due to power failure and both the shut down systems fail to shut