Analysis of PFBR Primary Containment Response Under Hypothetical Core Disruptive Accident

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INTRODUCTION

The design of fast reactor follows the traditional approach of 'Defence in depth' incorporating diversity and redundancy to enhance the safety and mitigate the consequences of an unforeseen events. All the same, a small residual risk may remain which may lead to accident conditions in fast reactors. For Prototype Fast Breeder Reactor (PFBR) the HCDA with a moderate energy release of 100-200 MJ is considered as DBA and following such an event, the integrity of primary containment consisting of main vessel and roof slab has to be demonstrated (Bhoje, 1987). This paper presents the results of analyses performed to investigate the response of the primary containment under the loadings due to an HCDA.

ANALYSIS METHODOLOGY

A two dimensional axisymmetric finite element program called 'FUSTIN' has been developed to theoretically predict the dynamic response of the reactor assembly components. This code incorporates all the complexities due to large fluid material distortion, shockwave propagation, geometrical and material nonlinearities of structure, flow around sharp transition, multidimensional fluid sliding interfaces, slug impact phenomenon etc. The fluid flow is described by Arbitrary Lagrangian Eulerian (ALE) coordinate system. The structural response is computed by elastic-plastic 8 noded isoparametric elements and 2 noded conical shell elements, formulated in convected coordinate system. The code has the option of continuous automatic rezoning facility which can maintain the computational mesh as regular as possible even under severe distortion involving flow over obstructions. The interaction between fluid and structure is accounted by rigorously enforcing the interface boundary conditions by means of either master-slave technique or Lagrangian slide line technique. The code is conceptually similar to EURDYN (Donea et al, 1980) and ALICE (Wang, 1988). The details of mathematical formulations employed in the code can be found in ref (Chellapandi, 1985). The performance of the code for two bench mark problems are illustrated in Fig.1 and 2 respectively.

ANALYSIS FOR PFBR

A preliminary analysis has been carried out for assessing the primary containment capability under HCDA loading using the FUSTIN code. The analysis aims at the following two objectives:

* Calculation of damage potentials of carbide and oxide fuel for the given input work potential of 200 MJ.
* Estimation of maximum possible stresses and strains in the main vessel and roof slab.

For the above analysis, two simplified models of the reactor assembly have been considered. The salient features of the models are:

* In line with the traditional approach, the two phase molten fuel region as well as the argon cover gas space has been treated as simple ¢gas bag' with a definite pressure - volume relation. A thermodynamic approach given in ref (Walter, et al 1980) is followed to get a compatible pressure-volume relation for 200 MJ of energy satisfying the thermal energy, maximum pressure and temperature of the vapourised fuel associated with post disassembly accident phase.
* In order to conservatively estimate the stresses/strains in the main vessel, a 2-D axisymmetric model of the reactor assembly excluding all the reactor interals with the roof as a rigid structure has been considered.
* A rigid vessel model has been employed to conservatively estimate the roof slab. In this model, the sodium flow is completely blocked in the radial direction along the periphery in the locations of pumps and IHXs. The neutron shields and blanket subassemblies, inner vessel and stand pipes are all assumed to be rigid. However the flexibilities of the main vessel and the roof slab in the axial direction are considered. The model is schematically illustrated in the Fig.3. This model is termed here as 'CONICAL FRUSTRUM MODEL'.

Analysis - Results

Strains in the main vessel

Towards estimation of strains in the main vessel, 2-D axisymmetric model has been employed. The initial FE mesh as well as the deformed mesh at about 130 ms when the vessel energy attains saturation, are depicted in Fig.4. Analysis indicated that there are 3 critical locations, viz. apex of the main vessel (A), spherical-toroidal junction (B), and the main vessel - roof slab junction (C). The accumulated plastic strains vs time at those locations are shown in Fig.5.

Stress in the Roof Slab

The 'CONICAL FRUSTUM MODEL' has been employed for conservatively estimating the roof loads. The computed pressure and impulse values on the reactor cover due to cover gas overpressurisation are shown in Fig. 6 and the pull down load on the roof slab via main vessel is shown in Fig.7. With the above upward pressure loads and peripheral pull down loads, the 15 deg. sector model of the roof slab has been analysed elastically. The summary of the results are tabulated in Table-I.

Table - I Summary of the important Results

Details		Carbide	Oxide
Bubble energy	(MJ)	200	200
Bubble pressure	(MPa)	2.1	19.5
Bubble Temperature	(K)	5548	5628
Maximum vessel strain	(%)	7.9	10.5
Peak Pressure on roof	(MPa)	5.7	12.5
Impulse on the roof	(MNs)	17.0	23.2
Pull down force on roof	(MN/m)	3.6	4.0
<u>Maximum stresses in roof (MPa)</u>			
Via flexible vessel model		150	228
Via conical frustum		868	1200

DISCUSSION

The following are some of the important points:

* for the given energy of the core bubble, the oxide fuel case gives higher stresses/strains in the vessel and roof slab.
* even with the conservative assumptions, the vessel strain is not exceeding 10.5%. The allowable strain limit has been derived based on the guide lines of ref. (Lurenz et al. 1980) and is found to be around 16% for SS 316 at about 773 K and hence integrity of main vessel is very much assured.
* The major load on the roof slab arises due to cover gas overcompression rather than sodium slug impact.
* As per the findings in (Bassindale, et al, 1983) the roof loads estimated using flexible vessel case will be more closer to the reality than those estimated using Conical Frustum Model. This indicates that the transient sodium flow through the gaps between the IHX and pumps contribute very much in reducing roof loads. Hence the roof stresses are overestimated in the case of conical Frustrum Model and thus it becomes important to model the IHXs and pumps to get the better results.

CONCLUSIONS

Capabilities to analyse primary containment response to HCDA has been established. The analysis for PFBR indicates that the maximum permanent strains in the main vessel are acceptable but roof stresses are overestimated. Towards a more accurate estimation of roof loads, a refined model incorporating transient sodium flow through the gaps and the holes in the reactor internals, is being developed.

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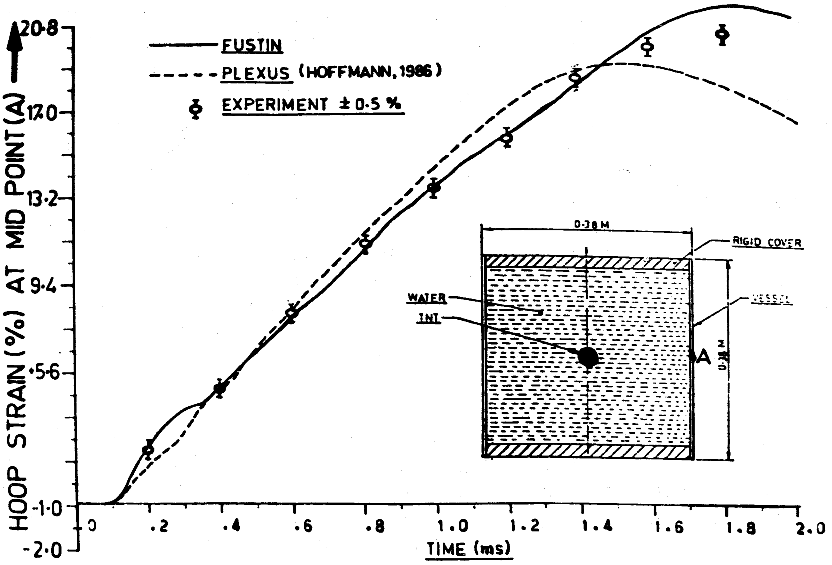
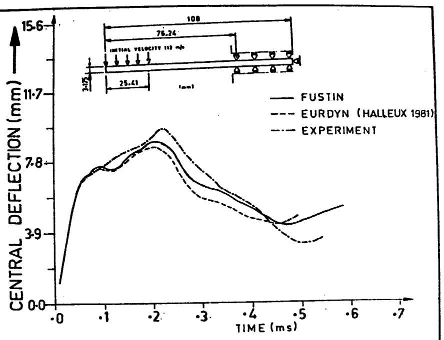
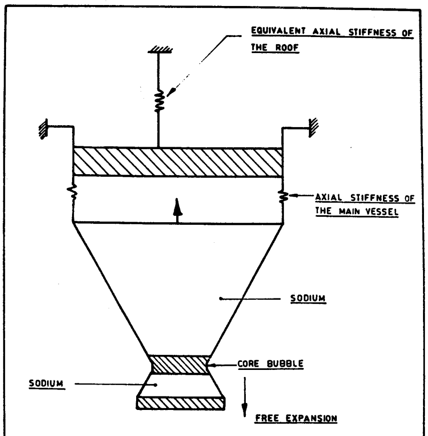


EXPLOSION IN WATER FILLED TANK FIG-1



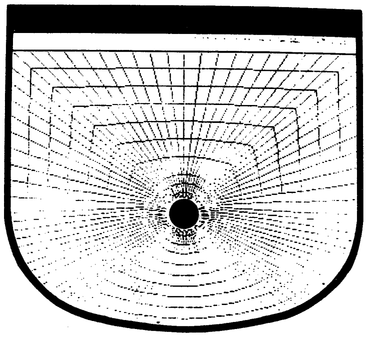
IMPULSIVELY LOADED CIRCULAR PLATE

FIG-2



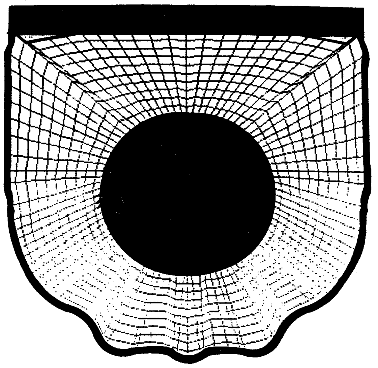
CONICAL FRUSTRUM MODEL

FIG-3



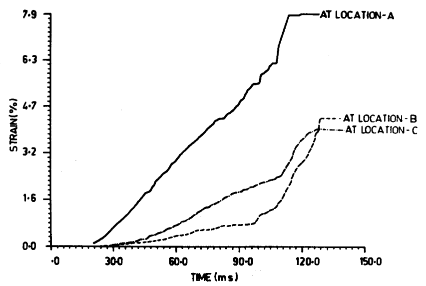
INITIAL MESH CONFIGURATION

FIG-4a

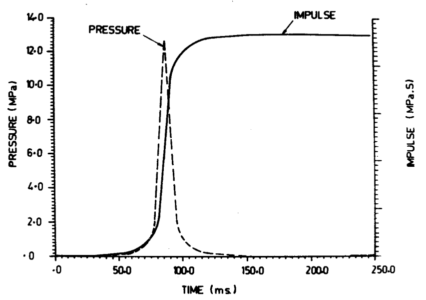


MESH CONFIGURATION AT 130 mS

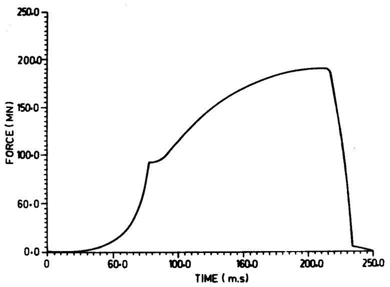
FIG-4b



PLASTIC STRAINS AT CRITICAL LOCATIONS FIG -5



PRESSURE & IMPULSE ON ROOF SLAB FIG - 6



PULL DOWN FORCE OF VESSEL ON ROOF

FIG -7