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Analysis of sagging behaviour of PHWR coolant channel following postulated severe accident

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ABSTRACT:The analysis of sagging behaviour of PHWR coolant channel following postulated severe accident (LOCA with failure of ECCS) shows the possibility of establishing a heat transfer mode to cool fuel bundles by using large amount of cold moderator. This enables a kind of limitation on the source term that containment has to isolate from reaching outside under such scenario.

1 INTRODUCTION

Coolant tube in a PHWR forms a primary heat transport system boundary. Each coolant tube is connected to rest of the coolant circuit through a rolled joint at either end. These rolled joints are designed and made to achieve adequate pull out strength and leak tightness. Design of the coolant tubes accounts for effects of pressure, temperature, irradiation, corrosion and many other environmental factors. Thus apart from limits in terms of stresses, one has to also satisfy limits in terms of other parameters, such as, creep induced deformations, thresholds for delayed hydride cracking, loss of ductility through hydrogen embrittlement, possibility of growth of a part thickness flaw to a critical size without the occurance of leakage and so on. While the above analyses are necessary as apart of design and in-service-review processes, the coolant tube also plays an important role in situations involving postulated beyond design basis accident. In a postulated accident involving loss of coolant accident and failure of emergency core cooling system, the heat up of coolant tube enables deformed coolant tube to come in contact with surrounding calandria tube, thus enabling a heat transfer mode to low temperature moderator in the calandria (reactor vessel). It is through establishment of such heat transfer mode that the maximum temperature of fuel even in such severe accident is limited to below melting point. This enables a kind of limitation on the source term that containment has to isolate from reaching outside.

The prefered mode of deformation of coolant channel should lead to maximum heat transfer contact area between pressure tube and calandria tube. The two independent modes of deformation of pressure tubes are sagging and ballooning. The sagging deformation of a pressure tube is essentially due to bending deflection caused by fuel bundle weight. A contact with the calandria tube due to this mode of deformation can initiate either at a point between the two garter springs or at a point between a garter spring and rolled joint. The ballooning mode of deformation is essentially due to circumferential membrane stretching of the pressure tube caused by remaining PHT pressure. Due to its localised nature of deformation, the entire length of the pressure tube is susceptible to ballooning mode of deformation except the zone near to garter springs. The conclusion which can be drawn through this discussion on the deformation pattern, is that the ballooning mode of deformation will lead to much higher contact heat transfer area than the sagging mode of deformation. Hence a ballooning mode of deformation is preferable over sagging mode. Such scenario may be achieved by delaying sagging mode during the heatup time of the pressure tube under accidental conditions, provided there is sufficient internal PHT pressure following LOCA.

One of the important considerations during ballooning mode of deformation is the possibility of rupture of pressure tube. This possibility further enhances in case there is an initial defect in the pressure tube inner surface. The defect may be caused due to unfavourable sliding of fuel bundles on the pressure tube inner surface during refuelling operation or following earthquake. A double ended rupture in pressure tube may lead to propagating damage. This may cause axial flying out of pressure tube into fuelling machine vault in case of axially free tube. This may also lead to high enthalpy jet in the calandria after rupturing thin calandria tube. This jet may cause further damage to the surrounding coolant channels. In one of our earlier publications(Dutta,et.al,1993), we discussed this issue of possibility of pressure tube rupture during ballooning under the presence of a flaw. The variation of critical flaw depth with the PHT pressure and circumferential temperature gradients were shown. In the subsequent sections of the present paper, we mainly discuss the sagging behaviour of a pressure tube. The effect of pressure tube axial restraint on the sagging temperatrure is also highlighted.

2 COMPUTER CODE TABS

The sagging analysis of a pressure tube at high temperature is essentially a thermo-mechanical problem with high temperature creep involving large deformations. Some of the complexities involved with this problem are material properties variation with temperature, multidirectional high temperature creep phenomena, large scale yielding of Zircalloy tube with the progress of yield front in thickness as well as axial directions, increase in reactions at garter spring locations with the progress in sagging, consideration of geometric nonlinearities due to inplane compressive stresses in case of axially restrained tubes, etc. Hence it is necessary to employ a powerful numerical technique, such as finite element, to account for these complexities in the analysis. In the present work a computer code TABS has been developed to suit the present study based on bending theory of finite element formulation. The code uses nine noded heterosis/ eight noded degenerate shell bending elements for modelling. The nonlinear variation of stresses along the thickness as a result of progress in plastic front is considered using layered approach. The stress is assumed to be constant over a layer and number of layers is an user's choice depending upon the available computational power. Plastic flow equation is solved by using Prandtl-Reuss flow rule, von-mises yield criteria and isotropic strain hardening. Minimisation of residuel unbalance load is done by using modified Newton-Raphson iterative procedure. The code is also modified to consider thermal stresses due to in plane as well as across the thickness temperature variation. The temperature variation across the thickness is considered by specifying temperature for each layer, which is assumed to be constant over the layer. The pseudo thermal load vector considering the temperature rise and the extent of yielding for each layer is calculated and assembled with the other load vectors of the different layers of a element, to obtain elemental load vector. Beside elastic, plastic and thermal strains, the code is capable of considering strain due to change in material properties with temperature and creep strain. The code is tested against large number of case studies to evaluate its different analysis capabilities.

3 HIGH TEMPERATURE CREEP EQUATION FOR ZIRCALLOY

One of the important characteristics to be modelled during sagging of the pressure tube is the material creep at high temperature. It is wellknown that the creep properties for Zircalloy is directional dependent. In our earlier study on ballooning of pressure tube (Dutta,1993), we used the high temperature creep model by Schefelt,1984. It may be noted here that this model was developed assuming a Zircalloy tube dominantly under ballooning mode of deformation. However, in the present analysis on sagging behaviour of Zircalloy tube, we have used the creep model NIRVANA (AECL-6412).

4 ANALYSIS PROCEDURE

One-fourth of the pressure tube has been modelled assuming symmetricity with respect to two vertical planes. The effect of garter springs have been modelled by considering equivalent stiffness at the appropriate locations. The Zircalloy property data base, ranging from operating temperature to sagging temperature, are used from MATPRO-11. These properties are modulus of elasticity, poisson's ratio, coefficient of thermal expansion and stress-strain relations. The model is first loaded with fuel bundle weights at the operating temperature. Then the temperature gradient varying with time is imposed on the model. This temperature data base is obtained by using corresponding thermal-hydraulics codes in a seperate analysis (Gupta,1994). One of the typicalities of this temperature data base is that the temperature value is constant over a significant length of the pressure tube at the centre region. This value drops down to operating temperature near to both the rolled joints. The gap between the pressure tube and calandria tube is monitored by calculating corresponding deformation of calandria tube analytically based on reaction at garter spring location. The computation is terminated once the gap is closed.

5 EVALUATION OF SAGGING BEHAVIOUR OF AXIALLY RESTRAINED AND AXIALLY UNRESTRAINED PRESSURE TUBES

Axially restrained and unrestrained pressure tubes form two seperate school of thoughts about their relative merits. The axially unrestrained tubes are free from any axial stresses, which may be induced due to thermal expansion and creep with the time of reactor operation. However, in case of double ended rupture of an axially unrestrained pressure tube, there is a possibility of ejection of a part of the pressure tube into the fuelling machine vault. The possibility of this event is eliminated in case of axially restrained tube. However, axially restrained tube experiences much more axial stresses during inservice operation.

We have tried to evaluate relative sagging behaviour of axially restrained and unrestrained tubes. The finite element model described above has been analysed for both these conditions seperately. The axially restrained tube has been assumed to be free from axial stress at the begining of the severe accident. Due to thermal expansion and creep, axially restrained tube experienced heavy yielding. The sagging behaviour of both these tubes are projected in attached figure, using the plots correspond to progress in sagging with the increase in central region temperature.

6 DISCUSSION

Deformation of the pressure tube with the increase in central region temperature shown in Figure-1 reveals the following points.

1. The sagging process of the pressure tube starts much earlier for axially restrained tube than axially unrestrained tube.
2. The sagging temperature of axially restrained tube is 785 Deg. Cel. and that of axially unrestrained tube is approximately 925 Deg. Cel. Hence, there is approximately

140 to 150 Deg. temperature difference exists betweenthe two sagging temperatures.

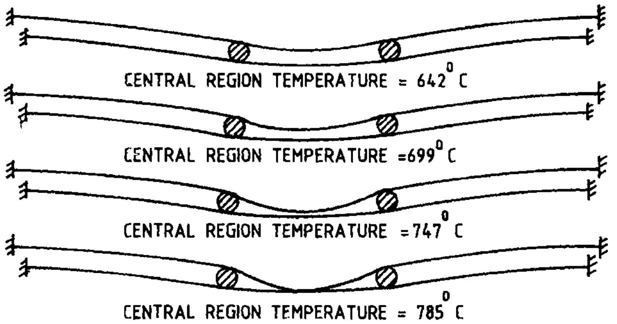
3. It may be noted here that the ballooning temperature of a typical pressure tube (Dutta,1993), is between 750 Deg. Cel. to 850 Deg. Cel., depending upon the remaining internal pressure after LOCA. In case the internal pressure is close to 10 MPa (i.e. drop in PHT pressure is insignificant following LOCA), the ballooning can occur at around 750 Deg.Cel. average pressure tube temperature. However, in case of very low internal pressure (Approximately 0.5 MPa), the ballooning temperature is close to 850 Deg. Cel.

4. Comparing point no. 2 and 3 of the present discussion, it may be said that for an axially restrained tube, the ballooning can preceed sagging only if drop in PHT pressure following LOCA is very low. However, for axially unrestrained tube, the ballooning can preceed sagging for the entire range of internal pressure ranging fron 10 MPa to 0.5 MPa.

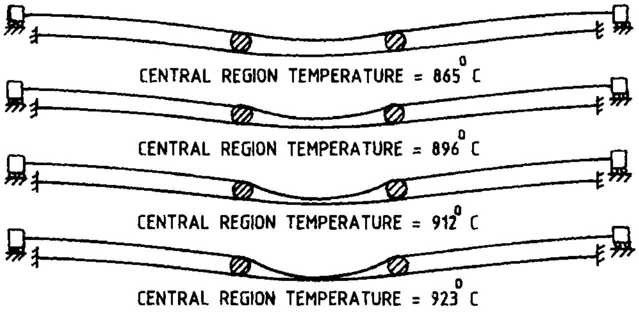
5. Hence, it is desirable to have axially unrestrained pressure tube if one aims for ballooning event to preceed sagging, this may lead to more heat transfer area.

REFERENCES

Dutta,B.K.,1993, SMIRT-12,Paper No.,J02/2
Shewfelt,R.S.W.,1984,JNM,p.p.228-235
Gupta,S.K.,1994,Personal Communications



PROGRESS OF AXIALLY RESTRAINED PRESSURE TUBE SAGGING WITH TEMPERATURE



PROGRESS OF AXIALLY UNRESTRAINED PRESSURE TUBE SAGGING WITH TEMPERATURE