Journal of Energy, Heat and Mass Transfer, Vol.15,285-291 (1993)

Temperature Transient Analysis of 500MWe PHWR End-Shield under Station Blackout Condition

D.S.CHAWLA, B.K.DUTTA, H.S.KUSHWAHA AND A.KAKODKAR

Reactor Engineering Division, Bhabha Atomic Research Centre, Trombay, Bombay

(Received 18 June 1991)

Abstract

The present paper describes the procedure adopted for computations of temperature transients in an End-shield of Pressurised Heavy Water Reactor (PHWR) under station blackout condition. The finite element modelling and heat loads with associated boundary conditions are shown. The temperature transients at different cross-section of End-shield is presented in graphical form if blackout persists for an hour.

Introduction

Pressurised Heavy Water Reactor (PHWR) has been adopted for the generation of nuclear power in India. In a PHWR, the nuclear heat is generated in the fuel located in horizontal coolant tubes. Heavy water coolant in primary heat transport (PHT) system flows through coolant tubes and acts as cooling medium. The coolant tubes in turn are located in a horizontal cylindrical vessel, called calandria. Calandria is filled with heavy water moderator. Circumferentially outer surface of calandria is in contact with light water, which is filled in between calandria and calandria vault. On either sides of calandria are located End-shields which are supported by the calandria vault. End-shields are used to provide necessary shielding against nuclear radiations and at the same time provide access to the reactor core for the purpose of refuelling. End-shields are cooled with light water to remove heat generated within its structure.

Under station blackout condition, circulation of End-shield cooling water, moderator, PHT and vault water will stop because there is no power supply. Under this condition temperature of the End-shield will rise due to heat generated by nuclear radiation due to decay of nuclear products, heat from moderator and PHT system. The cooling is available only by natural convection. The aim of present analysis is to compute the temperature transient in the End-shield and maximum temperature is attains if blackout persists for about an hour. This is necessary to assess requirement of fire fighting system to control the maximum temperature. The limit to maximum temperature depends on the deformations and thermal stresses produced in the structure.

Geometry and Boundary Conditions during Normal Reactor Operation

Figure 1a shows the isometric view of End-shield as seen through the fuelling machine valut. The schematic line diagram of End- shield is shown in Figure 1b. Each End-shield consists of two perforated tube sheets. The calandria side tube sheet is 0.055m thick whereas the thickness of fuelling machine side tube sheet is 0.08m. The outer profile of both the tube sheets are octagonal in shape. The maximum distance between two corners of the octagon is approximately 8.0 meter. These tube sheets are joined together by 392 lattice tubes. Beside this, there are two concentric cylindrical shells which surround all lattice tubes. These shells are welded to both the tube sheets. The outer shell is grouted in the wall of calandria vault for providing necessary structural support. The shielding is provided by steel balls and water mixture, which is filled between the two tube sheets. The water is constantly in circulation to act as a cooling medium for End- shield. Average

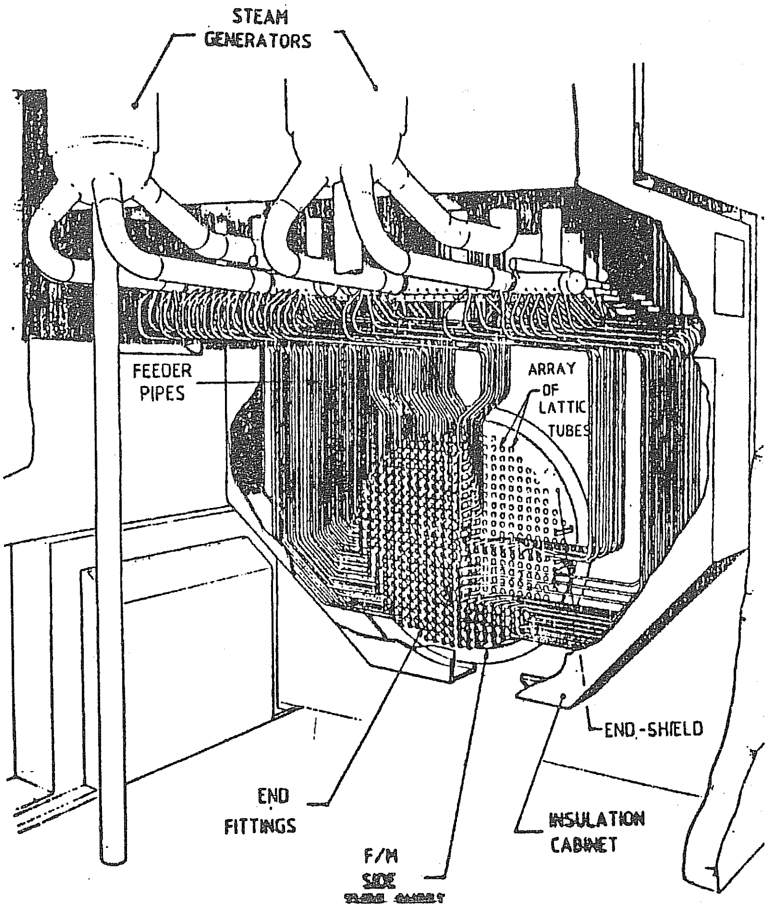

Fig. 1a: Isometric view of end-shield as seen through fuelling machine vault

Table 1: Bulk moderator temperature as a function of time after station blackout

Time	(min.)	0	1	2	3	5	10	15	20
Temp.	(deg.K)	348.0	349.25	350.1	350.9	352.34	355.5	358.3	360.9
Time	(min.)	25	30	35	40	45	50	55	65
Temp.	(deg.K)	363.3	365.6	367.9	370.0	372.0	374.0	375.9	379.5

Table 2: Calandria vault bulk temperature as a function of time after blackout

Time	(min.)	0	1	2	5	10	20	30
Time.	(deg.K)	327.0	327.03	327.05	327.09	327.19	327.39	327.59
Time	(min.)	40	50	60	70			
Time.	(deg.K)	327.8	328.02	328.25	328.49			

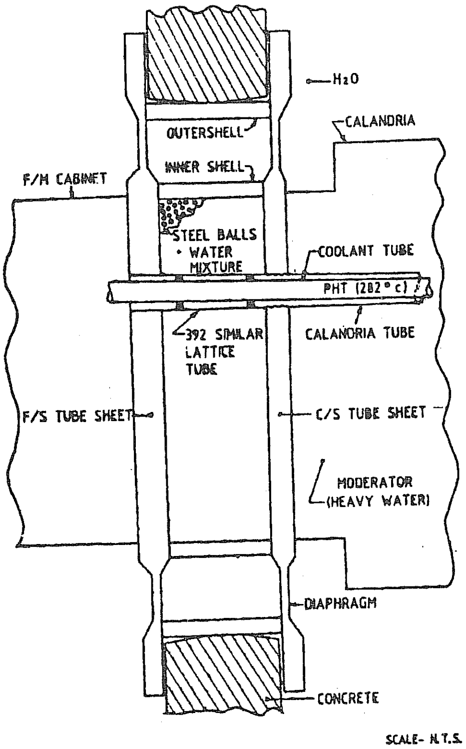

Fig. 1b: Schematic line diagram of end sheld

Table 3: Decay nuclear heat in end-shield as a fun of time ($x10^6 W/m^3$)

		After station blackout			
Distance from Cal. end ($x10^{-3}$m)	Normal Operation	0 Min	1 Min.	10 Min.	60 Min.
11.0	.26441	.0486	.02143	.013521	.009448
22.0	.23491	.03995	.01761	.0111114	.007767
33.0	.19191	.0312	.01375	.00868	.004617
44.0	.15191	.02375	.01047	.006607	.003470
55.0	.11941	.01785	.00787	.004966	.003470

Table 4: Coefficient of convective heat transfer (w/m^2 / deg.K)

Surfaces	L1, L3	L2	L10		S2	
Temp.K	h	h	Temp.K	h	Temp.K	h
335	00.00	000.00	347	000.00	327	000.00
343	615.35	523.26	354	665.58	337	678.14
363	900.00	1100.93	366	724.19	343	699.07
373	1000.46	1260.00	376	766.05	348	715.81
Surfaces		S3, S4	S5, S6	57, 58	S9	
Average	h	619.53	175.81	376.74	251.16	

temperature of End-shield cooling water is 335.5 degree kelvin.

Tube sheets of an End-shield are in contact with moderator on calandria side and are enclosed by feeder header insulation cabinet on Fuelling machine side. The portions of End-shield beyond inner shell are in contact with calandria vault water on calandria side and are open to fuelling machine vault water on the other side. During normal operating condition, moderator and calandria vault water are circulated through external cooling circuit to maintain bulk temperature of 348 degree and 327 degree kelvin respectively. Therefore temperature of various parts of End-shields are governed by the temperature of End-shield cooling water, moderator, PHT coolant and calandria vault water. During normal operation of reactor, the heat loads are nuclear heat, heat from the PHT system and insulation cabinet.

Station Blackout Conditions

Under station blackout condition, the circulation of End-shield cooling water along with process water will stop because there is no power supply. Similarly circulation of moderator and calandria vault cooling water along with their process water will also stop. Average temperature of PHT system (555 degree kelvin) will be maintained by controlled discharge of secondary side steam [2]. An approximate calculation shows that End-shield cooling water temperature will rise at the rate of 4.0 degree kelvin per hour in this condition. Temperature of moderator and calandria vault water will also rise with time. The temperature rise in moderator and calandria vault water as a function of time is given in Table-1 and Table-2 respectively. These temperatures are calculated by an overall heat balance in the respective system. Under station blackout condition though the reactor is tripped decay nuclear heat will be generated in End-shield. Nuclear heat generation data was acquired from reference [3]. In this reference heat generation has been calculated by using computer code SHELTEX. Heat generation is calculated for normal operating condition and also at the instant of reactor trip due to station blackout (i.e. at 0.0 minute of our calculations). Subsequent nuclear heat generation at different time intervals during blackout is calculated by using the formula $Ht = H0x(t)^{-0.2}$, where Ht is decay nuclear heat generated at some location at time t (in seconds) and HO is the nuclear heat generated at time 0.0 at the same location. This heat as a function of time is shown in Table- 3.

Geometrical Modelling and Material Properties

Due to geometrical complexity, it is necessary to go for a 3-D discretization of End-shield if modelled as a whole. This will require large computer time and cost will be prohibitive. To do the analysis in a reasonable computation effort, the present geometry is modelled in two parts. The array of lattice tubes which forms the major part of the tube sheets is a repeated regular pattern. Hence one of the lattice is modelled. Assuming no heat flows along the boundaries the geometry is further simplified by assuming it as an axisymmetric body. The discretization involves 507 nodes and 412 four noded axisymmetric elements. The second model is that of the periphery of End-shield (other than regular array of lattice tube). The geometry is again approximated as an axisymmetric body. The modelling is done by using 176 four noded axisymmetic elements and 269 nodes. Finite element mesh of these two models are shown in figure 2a and 3a respectively.

Material of End-shield is 304L stainless steel. Average conductivity of Material is taken as 15.5698 W/m/deg.K. The density and specific heat are 7817 Kg/m^3 and 460.2 J/Kg/deg.K respectively.

Heat Loads and Thermal Boundary Conditions

As mentioned earlier under station blackout condition, heat loads to End-shield are decay nuclear heat generated in the End-shield, heat from PHT system and insulation cabinet. Due to PHT system the concentrated heat flux at bearing locations P1 and P2 (figure 2a and 3a) is 34.7421 W/rad and 23.922 W/rad respectively and heat flux on the surfaces L4, L5, L6, L7, L8 and L9 are 2927.93, 2436.28, 2515.81, 1770.7, 2863.26 and 1814.86 W/m^2 respectively. Heat transfer to or from End-shield will also take place at the surfaces which are in contact with moderator, calandria vault water and End-shield cooling water. This heat transfer is due to natural convection as there is no force circulation. The coefficients of convective heat transfer for various surfaces were calculated analytically and are shown in various surfaces were calculated analytically and are shown in Table-4. The corresponding surfaces are shown in figures 2a and 3a.

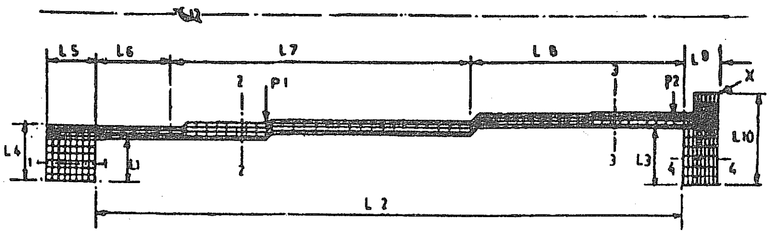

Fig. 2a: Finite element mesh of lattice tube of 500 MWe end-shield

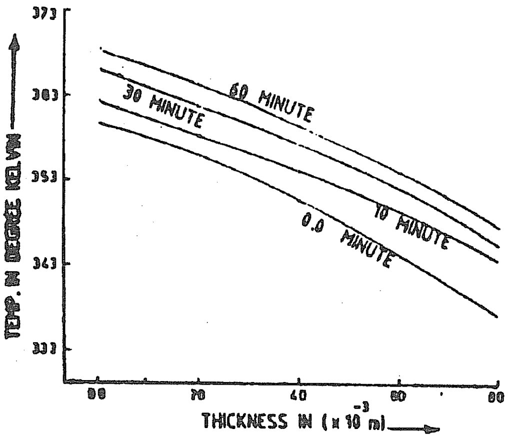

Fig. 2b: Temperature transient at section (1-1)of lattice tube under station blackout conditions

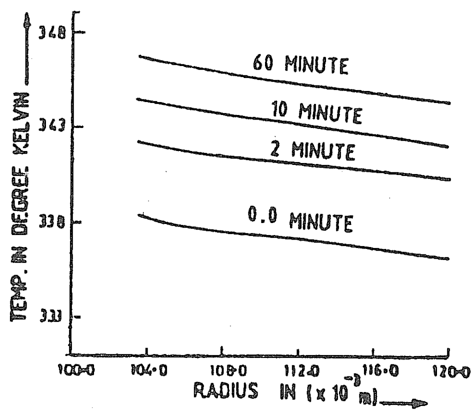

Fig. 2c: Temperature transient at section (2-2) of lattice tube under station blackout conditions

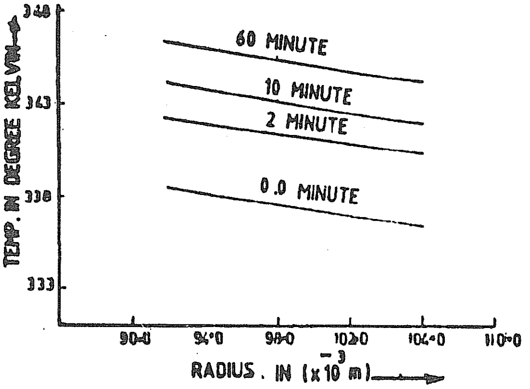

Fig. 2d: Temperature transient at section (3-3) of lattice tube under station blackout conditions

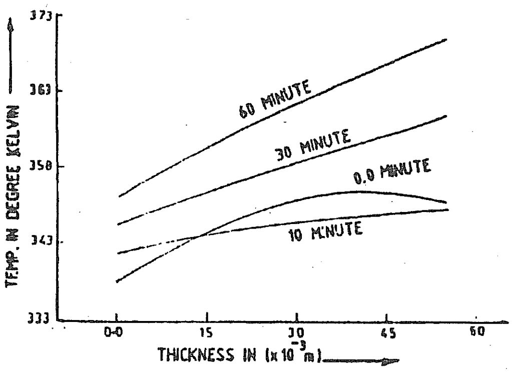

Fig. 2e: Temperature transient at section (4-4) of lattice tube under station blackout conditions

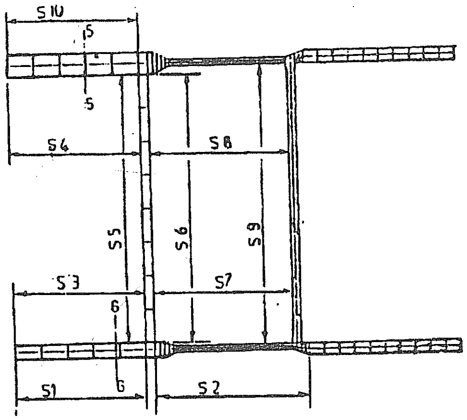

Fig. 3a: Finite element mesh of outer periphery of 500 MWe end-shield

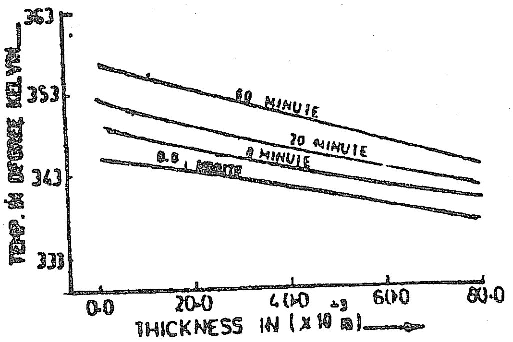

Fig. 3b: Temperature transient at section (5-5) of 500 MWe end-shield under station blackout condition

Computer Code 'WELTEM'

In the present calculation of temperature transient the computer code 'WELTEM' [1] is used. This is a finite element computer code for thermal analysis in 2-D bodies under steady state and/or transient condition. Any of the solution technique such as Crank Nicholson, Galerkin, Backward difference etc. can be used depending upon user's choice. It can consider radiative and convective heat transfer as boundary conditions. Convective heat transfer coefficient may be input as a function of temperature or time. It is also possible to consider the nonlinearity due to phase change and change in material properties with temperature.

Transient Analysis and Results

The variation of temperatures as a function of time was computed. The results are plotted across different thicknesses for certain selected locations.

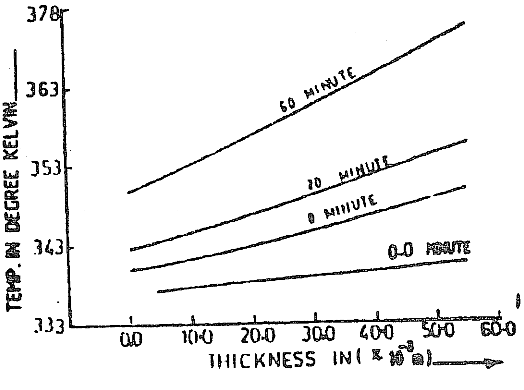

Fig. 3c: Temperature transient at section (6-6) of 500 Mwe end-shield under station blackout condition

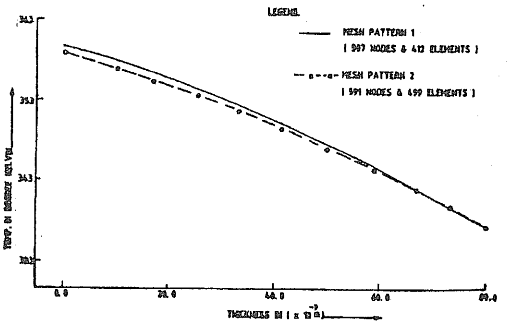

Fig. 4: Comparison of temperature distribution at location 1-1 of lattice tube model at 0.0 minute for two different mesh patterns

These locations are shown in figures 2a and 3a. The results are shown in figures 2b to 2e and 3b to 3c.

Mesh Convergence Study

A mesh convergence study has been performed to see the effect of mesh refinement. The study has been carried out for lattice tube portion only. This is because the maximum temperature and high rate of temperature change is observed in this region. A new mesh was prepared for lattice tube model (figure 2a) by using 591 nodes and 49 elements. Hence number of nodes has been increased by 16.6% in comparison to our previous model. This model has been used to compute temperature distribution at the beginning of the temperature transient. The temperature distribution at the beginning of temperature transient for two different models compared for location 1-1 in figure 4. The percentage variation in maximum temperature has been found to be 1.2%. This shows that mesh convergence has been achieved and further refinement in the mesh will not cause any appreciable change in the result.

Discussion and Conclusion

Temperature transient in End-shield was computed under station blackout condition. The computation is done for an hour because it is felt that during this time fire fighting system will be made available to limit the temperature by external cooling. Figure 2b, 2c, 2d, 3b and 3c show the monotonic increase in temperature at different locations. Figure 2e shows a temperature variation at 0.0 minute which is entirely different then its subsequent transient. The reason for this is as follows. The section 4-4 lies on the calandria side tube sheet. There is large internal heat generation when reactor is at full power. Hence steady state temperature distribution across the thickness of this tube sheet when reactor is at full power is as there in figure 2e. This temperature distribution is initial temperature (ie. at 0.0 minute) for our subsequent transient calculation. When blackout persists nuclear heat generation in the tube sheet is small as reactor is tripped and the temperature at section 4-4 is governed by heat transfer along boundaries. This tries to flatten temperature first then it shows monotonic increase. The maximum temperature and maximum rate of increase in temperature is obtained as 37 3.668 degree kelvin and 18.57 degree kelvin/hour respectively at location x of figure 2a.

Reference

1. Dutta, B.K., Kushwaha, H.S., Kakodkar, A., Computer program 'WELTEM' (Analysis of two dimensional heat transfer problem by finite element technique) Theory and user's manual, BARC internal report, B.A.R.C./ 1-671 (1981).
2. Seth, V.K., A note on stress analysis of End-shield under station blackout condition 500MWe group, NPC,5NP-I/5NP-C/31610/87/B6824
3. Dhawan, M.L., A note on nuclear heat generation in End-shield (Personal Communication).