THERMAL ANALYSIS OF BIOLOGICAL SHIELD OF FAST BREEDER TEST REACTOR

by

D. Saha, V. Sarda
Reactor Engineering Division
Bhabha Atomic Research Centre
Government of India, Bombay

Presented at the Third National Heat and Mass Transfer Conference held during December 11-13, 1975 at the Indian Institute of Technology, Bombay.

INIS-mf--3478 IN7700131

HMT-96-75

THERMAL ANALYSIS OF BIOLOGICAL SHIELD OF FAST BREEDER TEST REACTOR

D. Saha, V. Sarda
Reactor Engineering Division
Bhabha Atomic Research Centre
Government of India, Bombay

Abstract

A design optimisation of the biological shield of Fast Breeder Test Reactor was carried out using Computer Code HEATING. The effect of different heat sources, variation of coolant tube pitch circle radius, coolant temperature, angular pitch of coolant tubes and thermal conductivity of concrete on the temperature distribution within the shield has been studied.

I. INTRODUCTION:

The purpose of the biological shield surrounding a nuclear reactor is to attenuate the neutron and photon emission from the reactor down to a relatively safe biological level at the outer periphery of the shield. Absorption of neutrons and photons in the shield material is accompanied by liberation of energy which appears as heat. This internal heat source causes temperature rise in the shield. The external heat sources may also contribute towards shield temperature rise. Hence, adequate cooling is required to keep the shield temperature below the maximum permissible limit in order to ensure physical integrity of shield material. This necessitates evaluation of temperature distribution within the shield. As an essential aspect of the design of the biological shield of Fast Breeder Test Reactor, the effects of different types of heat sources and variation of certain design parameters on the temperature distribution in the shield have been studied using the computer program HEATING.

II. DESCRIPTION OF THE BIOLOGICAL SHIELD:

The biological shield is hollow-cylindrical in shape and located concentrically with and around the reactor vessel. The cross sectional view of a symmetry sector of the shield has been depicted in fig. 1a. It consists of two parts, an inner biological shield made of 2% borated concrete and an outer biological shield made of ordinary concrete, separated by an air gap of width 0.05 meters which acts as a bond breaker. Vertical coolanttubes are embedded in the inner biological shield in a circle at regular interval. Alternate tubes are connected to two independent coolant circuits.

III. HEAT SOURCE:

Heat sources causing temperature rise in the shield can be categorised as follows:

1. Internal Heat Source: Energy absorbed in the shield from neutrons and photons is ultimately converted to heat. The radial variation of heat generation rate in the shield is almost exponential in nature as shown in fig. 1b. Heat generated in the outer biological shield is insignificant and has been neglected in the present analysis.

2. External Heat Source: The biological shield receives heat from the high temperature reactor vessel also, which is incident on the inner wall of the shield. The magnitude of heat flux is 0.55 Kw/m^2.

IV. DESIGN PARAMETERS STUDIED:

Effects of variation of the following parameters on the shield temperature distribution have been studied:

1. Coolant Tube Pitch Circle Radius: The radial distance between the plane of maximum heat generation rate (inner wall of shield) and coolant tube is determined by the coolant tube pitch circle radius. The effect of changing the pitch circle radius from 2.47m to 2.48m has been studied.

2. Angular Pitch of Coolant Tube: Angular pitch of coolant tube is 2 degrees. Since, in the event of failure of one coolant circuit the alternate tubes will not receive any coolant, the effective angular pitch will become 4 degrees. This necessitated evaluation of temperature distribution for angular pitch of 2 degrees and 4 degrees.

3. Coolant Temperature: To check the necessity of using chilled water in the cooling system, the analysis was carried out for coolant temperatures of 15°C (for chilled water supply) and 40°C (for ordinary service water supply).

4. Thermal Conductivity of 2% Borated Concrete: It is difficult to ascertain the exact thermal conductivity of this special high-density concrete at operating conditions. Hence the analysis has been carried out for two extreme values of thermal conductivity, 1.5 and 4.8 watts/m°C, to take into account this uncertainity.

V. COMPUTER PROGRAM HEATING:

The program 'HEATING' [1] is a generalised heat conduction code which can solve steady state and/or transient heat conduction problems. This code was originally developed for IBM Computer and has been adapted for BESM-6 and CDC-3600 Computers. Analysis of one, two or three dimensional systems in either rectangular or cylindrical co-ordinators can be carried out using the program. The program accepts four types of boundaries, viz., insulated, contact, convective heat transfer and controlled temperature boundaries. Heat generation rates may be time and position dependent. The code assumes that the heat transfer within the material follows Fourier's Law of heat conduction and calculates temperature distribution by solving the partial differential equation by numerical method. The equations used, the limitations and scope of the program are given in reference 1 & 2.

VI. INPUT PARAMETERS FOR THE CODE 'HEATING' :

For the present study the code could not be used straight away. Some adjustments and modifications in input parameters had to be carried out which are discussed below:

1. Simulation of Incident Heat Flux: The PHWR biological shield has heat flux incident on it from the calandria vessel which is at high temperature. The program does not accept a boundary with heat flux incident on it straight away. Therefore a fictitious region is considered at the inner surface of the shield as shown by dotted lines in fig. 1a. The inner surface of this region is assumed to be an adiabatic one. A calculated heat generation rate is ascribed to this region which results in a net heat generation in this region equal to the net amount of heat incident on the shield inner wall. Again, proper simulation of normal incident heat flux requires the isotherms in the fictitious region to be parallel to the fictitious region-shield interface. To achieve this a very low value of thermal conductivity (1/100th of shield material) was assigned to this region. Isotherms thus achieved have been compared with those obtained with thermal conductivity of fictitious region equal to thermal conductivity of concrete in fig. 2a. It can be seen that isotherms obtained are parallel to the fictitious region-shield interface in the case of low thermal conductivity of fictitious region.

2. Boundary Conditions: At the outer surface of biological shield a controlled temperature boundary at 35°C was specified. However the code calculates heat flow rate through convective heat transfer type of boundary only. It also calculates total heat generation rate in the specified configuration. In the absence of any controlled temperature type of boundary (for which the code does not calculate the heat flow rate) total outward heat flow rate must be equal to the total heat generation rate. This provides a convenient way of checking the accuracy of results. For this reason, at the outer surface of the shield, instead of specified isothermal boundary at 35°C,

a convective heat transfer type of boundary with high film heat transfer coefficient (3000 w/m^2°C) and a bulk temperature of 35°C was assumed. Fig. 2b shows nodal temperatures at the outer periphery for a typical case and it can be seen that with this assumption, practically an isothermal surface having a temperature almost same as the specified one has been achieved.

An adiabatic boundary has been considered at the inner surface of the shield. To the coolant pipe a calculated value of film heat transfer coefficient (3640 w/m^2°C) was assigned. Longitudinal variation of coolant temperature, being small, was neglected and the coolant∠temperature was used for the ∠outlet analysis.

3. Convergence Criterion: The code calculates temperature of each node by performing a heat balance on the node taking into account the temperatures of adjacent nodes and conductances in between the nodes. These nodal temperatures are revised in the successive iterations till the variation in the nodal temperature in the two successive iterations is less than the specified convergence criterion at all the nodes. The convergence criterion affects the accuracy of results and computing time in opposite directions i.e. decrease in the value of convergence criterion improves accuracy of results but also increases the computation time. Value of convergence criterion equal to 0.00002 was used which gave less than 0.5% error in heat balance which was accepted. For a typical case, time taken by CDC-3600 computer with this value of convergence criterion was roughly 11 minutes.

VII. RESULTS AND DISCUSSION:

In order to optimise values of design parameters a total of twelve cases were studied and the values of design parameters for these cases have been listed in the table in fig.3. For the cases analysed considering the presence of air gap (cases 6 to 12) heat transfer between the inner and outer shield due to natural convection of air and radiation has been neglected to obtain conservative results. Figures 3 and 4 depict temperature profiles along the ∠x - x (fig. 1a) for cases 1 thru 12. For the sake of ∠ line clarity, temperature distribution in the inner shield and only a small part of outer shield are shown in these figures.

The analysis shows that the decrease in thermal conductivity increases the temperature gradients inside the pitch circle to a great extent whereas temperature gradients outside the pitch circle do not change significantly (9-10*, 11-12*). Comparison of curve 8 with 9 shows that an increase in angular pitch increases temperatures but reduces radial temperature gradient. It is seen that the high temperature in the region inside the pitch circle is mainly due to external heat source, whereas the internal heat source plays the dominant role in raising the temperature of the region beyond the pitch circle (1-3*, 2-4*). The analysis further reveals that for only internal heat source, increase in pitch circle radius causes temperature rise inside the circle but reduces the temperature outside the circle (3-4*). But when only external heat source is present temperatures in both the regions increase with increase in pitch circle radius (1-2*). Though it is evident from the curves in fig.3 that a reduction of pitch circle radius reduces the maximum temperature of shield, the lower limit of pitch circle radius was fixed at 2.47m due to structural limitations. The analysis also shows that with change in coolant temperature, temperature gradients in the inner shield do not change appreciably except near the outer edge (9-11*, 10-12*). Analysis of the cases 1,2,5,6 and 12 reveals the necessity of keeping provision for chilled water supply as the maximum shield temperature exceeds the limiting value (70°C).

ACKNOWLEDGEMENT:

The authors acknowledge the help rendered by Shri K.C. Khandelwal of Fast Breeder Test Reactor Project in preparing the paper.

REFERENCES:

1. T.B. Fowler, E.R. Volk "Generalised Heat Conduction Code for the IBM-704 Computer" ORNL-2734.
2. R.R. Liguori, J.W. Stephenson, "The Heating Program". ASTRA, Inc., Raleigh, North Carolina, 1961. ASTRA 417-5.0

* Comparison of curve x with y

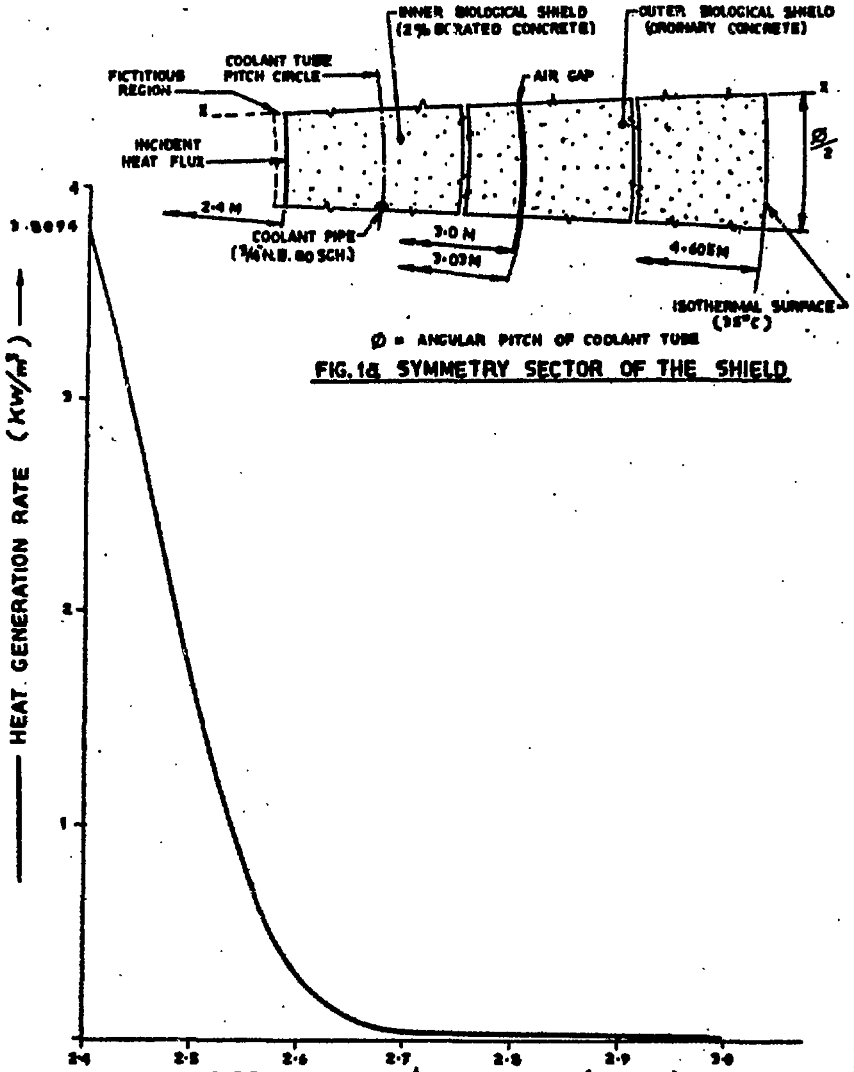


FIG. 1a SYMMETRY SECTOR OF THE SHIELD

FIG. 1b RADIAL VARIATION OF HEAT GENERATION RATE

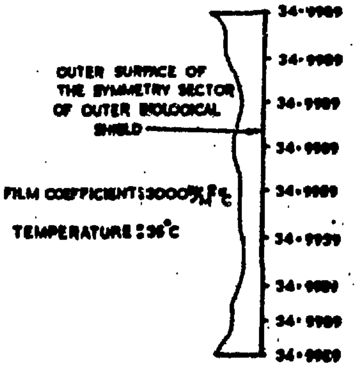


FIG. 2b (SCALE 1:1)

TEMPERATURE DISTRIBUTION IN THE OUTER ISOTHERMAL SURFACE.

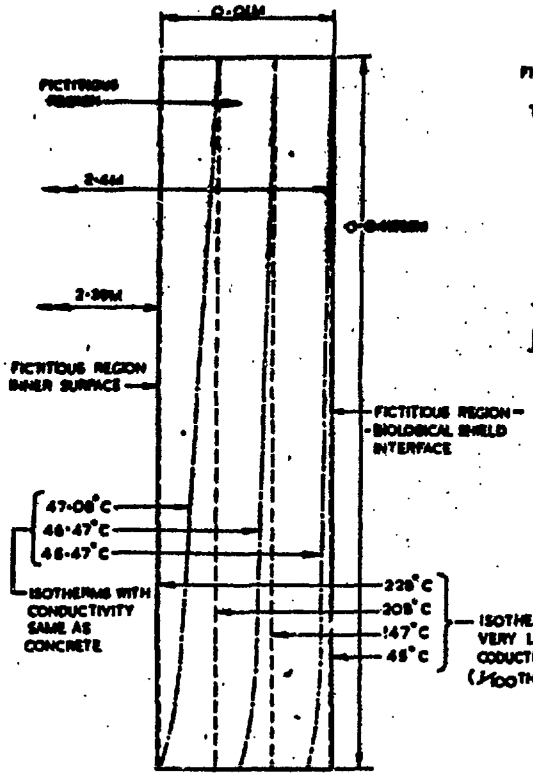
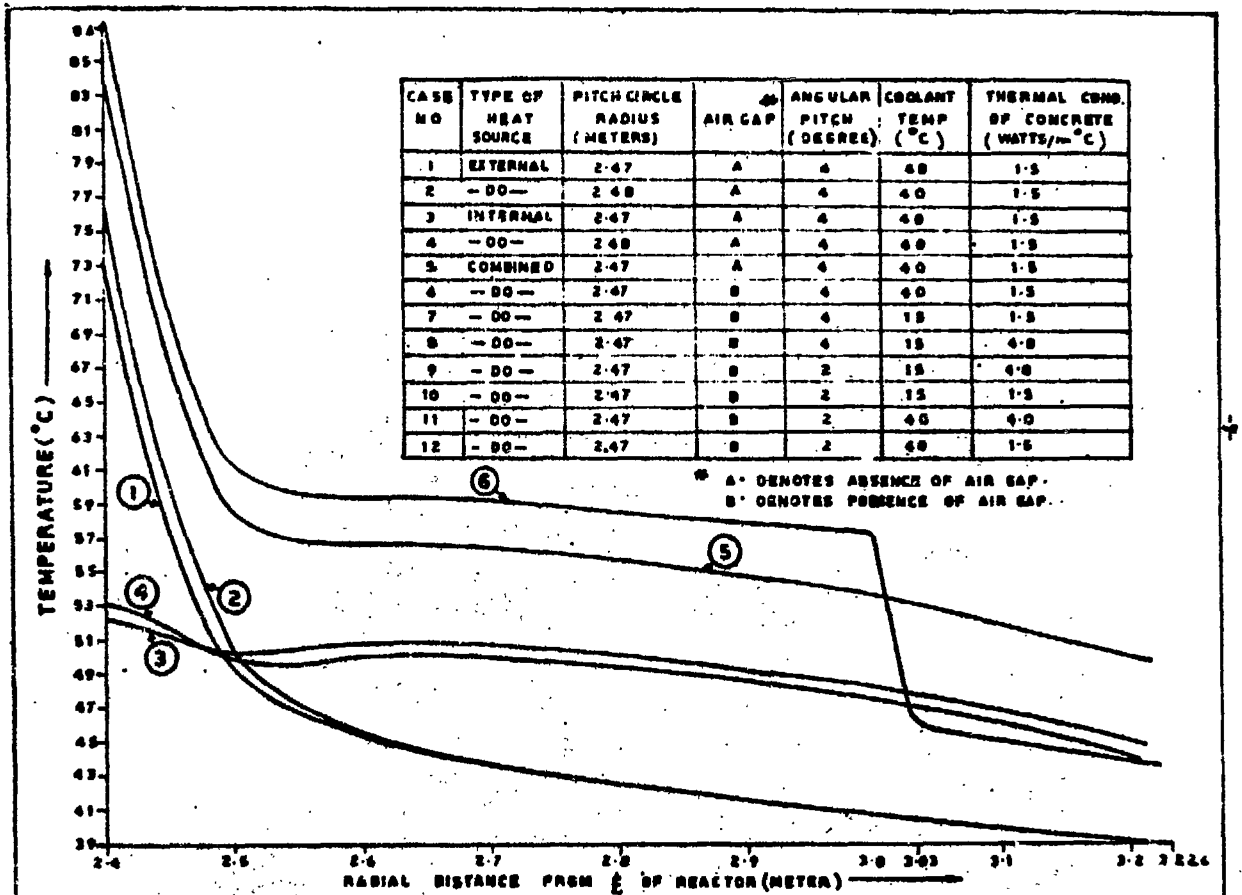


FIG. 2a (SCALE 4:1)

ISOTHERMS IN A SYMMETRY SECTOR OF FICTITIOUS REGION



CASE NO	TYPE OF HEAT SOURCE	PITCH CIRCLE RADIUS (METERS)	* AIR GAP	ANGULAR PITCH (DEGREES)	COOLANT TEMP (°C)	THERMAL COND. OF CONCRETE (WATTS/m-°C)
1	EXTERNAL	2·47	A	4	40	1·5
2	—DO—	2 48	A	4	40	1·5
3	INTERNAL	2·47	A	4	40	1·5
4	—DO—	2 48	A	4	40	1·5
5	COMBINED	2·47	A	4	40	1·5
6	—DO—	2·47	B	4	40	1·5
7	—DO—	2 47	B	4	15	1·5
8	—DO—	2·47	B	4	15	4·0
9	—DO—	2·47	B	2	15	4·0
10	—DO—	2·47	B	2	15	1·5
11	—DO—	2·47	B	2	40	4·0
12	—DO—	2·47	B	2	40	1·5

* A· DENOTES ABSENCE OF AIR GAP·
B· DENOTES PRESENCE OF AIR GAP·

FIG: 3 TEMPERATURE PROFILES FOR CASES 1 THRU 6

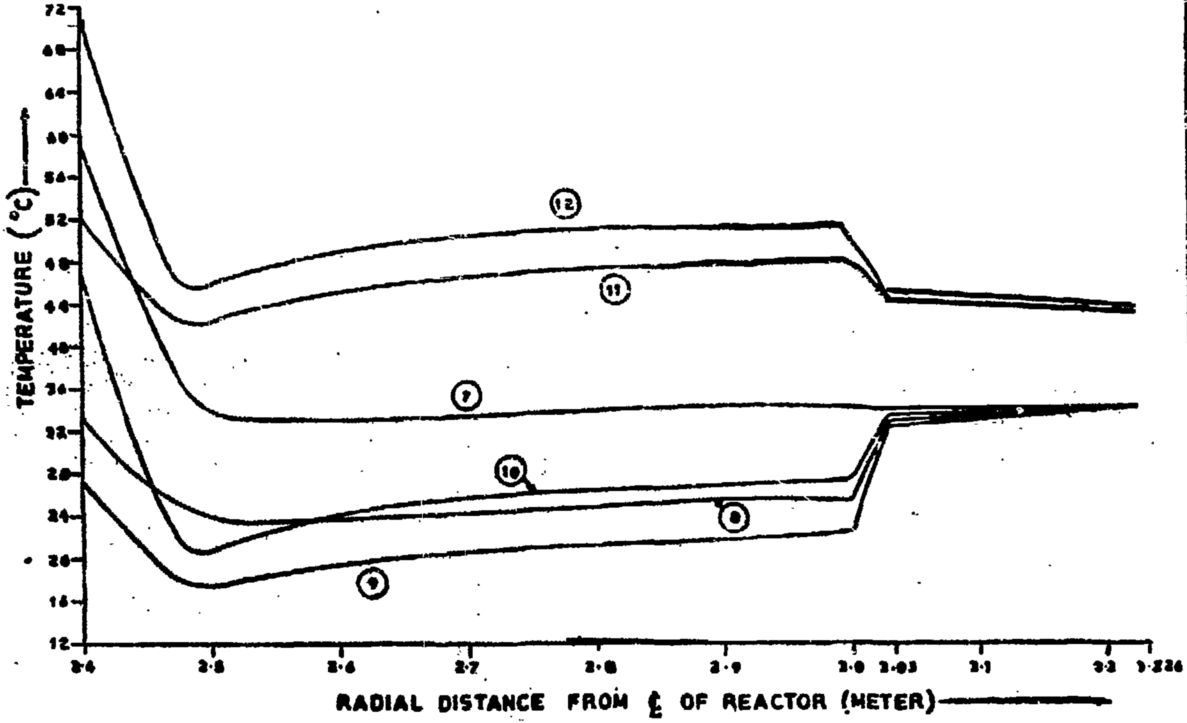


FIG. 4 TEMPERATURE PROFILES FOR CASES 7 THRU 12