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K-REACTOR - LOSS OF COOLANT
TEMPERATURE STUDY OF THE BIOLOGICAL SKIN

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K-REACTOR - LOSS OF COOLANT
TEMPERATURE STUDY OF THE BIOLOGICAL SKIN

INTRODUCTION

It is of interest to investigate the time following a complete loss of coolant incident when the pile would be exposed to the ambient air. This is of concern due to the fast propagation of graphite burn-up when brought in contact with air at or above the operating temperature of the graphite (1292°F). One possible way conjectured in which the pile can be exposed to the surrounding environment is for the centering flange gasket (neoprene) or the bellows gas seal (silicone) to fail.⁽¹⁾ This particular study was concerned with the temperature transient of the seals following the extreme accident condition of complete loss of coolant.

This problem is one of many being investigated in a concentrated effort to re-evaluate the effectiveness of the confinement system of the smaller reactors. The maximum credible accident for the DUN operated production reactors has been the loss of coolant to a single cross header. The Hanford philosophy of reactor safety has been the provision of reliable methods of cooling fuel in all accident situations short of severance of the primary coolant piping or destruction of the reactor building.⁽²⁾ However, for the present study the more serious accident of complete loss of coolant was investigated. This far exceeds the postulated maximum credible accident stated above, so therefore the results will be based on a highly hypothetical situation.

The fuel melt time following a complete loss of coolant and the corresponding heat-up of the graphite has already been investigated.⁽³⁾

A computer code (TIGER-5) was used to calculate the temperature transient of the biological and thermal shield region following the loss of coolant accident.

RESULTS

The temperature transient of the region between the reflector and the outside skin of the biological shield following the loss of coolant was calculated using the TIGER-5 computer code. The TIGER-5 program uses the method of finite differences to solve the differential equation of heat transfer.

The results of the calculations are shown in Figure 1. The temperature transient for the seals show that there will be no difficulty in maintaining the integrity of the pile atmosphere. Also shown on the plot are the temperature transients of the process tube, graphite tube block, and graphite filler block in the region of the first fuel slug. These latter calculations were performed on a computer code called ALOC⁽⁴⁾ developed to calculate fuel temperature transients following a loss of coolant.

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FIGURE I. TRANSIENT TEMPERATURE DISTRIBUTION

As can be observed from the results, the seal temperature drops during the transient period of interest. The drop in temperature is not too surprising a result when one considers from where the heat source to the seals is coming from. The heat to the seals can be broken down as coming from two sources. One source of heat is the process water and the other is from heat generated in the pile transmitted through the thermal and biological shields. Calculations show that during normal operation, approximately 85 percent of the heat to the seals comes from the process water and 15 percent from the pile generated heat.

DISCUSSION

Modeling of the problem was performed on a heat transfer computer code called TIGER-5.⁽⁵⁾ TIGER is a digital computer program which is used to solve the steady-state or transient temperature distribution in any three-dimensional configuration. The heat source may be externally conducted or internally generated. Since there is essentially no internal heat generation in the thermal and biological shields⁽⁶⁾ and very little in the reflector region the heat source is externally conducted. In addition to the solving of heat conduction in structural elements, TIGER may also be used in such cases as forced convection, free convection, or radiation where the output will yield temperatures and heat fluxes for points representing the surface of the structure.

Input to the program consists of structural geometry, physical properties, boundary conditions, and internal heat generation rates. The program solves the transient heat conduction equations for a three-dimensional field using a first forward difference method. Since the method of solution is based on nodal representation of the geometry, any type of configuration can be handled through the evaluation of the "equivalent resistances" of the nodal connectors, i.e., electrical analogy.

Figure 2 shows a cross-sectional view of the model used in the study. The cylindrical geometry represents a typical lattice cell of the pile from the region of the first fuel slug through the reflector, thermal, and biological shields to the face of the pile. Due to the symmetry involved and the limitation of the program as to the total number of allowable nodes a 90 degree cut was taken axially through the lattice. Between the reflector, thermal and biological shields there are gaps in which the pile atmosphere flows.

The material makeup of the various regions of Figure 2 are presented in Table I. The physical properties of these materials' input in the TIGER-5 program are given in Table II.

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Biological Shield

K - connector: Geometric

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Stop

Model - Nodal Distribution

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TABLE I

MATERIAL MAKEUP OF THE MODEL

Reflector	Graphite
Thermal shield	Cast iron
Biological shield	Concrete
Tie strap	Carbon steel plate
B tube	Carbon steel (1020)
Donut rings	Cast iron
Sleeve tube	Carbon steel (1020)
Gun barrel	Carbon steel (1020)
Process tube	Zircaloy-2
Pile atmosphere	50% He-50% N ₂

TABLE II

PHYSICAL PROPERTIES OF MATERIALS

<u>MATERIAL</u>	<u>Heat Capacity</u> <u>Btu/lb °F</u>	<u>Density</u> <u>Lb/in³</u>	<u>Conductivity</u> <u>Btu/hr ft° F</u>
Graphite	0.1721	0.0820	17.0
Cast iron	0.1189	0.2655	34.83
Concrete	0.1360	0.2131	0.933
Carbon steel	0.1200	0.2882	12.579
Zircaloy-2	0.0850	0.2366	8.0
Pile gas	1.0135	2.578 x 10 ⁻⁵	0.0748

The boundary conditions at the reflector end of the model were calculated with the aid of Reference 4 and act as the driving force for the transient part of the problem. The boundary condition at the face of the reactor is the large volume of circulating air immediately adjacent to the outside of the biological shield. The reflector end acts as the source and the ambient air acts as the sink. The inner and outer axial boundaries of the lattice are adiabatic planes which implies no net heat transfer across the lattice boundary. For the steady-state calculation process water flows down the process tube and the inner lattice boundary is no longer adiabatic. However, for the transient calculations, the assumption of the inner boundary being an adiabatic plane is permissible.

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The results of the calculations show that the seal temperature on the biological shield and sleeve will not heat up but rather drop in temperature until such time as the internal heat from the pile and particularly the first fuel slug and reflector region moves by the laws of energy transport to the skin of the biological shield. The slow transport of energy to the face of the biological shield is due to the large resistance of the materials. The resistance is calculated by the simple expression $(hA)^{-1}$, where h is the heat transfer coefficient and A is the cross-sectional area normal to heat flow. The resistances to heat flow are large for the concrete (biological shield) and the pile atmosphere regions because the thermal conductivities for these materials are very small. The resistances of the process tube, B tube, and gun barrel assembly are large because of the very small cross-sectional area normal to the heat flow.

The time at which the seal temperatures start to rise had not been reached as of 300 minutes (Figure 1). Due to the slow running time of the program and that times beyond 300 minutes were of little interest the calculations were stopped. It is anticipated that by the time indicated some corrective action will have been taken.

The drop in temperature is a result of the equilibrium heat being removed by the heating and ventilating system before the heat transporting from the reflector region reaches the biological skin. The circulating air of the heating and ventilating system has an average flow rate of 99,000 lb/hr⁽⁷⁾ past the rear face enclosure of the K-Reactors. The air flow in this region is operating approximately 16 percent above design conditions.

As stated in the results, the drop in seal temperature of the biological shield is not a surprising result when consideration is given to the source of heat to the seal. The heat can be thought of as coming from two sources. First the process water heat transferred through the process tubes, etc., at the face of the pile, and secondly, the heat generated within the pile and particularly the reflector region transferred by the laws of energy transport to the skin. Calculations show that during normal operation, approximately 85 percent of the heat to the seals comes from the process water and 15 percent from the center of the pile. The heating and ventilating system is adequate to remove the skin heat following a loss of coolant incident. Due to the small rate of rise of temperature (driving force) the added heat rate above 15 percent is dissipated by the heating and ventilating system, at least for the 300 minute period investigated. It is anticipated, however, that the temperature will rise somewhat at a later time.

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CONCLUSION

It is concluded from the foregoing results that seal temperatures will not be a problem following a loss of coolant incident. That is, the problem of seal failure to allow the surrounding environment (air) to enter the pile does not seem to be as serious a problem as conjectured.

Of course, the foregoing results are strictly from a thermal viewpoint and does not preclude the possibility of a pressure failure of the seals.

John A. White

Reactor Design Analysis
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2. DUN-200, "Status Report of Confinement Studies Douglas United Nuclear Operated Reactors," N.F. Fifer and J.R. Spink, November 30, 1965 (Secret).
3. DUN-407, "Fuel Melting Time Following A Loss of Coolant," D.E. Bush, January 3, 1966 (Secret).
4. ALOC "After Loss of Coolant," a computer code developed by D.E. Bush to determine fuel temperature transients following a loss of coolant.
5. TIGER-5 "Temperature from Internal Generation Rates," a three-dimensional heat transfer code first developed by A.P. Bray of Knolls Atomic Power Laboratory as TIGER. Revisions and modifications to the program have been made to increase the efficiency and versatility - TIGER -5.
6. Personal communications with H.P. Hamric, Research and Engineering, DUN.
7. See Drawing H-1-19727 through H-1-19729.

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