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MEMORANDUM

TO: Nuclear Safeguards Committee

FROM: R. A. Karam RAK

SUBJECT: Bismuth Block Leak and What To Do About It

Dr. Bernd Kahn was kept informed about the leak of the coolant, light water, used to remove the heat deposited by gammas, neutrons and activation products in the inner bismuth block of the Georgia Tech Research Reactor (GTRR). Dr. Kahn was briefed on 9/18/89 with regard to the leak location and what is being done to fix it.* Also a subcommittee composed of Dr. Kahn, Dr. Desai, and Dr. Mahaffey, of the Nuclear Safeguards Committee met October 19, 1989 with Dr. Revsin and Dr. Karam to consider possible solutions to the problem of the bismuth block leak.

The subcommittee was presented with a plan for a temporary solution. The solution consists of installation of a catch system which would collect the leaking water and channel it to a condensate pump. The pump would circulate this water through a 5 μ filter and return it to the cooling water storage tank (see attached blue print). Additionally the cooling water system for the bismuth block will be deionized by an ion exchange column.

The temporary solution is recommended for the following reasons:

1. Attempts at repair by application of epoxy to the block did not work.

2. Dose rates at the leaking block surface were ≈5 R/hour. This level of radiation limits the amount of time a person can spend in the vicinity of the block.

*The fix attempted was to use epoxy in combination with glass fiber. Once the epoxy hardened, a stop leak compound was added to the circulating water. This recipe for fixing the leak was used effectively the last time the bismuth block leaked, August 12, 1983. This time however the leak was not stopped.

3. The leaking water does not present a health hazard. Activity in the water is limited to 1.8×10^{-3} µCi/cc ^{3}H and 2.2×10^{-6} µCi/cc ^{65}Zn.

4. A class in reactor laboratory (the course is designed to measure reactor parameters) comprised of 16 N.E. students needs the reactor to finish the course.

5. The Center has several contractual obligations to run the reactor. One includes a contract with Savannah River for $75K.

6. The Center is negotiating with DOE for a short duration contract with large amount of dollars (≈$300K). This contract is essential for the Center's continued existence.

Questions raised by the subcommittee concerning the temporary solution were as follows:

1. The radioactivity content of the bismuth block cooling water needs to be evaluated.

2. Water - Bismuth block interaction needs review. Specifically, (a) has shielding properties of the block been affected?; (b) Are there any chemical reactions between water and bismuth or water and magnesium?

3. Heat removal with reduced flow should be evaluated. Estimates of temperature rise without cooling and with 3/4 normal flow of cooling, should be made.

4. Plan a test run for approximately one hour.

5. Permanent correction to problem should be assessed.

PERTINENT DATA ABOUT THE BISMUTH BLOCK AND THE COOLING SYSTEM

- Normal flow condition of cooling water is 1.25 gal/min

- Maximum temperature rise in cooling water = 28° F (Based on 4.75 MW run for 24 hours on 12/13-14/83. Water temperature into block was 75° F and out of block was 103° F)

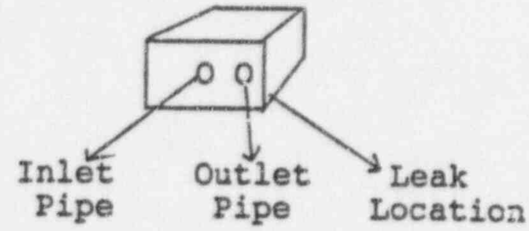
- Heat deposited in block = flow rate . cp . ΔT

  = 1.25 gal/min x 60 min/hr 8.33 lbs/gal x 454.54 g/lb x 1 cal/g x 15.55° C

  = 4.415×10^{6} cal/hour

  = 17523 BTU's/hour

- Location of leak in block is at lower right corner near the water outlet pipe. Note that no leak is observed at inlet or outlet pipes which are also located at lower right corner (see sketch)



- Fraction of water leaking is about 25%

- It appears that the leak location is at the outlet, thus providing full block cooling function. This observation is based on the difference in head pressure between inlet and outlet water.

- The pH of the water which has been circulating in the cooling system for many years is 6.8.

- The radionuclide analysis of the cooling water showed the following:

$^{3}H = 1.8 \times 10^{-3}$ µCi/cc
$^{65}Zn = 2.2 \times 10^{-6}$ µCi/cc

Response to questions raised by NSC subcommittee:

1. Radioactivity From The Bismuth Block System

Approximately 5 5-gallon buckets contained the water that was pumped from the block. A radionuclide analysis was performed on several of these buckets to determine whether the system contained radioactive material. The bismuth cooling system is a light water, self-contained system, which is not connected to the primary coolant system of the reactor in any fashion.

Tritium was found to be present in all containers at a concentration of 1.79×10^{-3} µCi/ml. This is a low concentration which can be released from the facility to the environment without further dilution (release limit 3×10^{-3} µCi/ml). A trace quantity of Zn-65 (2.19×10^{-6} µCi/ml) was found to be present when analyzed by gamma spectroscopy. As was the case with tritium, this concentration of Zn-65 can be released from the facility directly to the environment without further dilution (release limit 2×10^{-4} µCi/cc).

Since all samples were relatively the same, a single sample was counted for a total of 54,000 seconds to add validity to the earlier analyses. The presence of Zn-65 was confirmed at 2.21×10^{-6} μCi/ml. The remaining activity was found to be at background levels.

2. Gamma Ray Shielding Provided by Bismuth Block

Examination of facility records indicates that the radiation levels in the biomed facility when the reactor is at power are not well documented. This is due to a great extent to the decrease in reactor operating time over the past several years. However, a survey was performed this year with the reactor at a 1 MW power level. This showed that the general area radiation levels averaged approximately 40-50 mR/hour. Historical memory of individuals who have been here for a number of years indicates that dose rates in this area have remained essentially unchanged.

The above is consistent with the construction of the biomed facility in that unless some major deterioration of the inner bismuth block occurred, it is unlikely that changes in the radiation levels in the biomed facility would be noticeable. This is due to the fact that in addition to the inner bismuth shield (the leaking block), shielding in the biomed is also provided by 12 inches of concrete surrounded by a steel jacket, an outer bismuth block (≈ 4 inches) and an outer wall of lead (≈ 4 inches). Because of this additional shielding, as stated above, it is highly improbable that changes in the biomed radiation levels would be measurable unless major deterioration of the inner block had occurred. Visual inspectin of the inner block indicated that at least on the surface, the block was intact. Lack of residue in the water collected from the system when the leak began and the slightly acidic pH of this water support the hypothesis that the block itself has not suffered structural damage.

3. The Chemical Reaction Between Water and Bismuth and Between Water and Magnesium.

Dr. Barefield and Dr. Neumann, faculty members of the Chemistry Department as well as members of the Nuclear Safeguards Committee were asked these questions. Their responses are summarized as follows:

Magnesium will normally form a thin layer of oxide on the surface which will then act as a shield to prevent further oxidation. The formation of hydroxide of magnesium is possible but not likely at low temperature. Dr. Barefield thought that use of

magnesium clad might be connected with magnesium acting as a sacrificial anode to prevent oxidation of the bismuth.

With regard to bismuth, Dr. Barefield and Dr. Neumann felt the bismuth-water reaction would be less than one would anticipate with magnesium.

Both, Dr. Barefield and Dr. Neumann, did not profess any knowledge of what would be the chemical reactions over a long, long time period ≈ 10 years, or the tendency for the oxide to flake off. However, over a time span of 10 years or longer the pH of the cooling water remained acidic and the radionuclide analysis showed little activation thus suggesting little reactivity between the water and the metal.

4. Heat Removal With Reduced Flow

Dr. Prateen Desai, member of the NSC, performed scoping calculations using extremely conservative assumptions. Heat loss rates were assumed at 80 or 99%. Specifically Dr. Desai solved the following equation.

$$\rho C_p \frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial x^2} + q_g^{o'''}(x)$$

where

$$q_g^{o'''}(x) = q_{g,o}^{o'''} e^{-\lambda x}$$

λ = attenuation coefficient of bismuth for reactor gammas at average energy of 0.7 MeV

ρ = density of bismuth

C_p = specific heat of bismuth

T = temperature as a function of position in block

κ = thermal conductivity of bismuth

γ = fraction of heat source retained in block ($0 < \gamma < 1$)

$q^{o'''}$ = heat source assumed to be 18,000 BTU's/hour

The above equation was normalized as follows:

$$T^* = \frac{T(x,t) - T_i}{T_m - T_i} \qquad (2)$$

T_m = melting point of bismuth

T_i = initial temperature

$$X^* = \frac{X}{L};\ t^* = t/L^2/\alpha \qquad (3)$$

Where L is the thickness of the block, and $\alpha = \frac{k}{\rho C_p}$ with this normalization equation (1) becomes

$$\frac{\partial T^*}{\partial t^*} = \frac{\partial^2 T^*}{\partial x^{*2}} + \frac{L^2}{\kappa(T_m - T_i)} \cdot \gamma \cdot q_g^{o'''}(x)$$

Boundary Conditions:

$t^* \leq 0^-;\ T^* = 0$

at

$t^* = 0^+;\ q_g^{o'''}$ *is turned on*

The results are summarized in Figures 1 and 2. Figure 1 shows the normalized temperature as a function of distance from the inner to the outer surface of the block at various time intervals, at one MW power level assuming 80% heat removal rate. Figure 2 shows similar data but with assumption of 99% heat removal rate and one MW power level. Note that the normalized temperature reaches the melting point when $T^* = 1.0$. When T^* is 0.5 for example, $T = T_i + 0.5(T_m - T_i) = 30°C + .5(271 - 30°C) = 150.5°C$.

Figure 1 shows that 5 hours of operation at one MW power level, assuming 80% heat removal rate, the temperature of the inner surface of the block would be 150.5°C. The melting point of bismuth is 271°C.

The two end walls at $X^* = o$ and $X^* = 1$ are assumed to loose heat by convection at the outer surface of the block and by conduction at the inner. (Dr. Desai estimates that heat loss at the outer face by convection can be up to 1,500 BTU/hr.)

5. A Test For One Hour Is Planned With The Temporary Fix To Ascertain The Following:

a. Accurate determination of the fraction of water that leaks from the system. This will be done by measuring the flow rate of the leaking water.

b. Two thermocouples will be installed on the inner bismuth block to measure the temperature at 7 inches into the block (i.e., the inner surface temperature), and at the outer face (i.e., the outer surface temperature).

c. Comparison of the performance of the cooling system with the current leak to the performance prior to the leak will be made. This may be ascertained by comparing the temperature of the return water (hot leg) as measured now and previously for similar runs. Among other things such a comparison will help determine whether or not the leak is near the outlet. For a leak near the outlet would not affect the cooling performance of the circulating water and the ΔT rise would be similar to previously recorded data.

d. Should the temperature in the bismuth block as measured by the thermocouples reach 80° C, the reactor will be shutdown and the experiment terminated.

e. The thermocouples will be calibrated prior to making the one megawatt run.

f. Flow rate setting of bismuth block cooling system shall be lowered from 1 gal/min to 0.75 gal/min. The flow rate meter is located on the return leg of the cooling system. Since the leak is at the bottom of block, the return flow rate is decreased by about 25%. Consequently the setting for the flow rate needs to be decreased to 0.75 gal/min.

g. The safety blades and the regulating rod shall be calibrated prior to the one hour, one megawatt run in order to meet Technical Specifications requirements. The run for the calibration of control rods shall be at or below 10 kw power level.

h. Air sampling in the basement of the containment building will be performed before the run to establish a reference point and also during the run near the collection funnel. This will help establish whether or not volatile radioactive

substances (not expected) are released to the air.

i. Surveys to determine the levels of radiation, both neutrons and gammas, will be made in the bio-medical facility. Unfortunately no previous record exists for comparison. There is however an approximate "feel" for what these numbers should be.

j. Surveys for Po-210 in the cooling water will be made. The pH of the leaking water shall be determined prior to and during reactor operation.

The results of tests and measurements will be submitted to NSC for evaluation with regard to the efficacy of the temporary fix. Assuming that the results justify a request to operate the reactor with the temporary fix in place, the management of the NNRC intends to operate in this mode for a period not to go beyond the conversion to LEU. A permanent solution to this problem is currently being investigated and will be reported to the NSC as soon as preliminary analysis is completed.

Transient Temperature Distribution Bismuth Block Due To Heat Generation

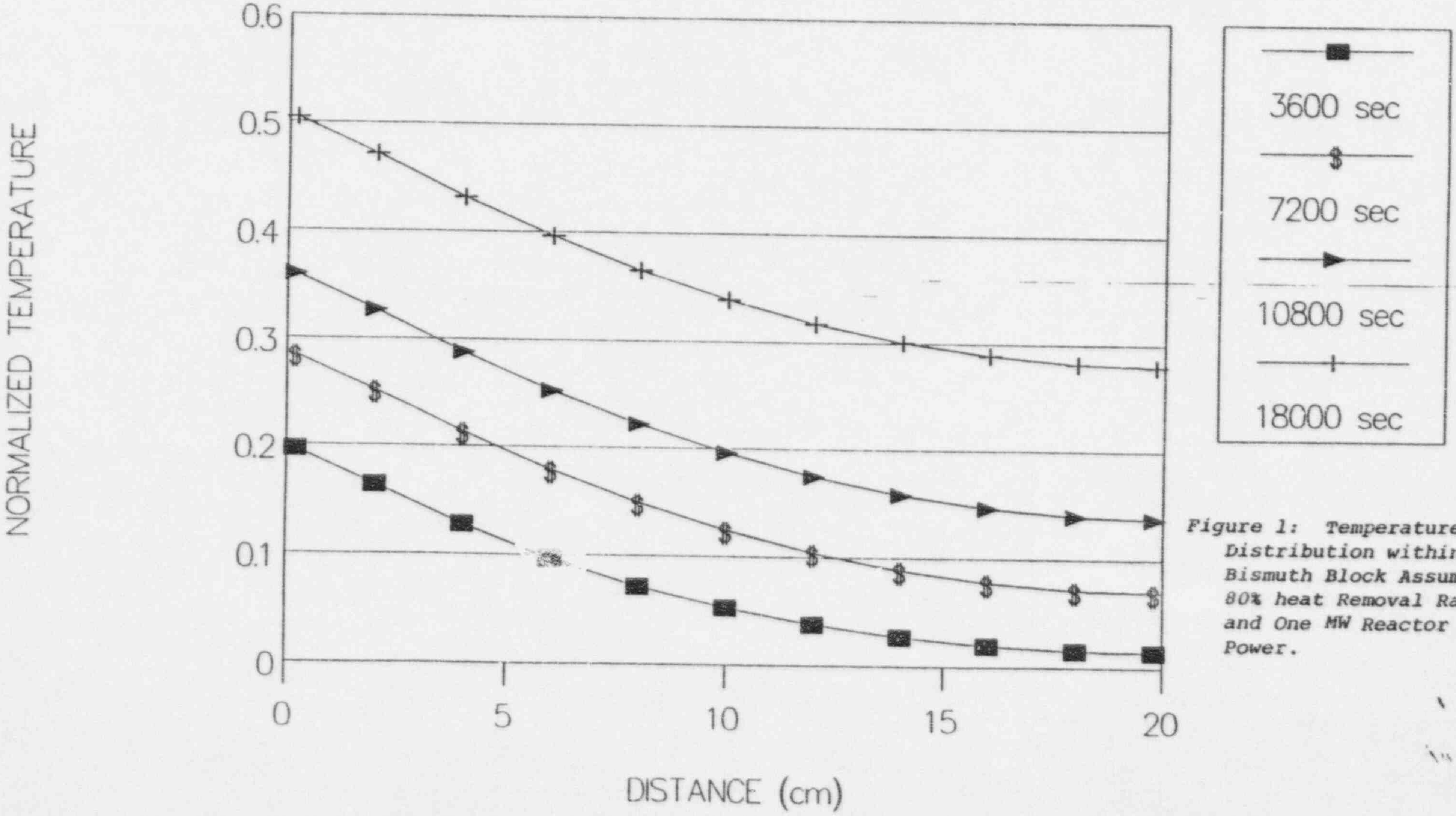


Figure 1: Temperature Distribution within Bismuth Block Assuming 80% heat Removal Rate and One MW Reactor Power.

Transient Temperature Distribution In Bismuth Block Due To Heat Generation

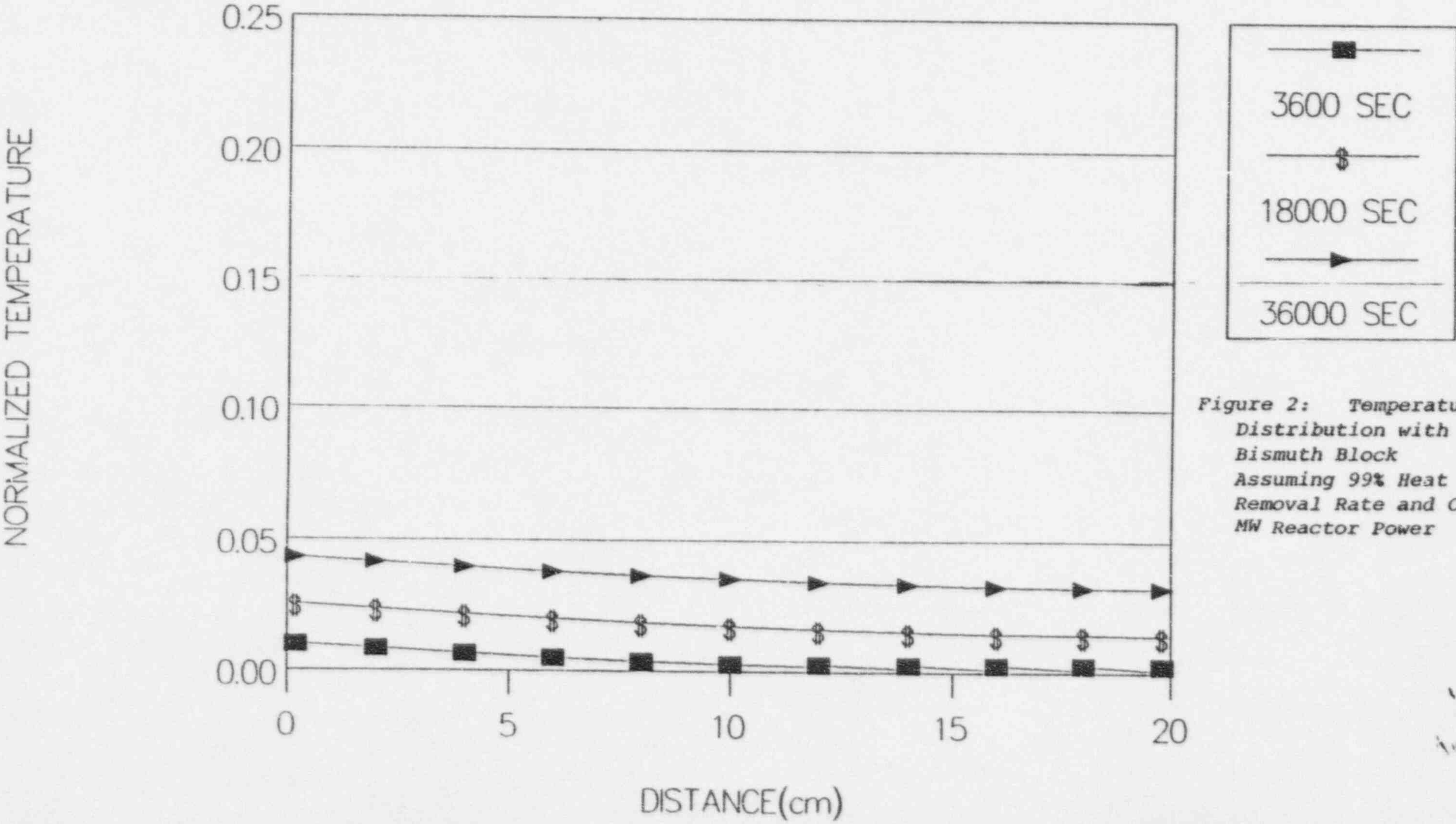


Figure 2: Temperature Distribution with Bismuth Block Assuming 99% Heat Removal Rate and One MW Reactor Power