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# KIWI B-5 SHIELD

## VOLUME II
## RADIATION
## DESIGN AND ANALYSIS

(Title Unclassified)

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SUBMITTED BY:

Westinghouse Electric Corporation
Astronuclear Laboratory
Pittsburgh 36, Pennsylvania

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PREPARED BY:

M.A. Capo

M.A. Capo

R.N. Nassano

R.N. Nassano

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# KIWI B-5 SHIELD

## VOLUME II
## RADIATION
## DESIGN AND ANALYSIS

(Title Unclassified)

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## ABSTRACT

The KIWI B-5 shield was designed as a prototype of the NERVA heated bleed shield. The purpose of the shield is to reduce the radiation heating in the liquid hydrogen propellant by a factor of 10. The shield is located above the reactor core support plate entirely within the pressure vessel. It is comprised of lithium hydride and boronated stainless steel pellets and steel discs, encapsulated in steel tubing. Seven capsules in an hexagonal array are held together by tie plates at each end to form a module. These modules are held between upper and lower support plates to form the shield.

The shield materials, thickness, radius, and general mechanical design were selected as a result of optimization studies performed during Phase I. As a result of those studies, the KIWI B-5 shield composition was selected as 63% by volume natural lithium hydride, 27% stainless steel, and 10% void for coolant passages. The shield had a uniform thickness of 31.4 cm over the core radius, with a conical lateral surface reducing to zero thickness at the beryllium outer radius.

This report describes the KIWI B-5 radiation design and analysis carried out during Phase II of the NERVA contract.

Part of the work carried out during Phase II involved modifications in the analytical methods used in the radiation analysis. These modifications effected design changes in the shield which are described in this report.

The expected radiation environment outside the final KIWI B-5 shield design is presented. The radiation environment data include total gamma ray dose rates and fast neutron fluxes (above 1 Mev) at many locations outside the pressure vessel.

Radiation levels inside the KIWI B-5 assembly are reported. These data include total gamma ray dose rates and fast neutron fluxes at various locations in the reflectors, core, support plate, and shield.

Heating rates in the shield as a function of reactor operating and shutdown time are included in this document. Shield activation data are also reported. The KIWI B-5 Shield Design and Fabrication and Thermal Design and Analysis are reported in Volumes I and III of this report respectively.

# KIWI B-5 SHIELD RADIATION DESIGN AND ANALYSIS

## SUMMARY

The final radiation analysis of the KIWI B-5 shield performed in Phase II of Contract NP-1 is presented in this report. Companion reports present the mechanical design and manufacture and thermal analysis of the KIWI B-5 shield.

Part of the radiation analysis carried out during Phase II involved modifications of analytical methods. The one dimensional multigroup diffusion code, Program P1MG[1*], was modified by changing the thermal group energy cut-off to 1.86 ev. The TEMPEST[2] code was used to obtain the thermal group constants used as input to this diffusion code. The two dimensional multigroup diffusion code CURE[3] was put into production to determine spatial neutron fluxes for use in heating rate calculations. The neutron flux calculated by P1MG was used directly rather than normalizing to point kernel results used during Phase I. The options coded in the point kernel Program 14-0[4] for calculating fast neutron number fluxes and differential gamma ray energy spectra were employed.

These modifications effected an increase in the calculated peak heating in the lithium hydride shield material closest to the reactor core. This heating rate was above design tolerance. Analyses resulted in replacing 3 cm of the lithium hydride in the bottom of each capsule by a steel pellet containing 1.5% by weight natural boron.

The final KIWI B-5 shield was analyzed to determine the radiation environment outside, and the radiation levels inside, the assembly. Detailed heating rates in the shield were also computed as a function of reactor operation and shutdown times. These radiation data include the effect of secondary gamma rays produced

* References are listed at the end of this report.

by neutron capture and inelastic scattering in materials both inside and outside the reactor core. Thus, these data are in general higher than the data presented in Reference 5. The radiation data are presented graphically in this report.

The dose rate expected from a B-5 shield after irradiation in the B-5 test was determined as a function of time after shutdown and is presented here in graphical form.

[redacted]



[redacted]

## 1. INTRODUCTION

This report presents the final radiation analysis of the KIWI B-5 shield and is a companion report to the KIWI B-5 Shield Design and Fabrication (Volume I) and KIWI B-5 Thermal Design and Analysis (Volume III) report. The shield was designed for test in the KIWI B-5 reactor experiments to be conducted by Los Alamos Scientific Laboratory. Essentially the same shield will be used in the hot bleed cycle design subsequently chosen for the NRX-A-1 reactor. However, the radiation analysis reported here does not reflect any effects due to the change in engine cycle. To orient the reader, a brief review is made of the shield development in Phase I of Contract NP-1. A detailed report on the shield radiation analysis performed in Phase I is given in Reference 5.

### Phase I - Background

The KIWI B-5 shield was designed as a prototype for use in the NERVA engine reactors using the heated bleed cycle. The primary purpose of the shield is to reduce the radiation heating in the liquid propellant by a factor of 10. The presence of the shield also reduces the radiation effects in the engine components located above the shield. The shield also supplies energy to the turbine drive fluid in the heated bleed cycle.

During Phase I, two nuclear radiation optimization studies were carried out. The first study dealt with a minimum weight shield system based on shield parameters of thickness, distribution and shape for a 90% reduction in total tank heating and at the minimum separation distance determined by engine component arrangement. The minimum weight shield system included the effect of vehicle interstage weight and plenum weight.

The second study, termed the optimization study, included the following parameters: separation distance of core and propellant tank, shield thickness, tank angle with respect to the reactor core center, and propellant pressure. The flow model within the tank during operation was the completely mixed case.

[redacted]

As a result of the Phase I studies, the KIWI B-5 shield material composition was selected as 63% by volume natural lithium hydride, 27% stainless steel, and 10% void for coolant passages. The shield had a uniform thickness of 31.4 cm over the core radius, with a conical lateral surface reducing to zero thickness at the beryllium reflector outer radius. The shield was based on a 30 foot diameter tank, the bottom of which was located 8.5 feet from the center of the reactor. The shield mechanical design consisted of lithium hydride pellets encased in stainless steel cylinders that were sealed with welded steel end plugs. The capsules were bundled between two steel support plates in a triangular array to form the shield. Calculations indicated that radiation streaming through the coolant channels between capsules was insignificant compared to the radiation penetrating the homogenized shield.

The shield is located above the reactor aluminum top support plate entirely within the pressure vessel. Twelve control drum actuator shafts penetrate the shield. Calculations indicated that the shafts did not seriously affect the attenuation properties of the shield.

This report describes the B-5 radiation design and analysis carried out during Phase II.

Part of the work carried out during Phase II involved modifications in the analytical methods used in radiation analysis. These modifications are described in this report, as well as design changes in the shield which resulted from the modifications in the analytical methods.

The expected radiation environment outside the KIWI B-5 shield design is presented. Radiation levels inside the KIWI B-5 assembly are presented in graphical form.

Heating rates in the shield as a function of reactor operation, and shutdown time are included in this report. The dose rate expected from a B-5 shield after irradiation in the B-5 test is reported as a function of time after shutdown.

[redacted]

[redacted]

## 2. ANALYTICAL METHODS

The major changes from Phase I to Phase II in the analytical methods employed are described below.

### Neutron Fluxes and Spectra

Three computer codes were used for calculating neutron fluxes and spectra: P1MG, CURE, and Program 14-0.

The multigroup, multiregion diffusion code, P1MG, was used to obtain neutron distribution on the reactor center line and midplane. This code solves the one dimensional P1 equations in the consistent Greuling-Goertzel approximation for fifty-five groups.

During Phase I, the version of P1MG in use employed a thermal group energy cut-off of 0.625 ev. The thermal group constants used as input to the diffusion code were obtained from the SOFOCATE code[6]. This code calculates a hydrogen moderated spectrum using a light gas kernel and performs averages over this flux spectrum to obtain the thermal group constants.

During Phase II, the P1MG code was modified by changing the thermal group energy cut-off to 1.86 ev. The thermal group constants used as input to the diffusion code were obtained from the TEMPEST code. This code calculates a graphite moderated spectrum using a heavy gas kernel and performs averages over this flux spectrum to obtain the thermal group constants.

Program P1MG calculates relative neutron fluxes. To obtain absolute value neutron fluxes a power factor constant is used. For an axial P1MG calculation the power constant is computed as follows:

[redacted]

$$C = \frac{(3.1 \times 10^{10})\,\nu P}{\lambda\, S_v\, \pi R^2} \qquad (2\text{-}1)$$

where

| | | |
|---|---|---|
| $3.1 \times 10^{10}$ | = | fissions/watt-sec |
| $\nu$ | = | neutrons/fission |
| $P$ | = | power in watts |
| $\lambda$ | = | eigenvalue for particular problem |
| $S_v$ | = | normalized P1MG source |
| $R$ | = | reactor core radius |

The CURE program is a multigroup, multiregion code that solves the neutron diffusion equations in two space dimensions. During Phase II, eight energy groups were used in the CURE program, seven fast groups and one thermal group. The thermal group constants used as input to the CURE code were obtained from the TEMPEST code described above. The fast group constants were obtained from MUFT[7] code which uses a Fourier transform to calculate the few group constants.

Program 14-0 evaluates point-to-point kernel functions and integrates over cylindrical source regions to perform reactor-shield penetration calculations. Coded in Program 14-0 is a kernel for calculating differential neutron number flux. This kernel is described in detail in Reference 8.

Gamma Ray Dose Rates and Spectra

Gamma ray dose rates were obtained using Program 14-0 in the same manner as during Phase I activity.

During Phase II the point kernel coded in Program 14-0 for computing differential gamma ray spectra was also utilized. This kernel utilizes bivariant polynomials fitted to moments method data in various materials.

As input to Program 14-0, a thirteen group gamma ray source energy spectrum in the active core was used. This spectrum consisted of contributions due to prompt fission gamma rays[9], short half life gamma rays, delayed gamma rays[10], and those due to neutron capture and inelastic scattering in the reactor core materials. Contributions due to capture gammas and inelastic scattering gammas in the core materials were computed by using reaction rates obtained from Program P1MG described above.

The sources of secondary gamma radiation produced in materials outside the reactor core were obtained from a one dimensional diffusion calculation, P1MG; off the center line these sources were adjusted to have the same radial spatial distribution as the fast flux computed by Program 14-0. The secondary gamma rays were then used as sources in Program 14-0 to obtain their contribution to the gamma radiation levels.

Heating Rates

The neutron heating due to the kinetic energy loss by the slowing down of neutrons was computed as follows:

$$H_{K.E.} = \int_u K\, C \left(\frac{1-\alpha}{2}\right) E(u)\, \Sigma_s(u)\, \phi(u)\, du \qquad (2\text{-}2)$$

where

$H_{K.E.}$ = heating rate, watts/cm$^3$

$K$ = conversion factor $1.6 \times 10^{-13}$, watt/sec-Mev

$C$ = power constant (Equation 2-1)

$\frac{1-\alpha}{2}$ = fraction of neutron energy loss per material where $\alpha = \left(\frac{A-1}{A+1}\right)^2$, and where $A$ is the mass number of the material

$E(u)$ = energy as a function of lethargy

$\Sigma_s(u)$ = scattering cross section of material as a function of lethargy

$\phi(u)$ = relative neutron flux as a function of lethargy

The integration over lethargy was performed trapezoidally using the 55 flux groups from Program P1MG. Off the center line the heating rates were adjusted to have the same radial spatial distribution as the fast flux computed by Program 14-0.

The neutron heating rate due to the n,α reaction was computed as follows:

$$H_{n,\alpha} = \int_u K\, C\, Q\, \Sigma_{n,\alpha}(u)\, \phi(u)\, du \qquad (2\text{-}3)$$

where

$H_{n,\alpha}$ = heating rate, watts/cm$^3$

$Q$ = reaction energy, Mev

$\Sigma_{n,\alpha}$ = n,α cross sections of material as a function of lethargy

The other variables were defined above.

The gamma ray heating rates were calculated using Program 14-0. The sources of gamma ray heating are the same as those described under Gamma Ray Dose Rates and Spectra.

## 3. MODIFICATION OF SHIELD PELLET MATERIALS

The neutron heating rates used in the preliminary thermal analyses were based on the point kernel-diffusion normalization method described in Reference 5. Using the unnormalized heating rates calculated with the diffusion power factor described in Section 2, thermal analyses showed that the lithium hydride temperature was above design limits in the end of the shield capsule facing the reactor. Methods of reducing this peak heating were investigated. It seemed advantageous to replace some of the bottom lithium hydride pellets with an alternate material, rather than combine a material with the lithium hydride in pellet form. The replacement materials investigated were $Li^7H$, beryllium oxide, and boronated steel. Using the method described in Section 2, heating rates were calculated with varying amounts of each material positioned at the bottom of the shield capsules. Typical results are shown in Figures 3-1 through 3-6.

The boronated steel was found to be the most effective material for reducing the peak heating in the lithium hydride. Detailed thermal and radiation analyses resulted in replacing 3 cm of the lithium hydride in the bottom of each capsule by a steel pellet containing 1.5% by weight natural boron. Introduction of the 3 cm boronated steel pellet reduced the peak heating in the lithium hydride from 75 to 26 watts/$cm^3$.

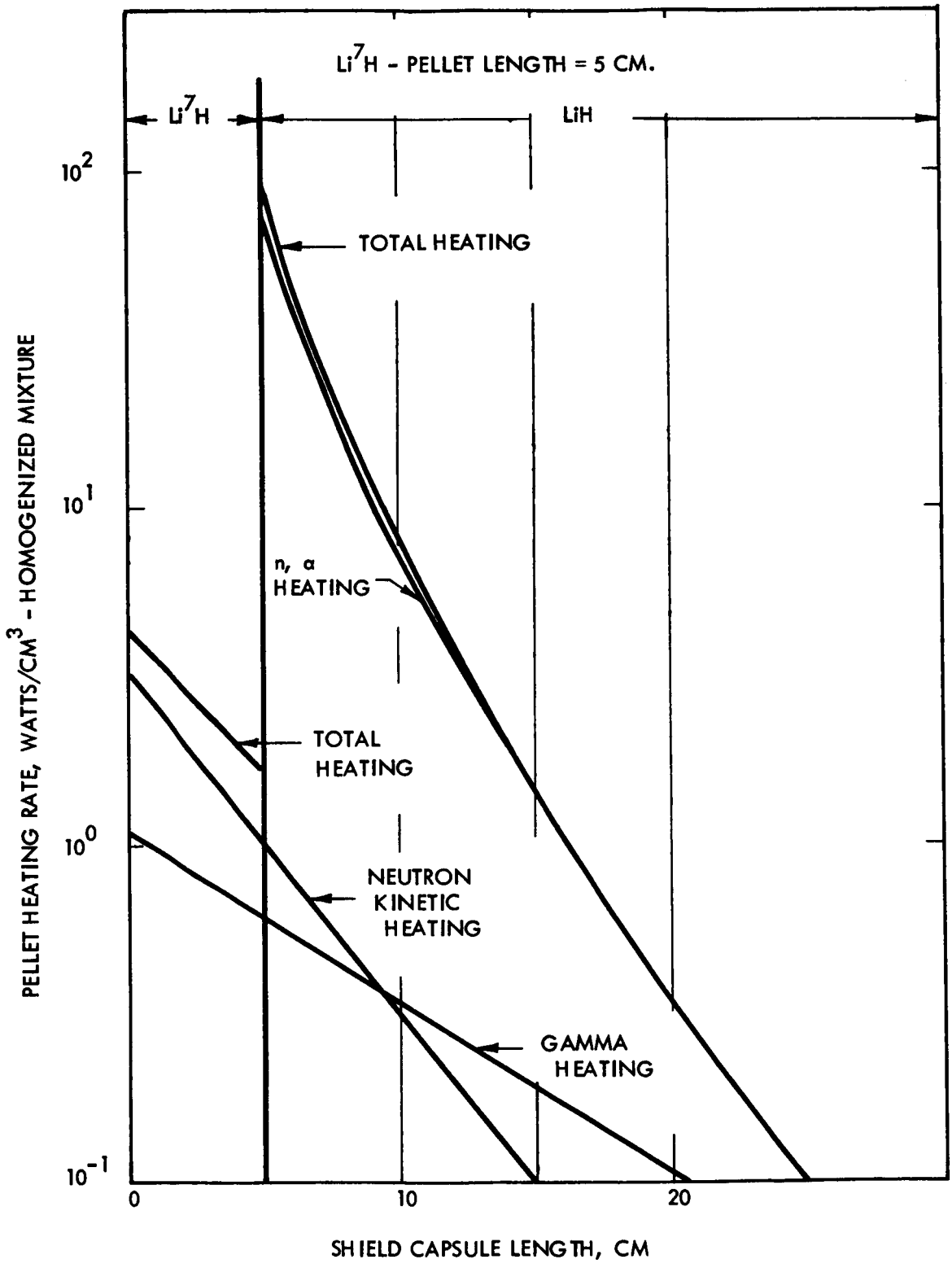




Figure 3-1 - Heating Rate Vs Shield Capsule Length

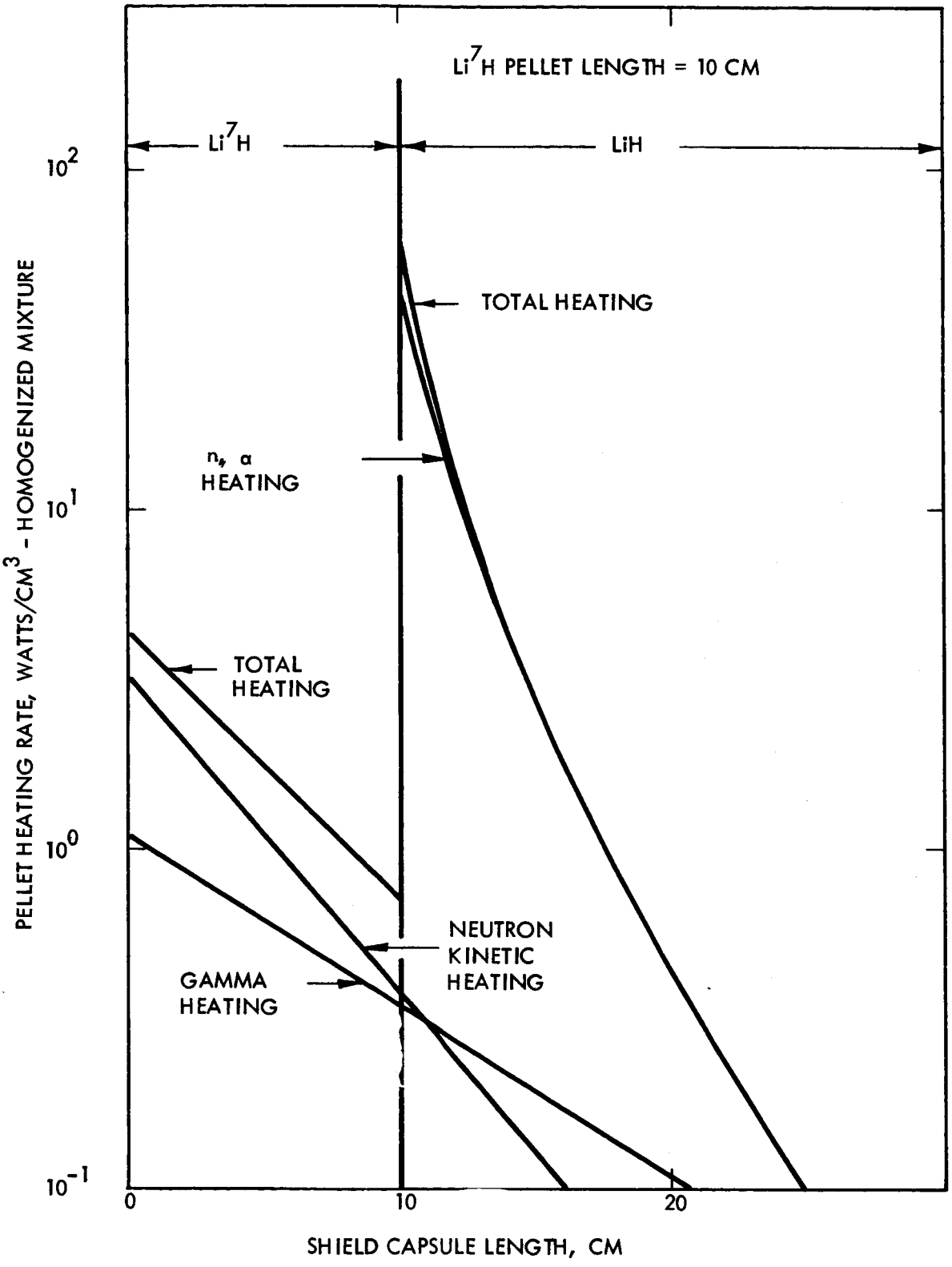


Figure 3-2 - Heating Rate Vs Shield Capsule Length

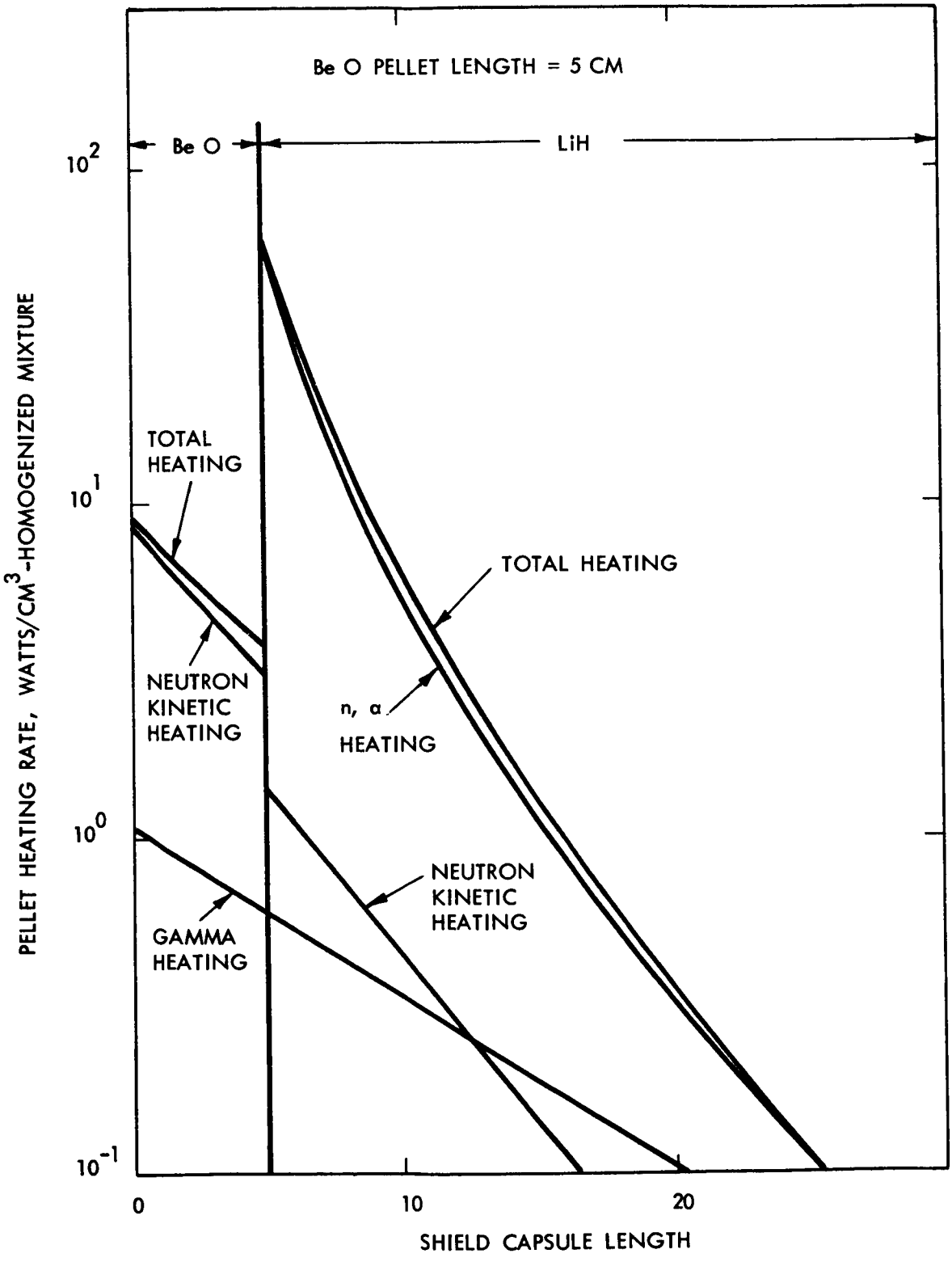


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Figure 3-3 - Heating Rate Vs Shield Capsule Length

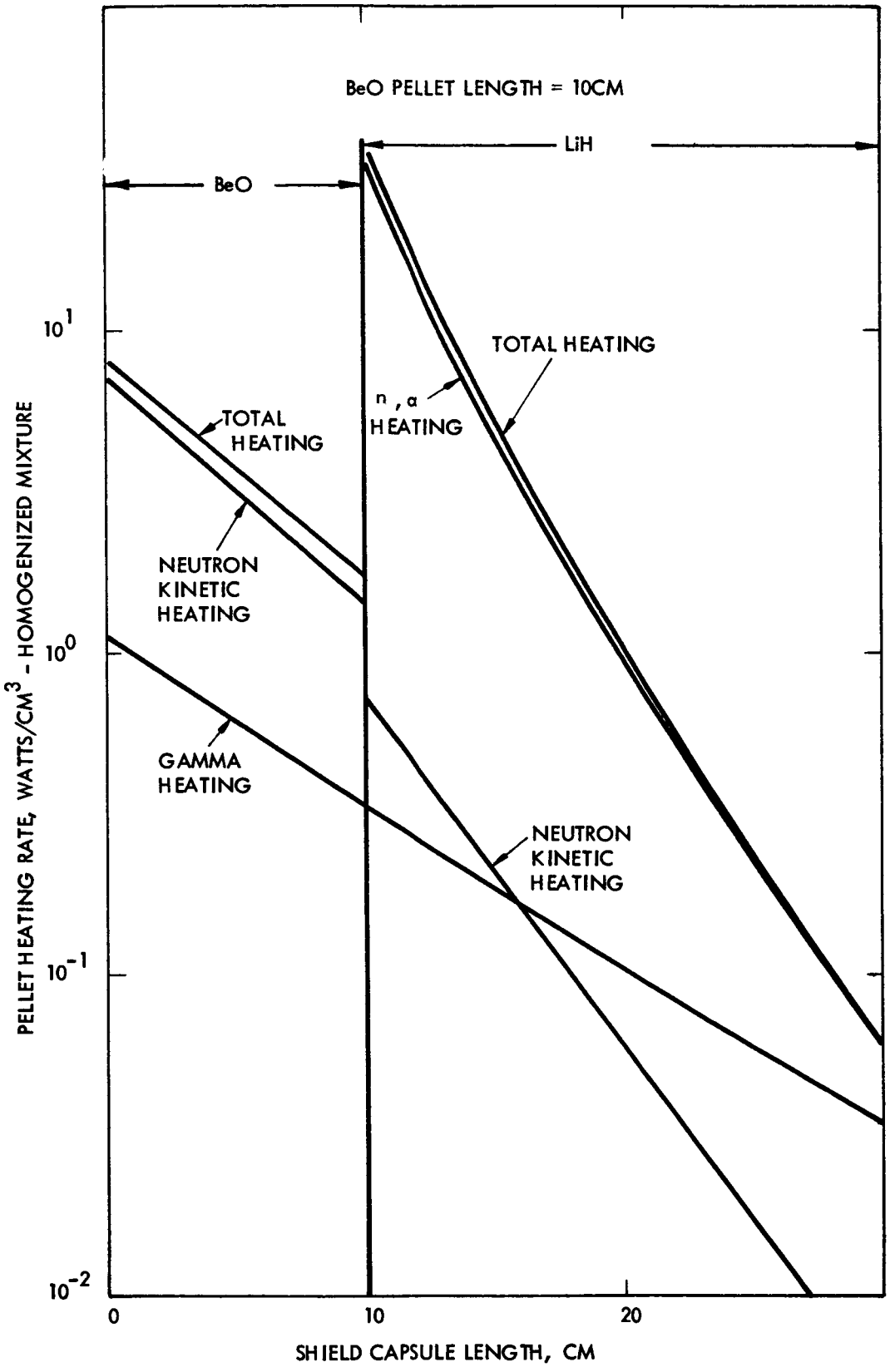




Figure 3-4 - Heating Rate vs Shield Capsule Length

[redacted]



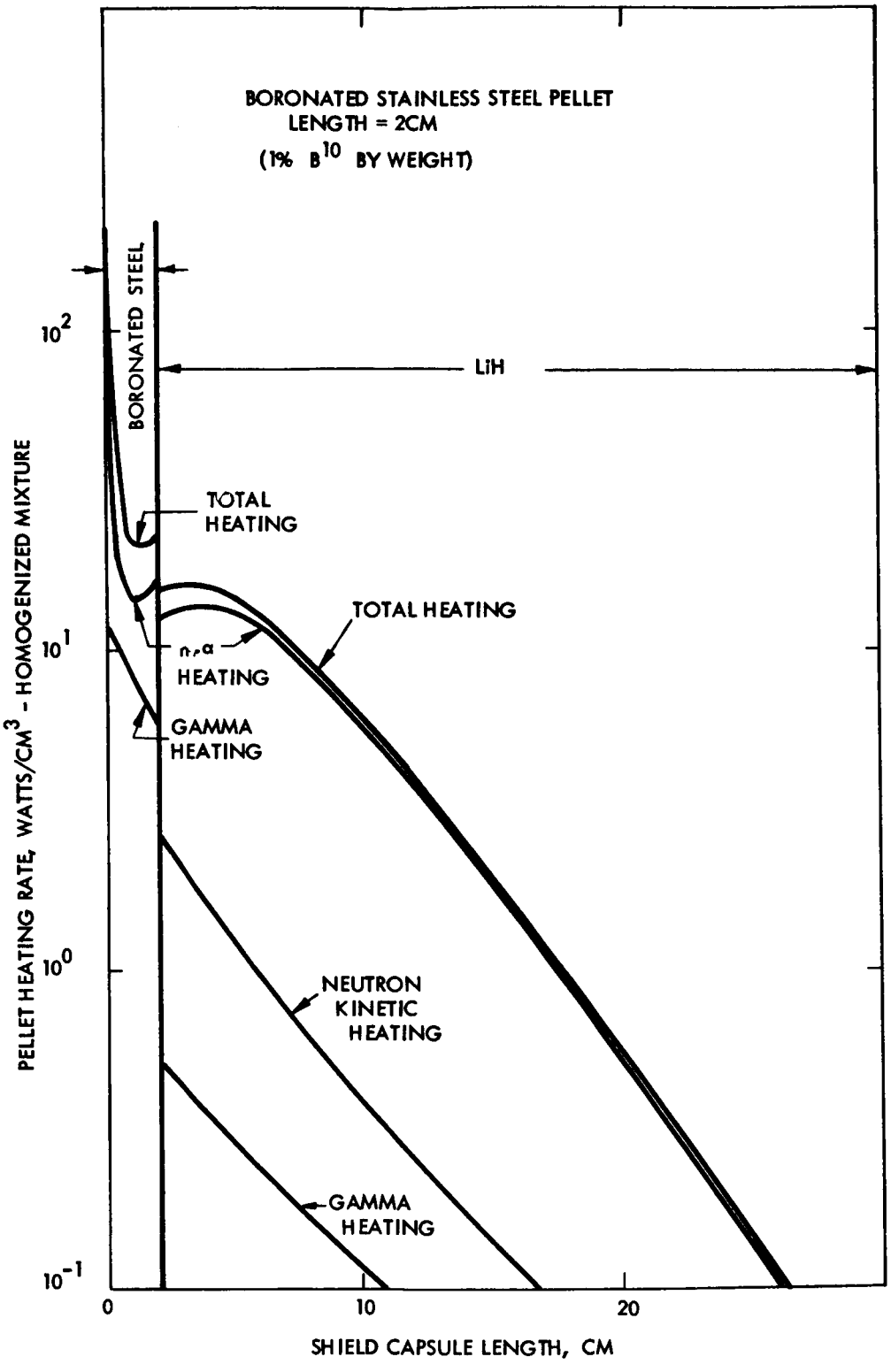


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Figure 3-5 - Heating Rate Vs Shield Capsule Length

[redacted]

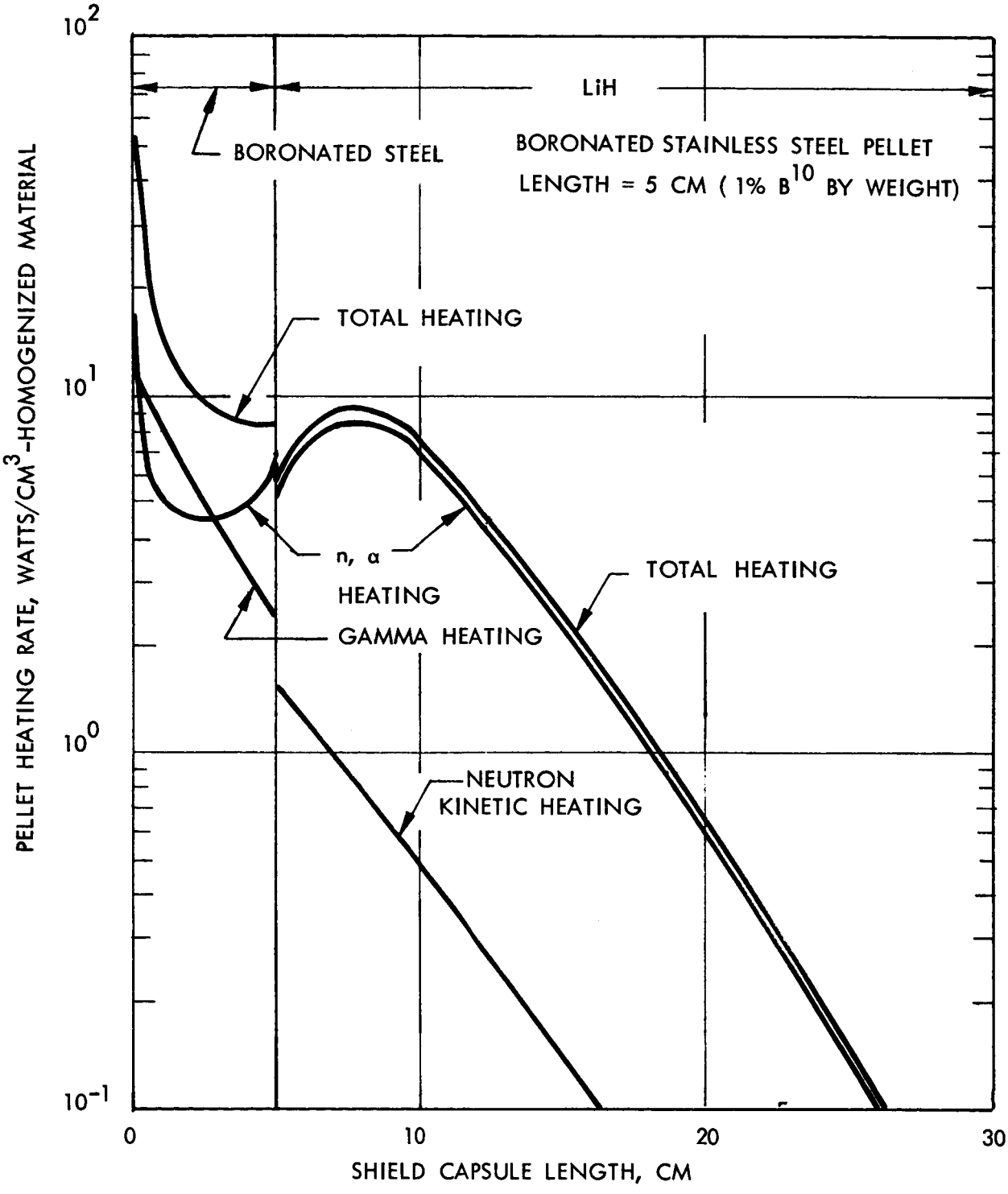


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Figure 3-6 - Heating Vs Shield Capsule Length

[redacted]

# 4. FINAL KIWI B-5 SHIELD DESIGN

## Physical Description

The KIWI B-5 shield is comprised of lithium hydride and boronated steel pellets, and stainless steel discs encapsulated in 5/8 inch diameter and 9/16 inch diameter stainless steel tubing with a wall thickness of 0.20 inches. The capsules are arranged in a triangular array with the hydrogen flow path parallel to the axis of the tubing. The flow area is the void area between the capsules. Seven capsules in an hexagonal array, called a module, are held together by tie plates on each end. The center capsule of each module is attached to the dome and nozzle end stainless steel support plates. The three flow passes are separated from one another by flow baffles 0.010 inches thick. Locally near the baffles 9/16 inch capsules are required to provide space for the baffle.

A schematic diagram of each type of shield capsule is shown in Figure 4-1. Full length capsules are located in the second and third passes, and 3/4 and 1/2 length capsules are located in the first pass flow regions. The relative position of each flow region is shown schematically in Figure 4-2. A more detailed description of the final shield design is presented in Volume I of this report.

## Preliminary Shield Heating Rates

The final shield design was analyzed to obtain radiation heating rate data for use in thermal analysis. Total heating rates are presented in Figures 4-3 through 4-6. These curves represent axial traverses through the shield at several radial positions from the core midplane.

The neutron component of the total heating was obtained from the two dimensional diffusion program, CURE. The gamma ray component was computed using Program 14-0. No contribution from secondary gamma rays produced in materials outside

[redacted]

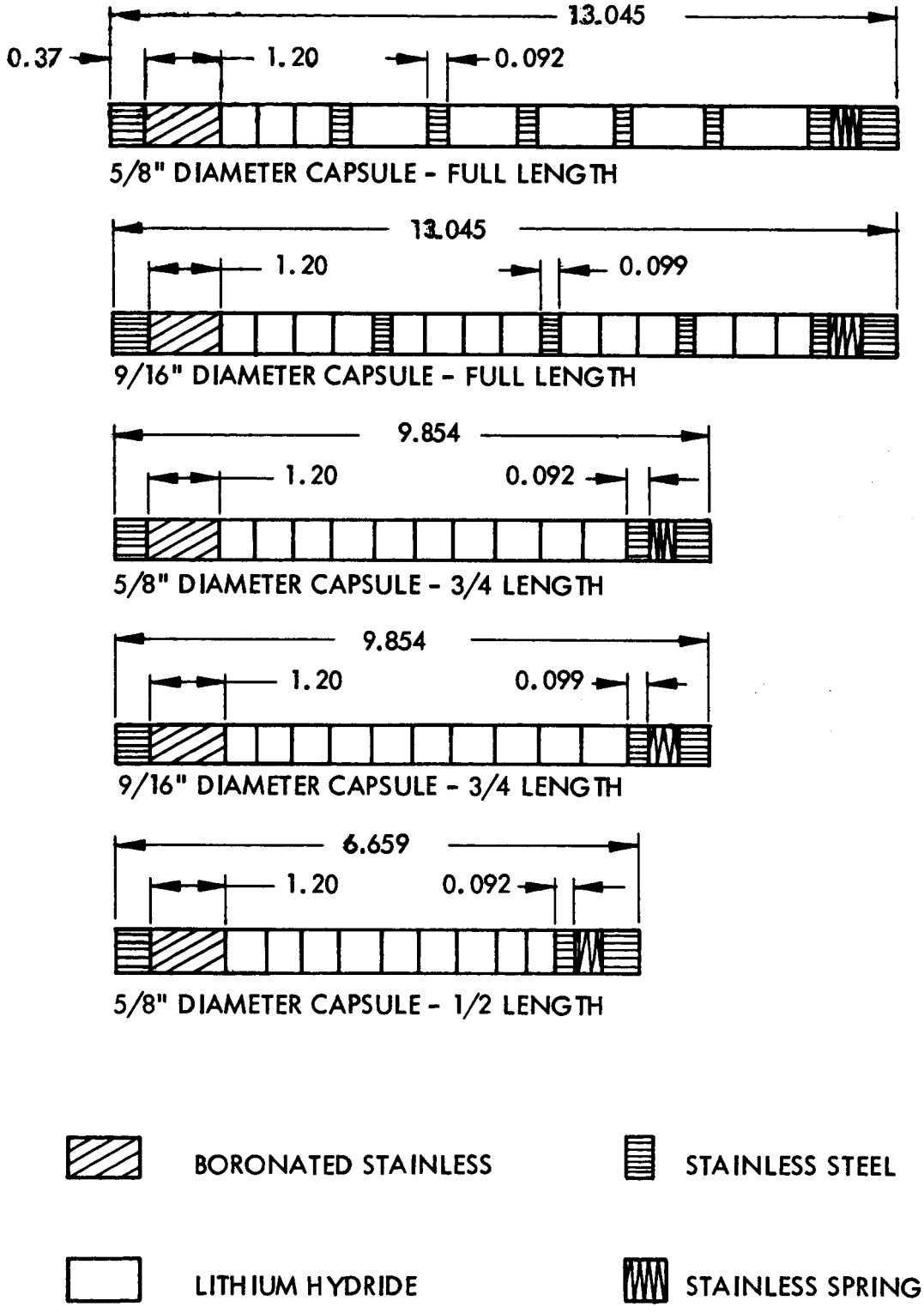


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Figure 4-1 - Capsule Loading and Dimensions

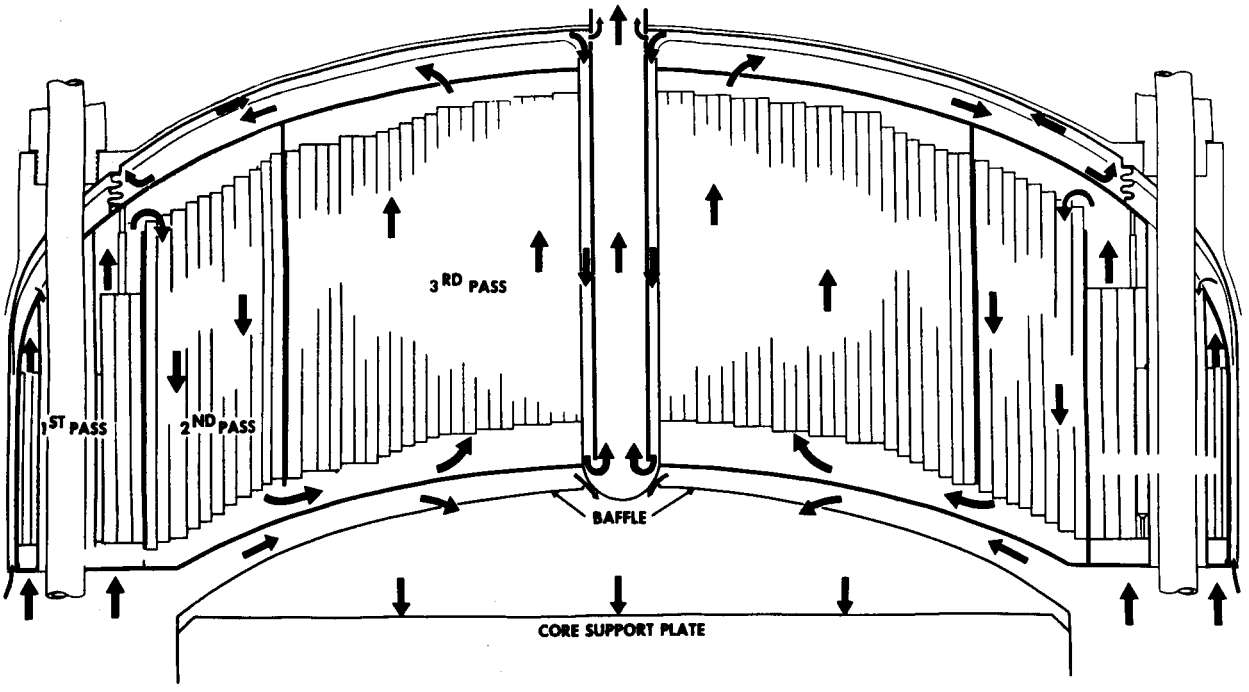


Figure 4-2 - KIWI B-5 Shield Flow Schematic

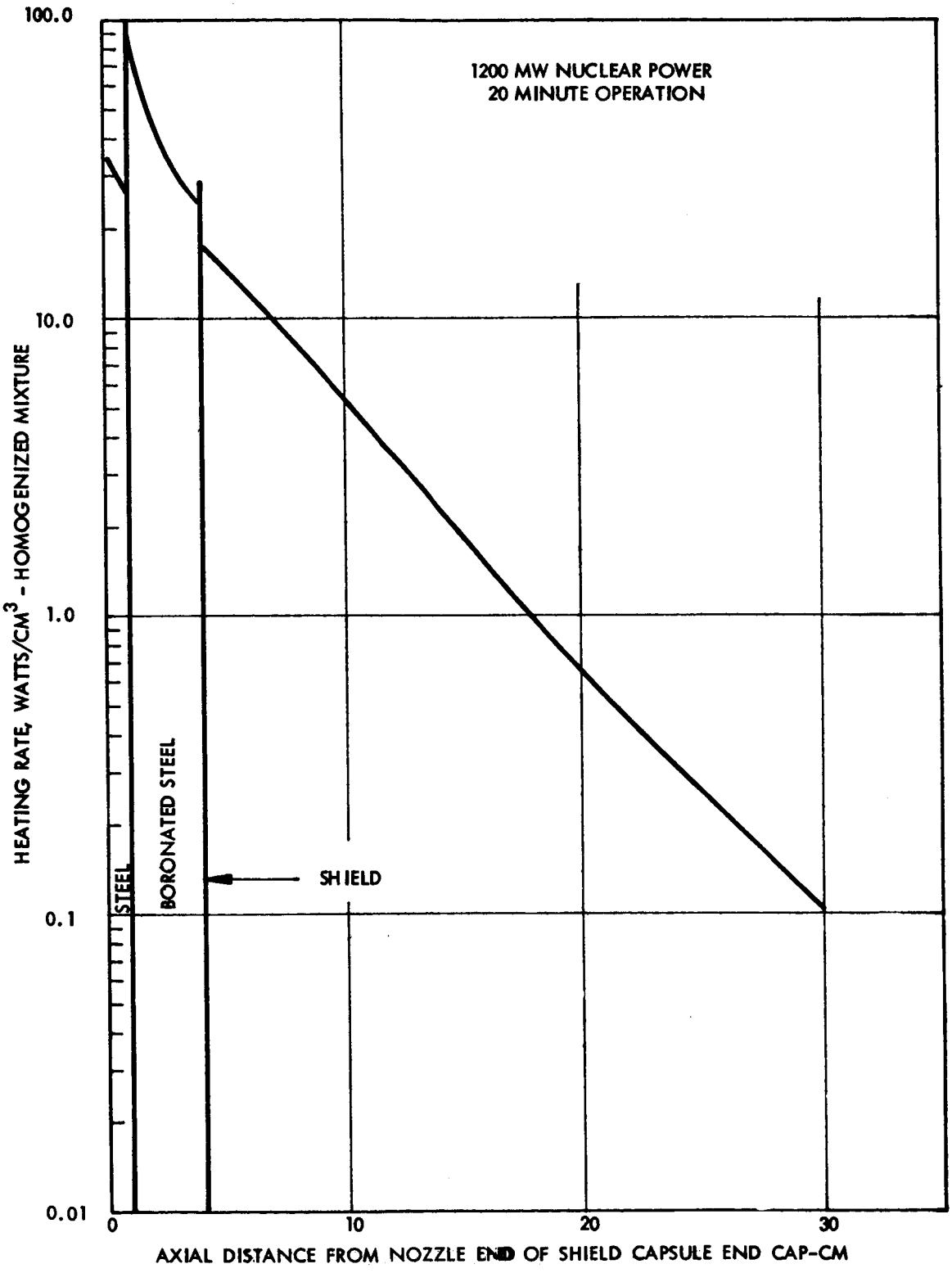


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Figure 4-3 - Total Heating Rate in Shield Along Instrumentation Port Per $cm^3$ of Homogenized

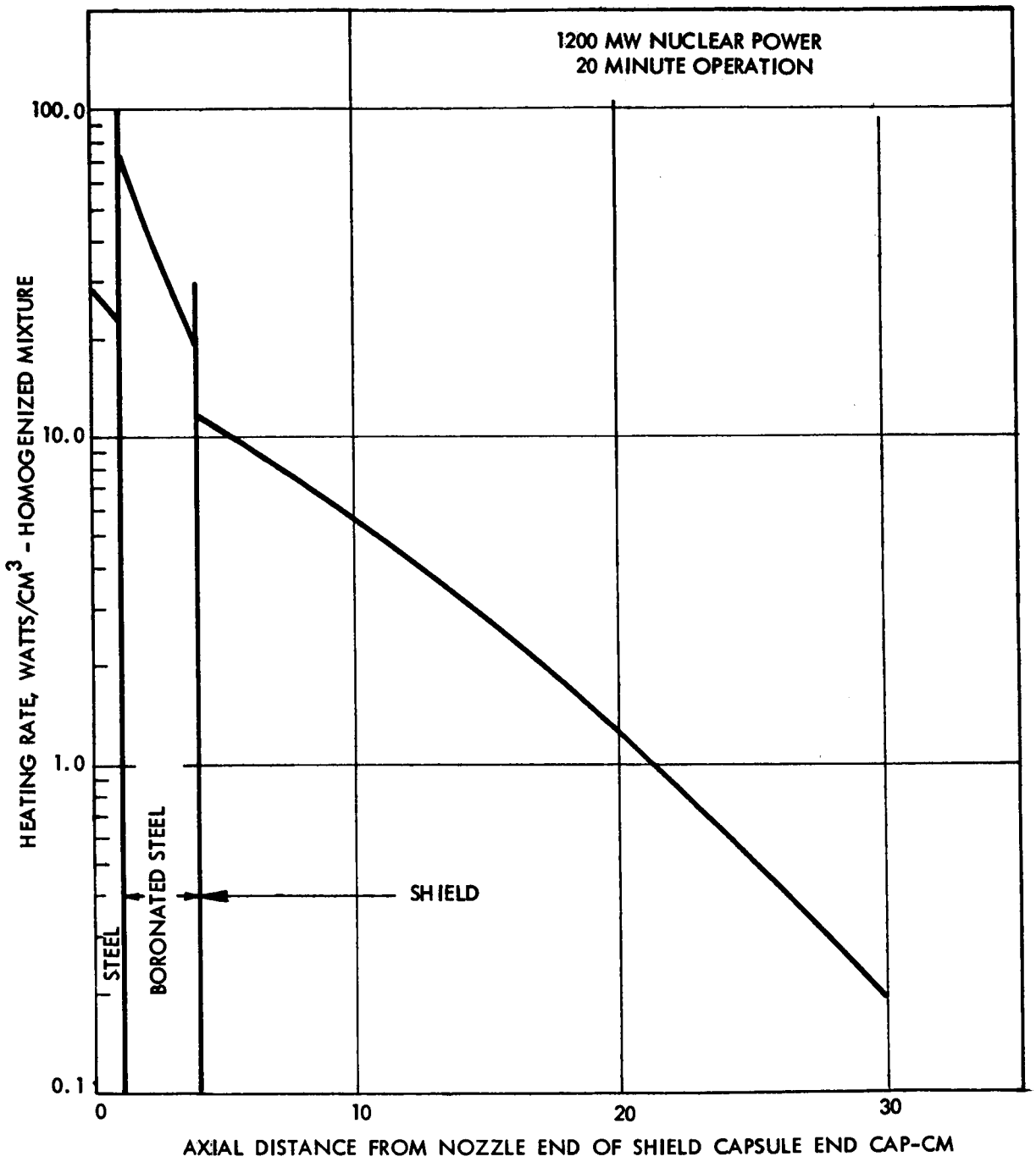




Figure 4-4 - Heating Rates at a Radius of 45 cm From Core Midplane Per $cm^3$ of Homogenized Mixture

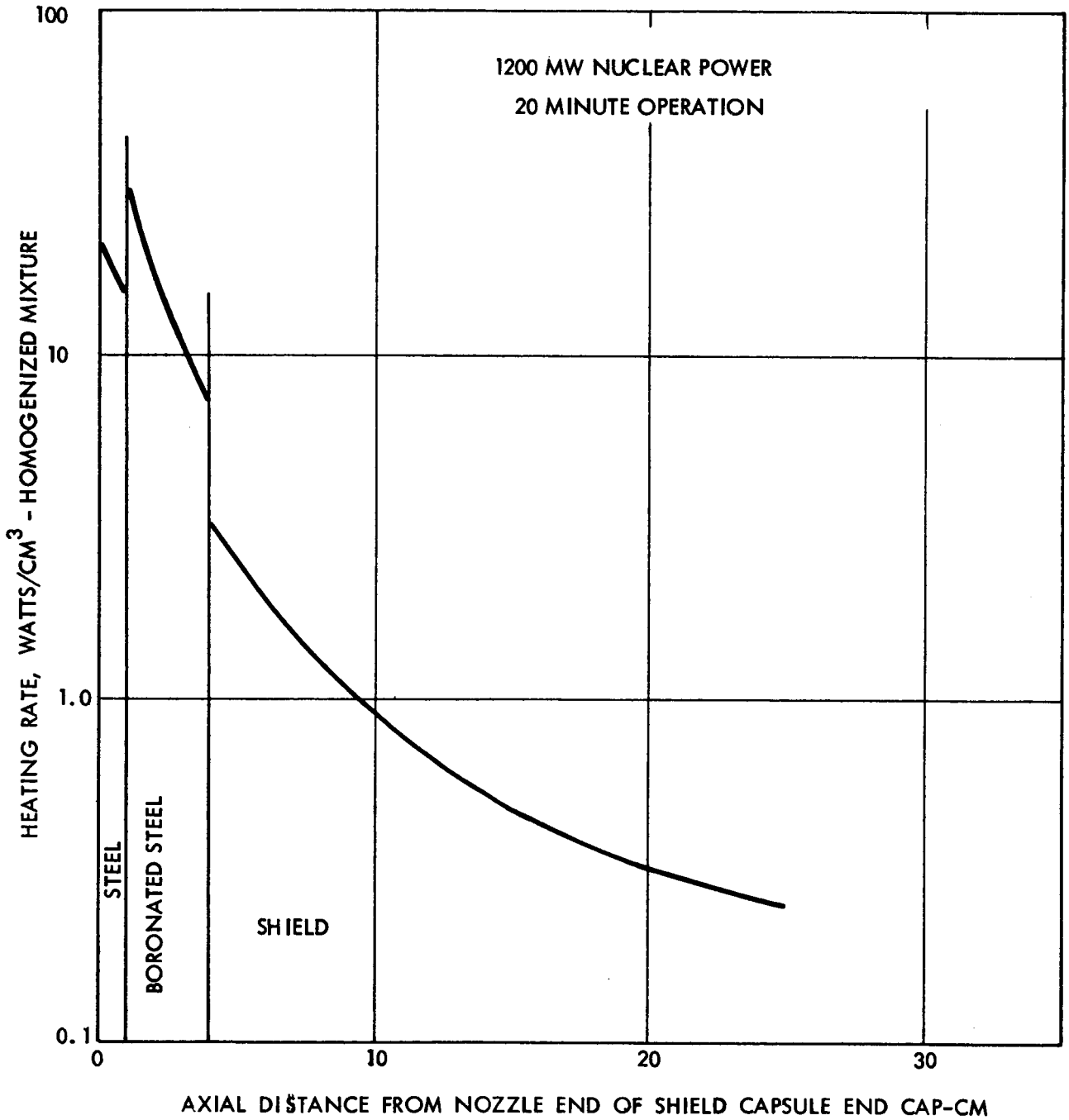


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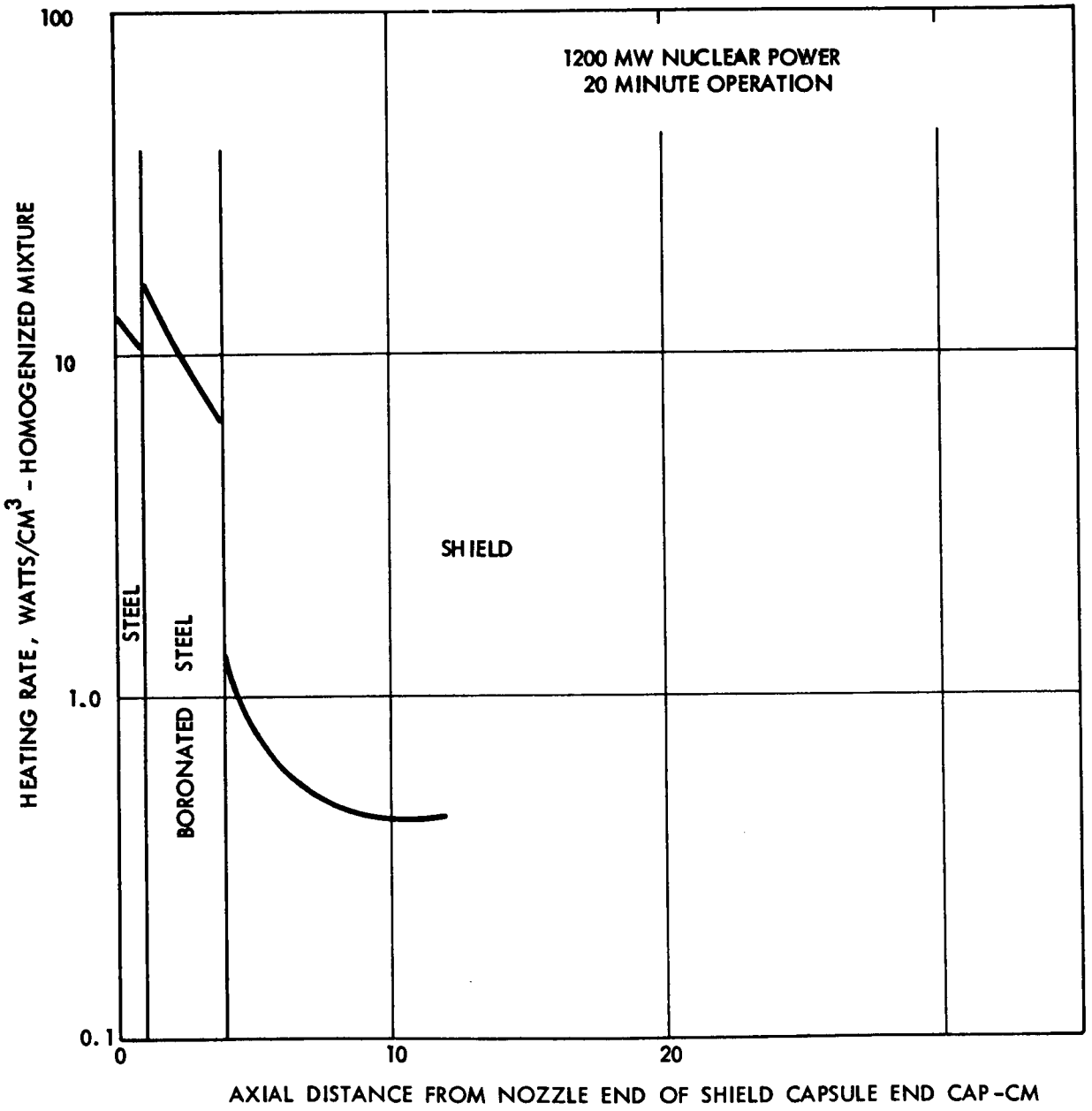
Figure 4-5 - Heating Rates at a Radius of 53 cm From Core Midplane Per cm$^3$ of Homogenized Mixture

[redacted]






[redacted] Figure 4-6 - Heating Rates [redacted] eld Per $cm^3$ [redacted] Homogenized Mixture [redacted]

the reactor core was calculated in this preliminary study. The nuclear power estimate for 1120 MW of thermal power delivered to the propellant used at the time of this analysis was 1200 MW.

Based on these calculations, the total power dissipated in the shield is about 2 MW.

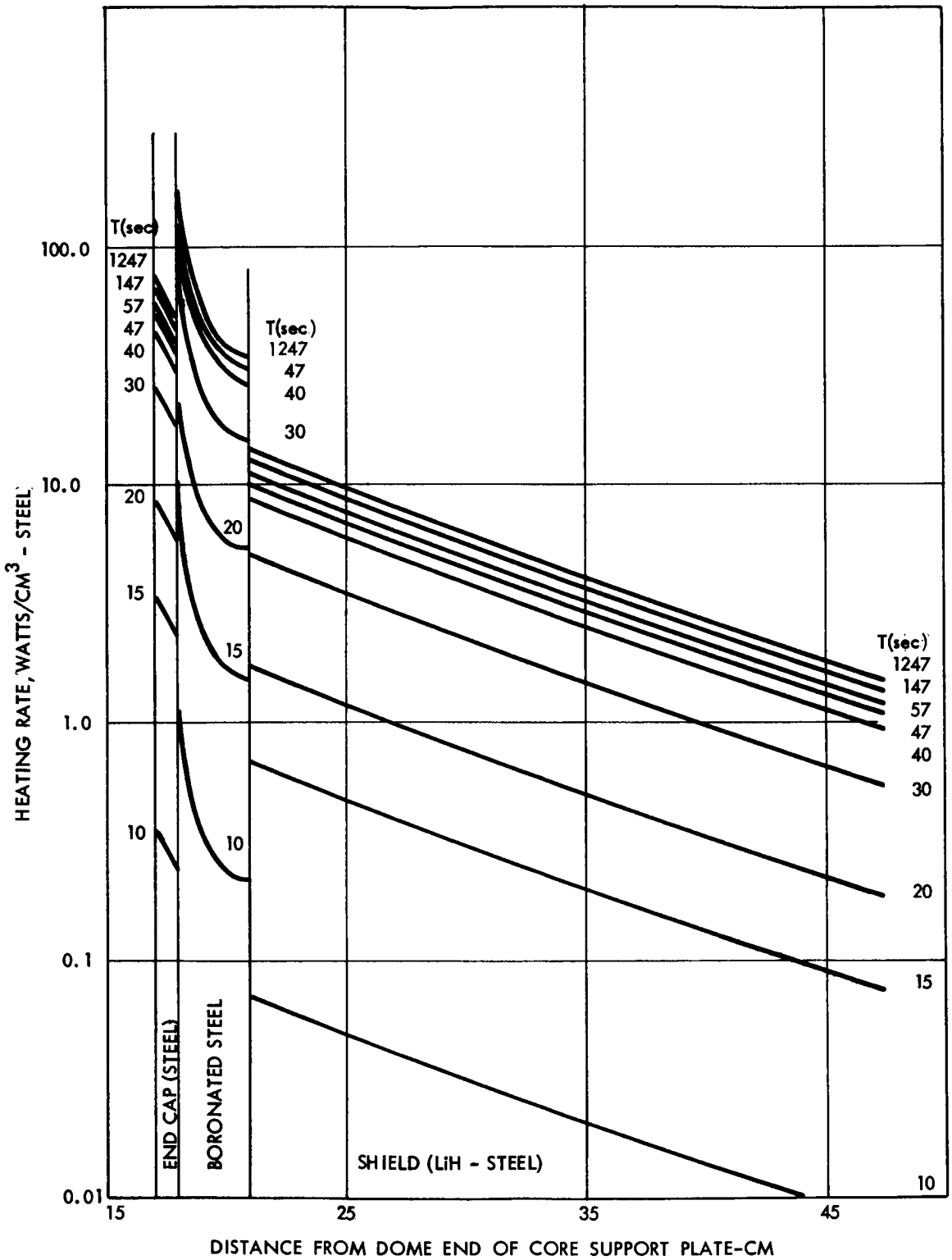
Final Shield Heating Rates

A detailed analysis of radiation heating in the KIWI B-5 shield was performed to include sources of heating not considered in the preliminary analysis. This study included the contribution to the total heating from secondary gamma rays produced in materials outside the reactor core.

Heating rates in stainless steel and in lithium hydride on the axial center line through the shield are shown in Figures 4-7 and 4-8, respectively, for various times after startup ranging from 10 to 1247 seconds, where the first 47 seconds are required to bring the reactor to full power. During the 1200 seconds at full power operation, the heating in the lithium hydride does not change significantly because the heating is due to the n,α reaction and is not due to gamma heating. Data for shutdown ranging from one to $10^6$ seconds are presented in Figures 4-9 and 4-10 for a 20-minute run. It was assumed that shutdown was achieved by a step insertion of -3.5% reactivity.

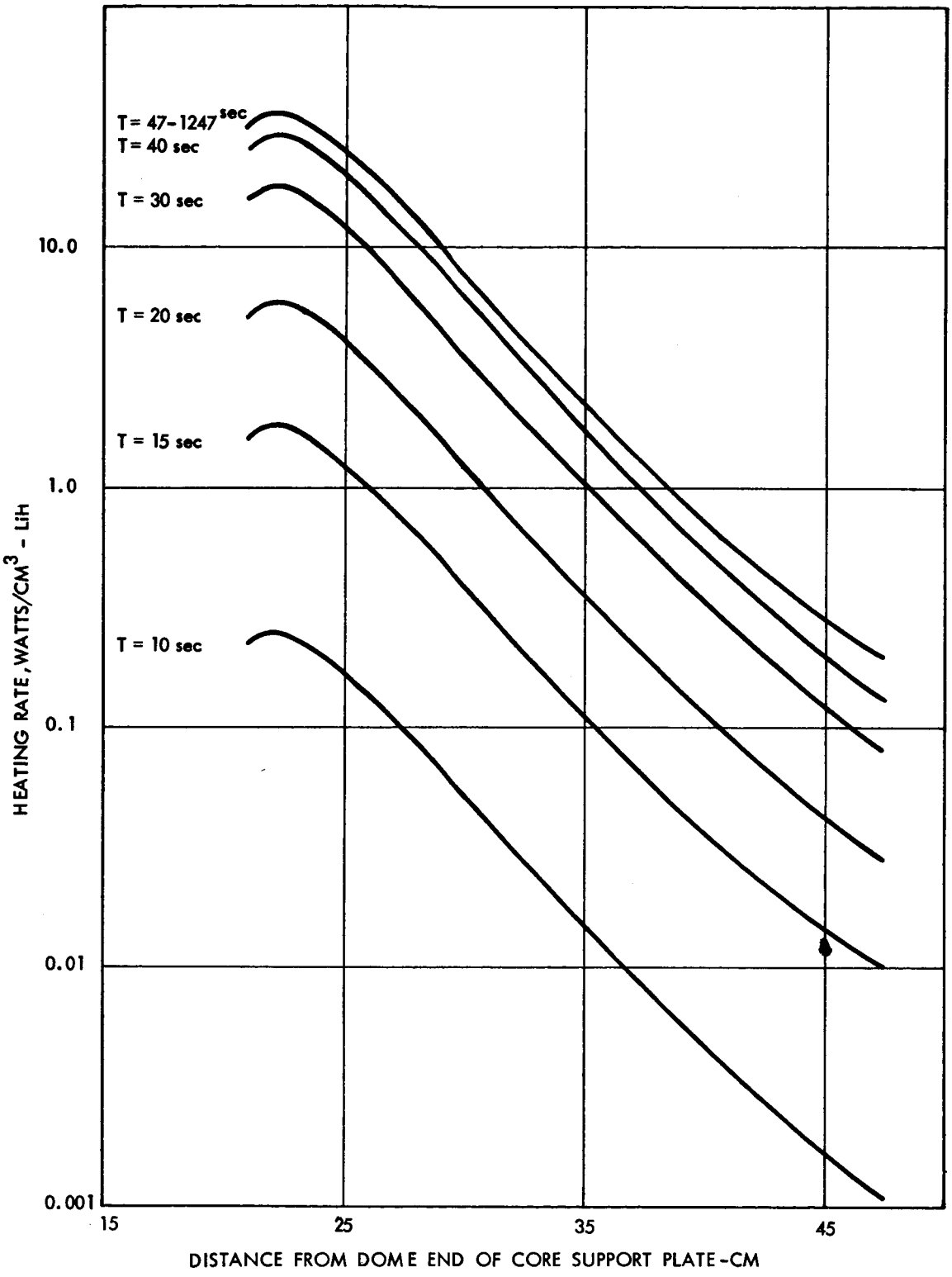
Heating rates in both the shield top and bottom steel support plates were also calculated as a function of reactor operation and shutdown time. Since these plates are quite thin, only the radial heating rate traverses are presented in Figures 4-11 through 4-14.

The heating rate per $cm^3$ of region at steady state operating conditions (1247 seconds) is presented in Figure 4-15. These data were obtained by multiplying the results in Figures 4-7 and 4-8 by appropriate shield region volume fractions indicated in Figure 4-15. The relative radial heating distribution is given in Figure 4-16. The total heat generated in the shield during full power operation is 2.9 MW based on the data shown in Figures 4-15 and 4-16. During the final analysis, it was calculated that 1165 MW




[redacted]

Figure 4-7 - Heating Rate in Stainless Steel on the Axial Center Line for Various Times (T) After Startup KIWI B-5, 1165 MW (Nuclear) at Full Power

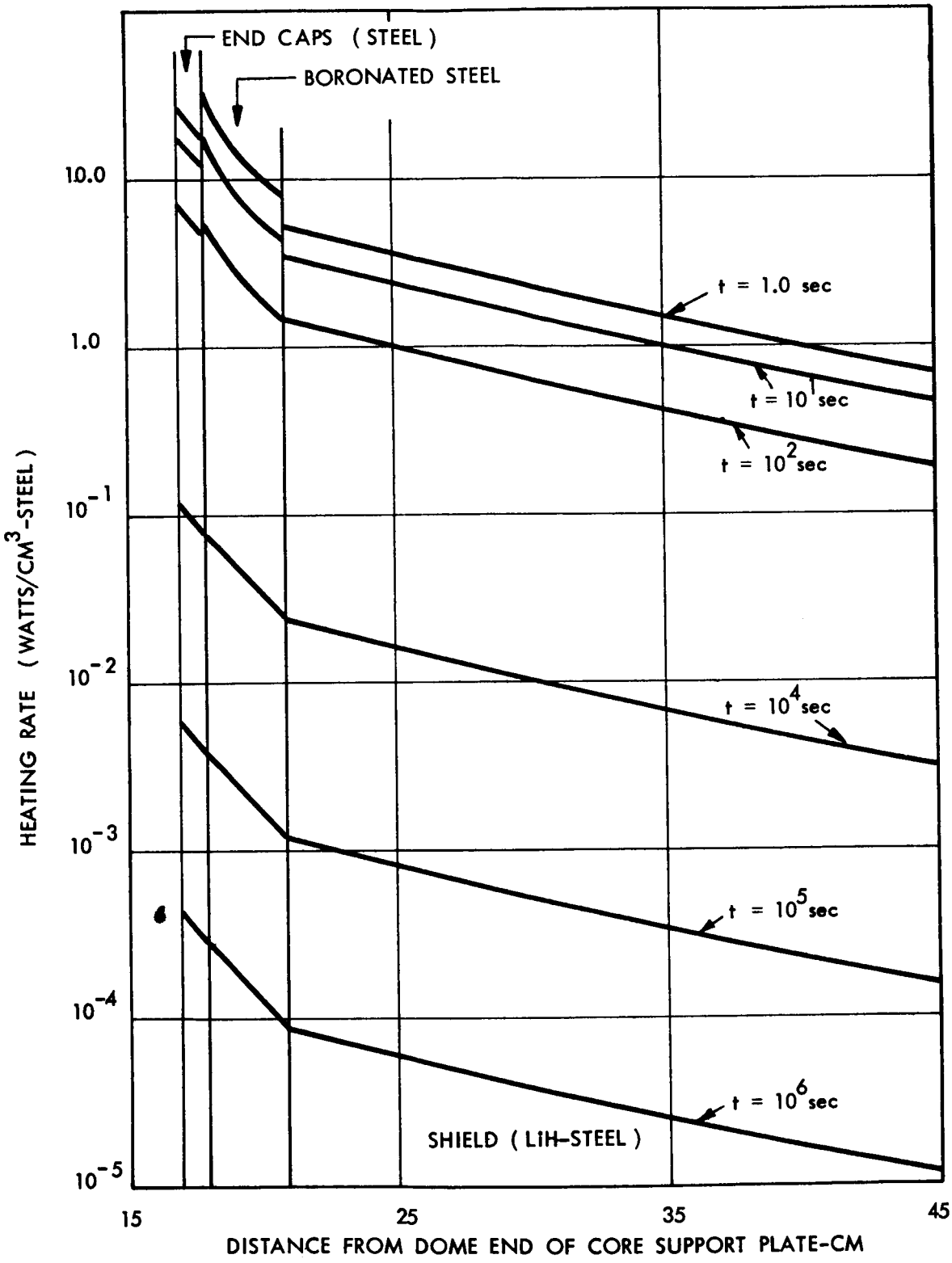



[redacted]

Figure 4-8 - Heating Rate in Lithium Hydride on the Axial Center Line for Various Times (T) After Startup KIWI B-5, 1-165 MW (Nuclear) at Full Power

[redacted]

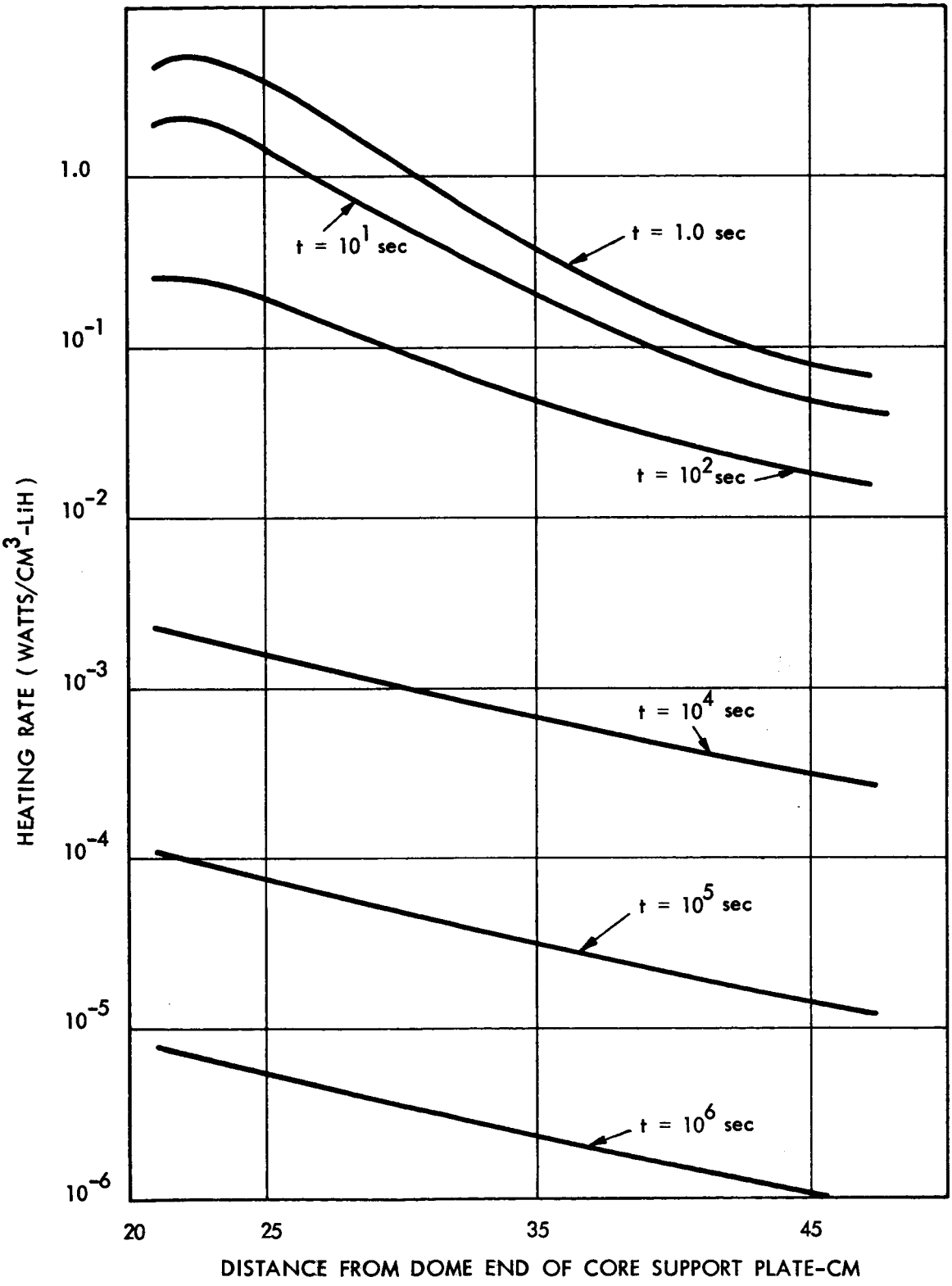





[redacted]

Figure 4-9 - Heating Rate in Stainless Steel on the Axial Center Line for Various Times (t) After Shutdown KIWI B-5, 1165 MW (Nuclear) at Full Power

[redacted]

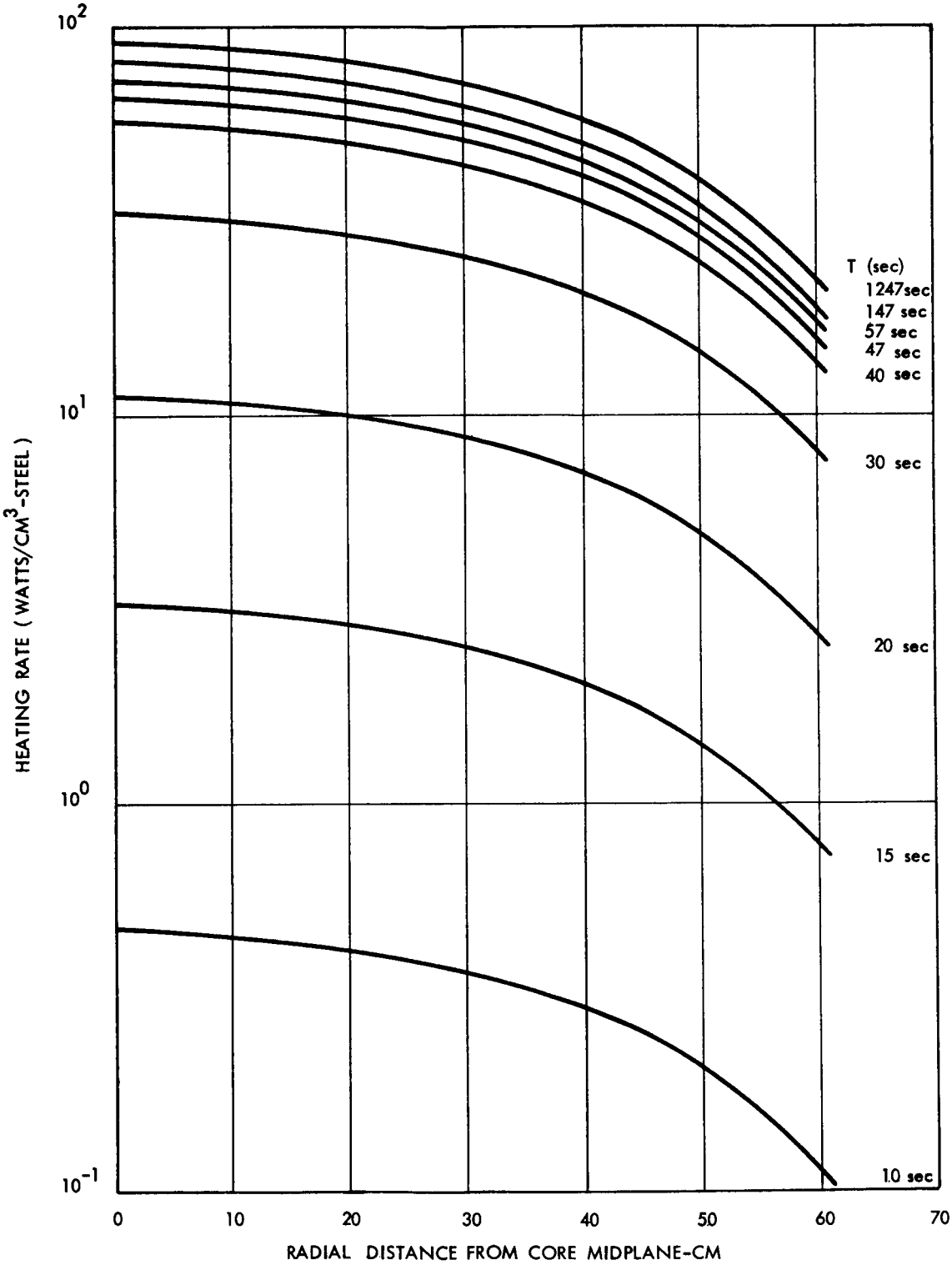



[redacted]

Figure 4-10 - Heatin[redacted]hydride [redacted] the Axial Center Line for [redacted] Times (t) After [redacted] Shutdown KIWI B-5, 1165 MW [redacted] Power

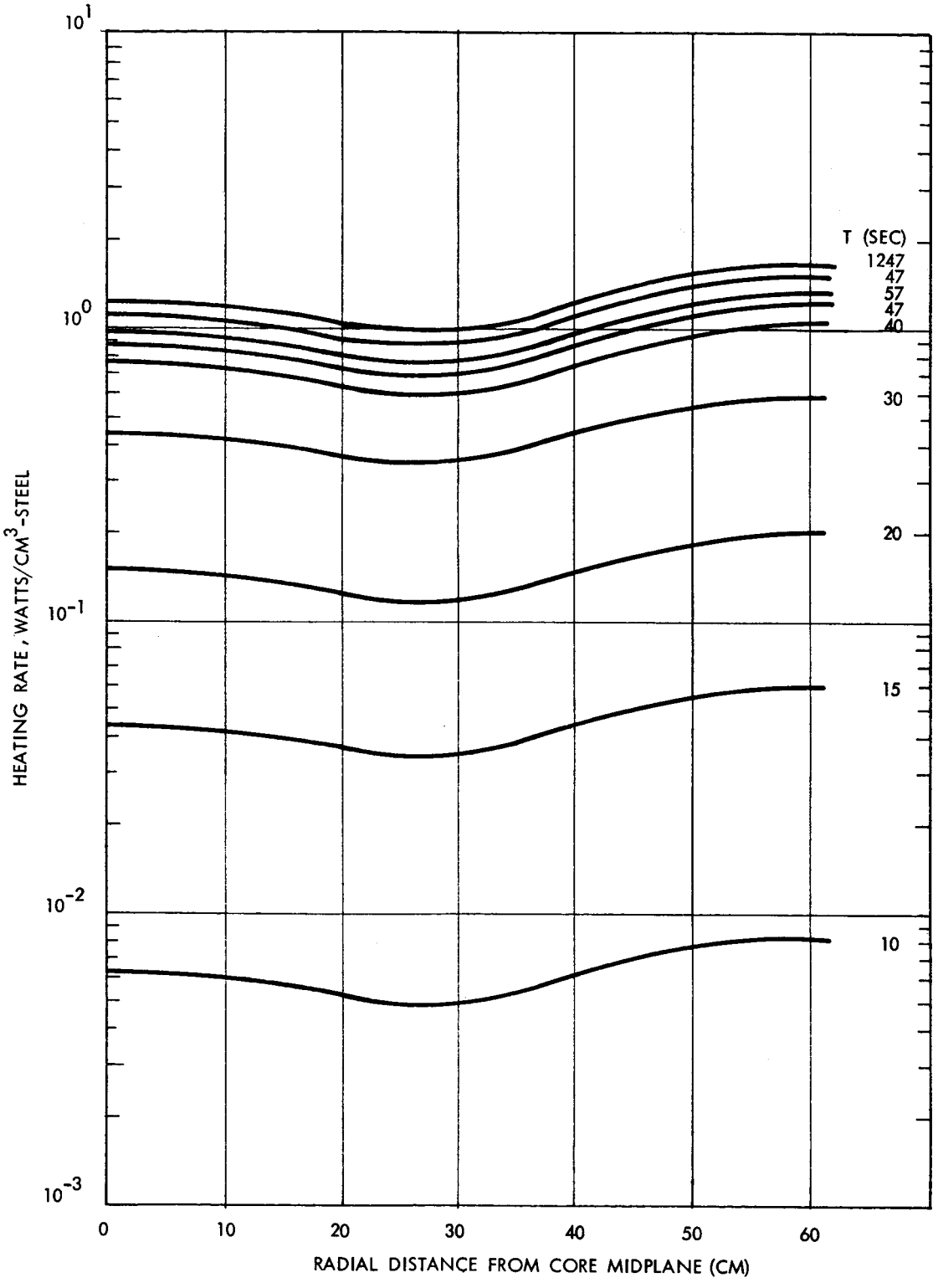
[redacted]






[redacted]

Figure 4-11 - Heating Rate in Shield Nozzle End Support Plate for Various Times (T) After Startup KIWI B-5, 1165 MW (Nuclear) at Full Power

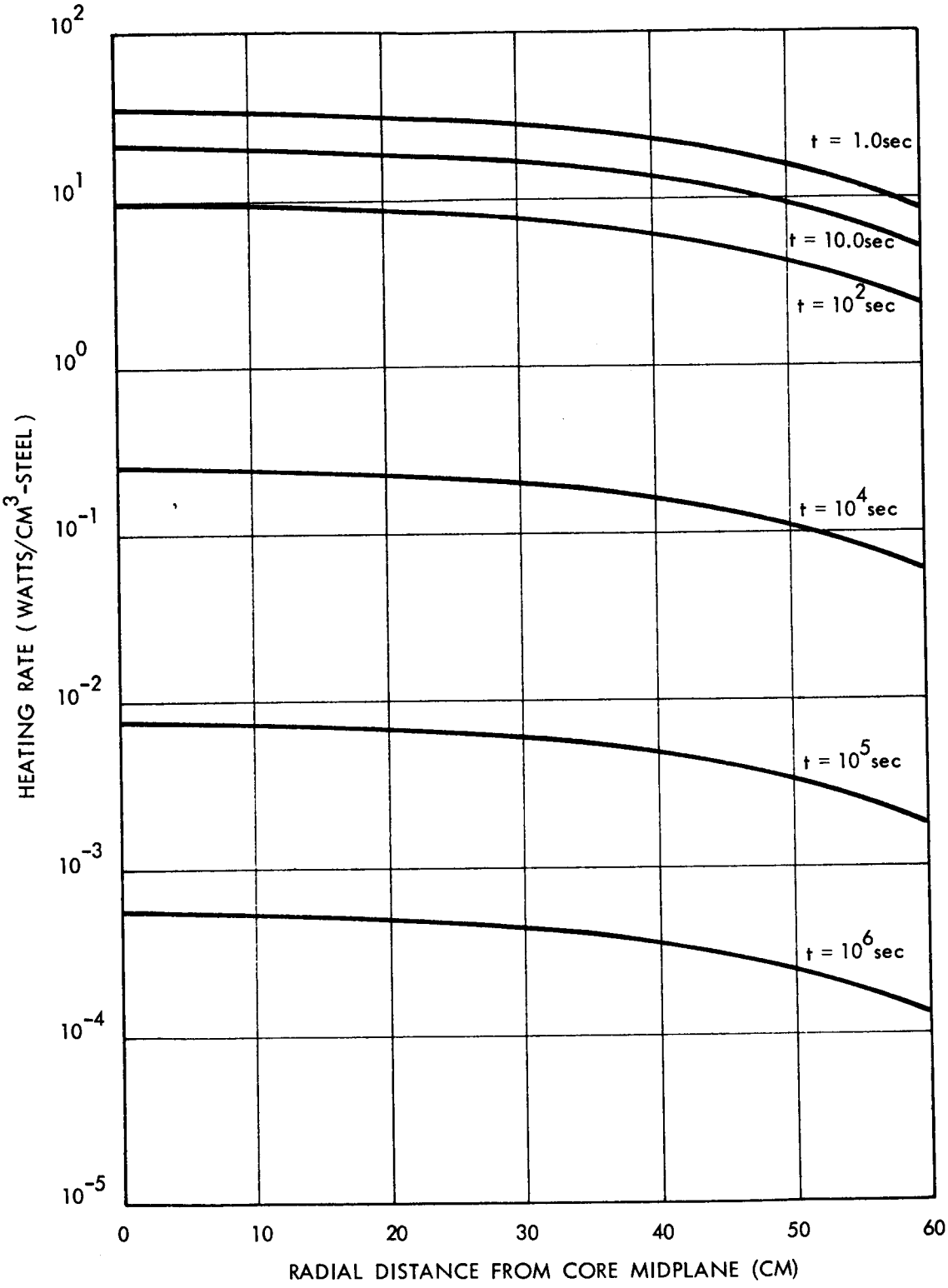



[redacted]

Figure 4-12 - Heat[redacted] Shield Dome End Support Plate for [redacted] After Start[redacted] WI B-5, 1165 MW (Nuclear) at Full Power [redacted]

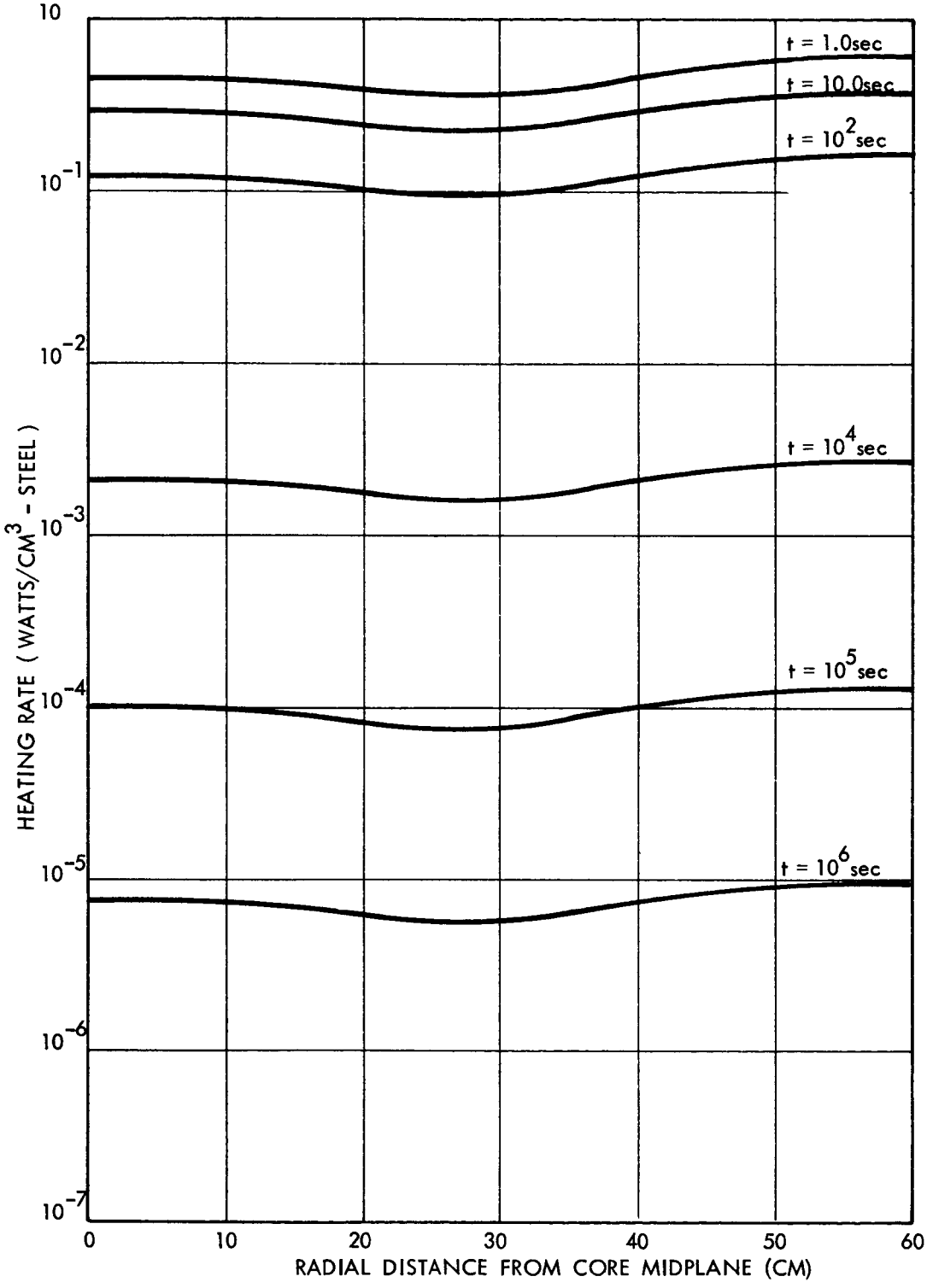
[redacted]





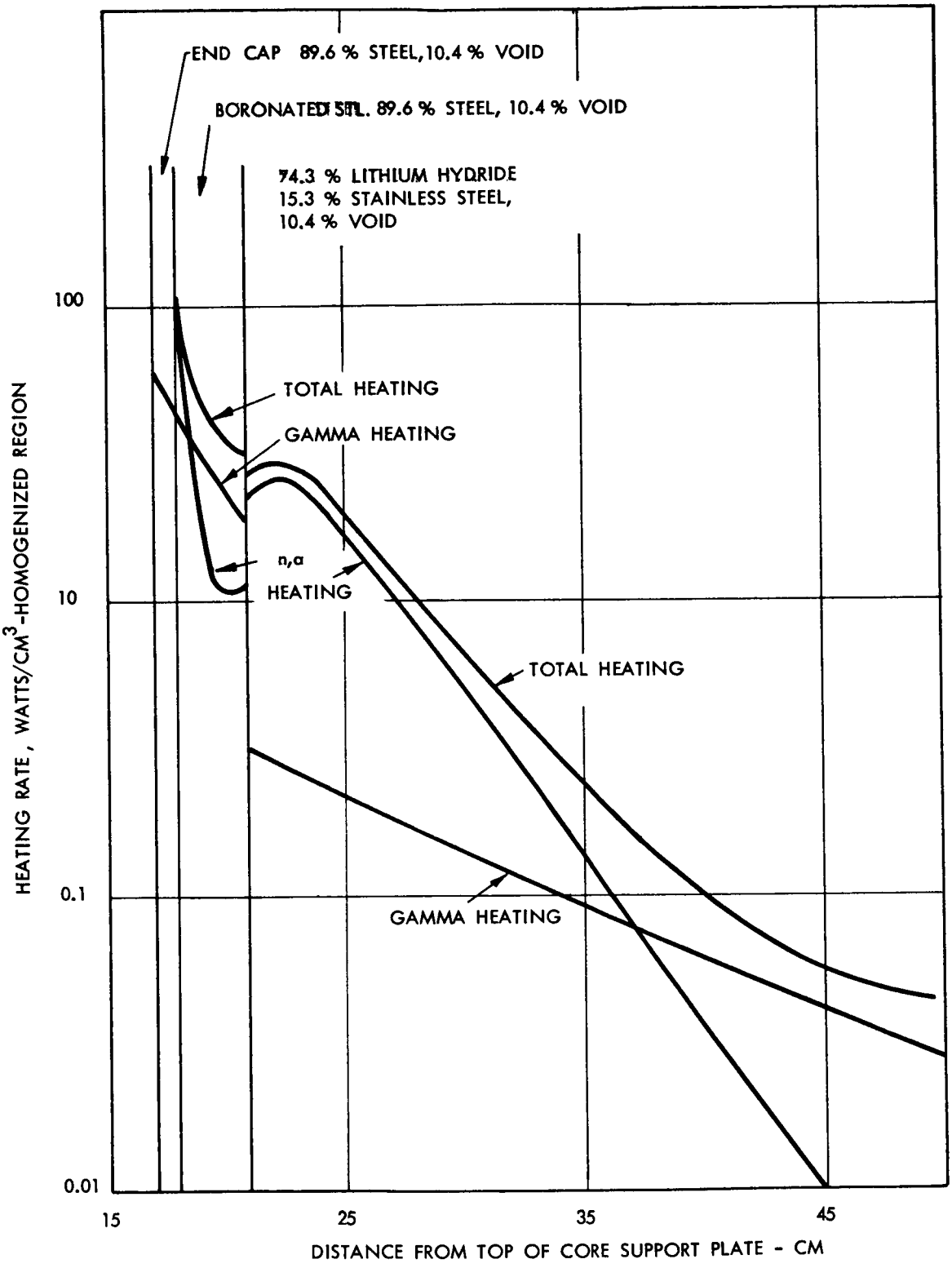

[redacted]

Figure 4-13 - Heating Rate in Shield [redacted]
Support Plate for Various Times (t) After Shutdown
KIWI B-5, 1165 MW (Nuclear) at Full Power




[redacted]

Figure 4-14 - Heating Rate in the Shield [redacted] Support Plate for Various [redacted] (t) After [redacted] KIWI B-5, 1165 MW [redacted] Nuclear) at Full Power

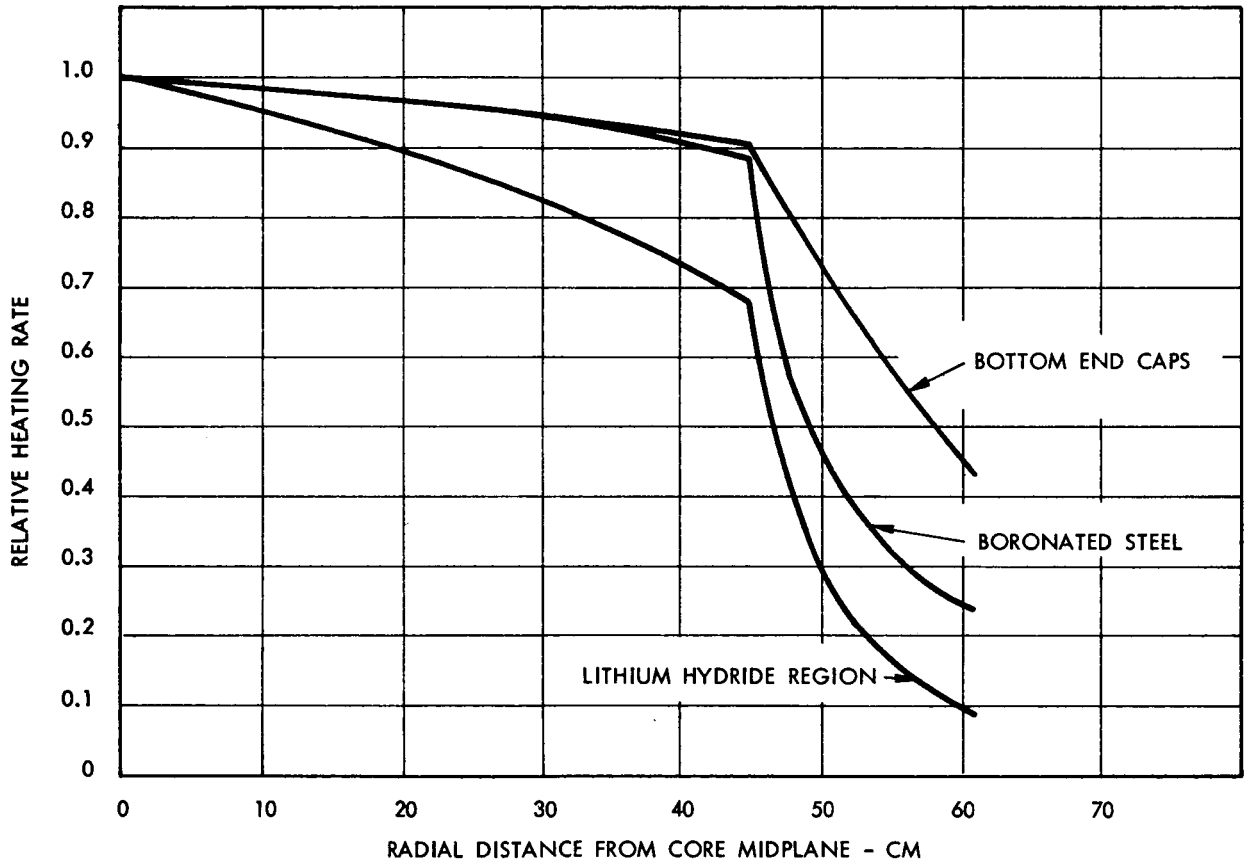



[redacted]

Figure 4-15 - Axial Heating in KIWI B-5 Shield Along the Center Line 1165 MW (Nuclear)

[redacted]






[redacted]

Figure 4-16 - Radial Distribution of Heating in the Various KIWI B-5 Shield Components

of nuclear power* were required to produce 1120 MW thermal power in the reactor core, reflectors, and reactor core support plate.

Radiation Environment

Presented in Figure 4-17 is the radiation environment outside the KIWI B-5 assembly. The gamma ray data are presented in units of total dose rate (R/hr), and the neutron data in units of flux above 1 Mev (neutrons/$cm^2$-sec).

The gamma ray dose rate includes the primary radiation from the reactor core and secondary gamma rays produced by neutron capture and neutron inelastic scattering in materials outside the reactor core. These data are higher than those presented in Reference 5 primarily due to the inclusion of the contribution of gamma ray sources outside the reactor core.

Shielding Computer Program 14-0 was used to calculate the gamma ray dose rates according to the method described in Section 2. A sufficient number of detector points were run to permit interpolation for all points shown in Figure 4-17.

The fast neutron fluxes shown in Figure 4-17 were obtained by using the differential neutron number flux option coded in Program 14-0. The fluxes presented here are based on moments data for lithium hydride.

The KIWI B-5 reactor axial and radial power distributions used in Program 14-0 are presented in Figures 4-18 and 4-19, respectively.

The KIWI B-5 core gamma source energy spectrum for thirteen energy groups as used in Program 14-0 is presented in Table 4-1. This spectrum assumes that the B-5 core would operate for 20 minutes.

* This corresponds to $3.77 \times 10^{19}$ fissions/second with a release of 193 Mev/fission.

TABLE 4-1

KIWI B-5 CORE GAMMA RAY SOURCE ENERGY SPECTRUM (Units-Mev/fission)

| Energy Group (Mev) | 0-.4 | .4-.9 | .9-1.35 | 1.35-1.8 | 1.8-2.2 | 2.2-2.6 | 2.6-3.0 | 3.0-4.0 | 4.0-5.0 | 5.0-6.0 | 6.0-7.0 | 7.0-7.5 | >7.5 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Primary Sources | | | | | | | | | | | | | | |
| Prompt | .965 | 1.873 | 1.320 | .878 | .656 | .503 | .363 | .559 | .252 | .111 | .040 | .015 | .003 | 7.538 |
| Short Half Life | .129 | .086 | .033 | .033 | .025 | | | | | | | | | .306 |
| Delayed | .219 | .941 | .837 | .701 | .493 | .419 | .326 | .522 | .213 | .039 | | | | 4.71 |
| Total Primaries | 1.313 | 2.900 | 2.190 | 1.612 | 1.174 | .922 | .689 | 1.081 | .465 | .150 | .040 | .015 | .003 | 12.554 |
| Secondary Sources (Radiative Capture) | | | | | | | | | | | | | | |
| Uranium-235 | .32042 | .62212 | .43814 | .29157 | .21751 | .16722 | .12006 | .18554 | .08381 | .03703 | .01325 | .00507 | .00078 | 2.50252 |
| Uranium-238 | .00257 | .00471 | .00277 | .00299 | .00272 | .00195 | .00132 | .00237 | .00181 | | | | | .02321 |
| Carbon | | | .00002 | | | | | .00004 | .00018 | | | | | .00030 |
| Iron | .00007 | .00039 | .00033 | .00069 | .00029 | .00033 | .00031 | .00059 | .00066 | .00121 | .00058 | .00099 | .00302 | .00946 |
| Nickel | .00002 | .00006 | .00003 | .00003 | .00004 | .00003 | .00003 | .00006 | .00006 | .00012 | .00018 | .00007 | .00059 | .00132 |
| Niobium | .00645 | .02678 | .04299 | .05541 | .05662 | .07105 | .05525 | .11485 | .07525 | .06250 | .01532 | .00306 | | .58553 |
| Chromium | .00004 | .00016 | .00008 | .00009 | .00006 | .00006 | .00004 | .00006 | .00008 | .00019 | .00021 | .00014 | .00109 | .00230 |
| Hydrogen | | | | | | .00025 | | | | | | | | .00025 |
| Total (Radiative Captures) | .32957 | .65422 | .48436 | .35078 | .27724 | .24089 | .17701 | .30351 | .16185 | .10105 | .02954 | .00933 | .00548 | 3.12483 |
| Inelastic Scattering | | | | | | | | | | | | | | |
| Uranium-235 | .00292 | .02947 | .01600 | .00609 | | .00519 | .00116 | .00016 | | | | | | .06099 |
| Uranium-238 | .00046 | .00129 | .00137 | .00350 | | .00128 | | .00118 | .00129 | | | | | .01037 |
| Carbon | | | | | | | | | .14094 | | | | | .14094 |
| Iron | | .00835 | .00130 | | .01014 | | | | | | | | | .01979 |
| Nickel | | .00016 | .00029 | .00073 | .00010 | | | | | | | | | .00128 |
| Niobium | .00098 | .02641 | .04116 | .00797 | .04291 | | | | | | | | | .11943 |
| Chromium | | .00021 | .00067 | .00295 | | | | | | | | | | .00383 |
| Total (Inelastic) | .00436 | .06589 | .06079 | .02124 | .05315 | .00647 | .00116 | .00134 | .14223 | | | | | .35663 |
| Grand Total (Primaries + Secondary) | 1.64693 | 3.62011 | 2.73515 | 1.98402 | 1.50439 | 1.16936 | .86717 | 1.38585 | .76908 | .25105 | .06954 | .02433 | .00848 | 16.03546 |

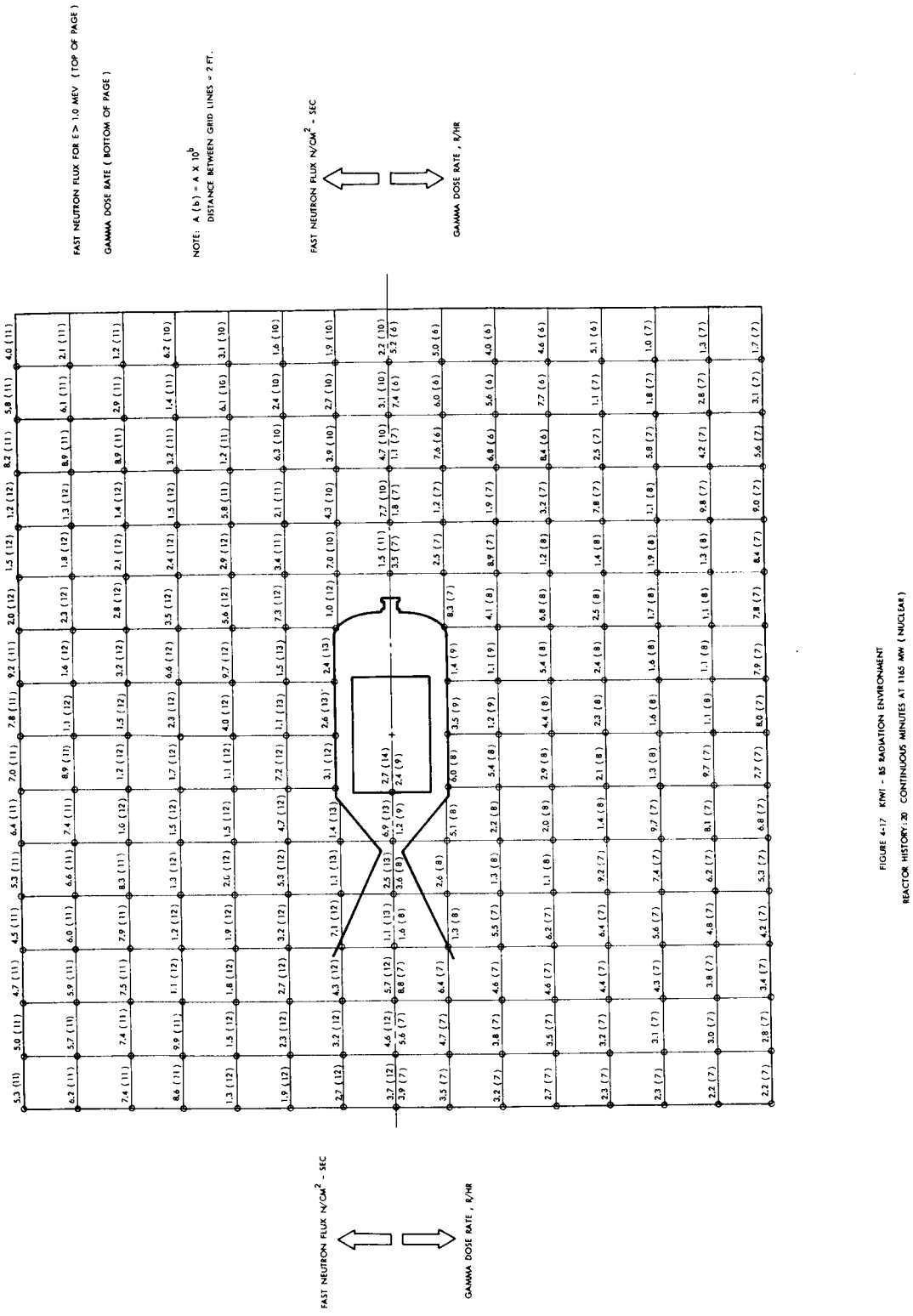



FIGURE 4-17 KIWI - B5 RADIATION ENVIRONMENT
REACTOR HISTORY: 20 CONTINUOUS MINUTES AT 1165 MW (NUCLEAR)

Figure 4-17 - KIWI B-5 Radiation Environment

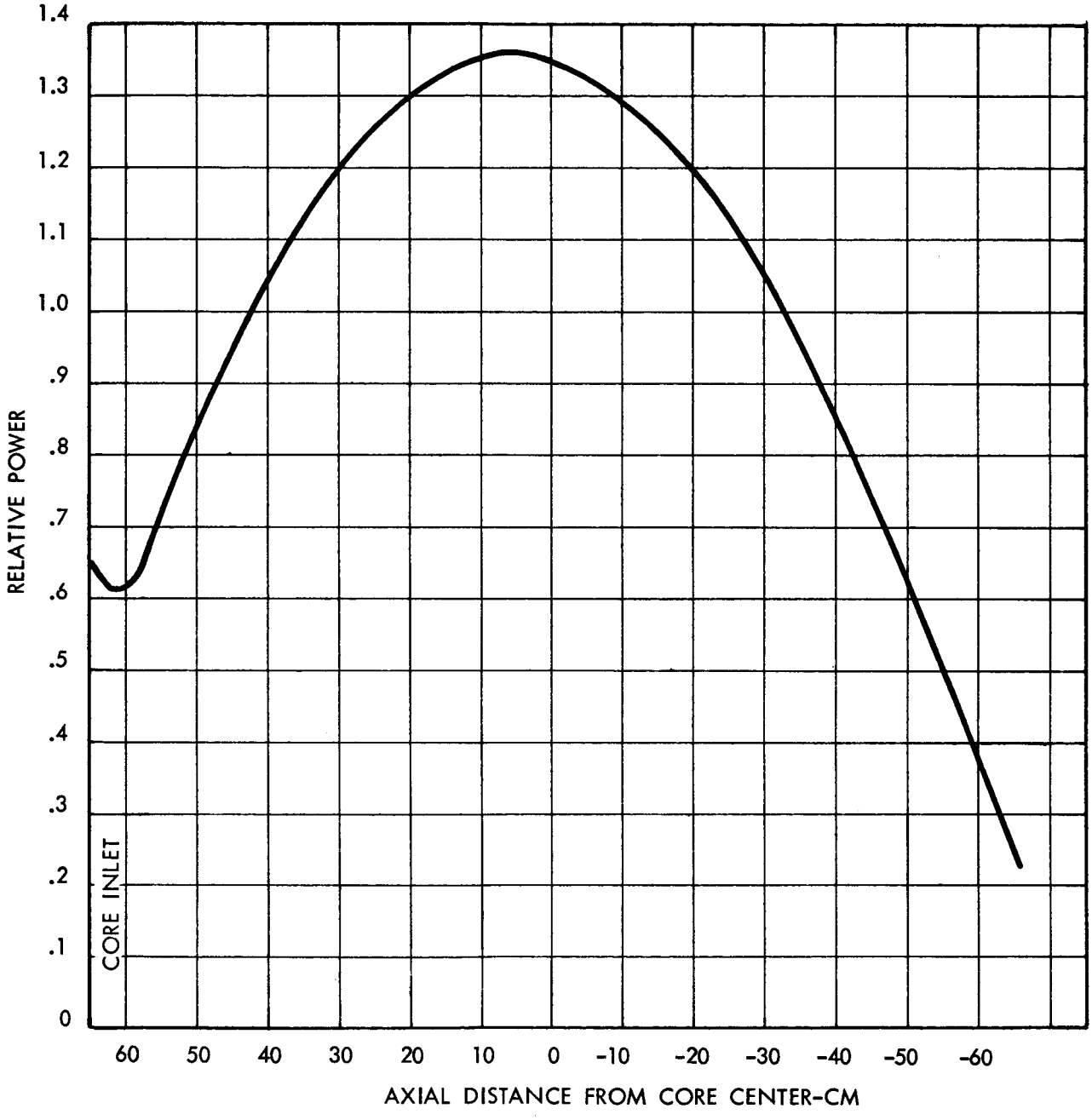
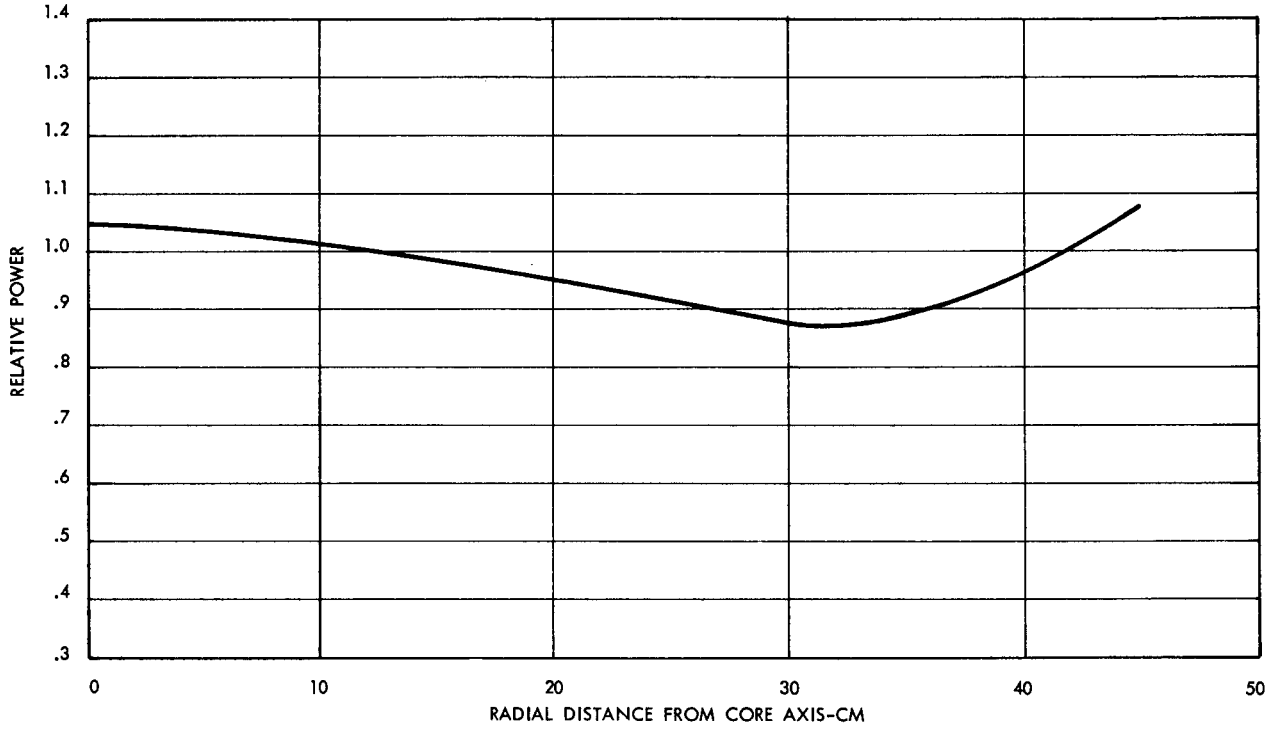



Figure 4-18 - KIWI B-5 Axial Power Distribution

[redacted]






[redacted]

Figure 4-19 - KIWI B-5 Radial Power Distribution

[redacted]

Presented in Figure 4-20 is a schematic diagram of the KIWI B-5 assembly. The geometry shown in this diagram was described in the computer programs used in this analysis. Table 4-2 gives the material volume fractions of regions shown in Figure 4-20.

The power distributions, source spectrum, and volume fractions described above were also used in the final shield heating rate analysis previously discussed.

Radiation Levels Inside KIWI B-5 Vessel

Gamma ray dose rates inside the KIWI B-5 vessel were calculated using Program 14-0. Axial traverses at several radii through the reactor, and the graphite and beryllium reflectors, are shown in Figure 4-21; axial traverses through the aluminum core support plate, shield, and pressure vessel are shown in Figures 4-22 and 4-23. These gamma ray dose rates include the radiation from the reactor core and secondary gamma rays produced by neutron capture and neutron inelastic scattering in materials outside the reactor core, and were obtained in the manner described in Section 2.

Illustrated in Figure 4-24 is the time integrated gamma dose in roentgens for a 20 minute reactor run. This axial traverse is located on the core center line. Similar data for a radial traverse along the core midplane are shown in Figure 4-25.

The option coded in Program 14-0 for computing differential gamma ray energy spectra was used to determine the spectra at several locations on the reactor center line. The spectral data shown in Figures 4-26, 4-27, and 4-28 are at positions located on the center line corresponding to the top of the aluminum support plate, the boronated steel-lithium hydride interface in the shield, and the top of the lithium hydride.

Presented in Figure 4-29 are fast neutron flux (above 1 Mev) axial traverses at several radial positions inside the B-5 vessel. An eight group two dimensional diffusion program, CURE, was used to obtain these data as described in Section 2.

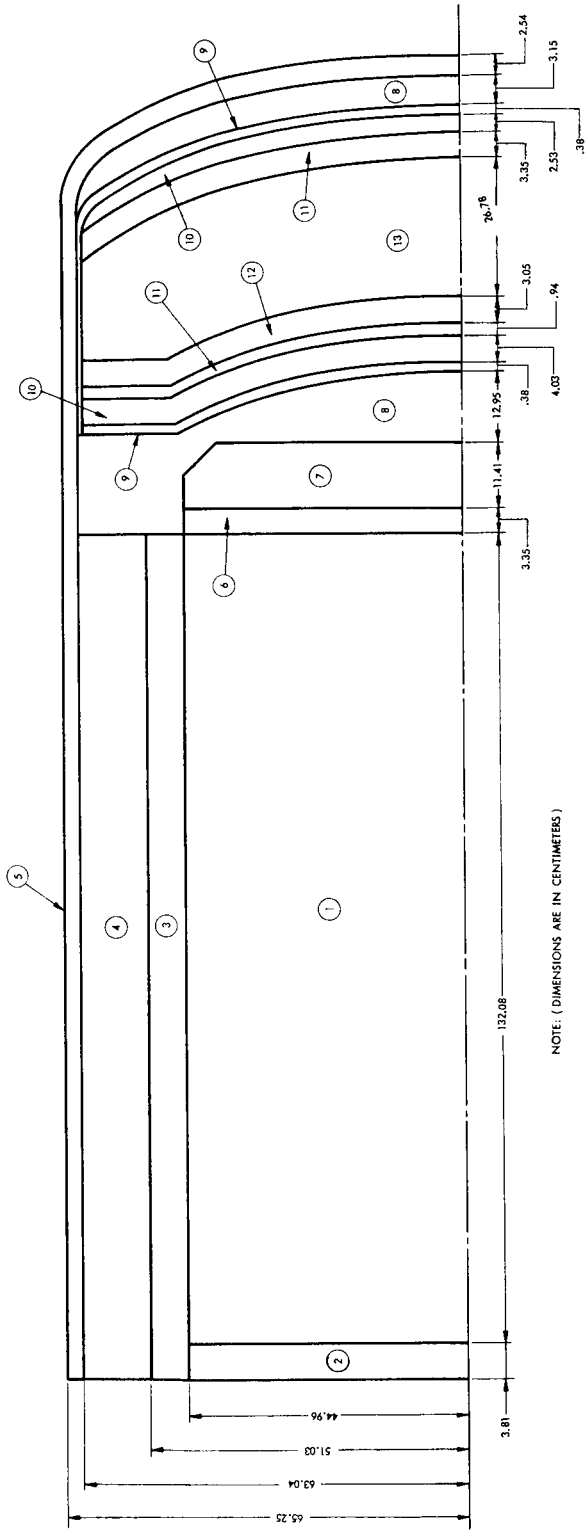



Figure 4-20 - Schematic Diagram of KIWI B-5 Assembly

[redacted]

[redacted]

TABLE 4-2

VOLUME FRACTIONS DESCRIBING KIWI B-5 ASSEMBLY

Region 1 - Reactor Core

| | | |
|---|---|---|
| C | - | 0.7812 |
| $U^{235}$ | - | 0.0133 |
| $U^{238}$ | - | 0.0009 |
| Fe | - | 0.0025 |
| Cr | - | 0.0006 |
| Ni | - | 0.0002 |
| Nb | - | 0.0119 |
| Coolant | - | 0.1894 |

(Coolant number density - $2.65 \times 10^{20}$ atoms/$cm^3$ of region)

Region 2 - Unfueled Graphite Cookie

| | | |
|---|---|---|
| C | - | 0.7945 |
| Nb | - | 0.0119 |
| Fe | - | 0.0025 |
| Ni | - | 0.0002 |
| Cr | - | 0.0006 |
| Coolant | - | 0.1903 |

(Coolant number density - $2.65 \times 10^{20}$ atoms/$cm^3$ of region)

Region 3 - Graphite Reflector

| | | |
|---|---|---|
| C | - | 0.9756 |
| Coolant | - | 0.0244 |

(Coolant number density - $1.45 \times 10^{20}$ atoms/$cm^3$ of region)

Region 4 - Beryllium Reflector

| | | |
|---|---|---|
| Be | - | 0.8810 |
| Steel | - | 0.0082 |
| Al | - | 0.0023 |
| Coolant | - | 0.1085 |

(Coolant number density - $6.43 \times 10^{20}$ atoms/$cm^3$ of region)

Region 5 - Pressure Vessel

| | | |
|---|---|---|
| Al | - | 1.0 |

[redacted]

[redacted]

[redacted]



Table 4-2 (Continued)

Region 6 - Core Cluster Plate Region

| | | |
|---|---|---|
| Al | - | 0.1838 |
| Steel | - | 0.0074 |
| Coolant | - | 0.8088 |

(Coolant number density - $4.61 \times 10^{21}$ atoms/cm$^3$ of region)

Region 7 - Core Support Plate

| | | |
|---|---|---|
| Al | - | 0.60 |
| Coolant | - | 0.40 |

(Coolant number density - $2.37 \times 10^{21}$ atoms/cm$^3$ of region)

Region 8 - Plenums

| | | |
|---|---|---|
| Coolant | - | 1.0 |

(Coolant number density - $5.93 \times 10^{21}$ atoms/cm$^3$)

Region 9 - Shield Support Plate

| | | |
|---|---|---|
| Steel | - | 1.0 |

Region 10 - Plenum

| | | |
|---|---|---|
| Coolant | - | 0.944 |
| Steel | - | 0.056 |

(Coolant number density - $5.93 \times 10^{21}$ atoms/cm$^3$ of region)

Region 11 - Shield Capsule End Caps

| | | |
|---|---|---|
| Steel | - | 0.879 |
| Coolant | - | 0.121 |

(Coolant number density - $7.18 \times 10^{20}$ atoms/cm$^3$ of region)

Region 12 - Borated Steel

| | | |
|---|---|---|
| Boronated Steel | - | 0.866 |
| Coolant | - | 0.134 |

(Coolant number density - $7.18 \times 10^{20}$ atoms/cm$^3$ of region)

[redacted]

Table 4-2 (Continued)

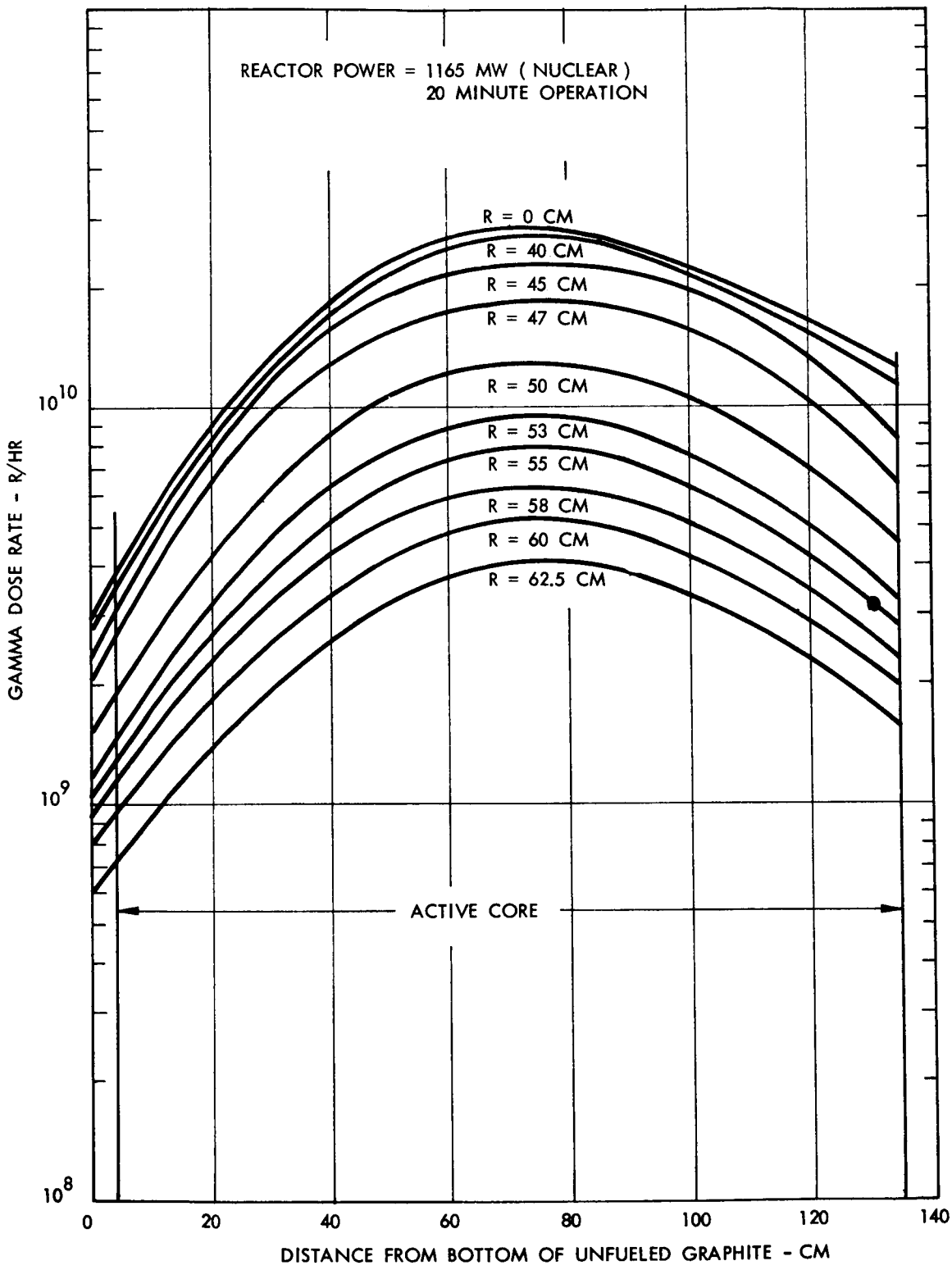
Region 13 - Homogenized Shield

| | | |
|---|---|---|
| Li H | - | 0.7174 |
| Steel | - | 0.1481 |
| Coolant | - | 0.1345 |

(Coolant number density - $7.18 \times 10^{20}$ atoms/$cm^3$ of region)

[redacted]

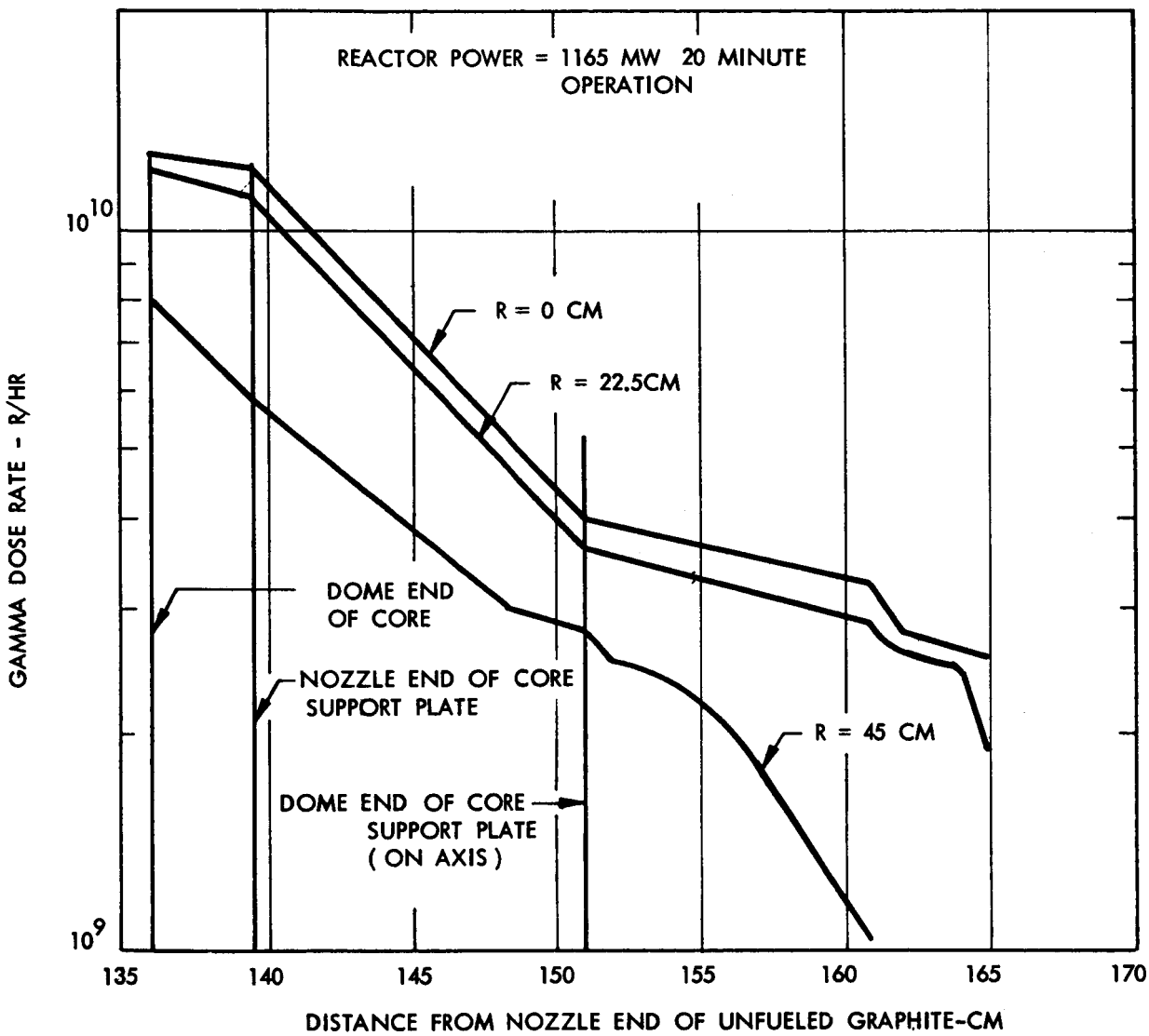





[redacted]

Figure 4-21 - Gamma Dose Rate - Axial Traverses Through KIWI B-5 Core, Graphite Reflector and [redacted]eryllium Reflector.

[redacted]

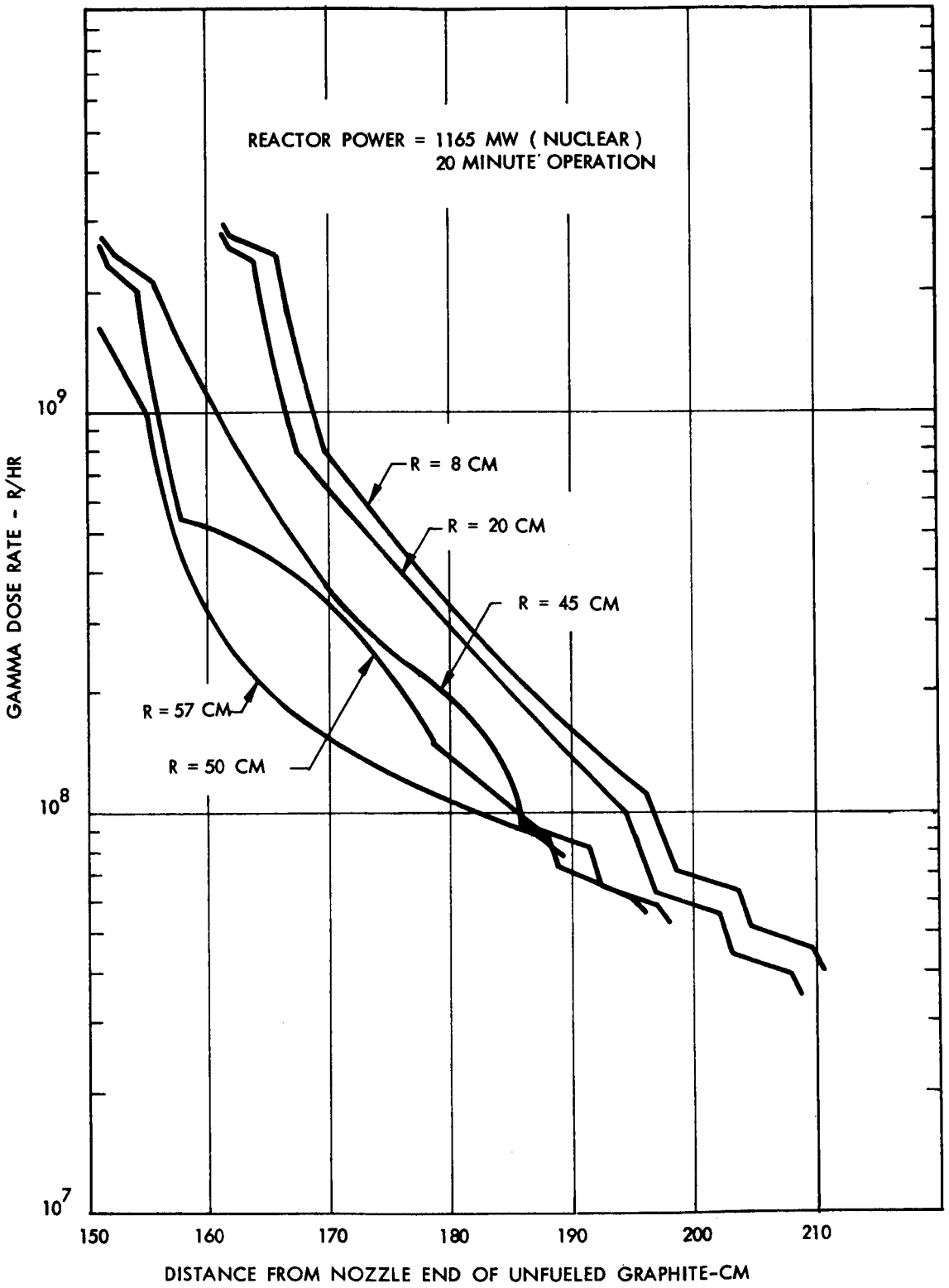



[redacted]

Figure 4-22 - Gam[redacted]
Through KIWI B-5 Aluminum Core Support Plate

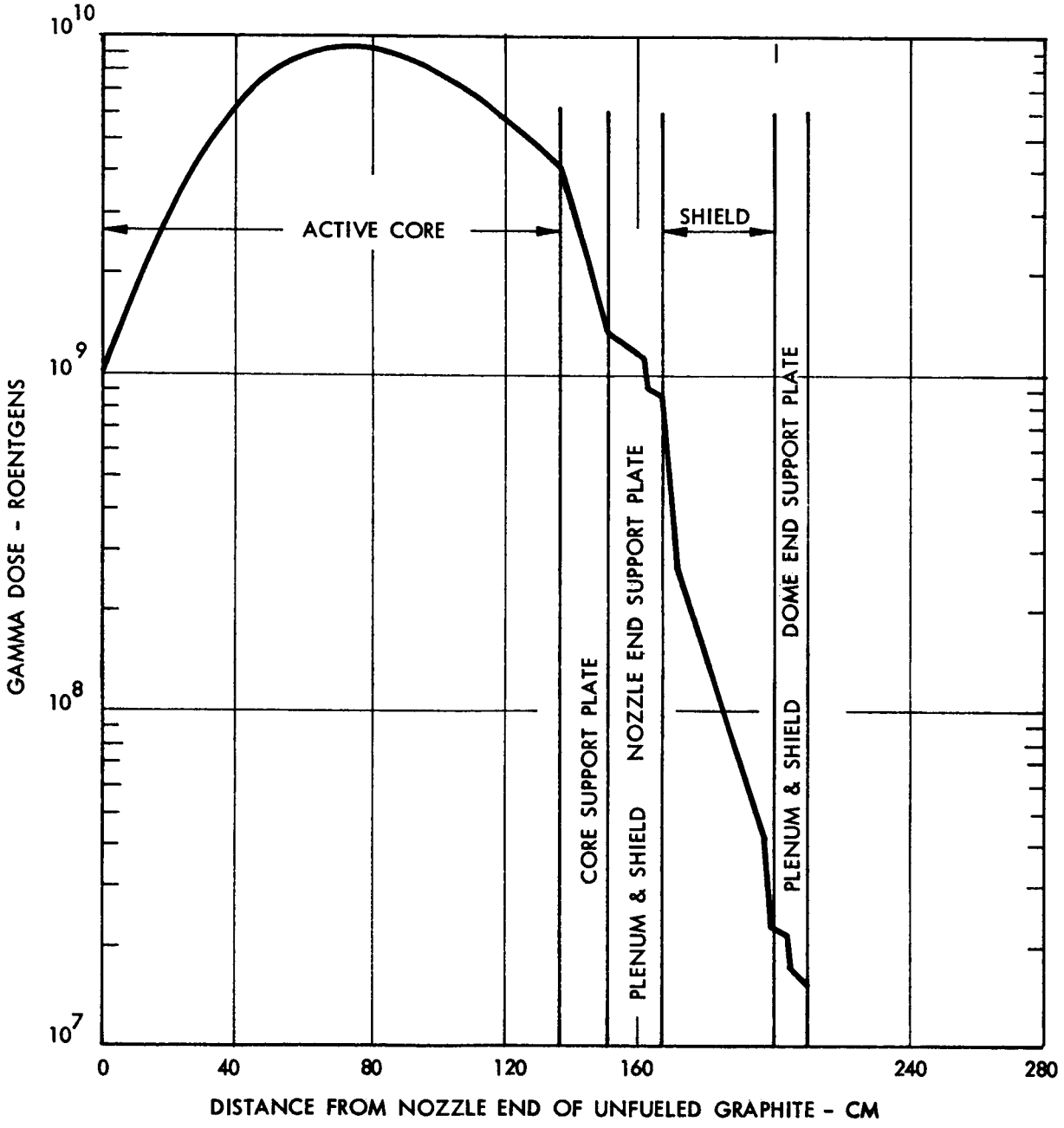
[redacted]





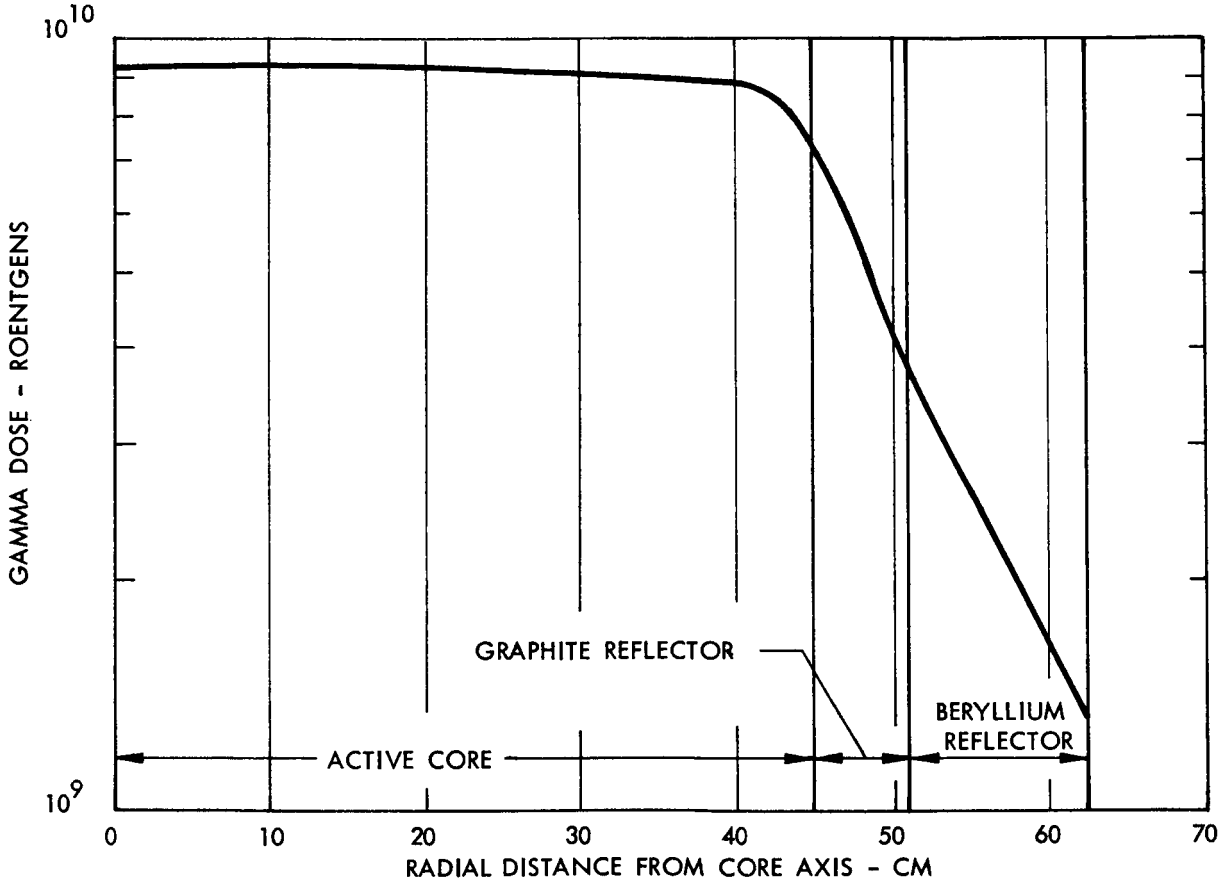

[redacted]

Figure 4-23 - Gamma Dose Rate - Axial Traverses Through the KIWI B-5 Shield and Pressure Vessel




[redacted]

Figure 4-24 - Total Gamma Dose in Roentgens for a 20-Minute Reactor Operation at 1165 MW (Nuclear) Axial Traverse in the KIWI B-5 Core and Shield




[redacted]

Figure 4-25 - Total Gamma Do[redacted] 20-Minute Reactor [redacted] Radial Traverse on th[redacted] Core Midplane

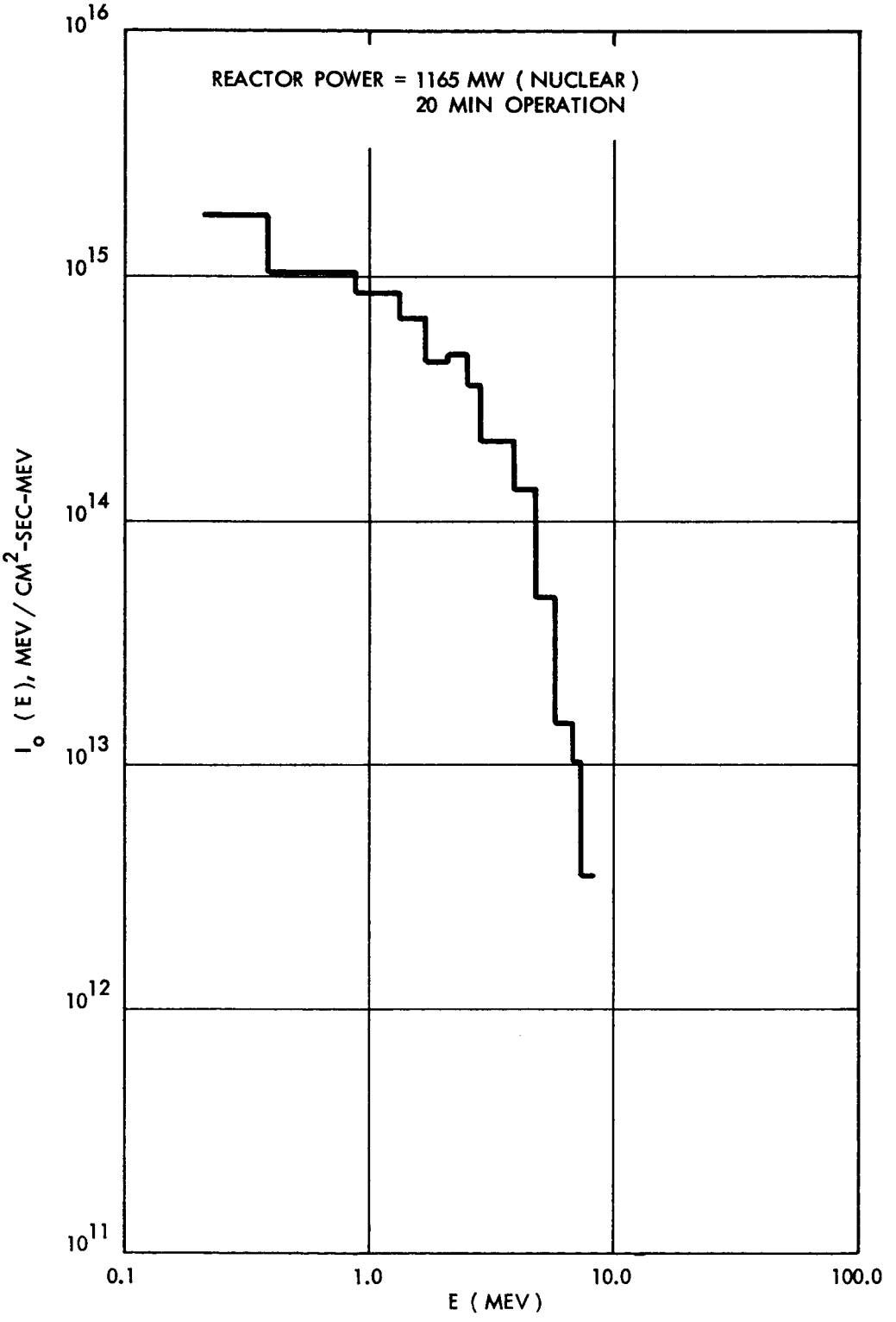
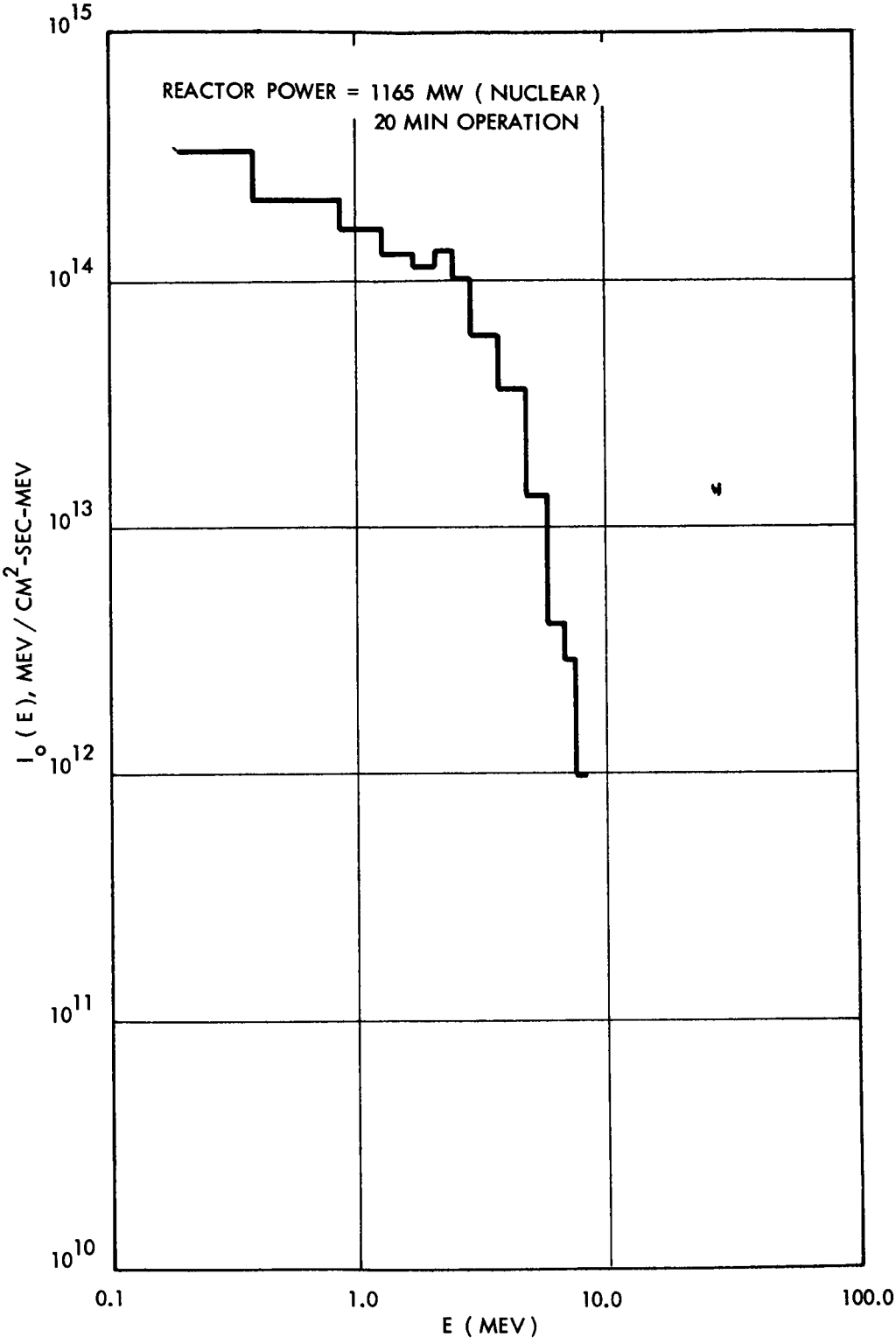



Figure 4-26 - Differential Gamma Ray Energy Spectra at the Dome End of the Aluminum Support Plate on the KIWI B-5 Axial Center Line

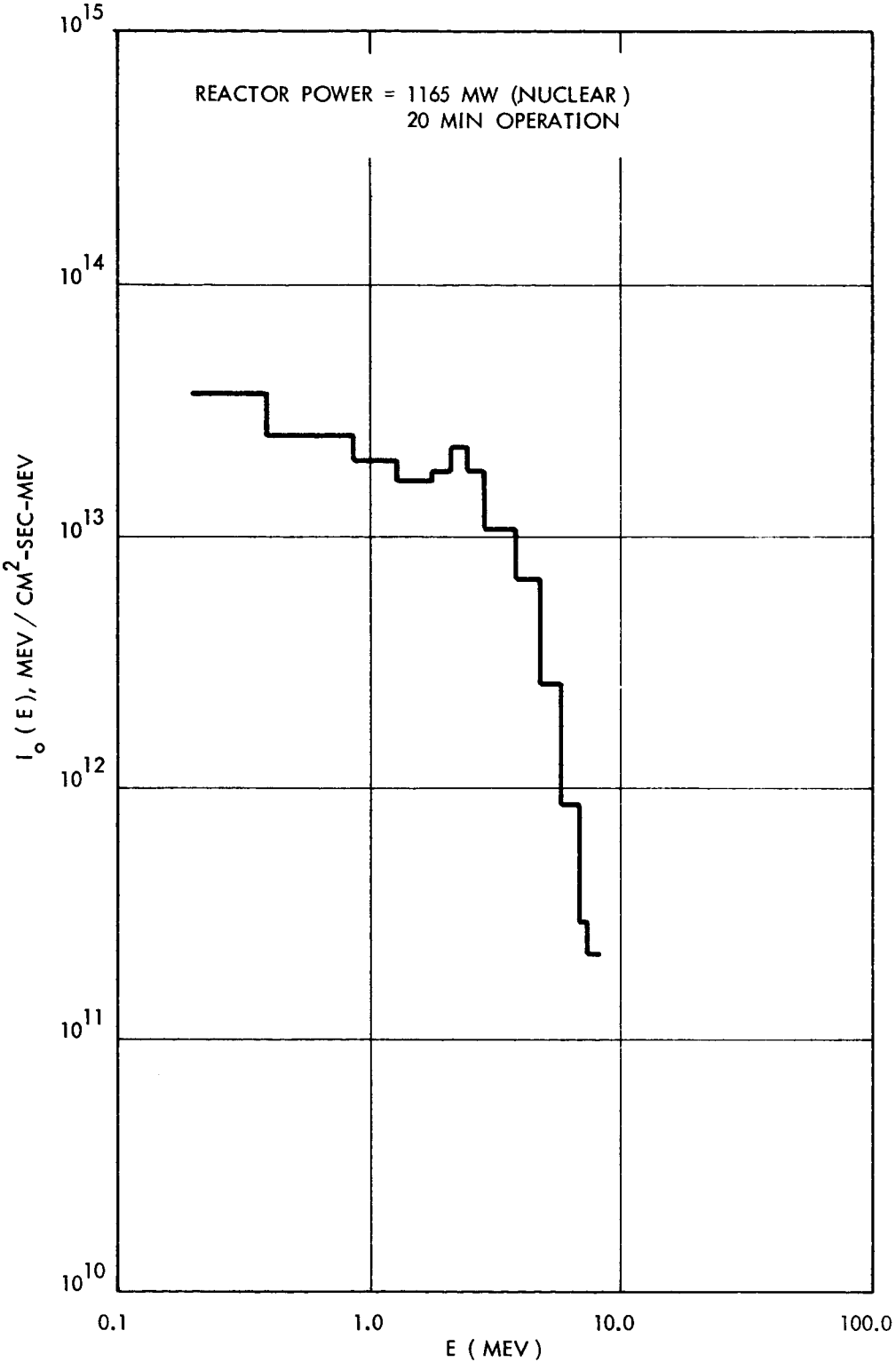
[redacted]






[redacted]

Figure 4-27 - Differential Gamma Ray Energy Spectra at the Boronated Steel-Lithium Hydride Interface on the KIWI B-5 Axial Center Line




[redacted]

Figure 4-20 - Differential Gamma Ray Energy Spectra at the Dome End of the Lithium Hydride on the KIWI B-5 Axial Center Line

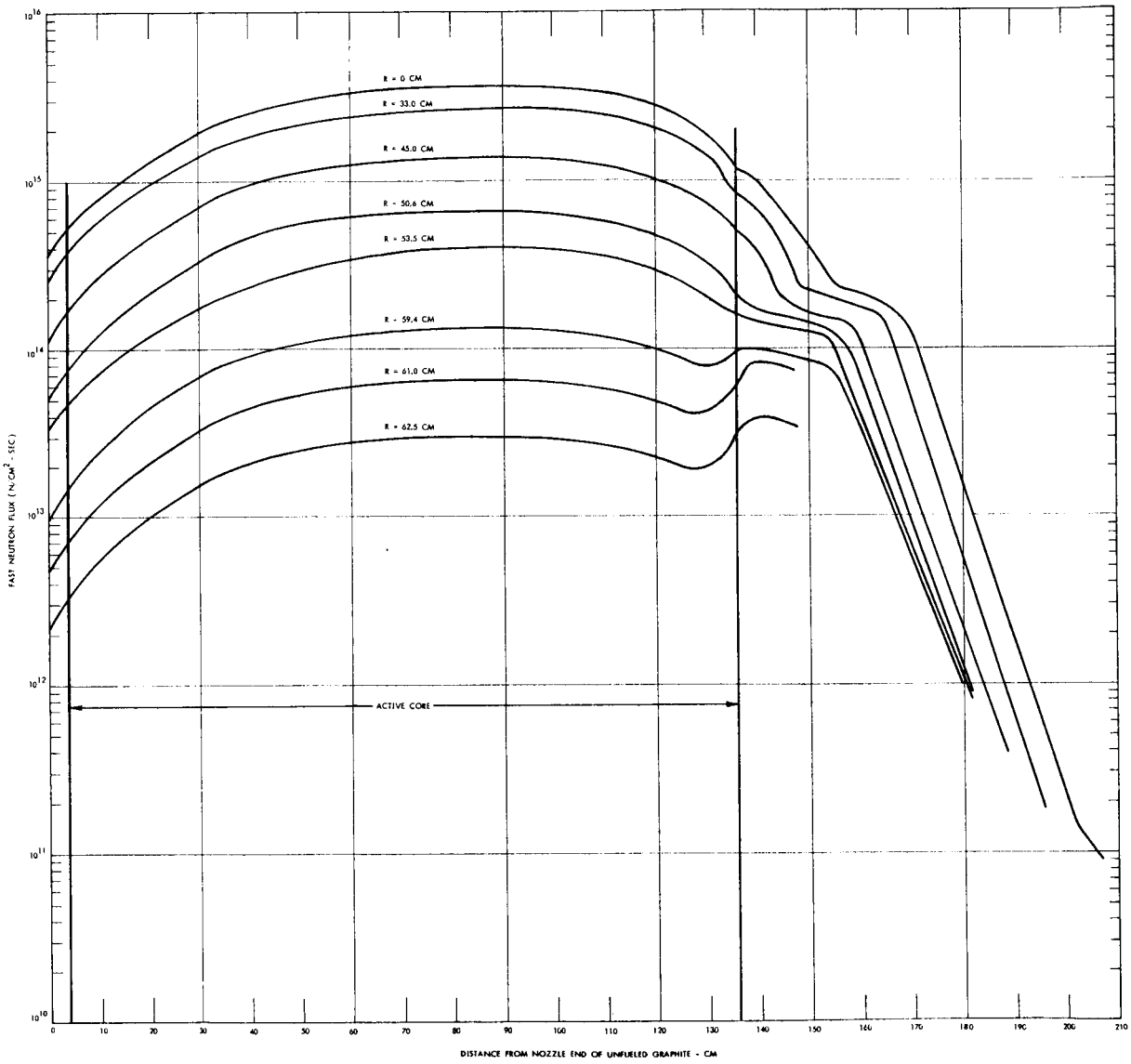



Figure 4-29 - Fast Neutron Flux - Axial

[redacted]erses in the KIWI B-5 Assembly

At the dome end of the shield, the CURE neutron fluxes were normalized to the 14-0 fast flux data to obtain consistent results inside and outside the assembly.

To illustrate the energy dependence of the neutron flux, data from the CURE program are presented at three axial positions in units of neutrons/$cm^2$-sec-Mev in Figures 4-30, 4-31, and 4-32. These axial positions located on the center line, correspond to the dome end of the aluminum support plate, the boronated steel-lithium hydride interface in the shield, and to the dome end of the lithium hydride farthest from the core.

Illustrated in Figure 4-33 is the time integrated fast (E > 1 mev) neutron flux in nvt units for a twenty minute reactor run. This axial traverse is located at the core center line. Similar data for a radial traverse along the core midplane are presented in Figure 4-34.

Activation Analysis

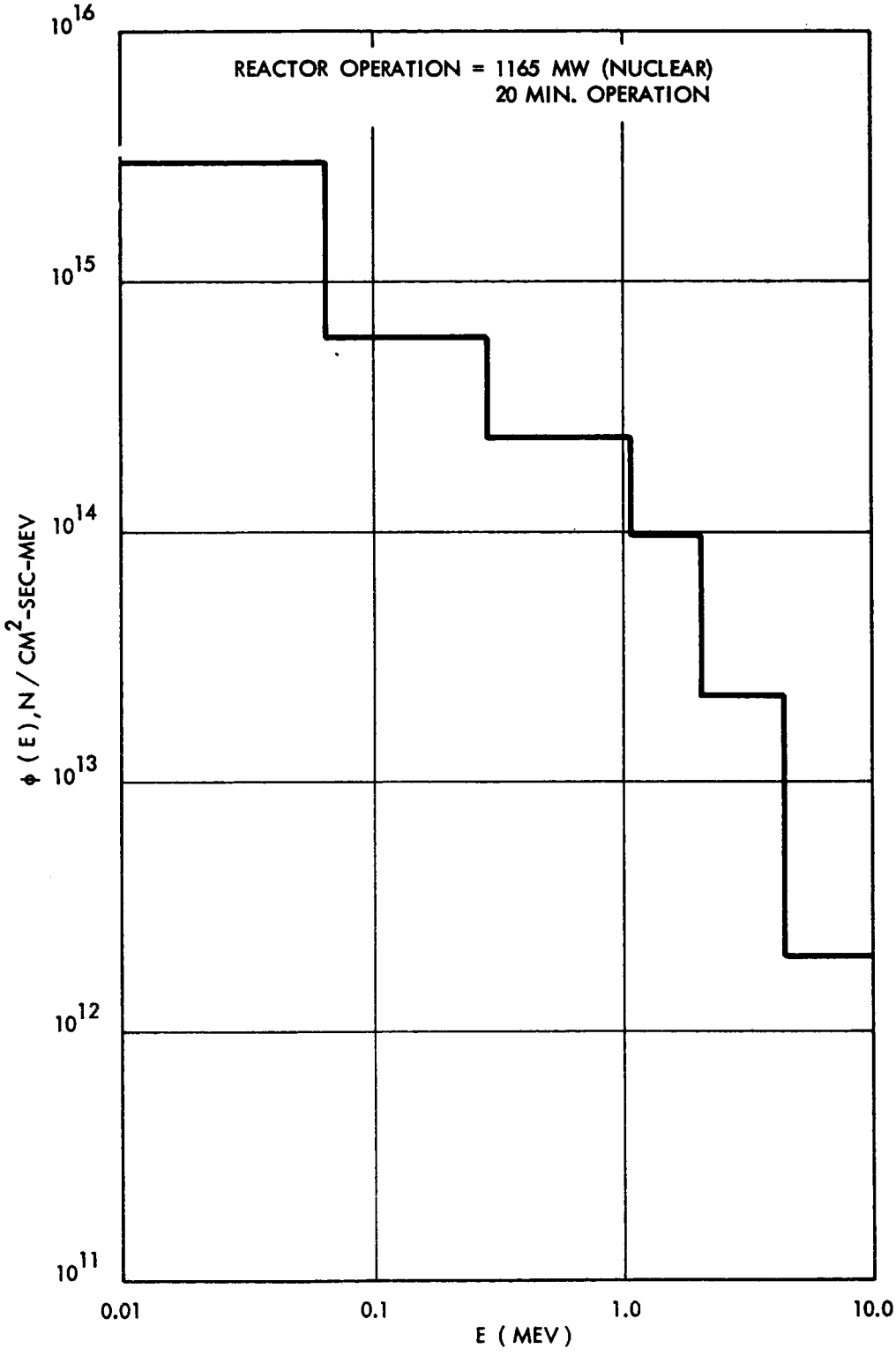
The dose rate from a shield capsule, a shield module, and from the entire shield assembly after irradiation in the B-5 test was determined.

The dose rates were calculated using shielding program 14-0, with source strengths obtained from activation program ACT-II[11]. The source distribution was assumed to follow the axial thermal neutron flux as predicted by CURE, a two dimensional multigroup diffusion code. The radial source distribution was assumed flat.

The dose rates were calculated on a perpendicular line 3 cm from the bottom end of the capsule and module where over 90% of the source is located. The dose rate for the shield assembly was calculated along a line perpendicular to the bottom face of the shield.

The activation source strengths were calculated for stainless steel by ACT-II for 5 and 10 minutes at 1120 MW. The strength at 10 minutes was twice the value at 5 minutes. The impurity content of the Li H was negligible compared to the constituents of the stainless steel. The steel composition used was that which contained activant concentrations as found from analysis of the end plugs and spacers and the capsule tubing.

Results are shown in Figures 4-35, 4-36, and 4-37 as a function of time after shutdown.




[redacted]

Figure 4-30 - Neutron Spectra (E > .01 Mev) at the Dome End of the Aluminum Core Support Plate on the KIWI B-5 Center Line

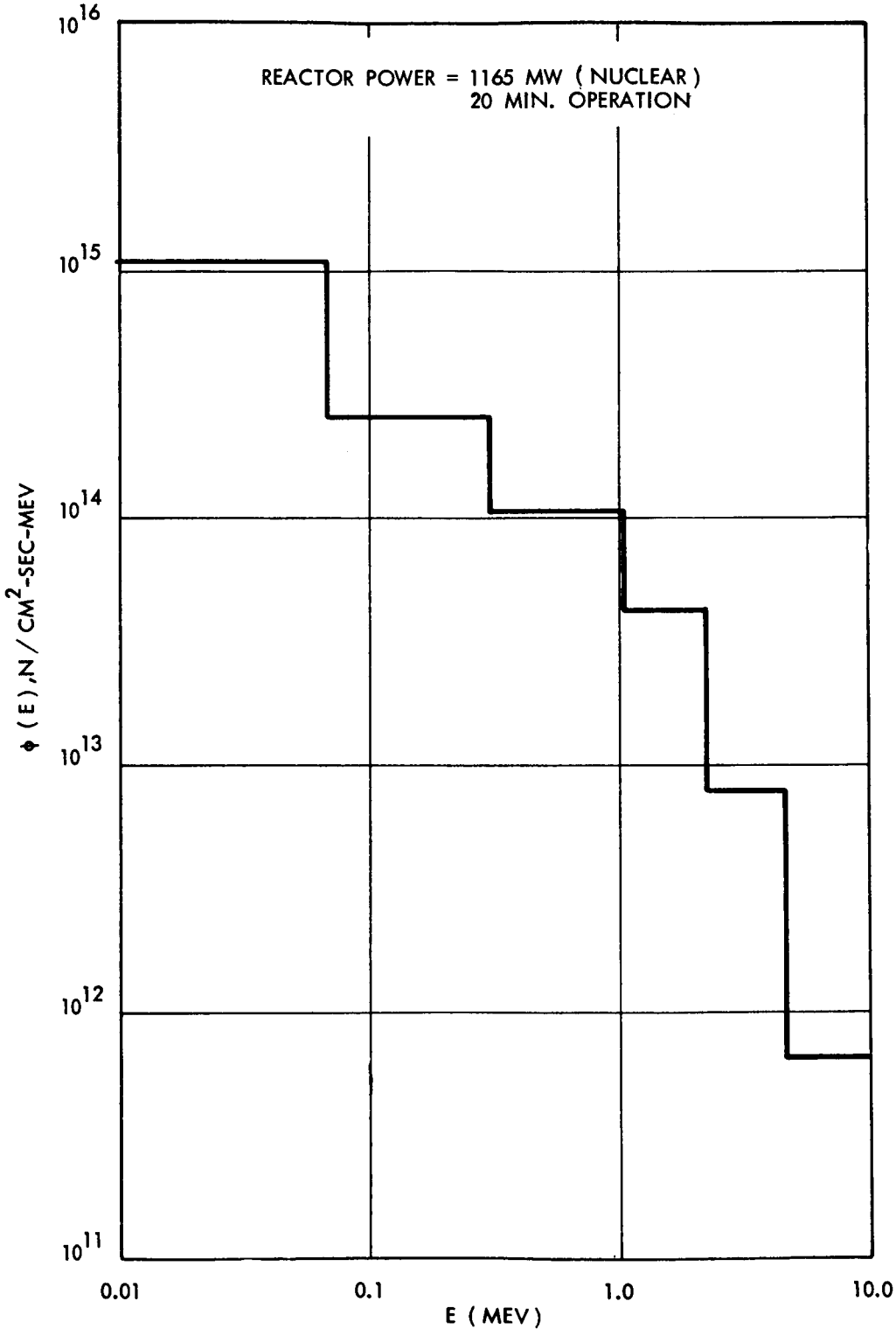
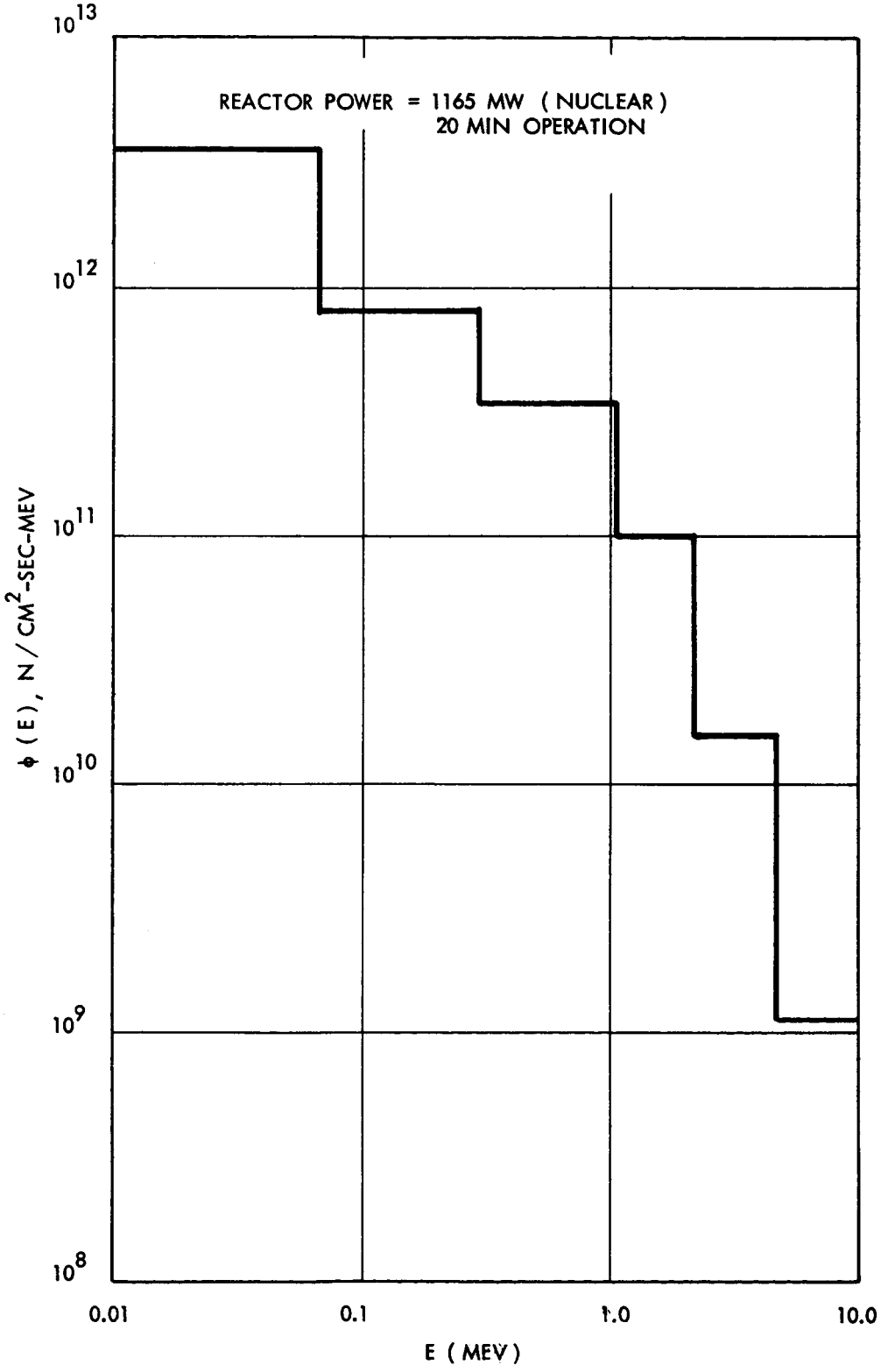



Figure 4-31 - Neutron Spectra (E > 0.01 Mev) at the Boronated Steel-Lithium Hydride Interface on the KIWI B-[redacted] Line

[redacted]

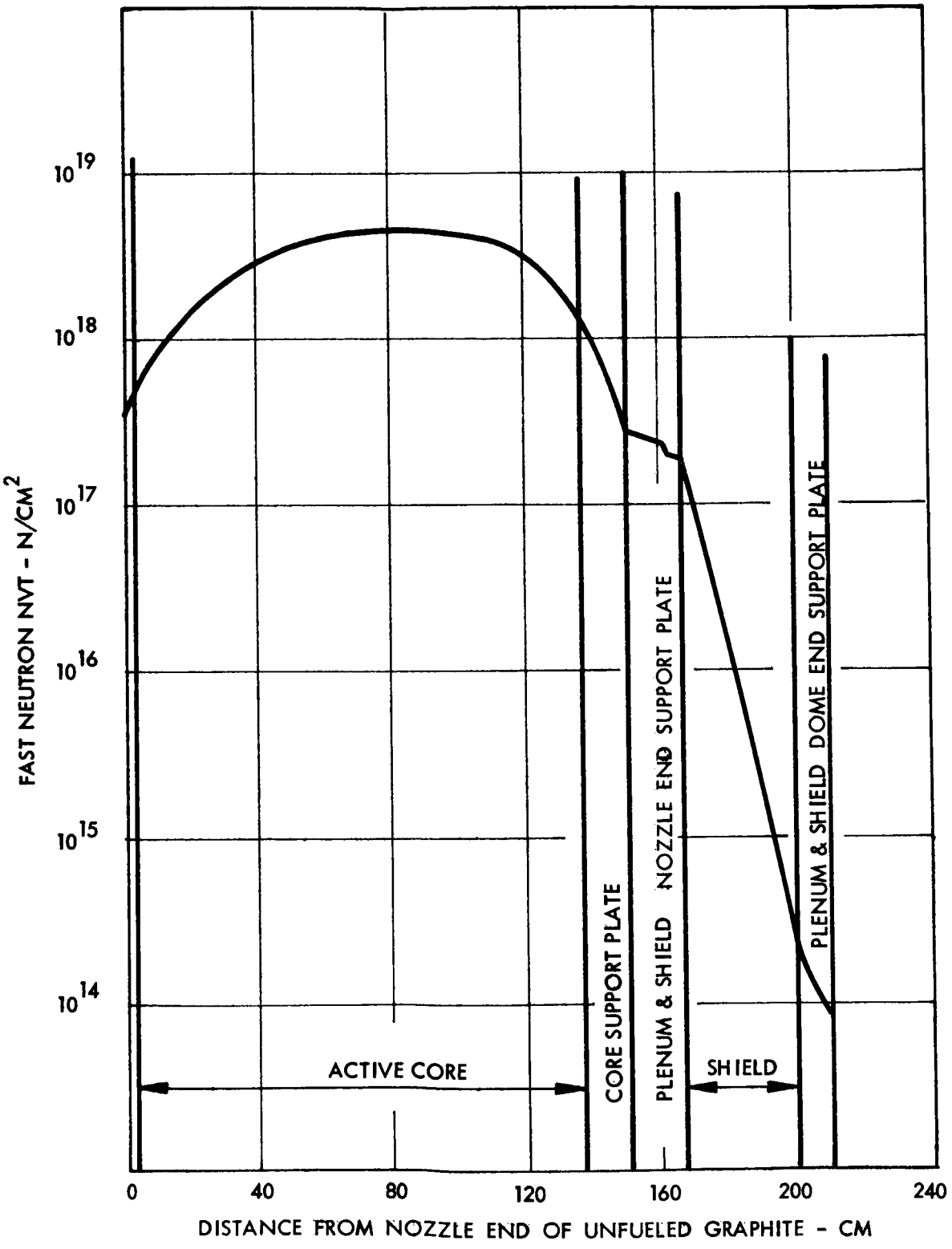



[redacted]

Figure 4-32 - Neutron Spectra (E > .01 Mev) at the Dome End of the Lithium Hydride at the KIWI B-5 Axial Center Line

[redacted]



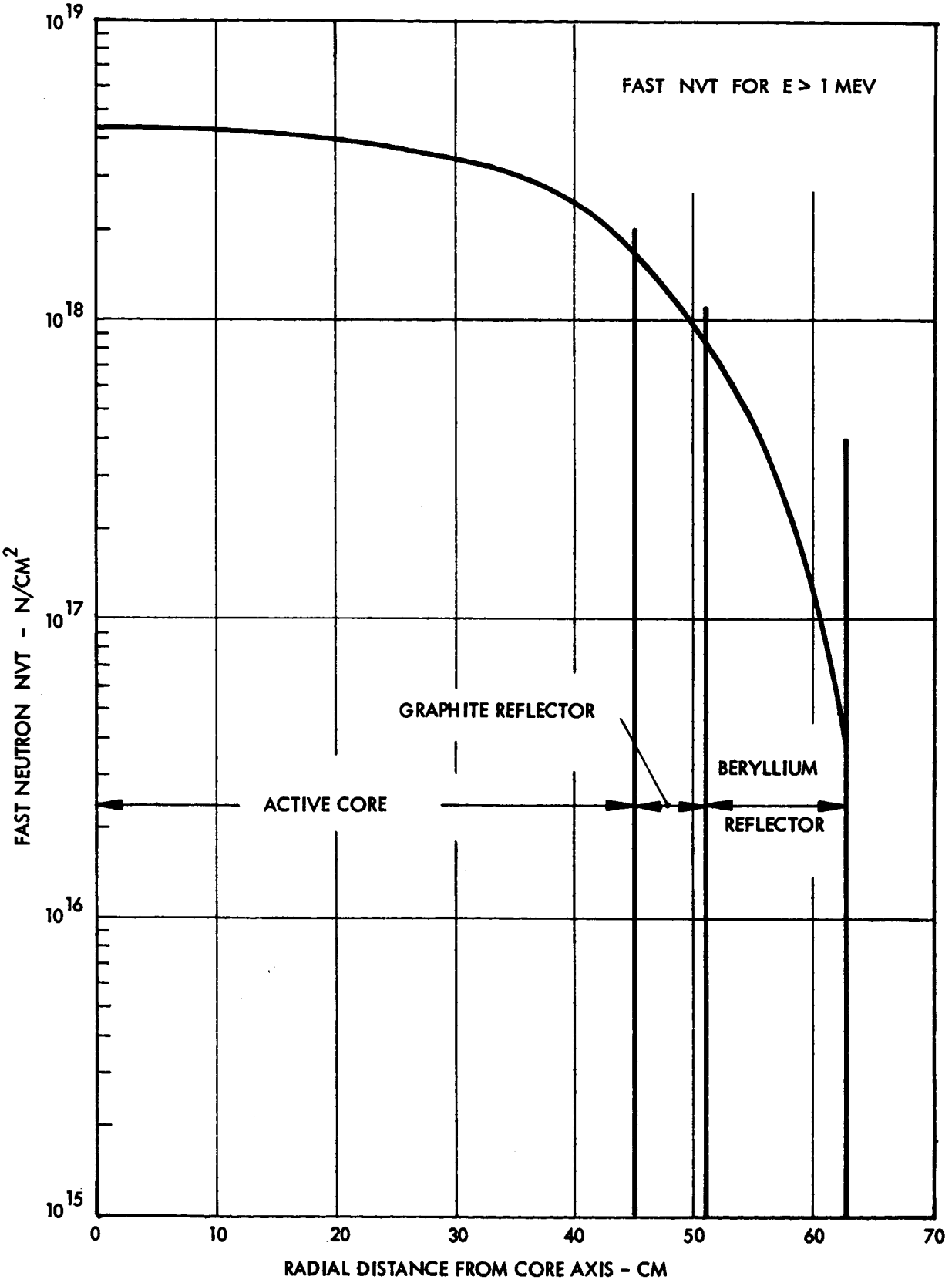



[redacted]

Figure 4-33 - Fast Neutron nvt (E > 1 Mev) for a 20 Minute Reactor Operation at 1165 MW (Nuclear) Axial Traverse in the KIWI B-5 Core and Shield Along the Core Center Line

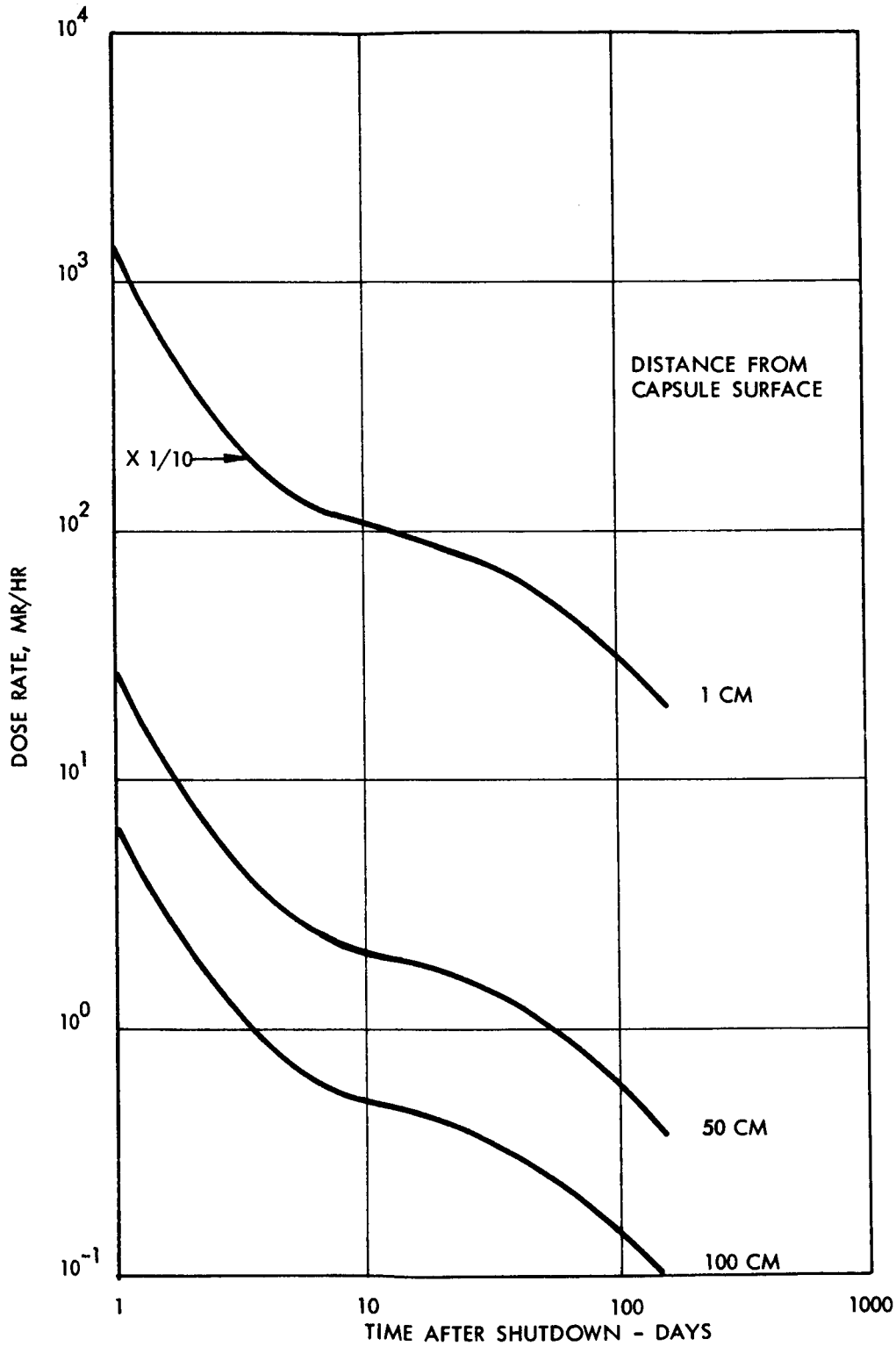
[redacted]





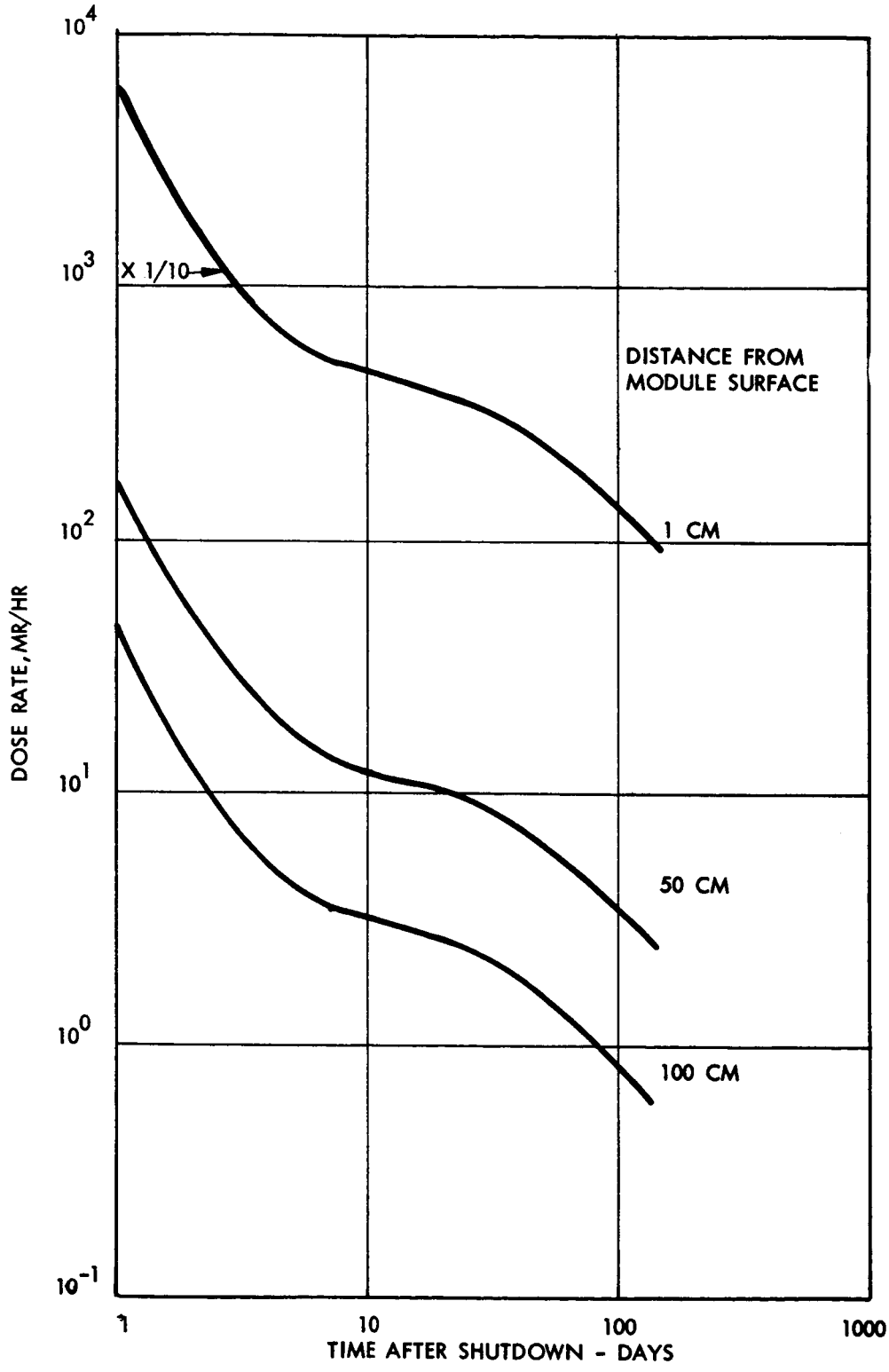

[redacted]

Figure 4-34 - Fast Neutron [redacted] 30 Minute Reactor Operation at 1165 MW (Nuclear) [redacted] Traverse on the KIWI B-5 Core Midplane



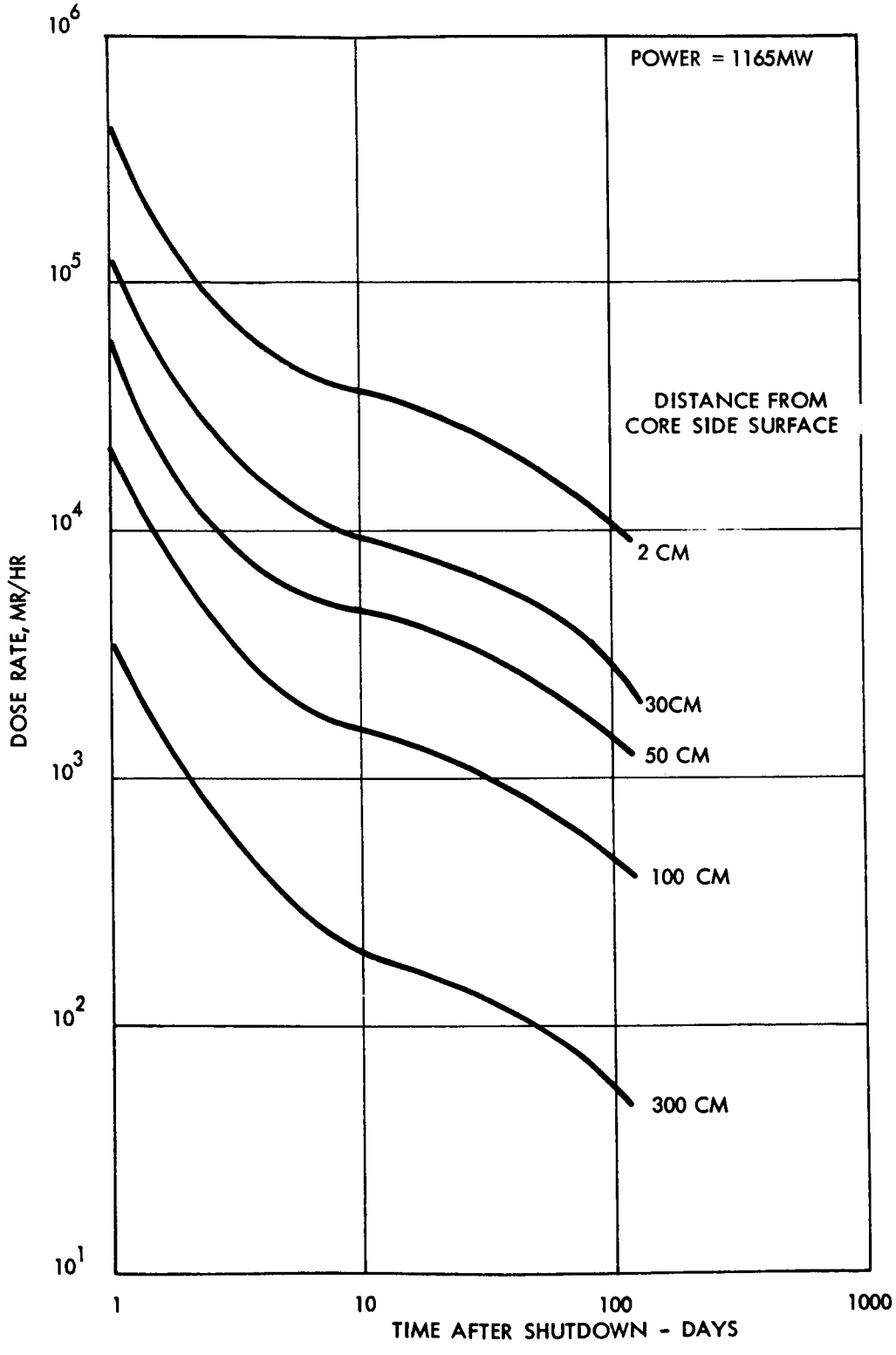

[redacted]

Figure 4-35 - Dos[redacted]
After 5 Minute Expos[redacted] the B-5 Test




[redacted]

Figure 4-36 - Dose Rate from a Shield Module After 5 Minute Exposure in the B-5 Test




[redacted] Figure 4-37 - Do[redacted]y
After 5 Minute E[redacted]

[redacted]



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## ACKNOWLEDGEMENT

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~~Atomic Energy Act 1954~~