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# A LABORATORY FACILITY FOR IRRADIATION AT ELEVATED TEMPERATURES

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.

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# A LABORATORY FACILITY FOR IRRADIATION AT ELEVATED TEMPERATURES

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## ABSTRACT

A laboratory irradiation facility has been designed and built using 2000 curies of cobalt-60 inside a 3-ton movable dome. Relatively large volumes can be irradiated with highly uniform dose rate distributions. Radiation levels are reproducibley adjustable from $10^4$ to $2.5 \times 10^6$ r/hr. The source was designed to permit irradiations at temperatures up to 450 C. Since the average external radiation level is less than 0.1 mr/hr, the facility can be used in a laboratory equipped with radiation measuring equipment and continuous access by personnel.

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# I. INTRODUCTION

A high intensity irradiation facility using 2000 curies of cobalt-60 has been designed and built for the laboratory irradiation of chemical samples at elevated temperatures. Shielded sources or chambers have been built in other laboratories.[1-4] The radiation source described here has a uniform dose rate distribution, low external radiation levels for easy access for experimentation, and a high degree of versatility. Irradiations may be performed at room temperature (or below) and up to about 450 C.

# II. CONSTRUCTION

## A. DESIGN

The design goals for the 2000-curie cobalt-60 irradiation facility are as follows:

1. Reproducible and variable radiation rates at high intensities
2. Uniform dose rate distribution in large samples
3. Irradiations below room temperature and up to 450 C
4. Two irradiation wells to permit setting up experiment while irradiating in the other well
5. Very low external radiation levels to permit use in laboratory equipped with radiation measuring equipment and to allow continuous access during operation
6. Access conduits into irradiation wells for use of external electrical or mechanical equipment
7. Can be disassembled for movement from one laboratory to another
8. Shipping casket part of irradiation assembly

The facility was designed for an average surface radiation intensity of 0.1 mr/hr. A design criterion of 13 inches of lead in all directions was selected. Steps and barriers at shielding junctions minimize scattered radiation. The facility, shown in Fig. 1 and 2, consists of approximately 10 tons of lead sheathed in a mild steel casing of 1/4-inch thick plate with all cavity liners of 1/8-inch thick stainless steel.

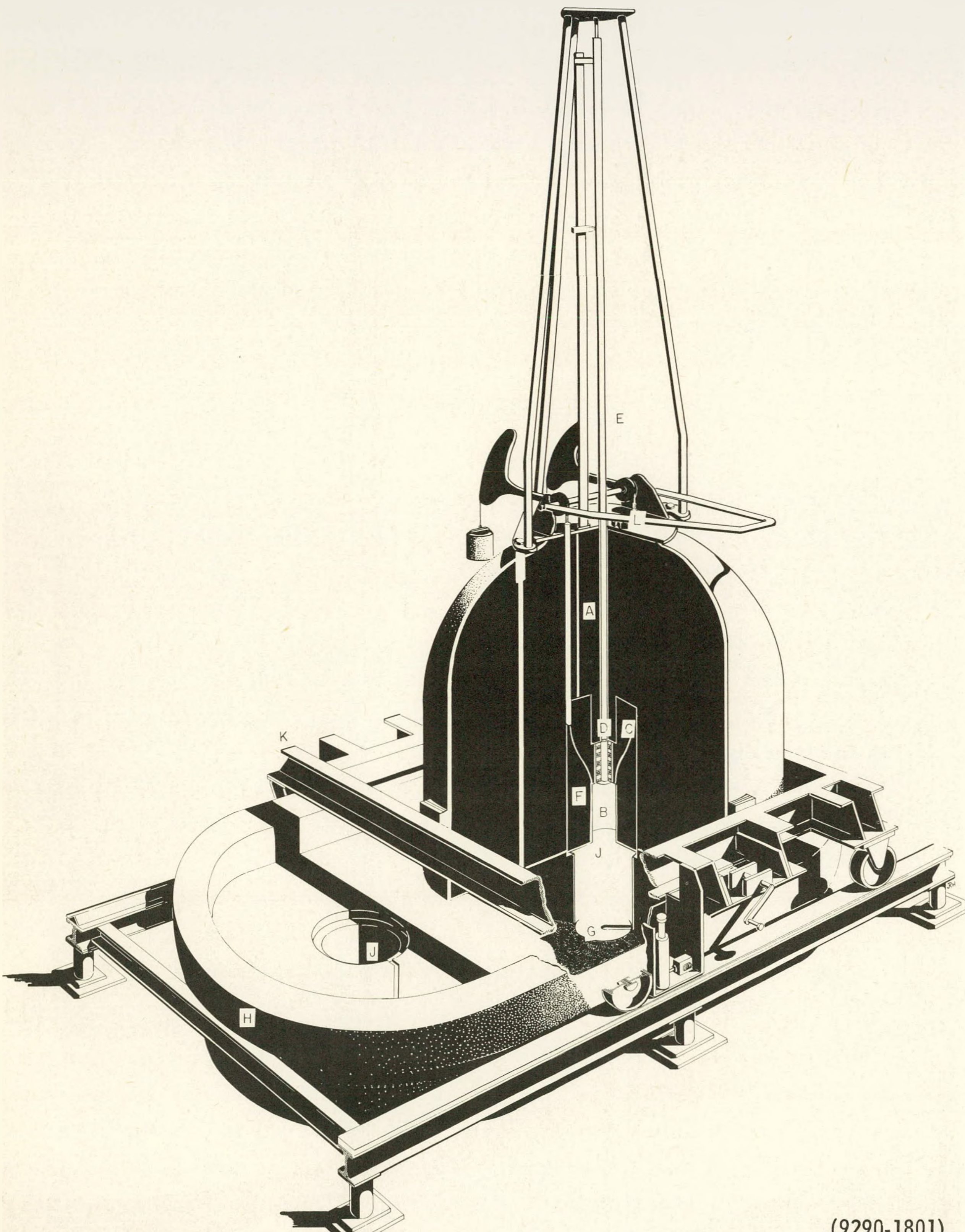


Fig. 1. Sectioned View of Irradiation Facility

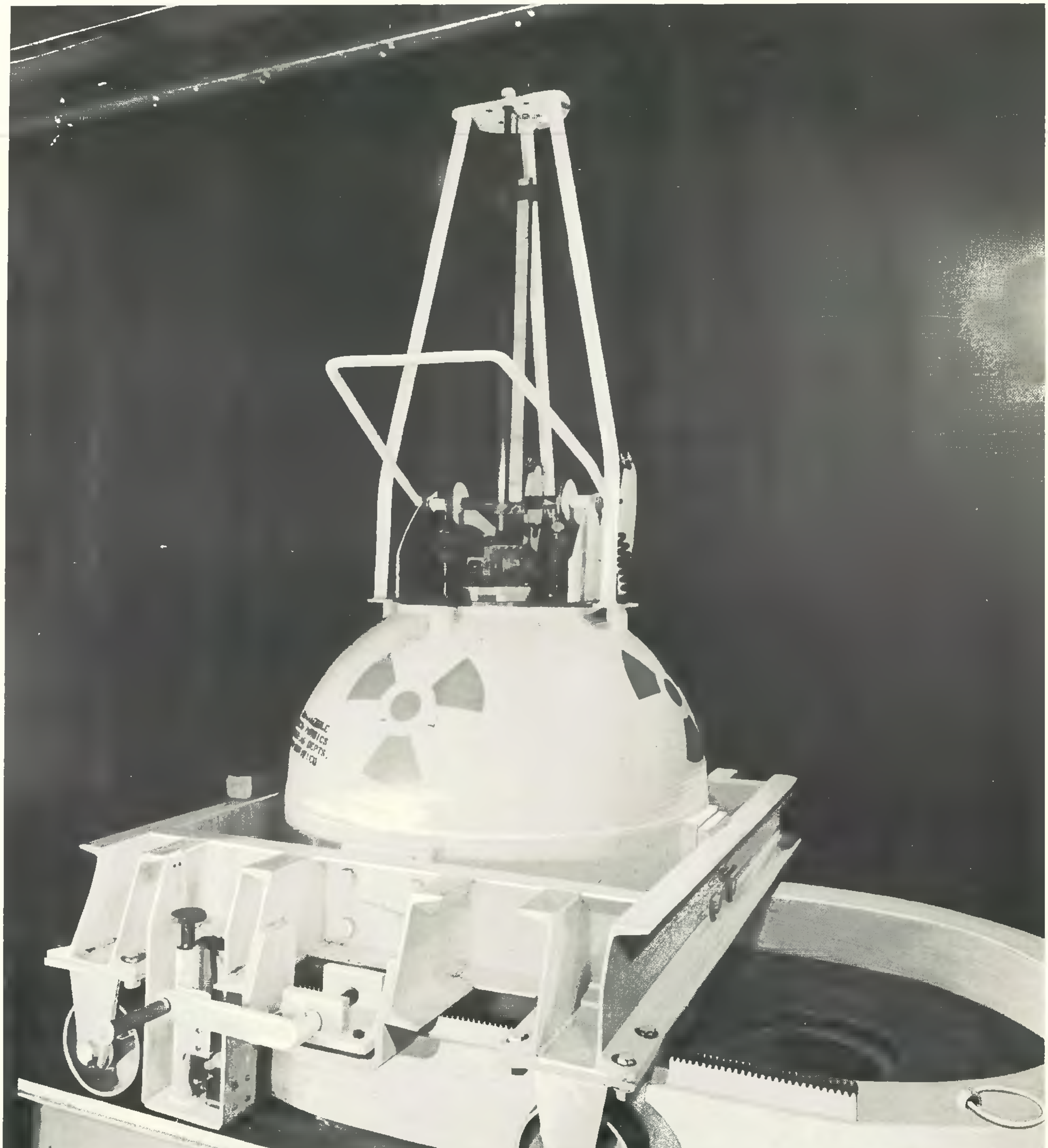

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Fig. 2. Photograph of Irradiation Facility

B. SHIELDING DOME

The shielding dome is 30 inches in diameter, 28 inches high and weighs 6000 pounds (Fig. 1). It serves as a shipping casket as well as a permanent housing for the gamma source. The upper plug (Fig. 1, A) permits easy initial loading of the source.

For shipping purposes, a lead plug is installed in the source cavity of the dome (Fig. 1, B) and a plate is screwed to the bottom of the dome. The plug may be removed and installed by means of wires which reach through tubes from the top of the casket (Fig. 1, C). During this operation, the assembly is used as a shielded enclosure.

A movable inner shield (Fig. 1, F) is provided to prevent gamma ray streaming during lowering or raising of the source. It is counter-balanced in such a way that approximately 20 pound-inches hold it in either up or down position. The total movement of the inner shield is only about 1-1/4 inches.

C. SOURCE

The source container (Fig. 1, D and Fig. 3) is made up of eight stainless steel tubes, 4-1/2 inches long. The source consists of 40 cylinders of cobalt, 50 curies each, 1 cm high by 1 cm in diameter. Screw plugs at the top and a cap at the bottom of each tube retain the cobalt. Cylinders of quarts are used as alternate spacers between each cobalt disc (Fig. 3) to increase the volume available for uniform irradiation. On the top of the source assembly is a boss to which the control shaft is screwed and pinned. An expansion shaft (Fig. 1, E) is screwed to the control shaft and a counter-weight is added for operating ease. A meter stick and an indicator on the rod tell the operator the position of the source.

D. BASE

The base is made up in two assemblies, each of which has a test hole (Fig. 1, G). The base assemblies are bolted together and the crack between the two is leaded. Tests indicate that there is no appreciable rise in radiation when the casket passes directly over the crack. A step at the outside top of the base was provided to allow the addition of a "scatter fence" (Fig. 1, H), 4 inches thick by 6 inches high. A channel (Fig. 1, J), with a 45 degree angle in the middle to

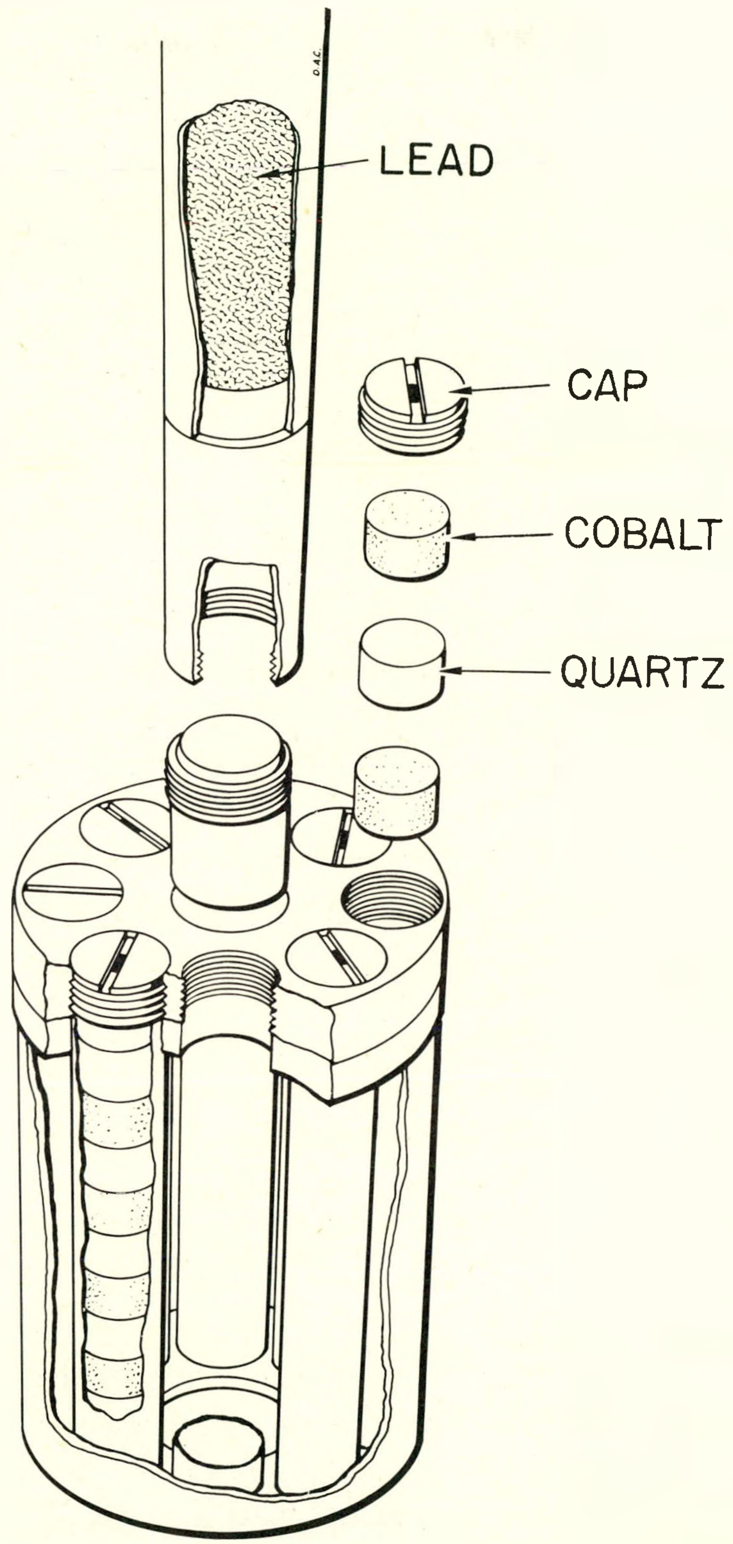


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Fig. 3. Source Holder

prevent streaming, is used to introduce thermocouple and power leads into each test hole. These channels are 1/2-inch deep by 1-inch wide and parallel to the upper surface of the base. There are similar channels down one side and across the bottom to the center of each hole.

### E. CARRIAGE

A carriage (Fig. 1, K), bolted to the shielding dome and rolling on steel casters on one flat and one "V" track, carries the dome with a clearance between dome and base of 0.15 inch. A pin in the carriage and holes in the flat track locate the dome over either test hole. The dome is easily moved between holes by a crank-driven pinion on the carriage and a rack mounted on the base.

### F. INTERLOCK SYSTEM

A three-way, fail-safe electrical interlock system (Fig. 1, L) prevents lowering of the source or inner shield until the dome has been located over a test hole and indexed in place with the carriage indexing pin. This releases the inner shield lock. When the inner shield has been completely lowered into the recess at the top of the test hole, the source control is unlocked and the indexing pin is locked. With the source anywhere but in its uppermost position, the inner shield is locked in the down position. If power fails during an exposure, the source may be raised to the up position, where it is automatically locked. This is the only operation possible. If the power fails with the source and the inner shield in the up position, the index pin may be lowered but the inner shield and the source rod remain locked.

## III. GAMMA RAY INTENSITIES

### A. CALCULATED

The intensity in the interior of the source assembly was calculated by evaluating the volume integral

$$r/hr = k\rho \int \frac{dv}{R^2} , \qquad \ldots(1)$$

where $k$ = intensity at 1 cm from 1 mc in r/hr

$\rho$ = specific activity in mc/cc

dv = element of volume in the source

R = distance between dv and point in space

Although self-absorption in the source and its container is neglected, the decrease in the calculated dose rate by self-absorption is offset to some extent by the contribution from scattered radiation.

The integral was evaluated by assuming the source assembly consisted of eight, 250-curie, homogeneous cylinders of Co-60. Using the geometry shown in Fig. 4, the radiation intensity from one of these cylinders is approximately

$$r/hr = 4k\rho d\,[\theta_2(d) - \theta_1(d)]\,[K(\tfrac{r}{d}) - E(\tfrac{r}{d})]\,, \qquad \ldots(2)$$

where

$$K(\tfrac{r}{d}) = \int_0^{\pi/2} \frac{d\theta}{\sqrt{1 - (\frac{r}{d})^2 \sin^2\theta}} \qquad \ldots(3)$$

$$E(\tfrac{r}{d}) = \int_0^{\pi/2} \sqrt{1 - (\tfrac{r}{d})^2 \sin^2\theta}\; d\theta \qquad \ldots(4)$$

and

$k$ = 13.5 r/hr-mc at 1 cm from Co-60

$$\rho = \frac{250 \times 10^3}{\pi\ 0.5^2 \times 10} = 31.8 \times 10^3 \text{mc/cc.}$$

The spatial variation of the dose rate from one cylinder is shown in Fig. 5.

The dose rate along the axis of the source assembly, shown in Fig. 6, is eight times the intensity indicated in Fig. 5. The dose rate in the plane of the perpendicular bisector of the axis of the source assembly, computed by summing the contribution from each of the eight sources at a particular point, is shown in Fig. 7.

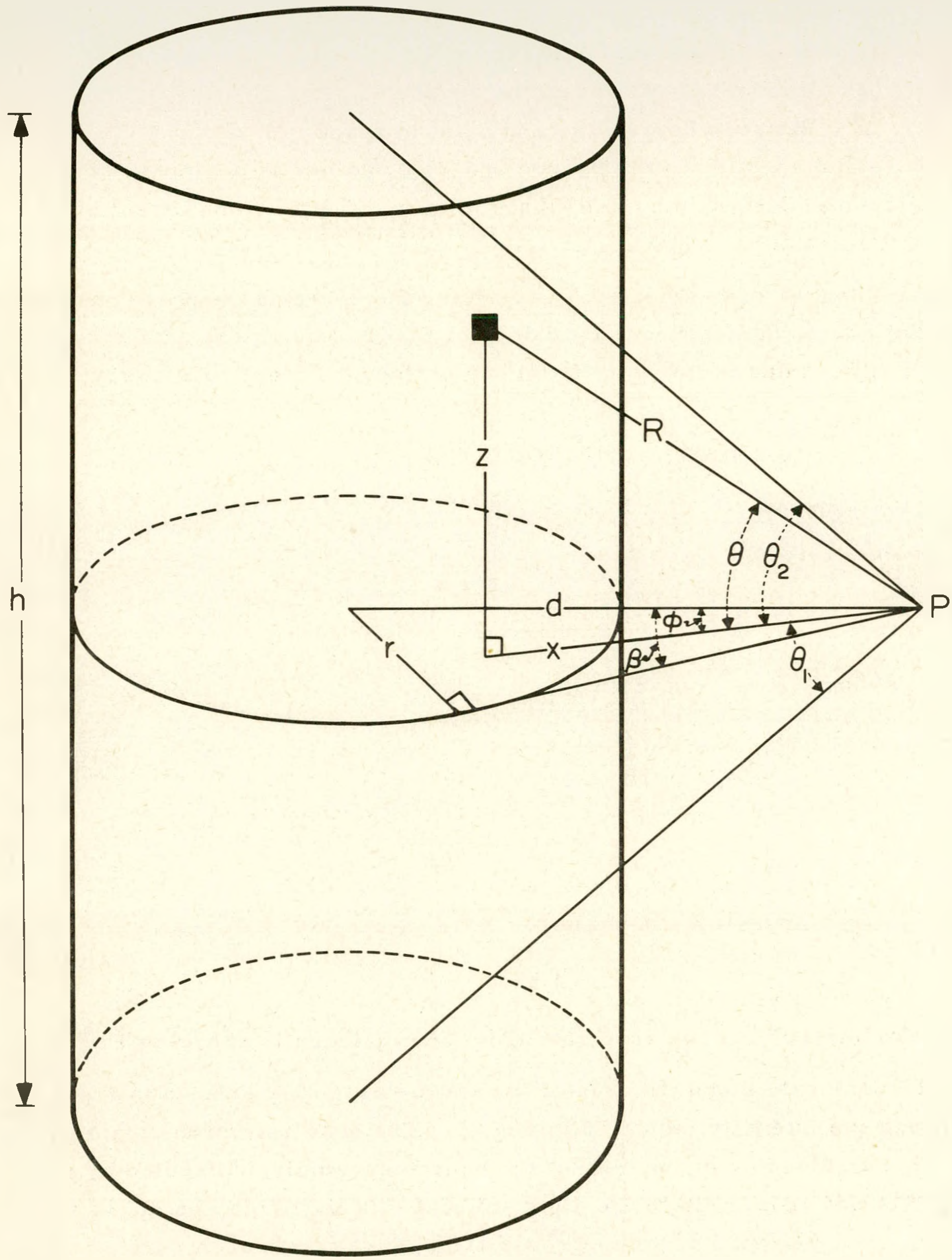


Fig. 4. Geometry of a Co-60 Cylinder

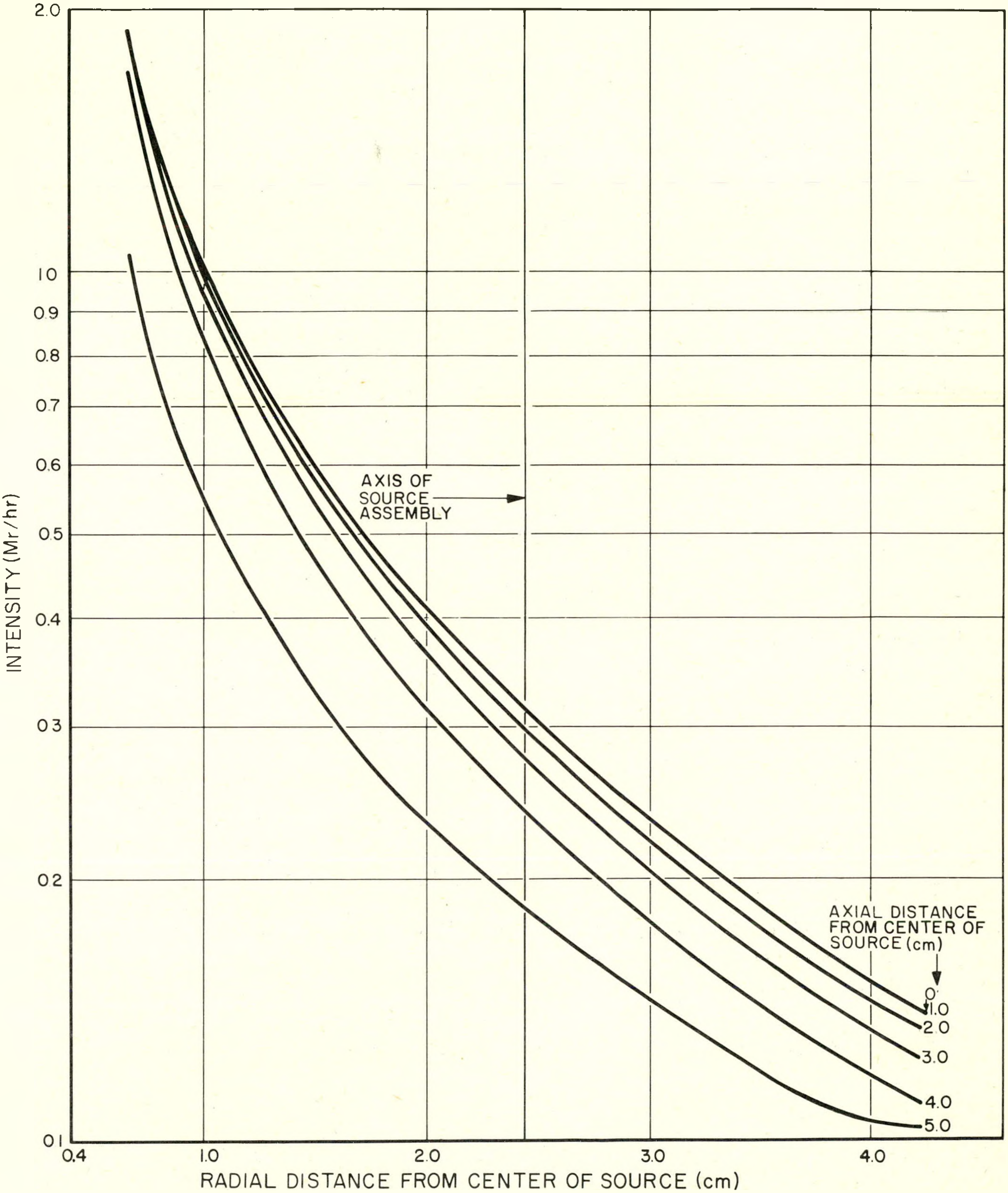


Fig. 5. Dose Rate from a 250-Curie Co-60 Cylinder (1.0 cm Diam. x 10.0 cm High)

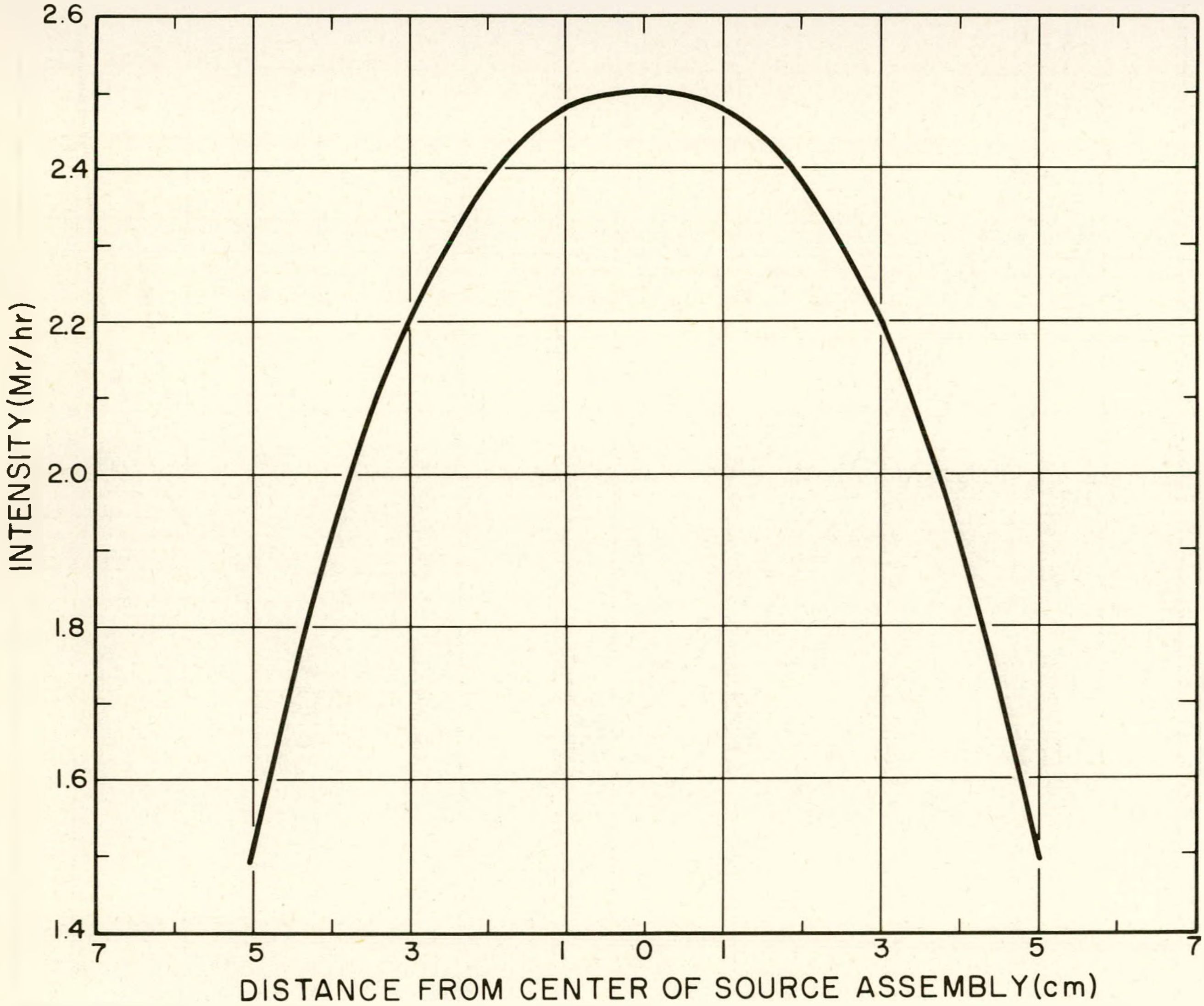


Fig. 6. Dose Rate Along Axis of Co-60 Source Assembly (Vertical Traverse)

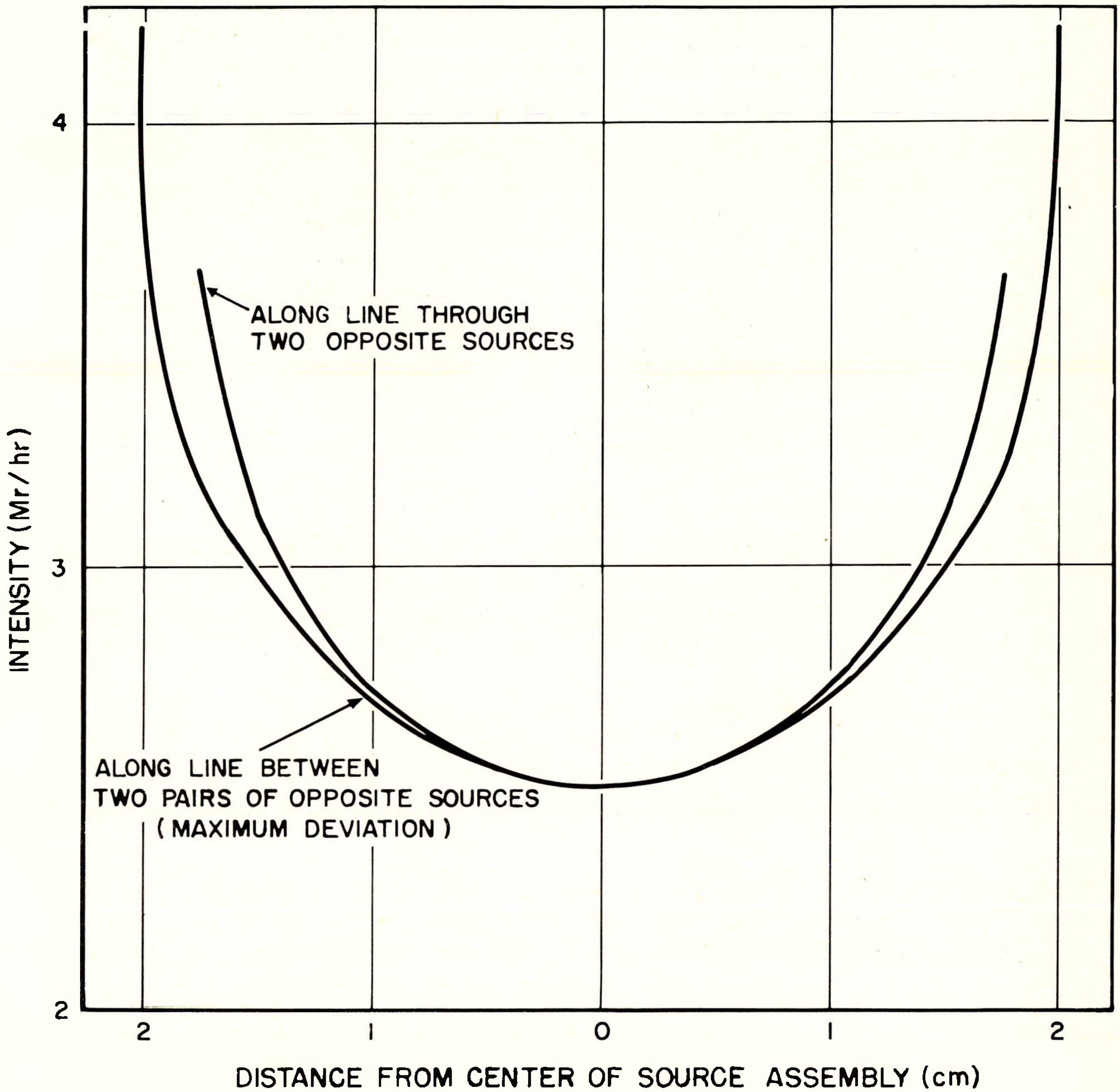


Fig. 7. Dose Rate in Center of Co-60 Source Assembly (Horizontal Traverse)

The calculated dose rate at the geometric center of the source assembly is $2.51 \times 10^6$ r/hr. The parameters illustrating the dose rate uniformity available from this cylindrical arrangement of the radiation source is shown in Table I.

TABLE I

DOSE RATE UNIFORMITY OF CYLINDRICAL SOURCE

| | Maximum Variation | |
|---|---|---|
| | ± 10 Per Cent | ± 25 Per Cent |
| Average intensity (r/hr) | $2.56 \times 10^6$ | $2.61 \times 10^6$ |
| Diameter (cm) | 2.3 | 3.0 |
| Height (cm) | 5.6 | 8.3 |
| Volume (cc) | 23 | 60 |

B. MEASURED

The maximum intensity attainable within the Co-60 source (Fig. 1, D) was determined experimentally based on chemical dosimetry with ferrous sulfate and ceric sulfate. Values and method were those employed by Hochanadel and Ghormley.[5] The average maximum intensity, September 1954, was $2.5 \times 10^6$ r/hr, confirming the calculated value above.

Ceric sulfate[5] was used in determining that a 3-liter aqueous sample (cylinder approximately 6-inch diameter by 7-inch height) received an average dose of $10^4$ r/hr when the source was completely within the dome.

Intensities at various intermediate positions to the two extreme positions (described above) were determined experimentally using the chemical dosimetric method with ferrous sulfate. All of the exposures were done in lucite capsules 1 inch high and 1 inch in diameter and containing approximately 5 cc of the ferrous sulfate solution. The location of these capsules at the bottom of the exposure well and the relative position of the source is shown in Fig. 8. Measurements were made at various source heights ranging from zero centimeters to 12 centimeters as measured from the bottom of the well to the bottom of the cobalt source. The source enters the lead shield above 12 centimeters and inconsistent scattering

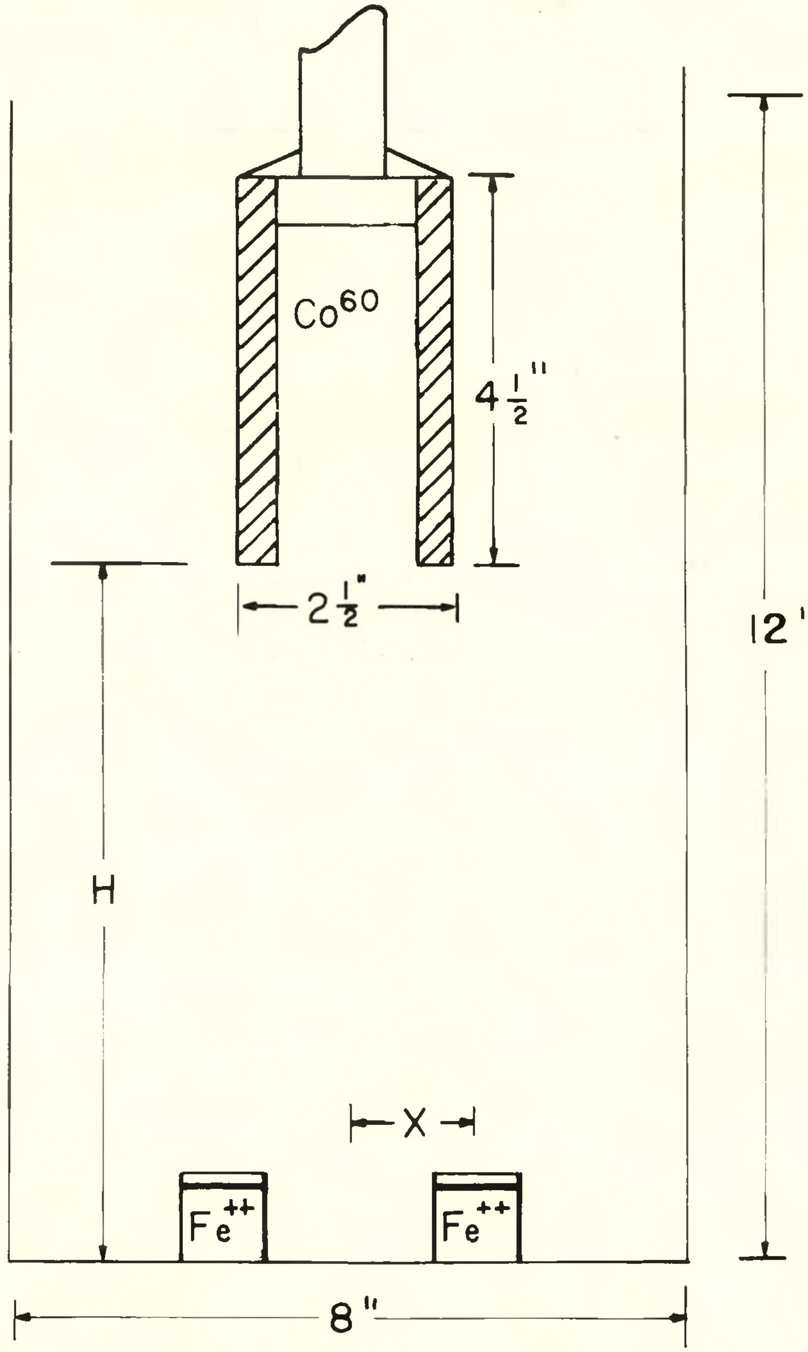


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Fig. 8. Side View of Source and Well

results in non-uniform radiations unless the sample covers the entire bottom of the well. Thus, these determinations were all made with the source outside the shield. Figures 9 and 10 show the variation of dose rate first as a function of horizontal displacement of the receptor and second as a function of vertical source height. Each experimental point represents the average of two or three runs.

The internal and maximum external radiation intensities are as follows:

1. Adjacent to dome surface and base - 0.1 mr/hr
2. At access conduit - 0.3 mr/hr
3. Above dome - 1.5 mr/hr
4. Maximum (gap between casket and base with source opposite) - 15 mr/hr
5. At center of source - $2.5 \times 10^6$ r/hr
6. With source up in dome and 3 liter sample filling bottom of well - $1 \times 10^4$ r/hr
7. External to source at vertical source heights (0 to 12 cm) and horizontal distances from source center (0 to 3.5 inch) - 0.75 to $6.0 \times 10^5$ r/hr.

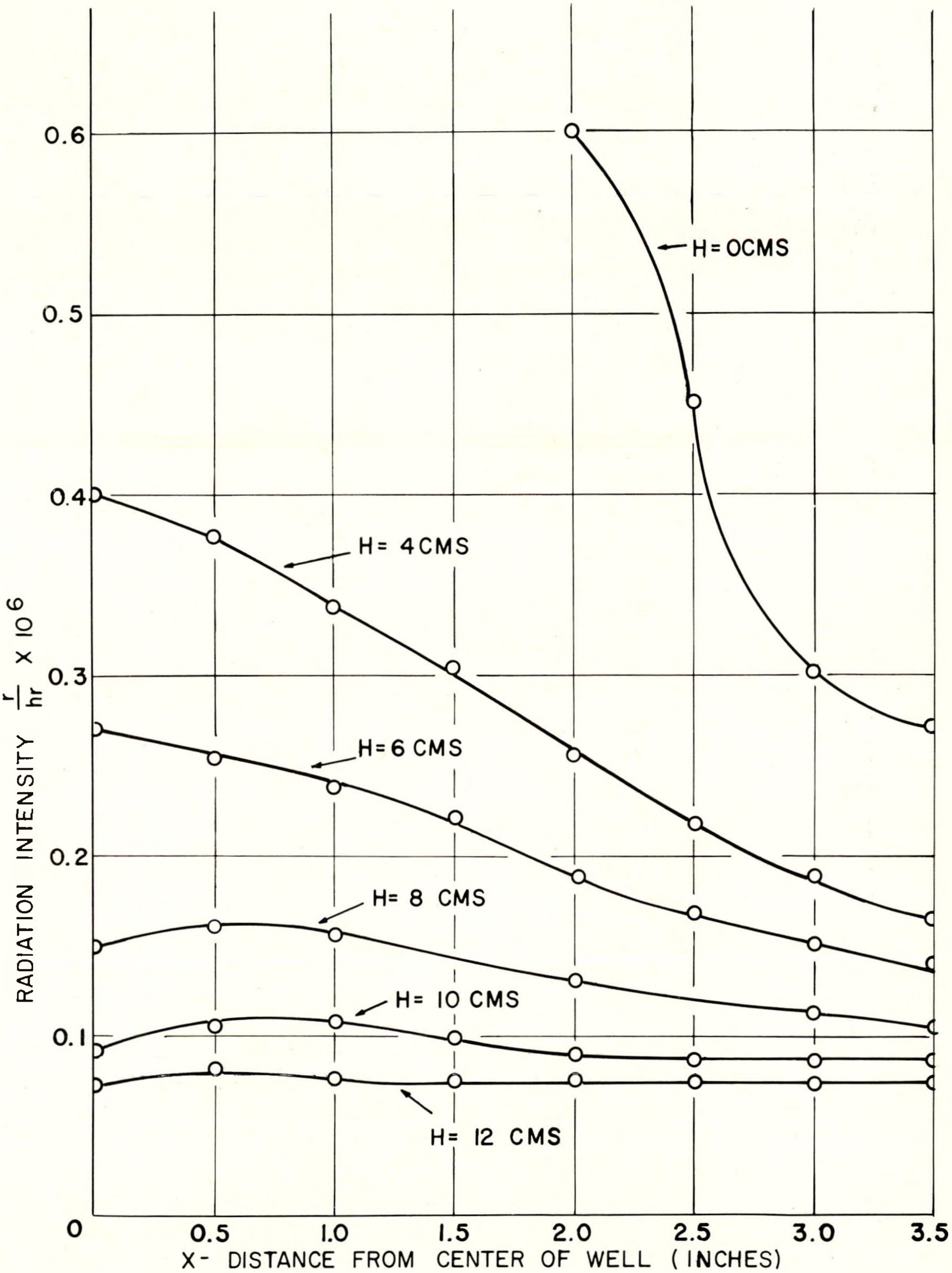


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Fig. 9. Horizontal Variation of Dose Rate at Bottom of Co-60 Well (Parameters are Vertical Source Heights)

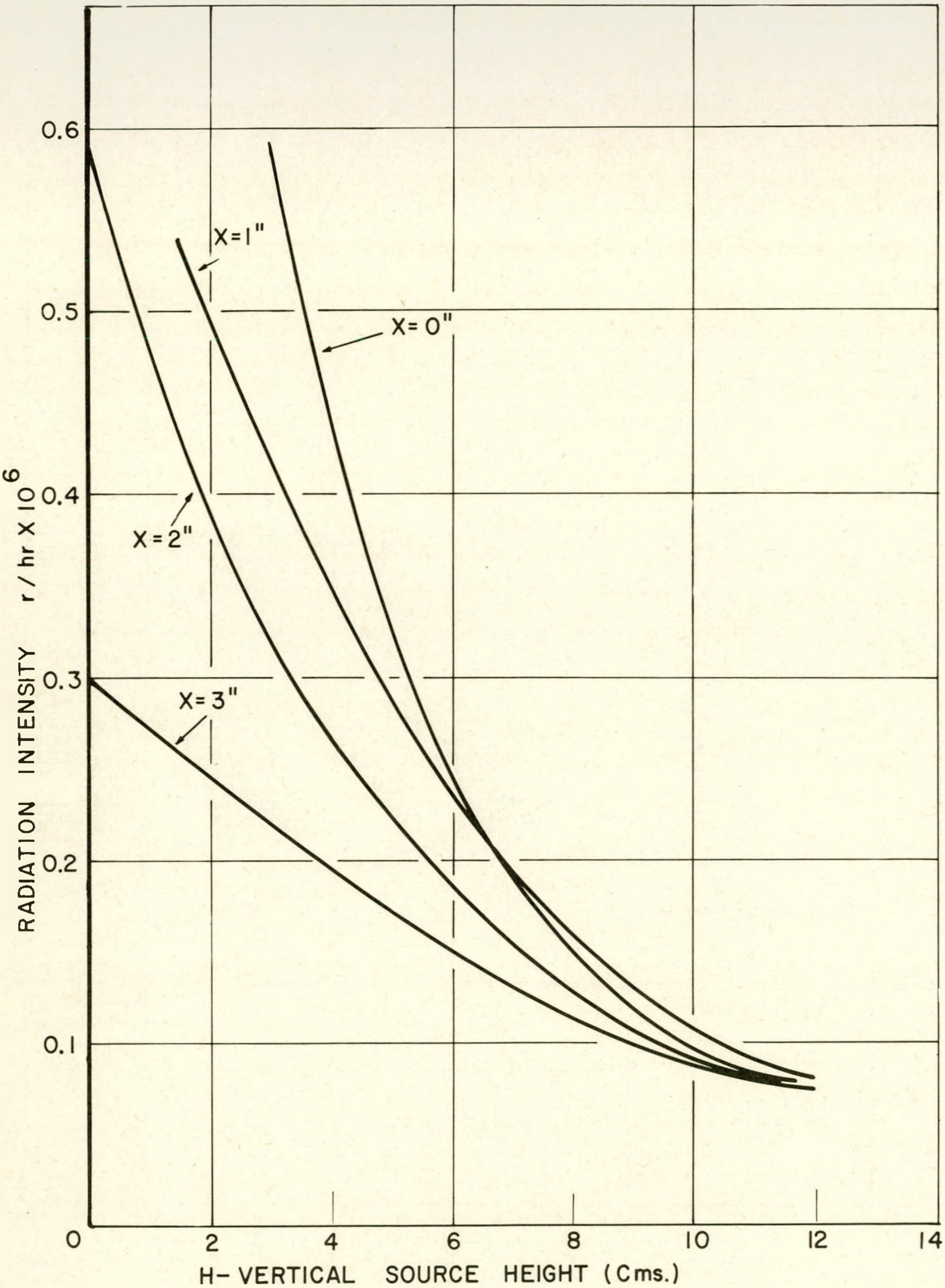


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Fig. 10. Vertical Variation of Dose Rate as Measured from Bottom of Source (Parameters Are Off-Centered Distances)

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