DPG1.941213.002(D-22

517920

DUGWAY COBALT-60 IRRADIATION FACILITY

by

Carl J. Christensen
Andrew T. Jacobsen
Quentin Klingler
Merrill D. Evans

TECHNICAL REPORT
January 15, 1959

Contract Number
DA-18-108-CML-5347

University of Utah
Salt Lake City

517920

DUGWAY COBALT-60 IRRADIATION FACILITY

C. J. Christensen, T. Jacobsen, Q. Klingler, M. D. Evans

The irradiation facility described herewith was designed and constructed by the University of Utah for use in the food preservation program of the Food and Container Institute of the Quartermaster Corps of the U. S. Army. It is used at the Dugway Proving Ground in Utah.

Specifications

The radiation source is approximately 4000 curies of cobalt-60 in the form of 5 plates, each with dimensions of 14" x 2 3/8" x 3/8". These are disposed about a cylindrical irradiation chamber capable of handling #10 food cans, (standard in the food industry), in a continuous sequence through the irradiation chamber. The facility provides for the irradiation dose rate to be continuously alterable over a range of at least 100 to 1. The temperature of the irradiation chamber is continuously variable from -15 to 100 degrees centigrade.

Character of Radiation Incident on the Food

Cobalt-60 is known to decay by several paths. The path by which over 99% of the decay takes place is the sequence: 0.31 Mev β^- particle; 1.172 Mev γ ray; 1.332 Mev γ ray.[1] The β^- particle which are ejected in the direction of the irradiation chamber are readily absorbed by the metal which forms the walls of this chamber and the iron sheet of which the #10 food cans are constructed. Hence this particle has little or no effect on the food in the irradiation chamber.

---

(1) Strominger, Hollander, and Seaborg, "Reviews of Modern Physics," 30, #2, p. 631, (April, 1958).

Neither of the two γ rays (photons) have enough energy to produce neutrons on interaction with the food. Most processes of this kind require photons of the order of 10 Mev energy. The most likely process to release neutrons in the food system would be the interaction with deuterium of the 2.158 Mev photons, which arise from the disintegration of .004% of the cobalt-60 atoms.[1] However, this photon is slightly less energetic than required to give neutrons on interaction with deuterium.[2] Accordingly, we believe the neutron flux in this irradiation system to be negligible.

The attenuation of gamma radiation is known to be effected mainly by three processes, which are: photoelectric absorption, Compton scattering, and electron pair formation. The relative importance of these three processes varies with the energy of the photon. Davisson and Evans[3] give data from which this relative impottance may be determined. For cobalt-60 radiation (average $h\nu = 1.25$ Mev) lead has the following absorption coefficients for the three types of attenuation phenomena:

photoelectric absorption coefficient = 4.65 Barns/atom,

Compton absorption coefficient = 15.58 Barns/atom,

electron pair absorption coefficient = .13 Barns/atom.

Accordingly, the absorption ratios are 1:36:120 for electron pair: photoelectric:Compton scattering, respectively.

---

(2) Kaplan, "Nuclear Physics, Addison-Wesley Publ. Co., p. 446, (1955).

(3) Davisson and Evans, "Reviews of Modern Physics," 24, 79-107, (1952).

In this range of photon energy electron pair production can be neglected in our considerations since it accounts for less than 1% of the total absorption.

In photoelectric absorption an electron is ejected from the absorber with energy roughly equal to the energy of the incident photon. The energy of the photoelectron is largely and quickly dissipated in collision processes, and hence is not likely to penetrate inside the food irradiation chamber.

This leaves the Compton scattering as the process largely responsible for the attenuation of the cobalt-60 radiation. This is a process by which the energy of the scattered cobalt-60 photon varies continuously from that of the incident photon to about 1/6 of this energy; the exact energy of each scattered photon being a function of the angle between the path of the incident and the scattered photon.

Since Compton scattering is the principal process by which the energy of the radiation field is dissipated, and there appears to be no geometrical arrangement of the shielded pot system by which a continuum of scattered gamma photons can be avoided, it seems quite unlikely that a closed system of the sort required can be constructed which will dose the food being irradiated with the substantially monochromatic gamma photons characteristic of the primary processes of cobalt-60 radioactivity .

Pot Construction

The shielding characteristics of the pot must be such that the device is safe for workers in the immediate vicinity, hence the shielding must be able to attenuate the gamma flux so that the intensity of the

emergent gamma field is near background level. The data of Davisson and Evans[3] gives the basis for calculating the attenuation due to steel and lead, of which materials the pot is constructed.

The absorption coefficients for 1.25 Mev photons, (average for the two principal photons from cobalt-60), by iron and lead are as follows:

Coefficient	Iron	Lead	Unit
μ/ρ	.0538	.0599	cm^2/gm
μ	.429	.679	cm^{-1}
$X_{\frac{1}{2}}$	1.61	1.02	cm

μ/ρ is called the "mass absorption coefficient",

μ is called the "absorption coefficient", and

$X_{\frac{1}{2}}$ is called the "half-thickness", or the thickness of the material necessary to attenuate the gamma field to one-half its intensity.

The original design of the pot called for 1¼ inches of steel and 7 3/4 inches of lead in the wall. According to the above table this gives 21.3 half-thicknesses of shielding. The attenuation (A/A_o) would then be

$$A/A_o = (\tfrac{1}{2})^{21.3} = 3.9 \times 10^{-7}.$$

The data used in calculating this attenuation assumes that no scattered radiation is present outside the pot. Since the attenuation is almost entirely due to Compton scattering, this obviously does not give an exact answer, and the radiation experienced at a point outside the pot is greater than that calculated. R. D. Evans[4] gives data showing that a suitable correction can be made by multiplying the value calculated above by 3.3. Hence the corrected value would be:

(4) R. D. Evans, The Atomic Nucleus, McGraw-Hill Co., pp. 730-733, (1955).

$$(A/A_o)_{corrected} = 3.3 \times 3.9 \times 10^{-7} = 1.3 \times 10^{-6}.$$

This proved to be somewhat less attenuation than desired, accordingly another 2 inches of lead was added to the inner cylindrical wall of the pot. The attenuation factor for the wall of the pot now represents 26.5 half-thicknesses, and the attenuation is

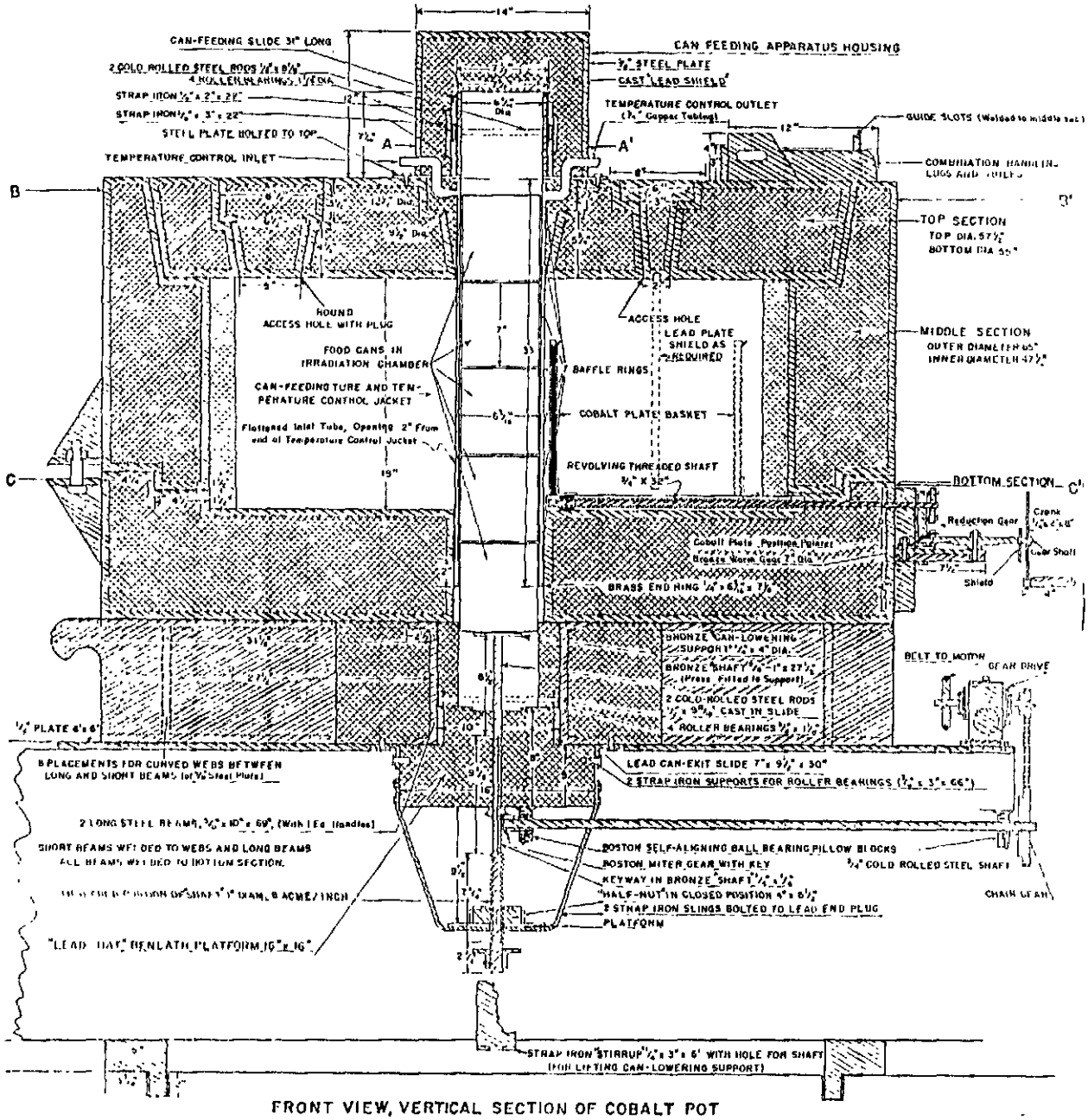
$$(A/A_o)_{corrected} = 3.3 \times (\tfrac{1}{2})^{26.5} = 3.3 \times 10^{-8}.$$

This amount of shielding (1¼ inches of steel plus 9 3/4 inches of lead) proved to be entirely adequate. A survey instrument placed next to the outside walls of the pot showed no appreciable radiation above background.

Design and Construction of the Irradiation Pot

The design of the pot is shown in figures 1 and 2, which are the vertical section of the pot and an exploded view, respectively. Sections A - A', B - B', and C - C' (designated in figure 1) are shown in figures 3, 4, and 5 respectively.

The pot consists essentially of a vertical irradiation chamber in cylindrical form so dimensioned as to permit a #10 food can to press easily through it along its cylindrical axis. The five cobalt-60 plates are disposed vertically around the irradiation chamber and are mounted in moveable racks, actuated from outside the pot by individual screws, so that the intensity of the radiation field in the irradiation chamber can be continuously varied by changing the position of the cobalt-60 plates with respect to the irradiation chamber. Further attenuation of the radiation field inside the irradiation chamber can be achieved by attaching a lead shield to each of the



FRONT VIEW, VERTICAL SECTION OF COBALT POT

10 INCHES

Figure 1

35,000 lbs. approx

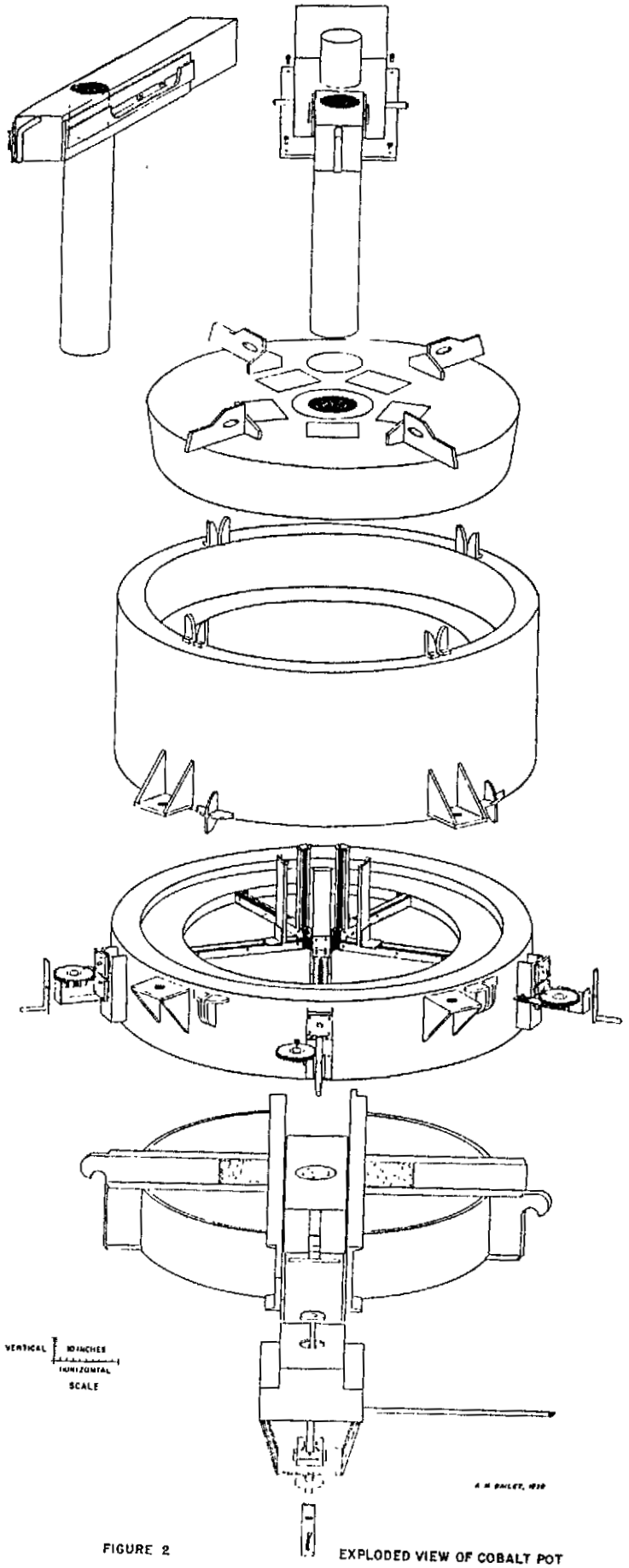
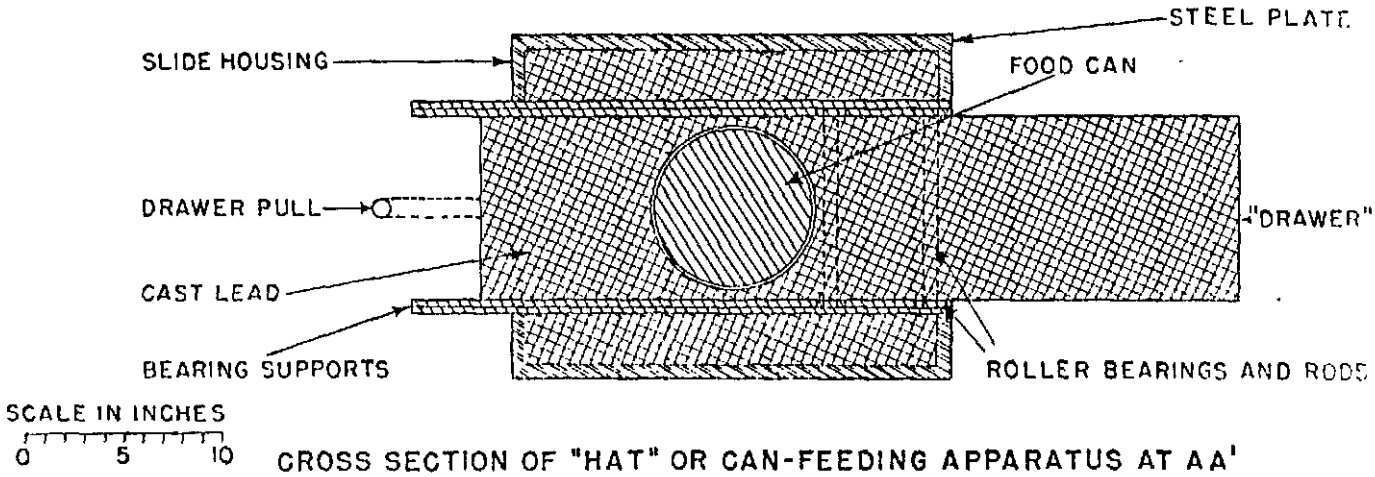
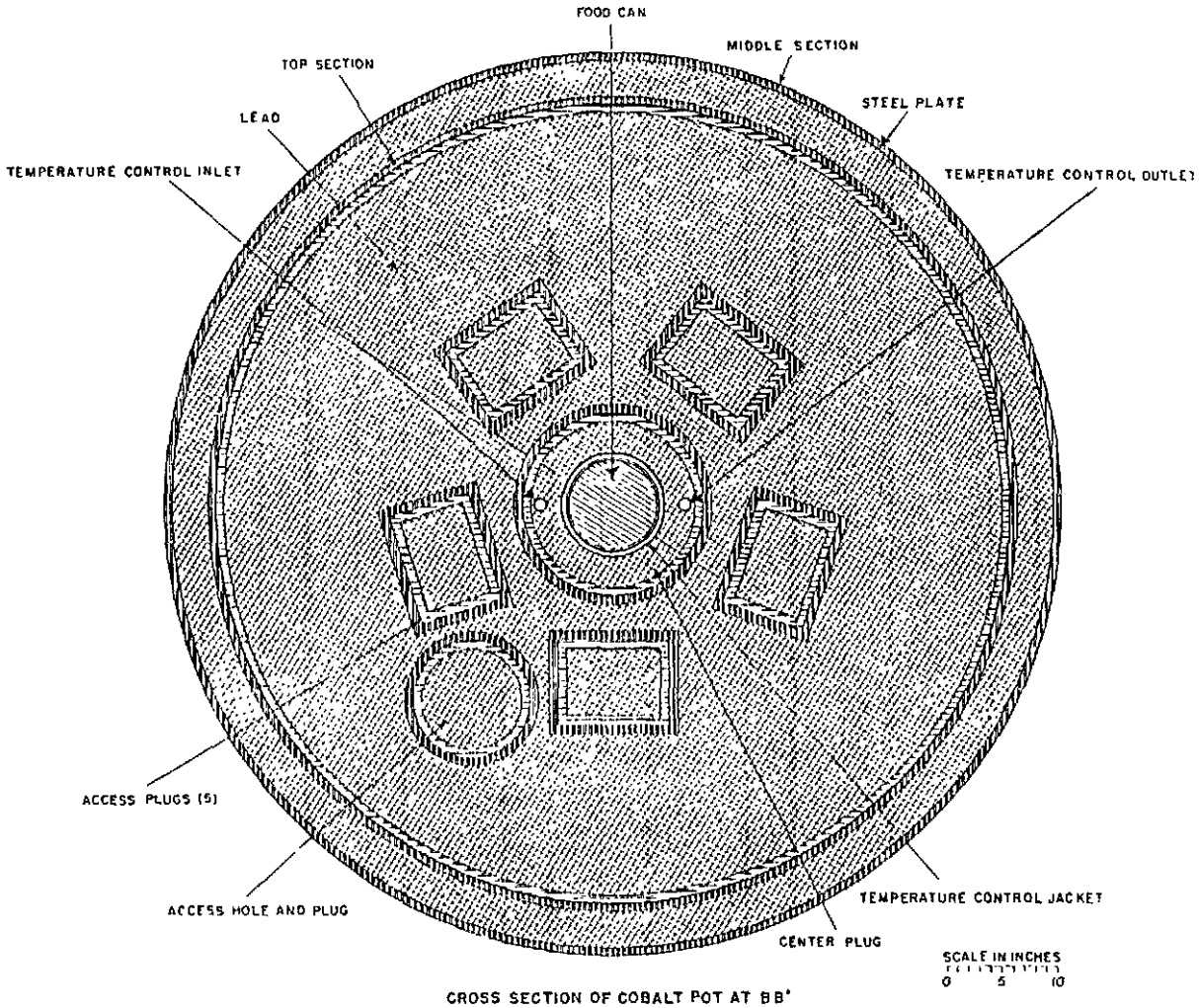


FIGURE 2 EXPLODED VIEW OF COBALT POT



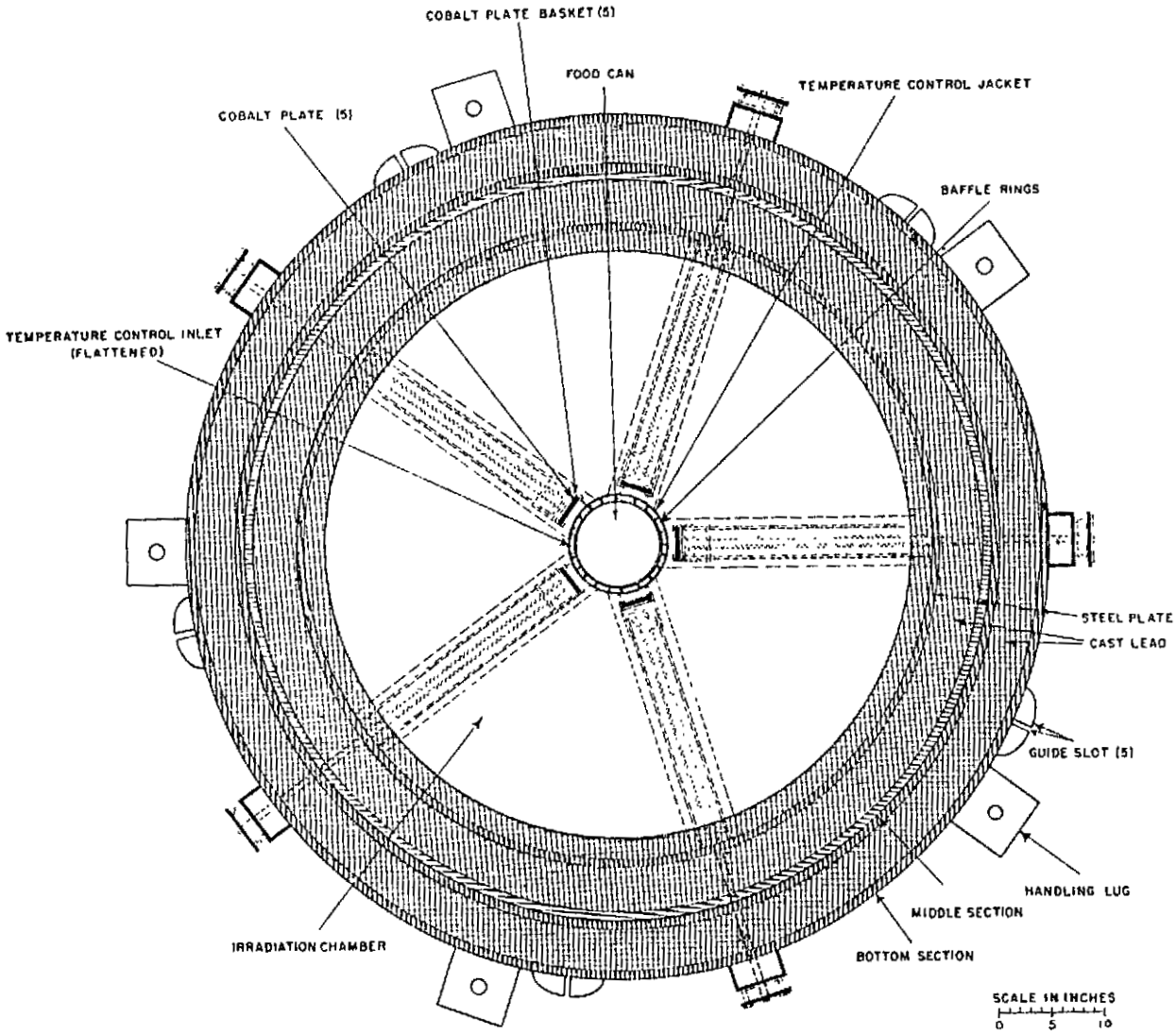
CROSS SECTION OF "HAT" OR CAN-FEEDING APPARATUS AT AA'

Figure 3



CROSS SECTION OF COBALT POT AT BB'

Figure 4



CROSS SECTION OF COBALT POT AT CC'

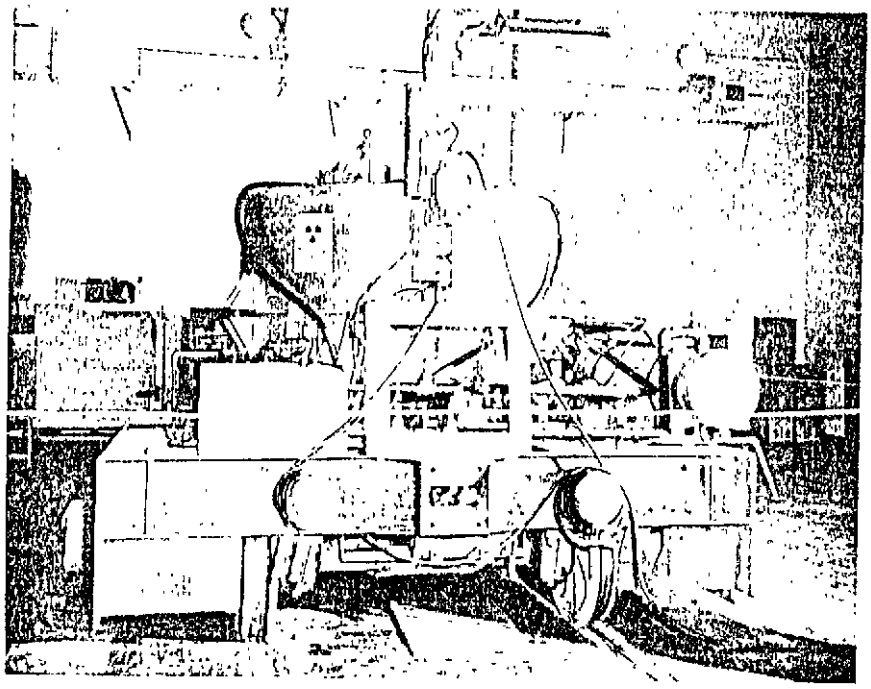
Figure 5

access hole plugs and placing this shield between the cobalt-60 plate and the irradiation chamber. This feature is illustrated in figure 1.

The pot is mounted on a small flat car, figure 6, which operates on a standard gauge railroad track. (It could as easily be placed on a flat bed truck of conventional design.) In the Dugway facilities there is available a large "cave" with suitable manipulators to handle the loading and unloading of the cobalt-60 plates. Also available is a 15 ton gantry crane to handle the heavy sections of the pot. In operation the top of the pot is removed by the crane, the pot rolled into the "cave", the cobalt-60 plates inserted or removed as desired, the pot then is moved to the crane and the top of the pot replaced. In this operation the top is off while the cobalt-60 plates are in place in the pot. No personal hazard is experienced in the out-of-doors however, for the flat car is handled with a 50 foot long boom on a tractor. (See figure 7.) Under these conditions the small back scattering from the atmosphere above the open pot is within acceptable limits at the driver's position in the tractor.

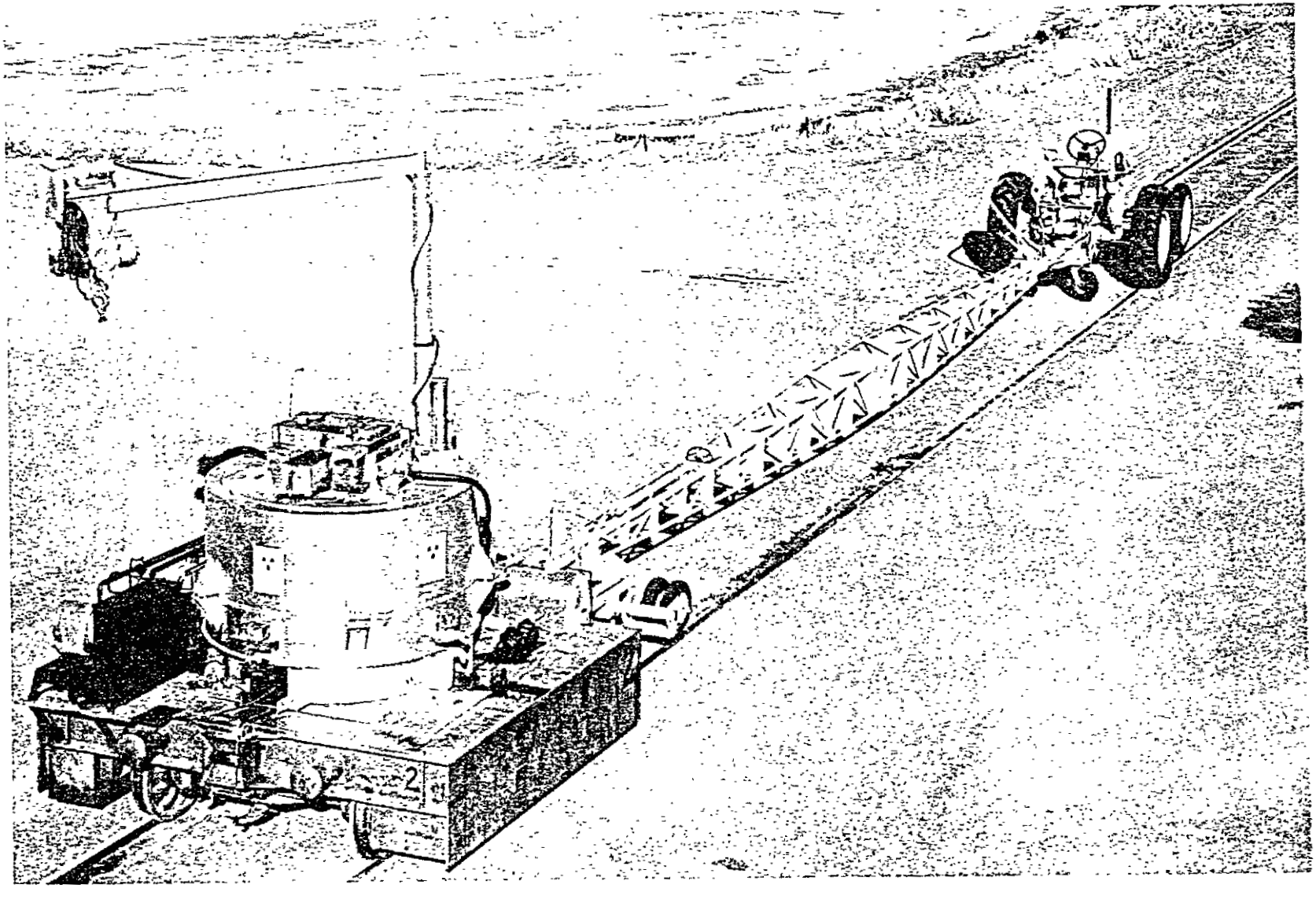
The pot is constructed in sections, (figure 2), so as to be easy to manipulate, and to facilitate alterations as these might be required in the development work. The efficacy of this design feature became evident when a change was made in the facility to handle #10 cans on a continuous "through the field" basis, rather than #2 cans on an "insert and withdraw" basis.

The inlet tube carrying the thermostated fluid (coolant or "heatant") to the annular shell of the irradiation chamber is



Pot Mounted on Flat Car.

Figure 6



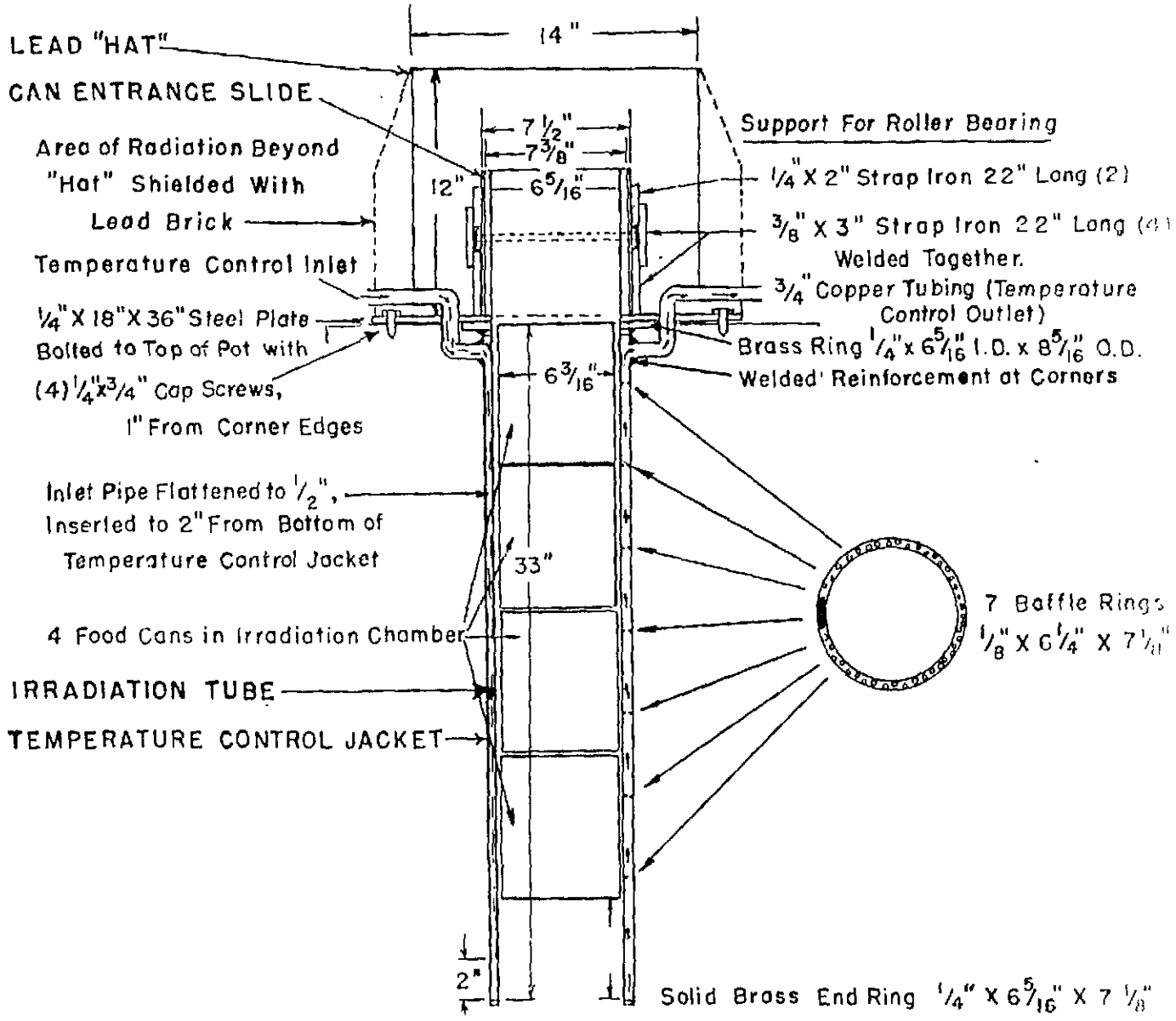
Boom and Tractor Attached to Flat Car with Pot.

Figure 7

flattened, as shown in figures 1 and 8, so as to permit the tube to extend to the bottom of the shell; thus the thermostated fluid enters the annular shell at the bottom and exits at the top.

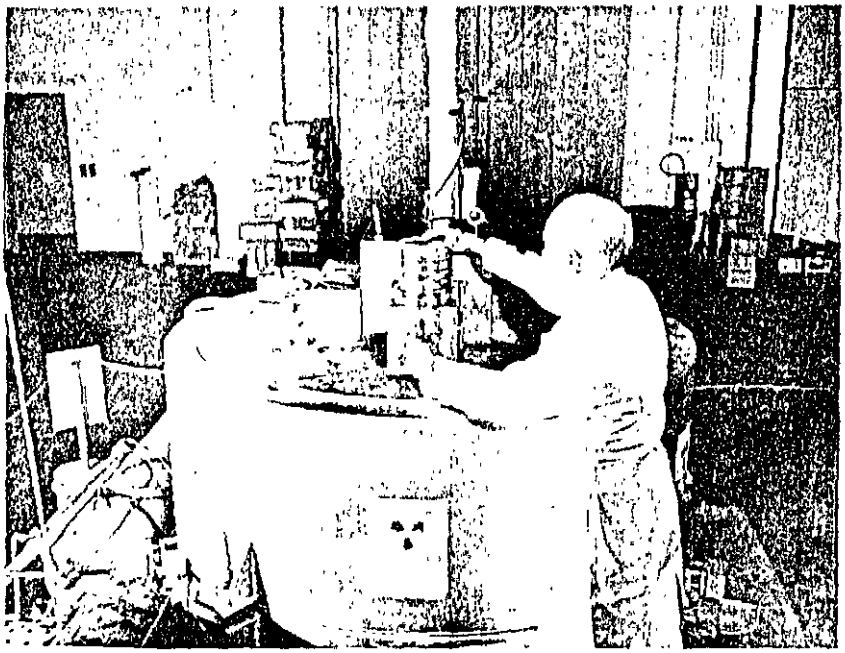
The pot is so constructed that the #10 food cans are fed in at the top of the food irradiation chamber (figure 9) and removed at the bottom. A cross section of the can feeding mechanism is shown in figure 3. A solid block of lead is arranged as a sliding (on rollers) "drawer" with a hole sized to admit a #10 food can. As the "drawer" is pulled out, the far end of the drawer, which is a solid lead block, shields the entrance to the irradiation tube; the hole in the drawer is outside the housing and is thus available for the insertion of a new food can. As the lead drawer with the food can is pushed in, the can is positioned over the inlet to the irradiation tube and drops into the topmost position of the column of cans in the irradiation chamber.

The "can-lowering support", (see figure 1), which holds the column of food cans in place in the irradiation chamber, is provided with a turntable mechanism which rotates the column of cans resting upon it. Thus, complete cylindrical uniformity in the radiation dosage is achieved. The "shaft" holding the "can-lowering support" is threaded on the lower end with 8 threads per inch. This shaft is held in position by removable "half-nuts" (see figure 1). As the "shaft" is turned, the "can-lowering support" lowers the column of food cans in the irradiation chamber until the bottom can rests in a "lead hat" at the bottom of the irradiation chamber and the "can-lowering support" is in the depression in the "lead hat", so that the lower, or unloading drawer, with the food can at the bottom of the



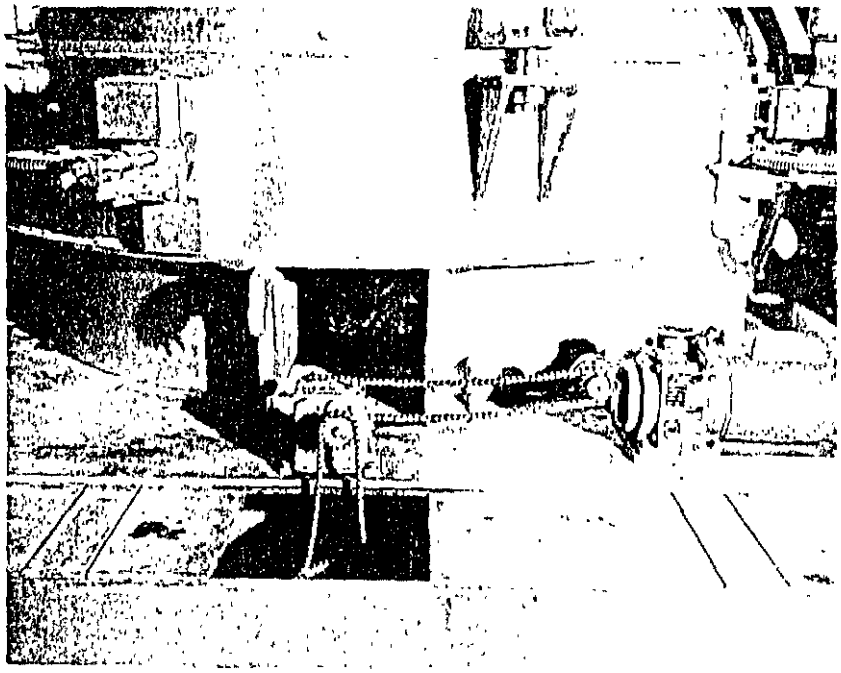
Detail of Can Feeding and Temperature Control Apparatus.

Figure 8



Food Can Being Inserted Into Pot.

Figure 9



Motor and Reduction Gear for "Can-lowering Support".

Figure 10

column in its recess hole can be slid out from under the remainder of the column. The food can at the bottom of the column is thus removed from the irradiation chamber.

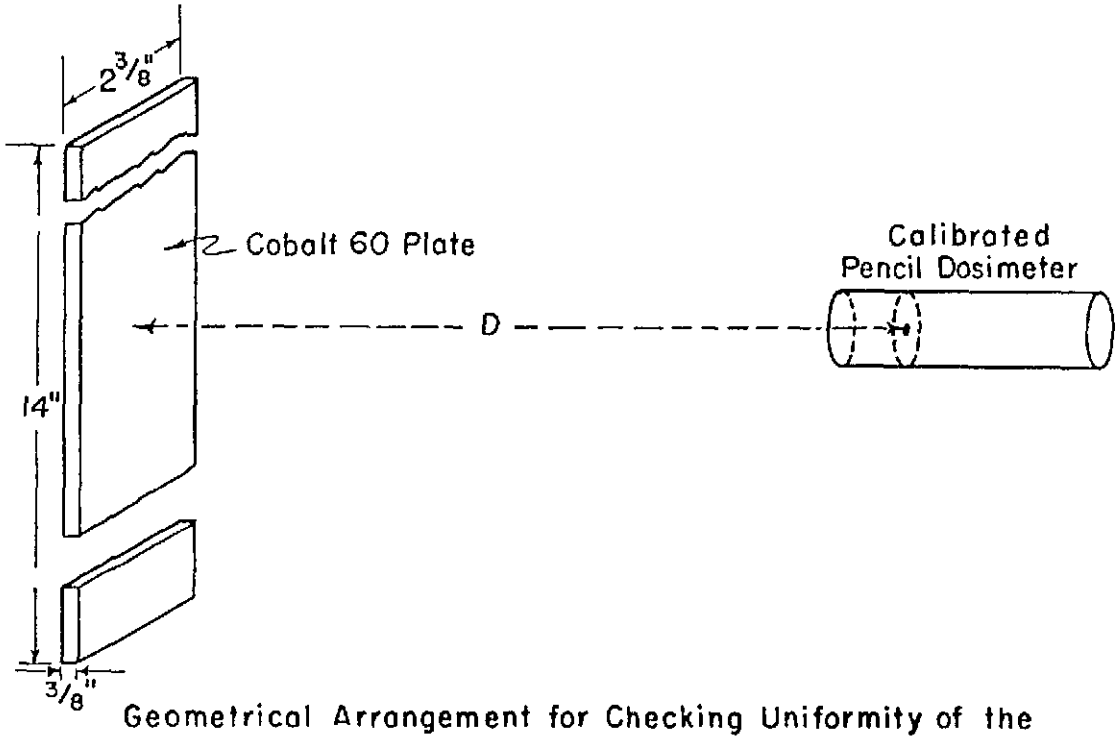
The drawer, minus the can, is then pushed in, just short of full way, so that the column of cans rests on the edge of the hole in the drawer. The "can-lowering support" and associated "shaft", which is of smaller diameter than the hole in the drawer, is then raised by a "stirrup", suitably attached to an external elevating device, so that the support contacts the column of cans and holds them in place in the irradiation chamber. The "half-nuts" are then engaged with the threads of the "shaft" in position to permit another descent cycle. The bottom lead drawer is then pushed all the way in so that the column of cans can be gradually lowered once again until the lowest can is in position in the drawer to be removed.

The total amount of radiation dosage is controlled by the rate at which cans are inserted and removed from the irradiation chamber, and this is controlled by the speed at which the "shaft" holding the "can-lowering support", is rotated by the motor and gears provided for this purpose. (See figure 10.) The motor is of the wide ratio continuously variable speed variety. This, with a change in the reduction gear, makes possible almost any desired speed of rotation of the shaft and thus any desired total radiation dosage.

To evaluate the uniformity of activity of the cobalt-60 plates the radiation field emanating from each of them was individually measured with standardized 200 MR pencil dosimeters. The arrangement was as shown in figure 11. The data are given in the following table.

TABLE I

Plate	D (Feet)	Dosage Time (Minutes)	Dosage (REP)	Calculated (REP/Hr at 3 feet)
1	34	1	.143	1100
2	34	1	.129	990
3	34	1	.123	945
4	34	1	.139	1070
5	34	1	.127	975
1	62	4	.151	970
2	62	4	.141	905
3	62	4	.127	816
4	62	4	.142	910
5	62	4	.139	893



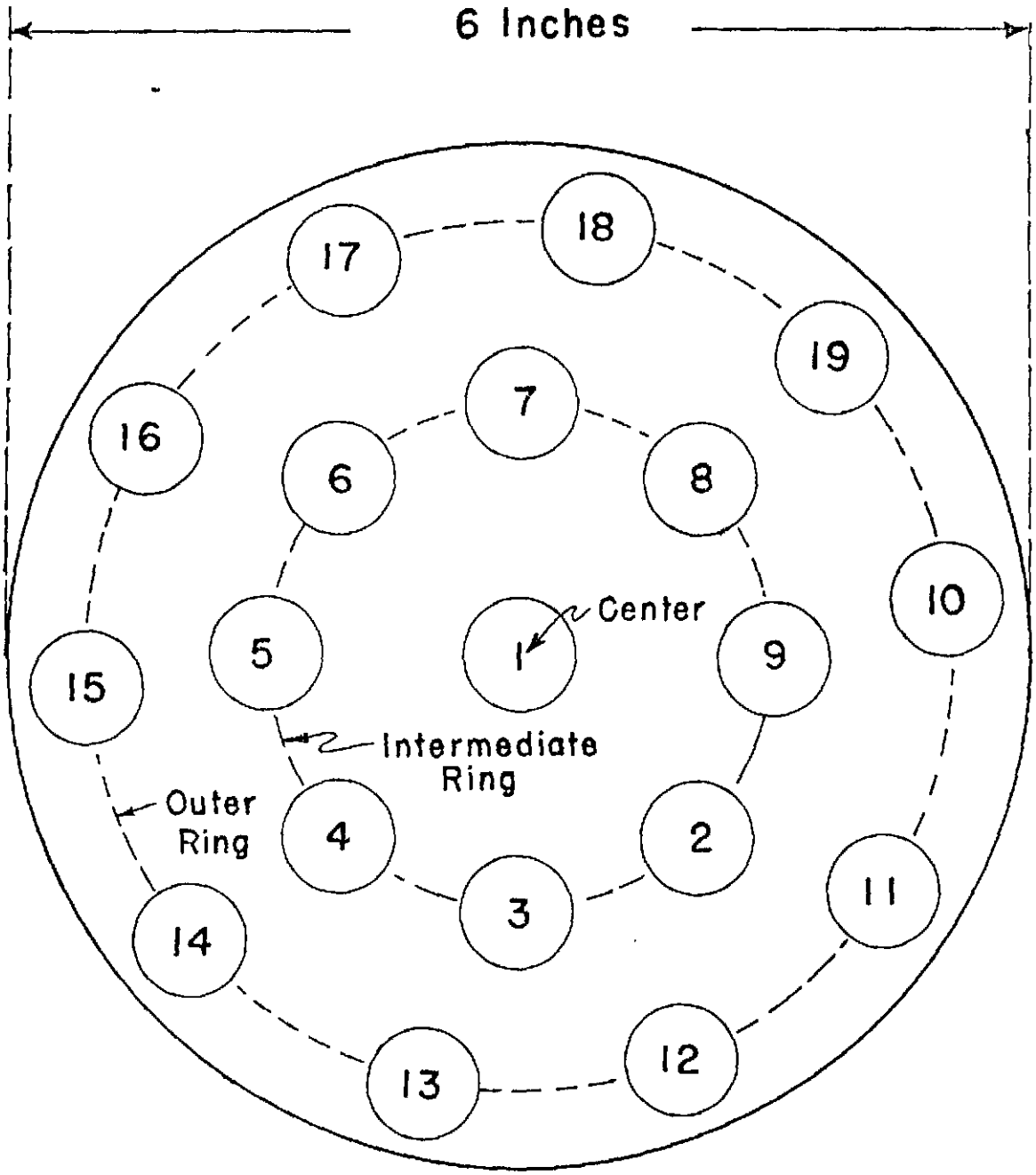
Geometrical Arrangement for Checking Uniformity of the Five Cobalt 60 Plates.

Figure II

From these data it appears that the overall activity of the 5 cobalt-60 plates did not vary by more than ± 8% from the average value.

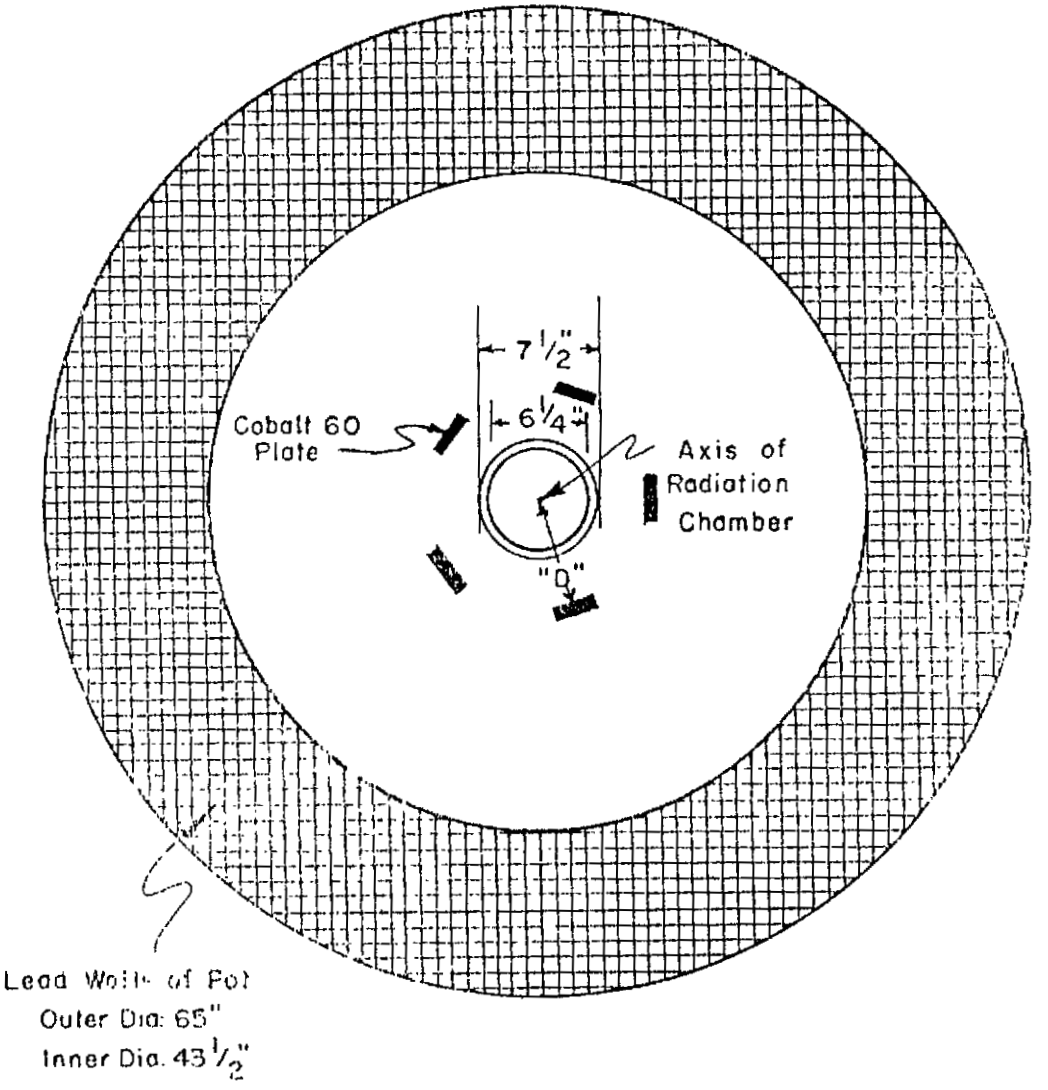
Dosage Distribution in a Number 10 Food Can

The irradiation cavity was designed to accept a #10 food can in common usage in the food industry. The product to be irradiated would be placed in this can. The uniformity of the radiation dosage over the cross section of the can was determined by placing suitable chemical dosimeters, of the ferrous-ferric or cerous-ceric type, depending on the dosage to be measured, in particular locations within the can, filling the can with water, irradiating the assembly, then removing the dosimeters and determining the dosage received. The dosimeters were held in their various locations within the can by a polyethylene holder, a scale template of which is shown in figure 12. Readings were made with the cobalt plates in 6 positions within the pot cavity, from a position contiguous to the outside wall of the radiation chamber to a position against the inner wall of the pot; (from 3 3/4 inches to 21 inches from the cylindrical axis of the irradiation chamber). (See distance "D" of figure 13.) The results for the cobalt plates disposed 8 3/4 inches from the center of the radiation chamber (D = 8 3/4" in figure 13) are given in table II. During irradiation the cans were rotated on a vertical axis so as to give cylindrical uniformity in the radiation dosage. As is to be expected the dose rate is greatest at the periphery of the can and least at the center.



Scale Diagram Showing Arrangement of Dosimeters in Cross Section of No. 10 Can.

Figure 12



Arrangement for Determining Dosage Rate Over The Cross Section of the Radiation Chamber.

Figure 13

TABLE II

Dosage distribution over the cross section of a #10 food can placed in the center of the radiation field for 24 minutes. The faces of the cobalt-60 plates were 8 3/4 inches from the cylindrical axis of the irradiation chamber, (distance "D" on figure 13).

Position of Dosimeter	DOSAGE RATE REP/HOUR	Position in Can	AVERAGE DOSAGE RATE REP/HOUR
1	60,000	center	60,000
2	62,800		
3	61,800		
4	60,000		
5	--	intermediate ring	62,500
6	--		
7	63,500		
8	65,000		
9	61,800		
10	67,000		
11	69,800		
12	67,300		
13	68,300		
14	67,800	outer ring	67,300
15	66,000		
16	66,500		
17	67,000		
18	68,200		
19	65,500		

In table III are given the average values of the radiation intensity (I) for 6 values of "D", (figure 13). These data are plotted in figure 14. This plot is on a logarithmic scale in the radiation intensity, hence the vertical distance separating the dose rate at the center of the can from that at the periphery of the can is a measure of the nonuniformity of the radiation over the circular cross section of the can. It is thus observed that the nonuniformity of radiation over the can cross section is greatest when the cobalt plates are

TABLE III

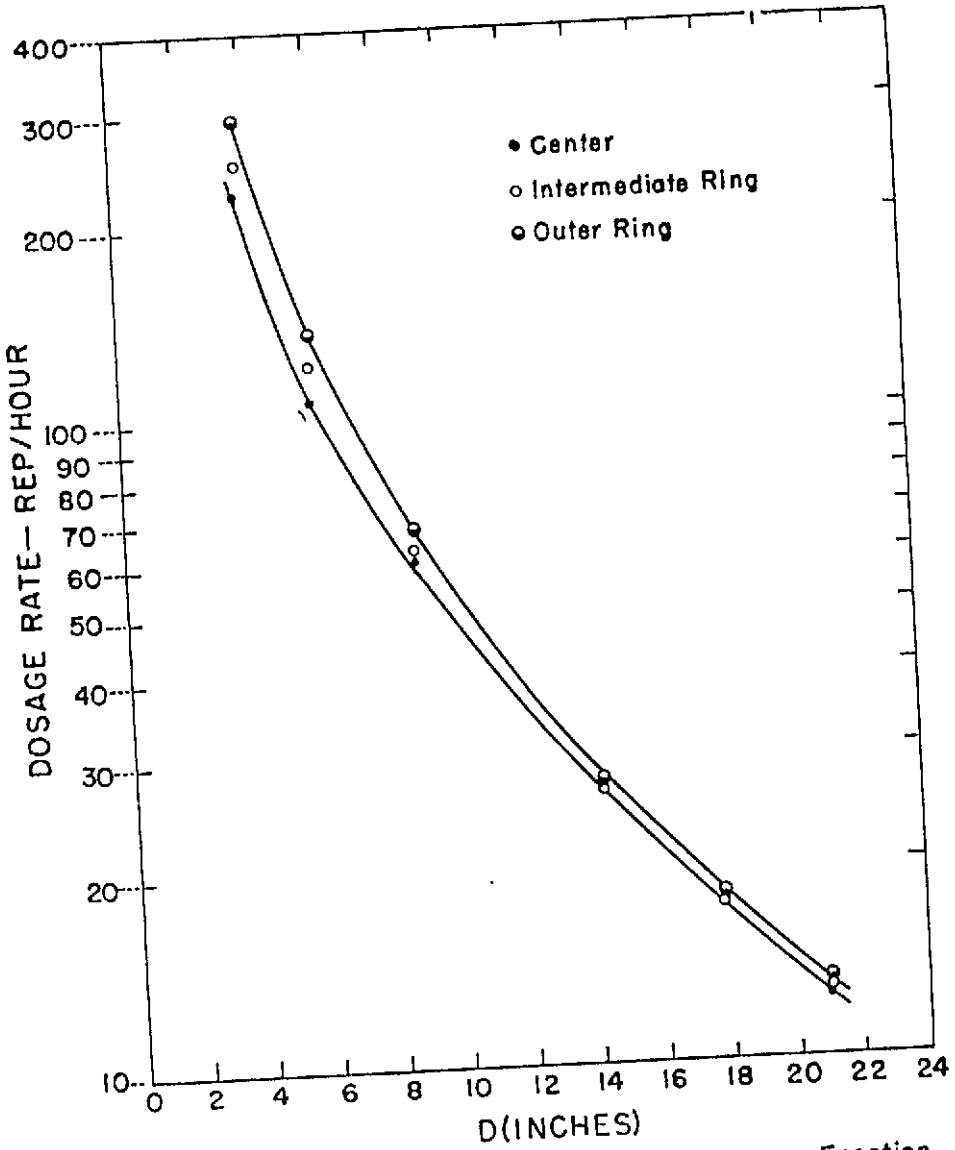
RADIATION INTENSITY (I)
(REP/HOUR)

D (inches)	CENTER	INTERMEDIATE RING	OUTER RING	ID^{2*}
3.75	225,000	251,000	294,000	3.52×10^6
5.75	107,000	122,000	138,500	4.03×10^6
8.75	60,000	62,500	67,300	4.77×10^6
14.25	--	26,100	27,500	5.30×10^6
17.75	--	17,500	18,100	5.51×10^6
21.00	12,500	12,800	13,200	5.62×10^6

* At intermediate ring.

contiguous to the irradiation chamber, and least when moved farthest away from it. This is to be expected since the nonuniformity of irradiation over the cross section is due to two factors: 1) the divergence of the radiation field from the cobalt-60 plates, and 2) the absorption by the can contents. The first factor is responsible for the decrease in the nonuniformity of the irradiation over the cross section of the can as the cobalt plates are moved farther from the irradiation chamber. If the cobalt plates were placed at infinity from the irradiation chamber, then the radiation field would have no divergence at the irradiation chamber, and all the nonuniformity would be due to the second factor. To place the cobalt-60 plates an infinite distance away is obviously unreasonable, for then there would be little or no intensity in the radiation field at the irradiation chamber.

The ratio of the radiation intensity (dosage rate) at the center of the #10 can to that at the outer ring (figure 12) is .77 when the cobalt plates are contiguous to the irradiation chamber and .95 when



Radiation Intensity in the Radiation Chamber as a Function On the Position of the Cobalt 60 Plates in the Pot.

Figure 14

furthest removed from the irradiation chamber. Thus, if uniformity of dose rate over the cross section of a can is desired, one must irradiate with the cobalt plates all the way out and compensate for a loss of radiation field intensity in the irradiation chamber by increasing the irradiation time.

The data of table III also show that one obtains approximately a 20 fold diminution of radiation intensity when the cobalt-60 plates are moved from a position contiguous to the radiation chamber to a position as far from this as the pot will permit. The ratio is as follows for various positions in the #10 can:

center position ratio is 18.0,

intermediate ring position ratio is 19.6,

outside ring position ratio is 22.3.

If the cobalt-60 plates constituted a point source, and there were no gamma ray scattering, one would expect the radiation intensity to vary inversely as the square of the distance of the cobalt-60 source from the position where intensity was measured. Thus, ID^2 would be constant. The actual situation is given in figure 15. It is obvious this source of gamma rays acts not at all like a point source without scattering at the radiation chamber. This deviation is fully expected due to the geometry of the cobalt-60 plates and the Compton scattering of gamma rays.

Dose Rate Profile

In a facility of this kind where the cans move through the radiation field on a continuous basis there is of necessity a dose rate

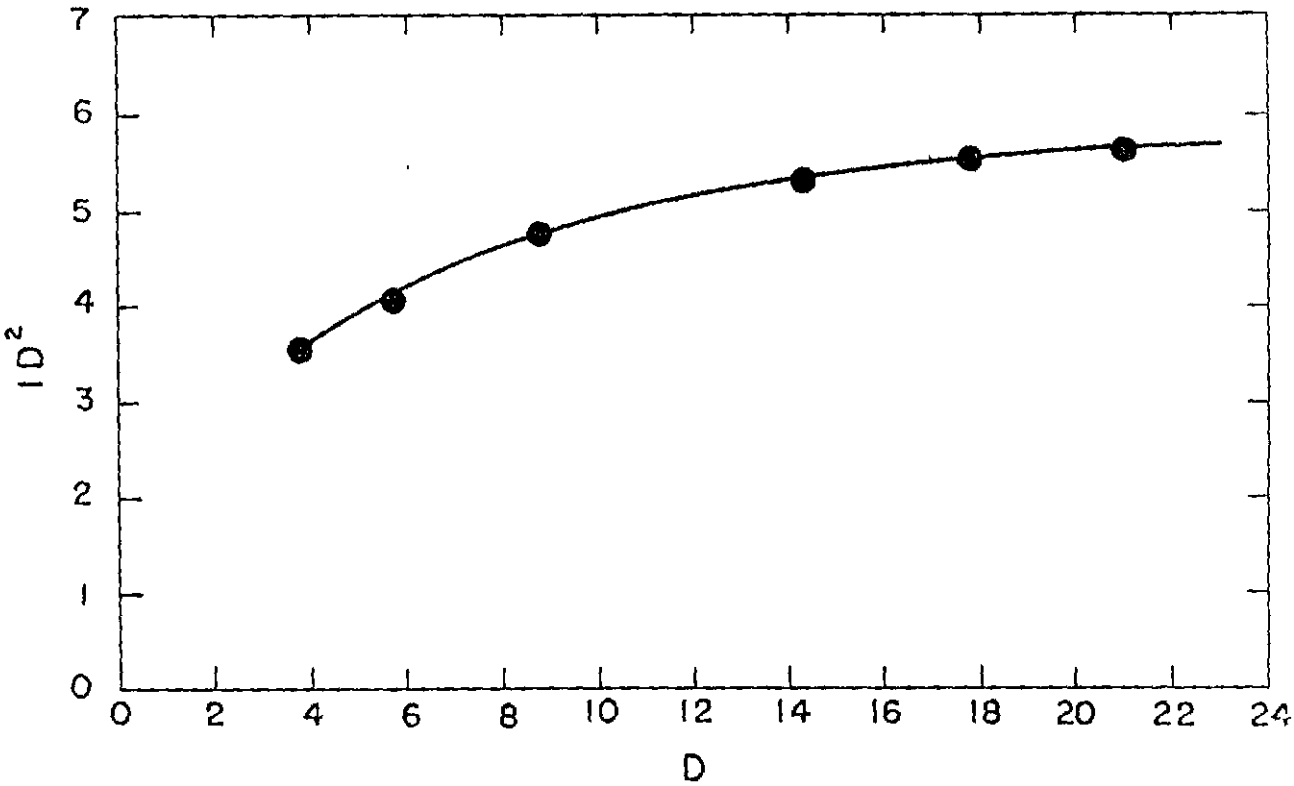


Figure 15

profile and this profile will change with each new setting of the cobalt-60 plates or the introduction of shielding between the cobalt-60 plates and the irradiation chamber. In most cases, where total radiation dosage alone is important, this dose rate profile is of little or no practical importance. However, if it were important, it would have to be measured for each new setting of the geometry associated with the radiation field. For an understanding of the nature of the dose rate profile along the cylindrical axis of the irradiation chamber this profile was measured with the cobalt-60 plates disposed contiguous to the irradiation chamber. These data are plotted in figure 16.