A Versatile Cobalt-60 Irradiation Facility

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A new versatile Co^{60} gamma-ray irradiation facility has recently installed at the Takarazuka Radiation Laboratory of the Sumitomo Atomic Industries Ltd. in Takarazuka. This facility, being capable of storing about two kilo-Curies of Co^{60}, was designed and built by taking account of its versatility of being used for many research purposes. The whole unit is constructed in a hot-cave with a viewing window of shielding glass and a couple of manipulators. The radiation dose for the sample to be irradiated and placed at a fixed position can be easily changeable by replacing the source pencil in the cage with the other ones. The experimental and theoretical estimation of the dose rate distribution around the source and in the labyrinth of the hot-cave was carried out. Some features of the facility as well as the results of the dose rate estimation are described in this paper.

INTRODUCTION

In response to remarkable increase of application of gamma-ray irradiation in various fields of researches, many irradiation facilities of different features with Co^{60} of order of 1 kilo-Curies or more have recently been installed in the world. At our Laboratory a 2 kilo-Curies Co^{60} irradiation facility for radiation chemistry had been installed in August of 1959[1]. It is now in planning to strengthen the Co^{60} source up to 5 kilo-Curies. This facility has, however, no viewing equipment except a closed circuit television, and the regular irradiation position of the samples is fixed. To improve these disadvantageous features of the facility as well as to respond to abnormal increase of users, a new Co^{60} facility available for more versatile applications has recently installed in our Laboratory. The source strength of this second unit is about 1 kilo-Curie, and the maximum exposure rate is about 1×10^6 r/hr. And this dose rate will be increased by increasing strength of the source up 2 kilo-Cureis in the near future. The source of this unit can be divided into several parts and various dose rates can be available at the same position. In this paper, some characteristic features of this facility are mentioned and the dose rate estimation by experimental as well as theoretical procedures is also reported. The spatial distribution of does rates in the irradiation room and labyrinth is also given in the last section.

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CONSTRUCTION

Source. All Co^{60} coins, each of which being 10 mm diameter by 1 mm thick with a specific activity of 18.0~26.3 C/g, were obtained from Oak Ridge National Laboratory. The total serength of the source is about 1008 Curies (Feburary, 1961). Sixty pieces of Co^{60} coins are divided to five groups of 12 pieces; each group is doubly enclosed in two capsules, the outer and inner ones. Five capsules

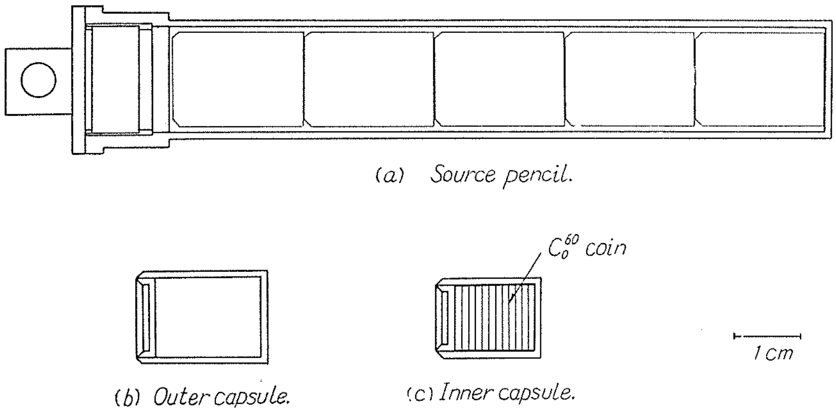

Fig. 1. Vertical section of the source pencil.

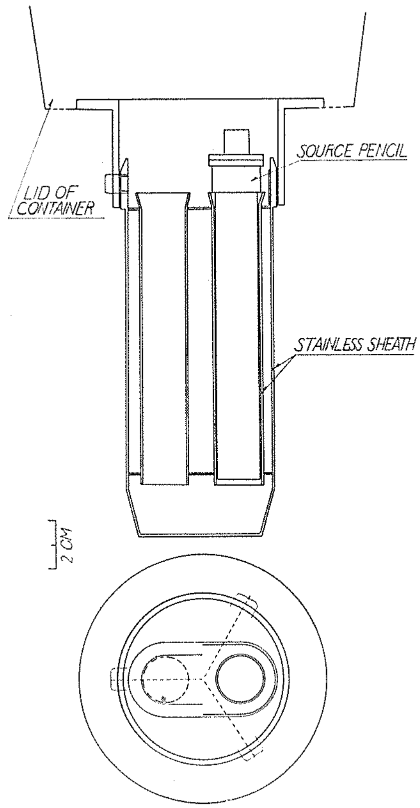

Fig. 2. Vertical section of the source cage.

are inserted together into a pencil with an inside diameter of 15.5 mm, a wall thickness of 1 mm and an effective length of about 100 mm, as shown in Fig. 1. The source strength of each capsule is 201.0~202.8 Curies. The source cage can hold up two pieces of this pencil, as shown in Fig. 2. The source assembly is made of stainless steel and the outer sheaths are of 5 mm thick in all. When

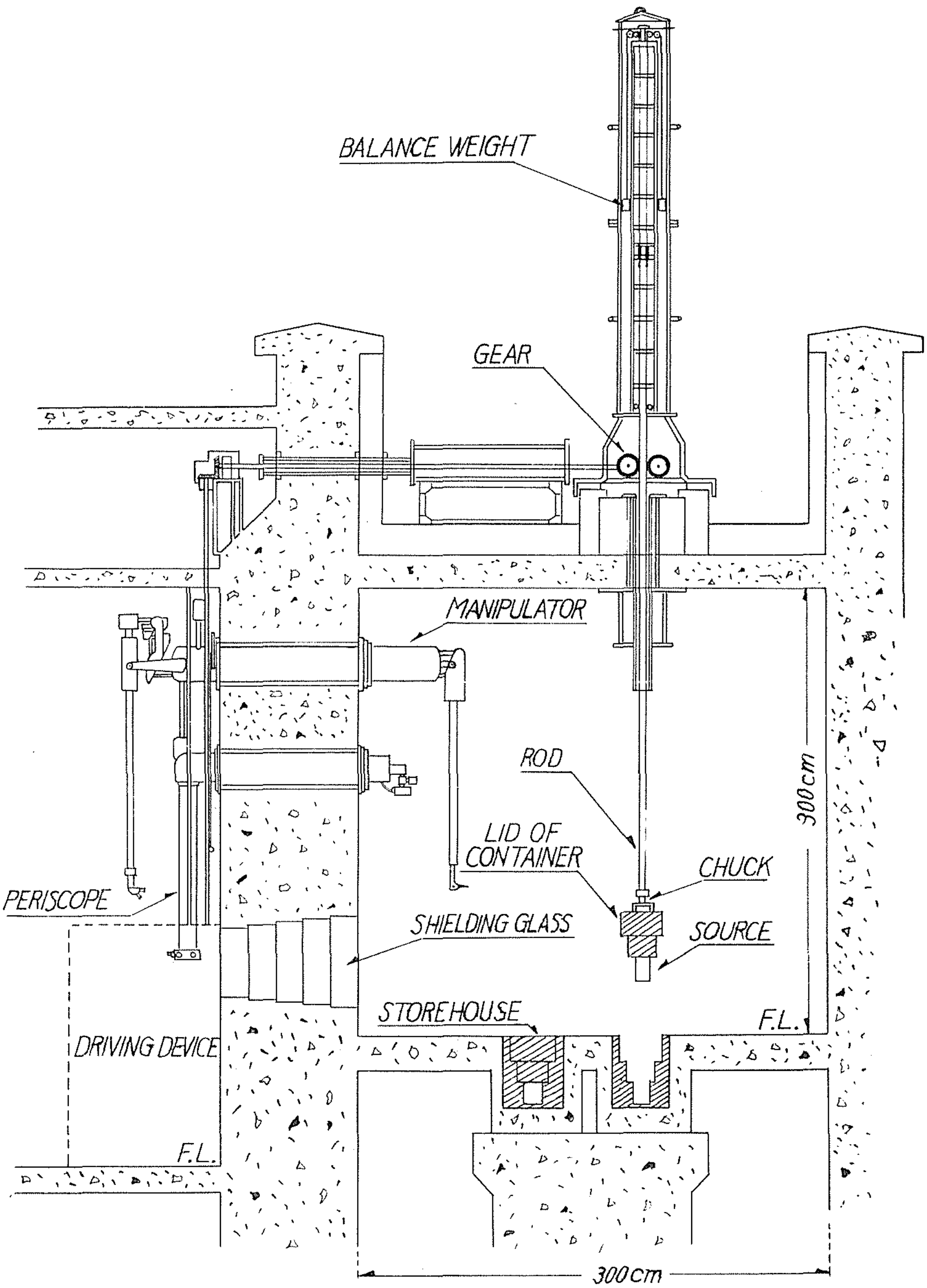

Fig. 3. Elevation view of the irradiation facility.

the source is not used, it is held fast under the lid of a lead container, which is installed in the floor of the irradiation room.

Mechanical. In Fig. 3 the elevation view of the irradiation facility is shown. The source assembly is kept in the cave under the floor level when it is not use. The rod, carrying the assembly, is loaded with a chuck on its lower end and is operated by a motor-driven mechanism. When a sample to be irradiated is completely set and a worker escapes from the irradiation room and closed its door, the rod begings to shift down and hooks the lid of the container. And the assembly with the lid is lifted up to the favorable position for irradiation. These procedures to carry the assembly can be done succesively by only one operation. When the irradiation is over, the source assembly is brought down and again kept in the cave and the rod returns its former upper position through the reverse process. If the preset timer is set, these procedures can be performed automatically.

If different geometries of the source unit are desired, the capsules in pencils can be replaced suitably. The other excess capsules are kept in the storehouse. These procedures are performed, certainly and carefully, by operating the manipulators and observing the inside of the hot cave through the viewing window of shielding glass or the periscope.

MEASUREMENT OF DOSE RATE

The chemical measurement of dose rates was performed around the source assembly by the ferrous-ferric dosimeter. In the present work, however, the solution used for dosimetry is limited to the O_2-saturated one, though in the former work with our first facility two N_2- and O_2-saturated solutions were used

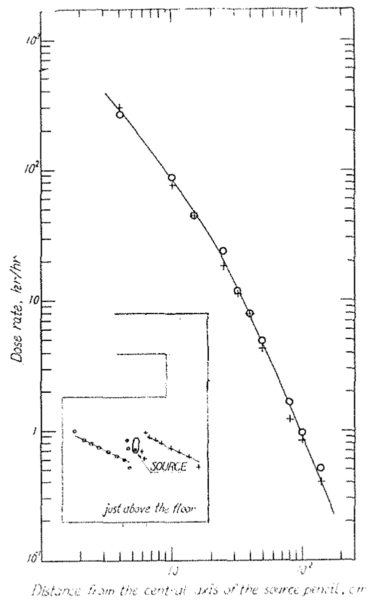

Fig. 4. Experimental dose rate (July 11, 1961).

in parallel[1].

The observed results are given in Fig. 4. The location of points measured is shown also in the figure. The height of the source cage was selected so that its lowest end reached the floor level. And then the glass test tubes employed for dosimetry were directly placed upright just above the floor.

CALCULATIONS OF DOSE RATE

Before the construction of this facility, the dose rate was estimated over the three source geometries: the cylindrical, the pencil and the point source. Since little differences were found at more than 30 cm of distance far from the central axis of the source unit, the pencil source mentioned in the preceding section was adopted because of its simplicity. After the installation the more detailed calculations of dose rate were performed.

The geometry of this facility is simpler than our first irradiation facility. The cage now contains only one source pencil, though it leaves room for another one. For calculation the line source was adopted as a model and the all activity of the pencil was assumed to be concentrated on its symmetric axis with uniform specific activity. And further, it was assumed that the gamma photons emitted from the source were absorbed in the source itself and the stainless steel sheathes. The linear absorption coefficient of the latter is chosen to be equal to that of iron.

The dose rate at a given point P is given by the following expression[2] (see Fig. 5):

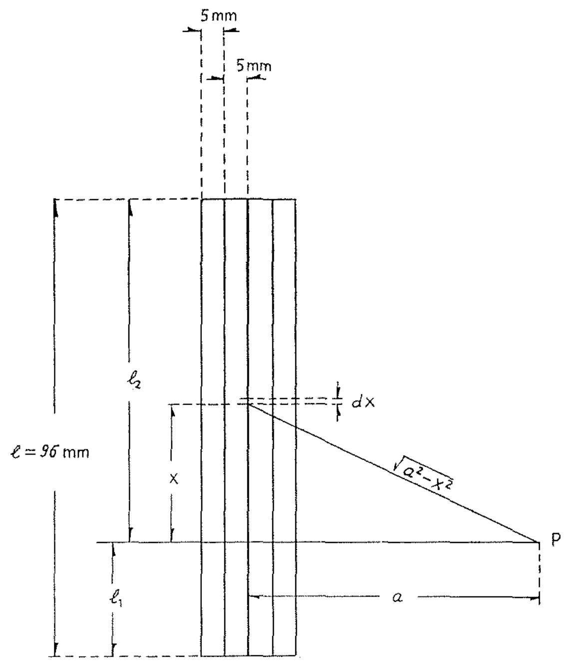

Fig. 5. Geometry of an assumed pencil source.

$$I_P=\frac{S\varepsilon}{a}\left\{\left(\tan^{-1}\frac{l_2}{a}+\tan^{-1}\frac{l_1}{a}\right)-\mu t\log\frac{l_2+(a^2+l_2^2)^{1/2}}{-l_1+(a^2+l_1^2)^{1/2}}+\frac{(\mu t)^2 l}{2a}\right\}, \quad (1)$$

where

$S=13.56\times10^3$ r/hr/C at 1 cm,

ε = linear specific activity = 104 C,

Table 1. Calculated dose rates in units of kr/hr.
(Normalized to February, 1961)

Distance* (cm)	Plane		
	l_2=0.0 cm	l_2=2.4 cm	l_2=4.8 cm
2	587	937	998
4	249	354	389
6	147	189	204
8	97.2	117	124
10	68.9	79.0	82.8
12	51.1	56.8	58.9
14	39.3	42.7	43.9
16	31.0	33.2	33.9
18	25.1	26.5	27.0
20	20.7	21.7	22.0
22	17.3	18.0	18.2
24	14.7	15.2	15.4
26	12.6	13.0	13.1
28	11.0	11.2	11.3
30	9.61	9.82	9.89
32	8.49	8.65	8.70
34	7.55	7.67	7.72

* Distance from the central axis of the source pencil.

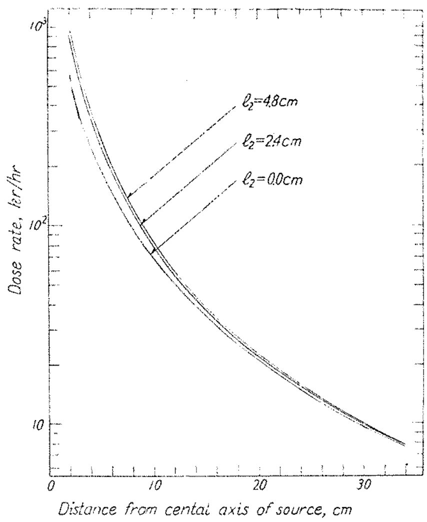

Fig. 6. Calculated dose rate outside the source cage on the planes perpendicular to the central axis.

$l = l_1 + l_2 = 9.6$ cm,

$\mu t = \mu_1 t_1 + \mu_2 t_2$,

μ_1 = linear absorption coefficient of Co^{60} gamma-rays for cobalt = 0.447 cm^{-1} [3],

μ_2 = linear absorption coefficient of Co^{60} gamma-rays for iron = 0.408 cm^{-1} [3],

t_1 = effective path of a photon in the source,

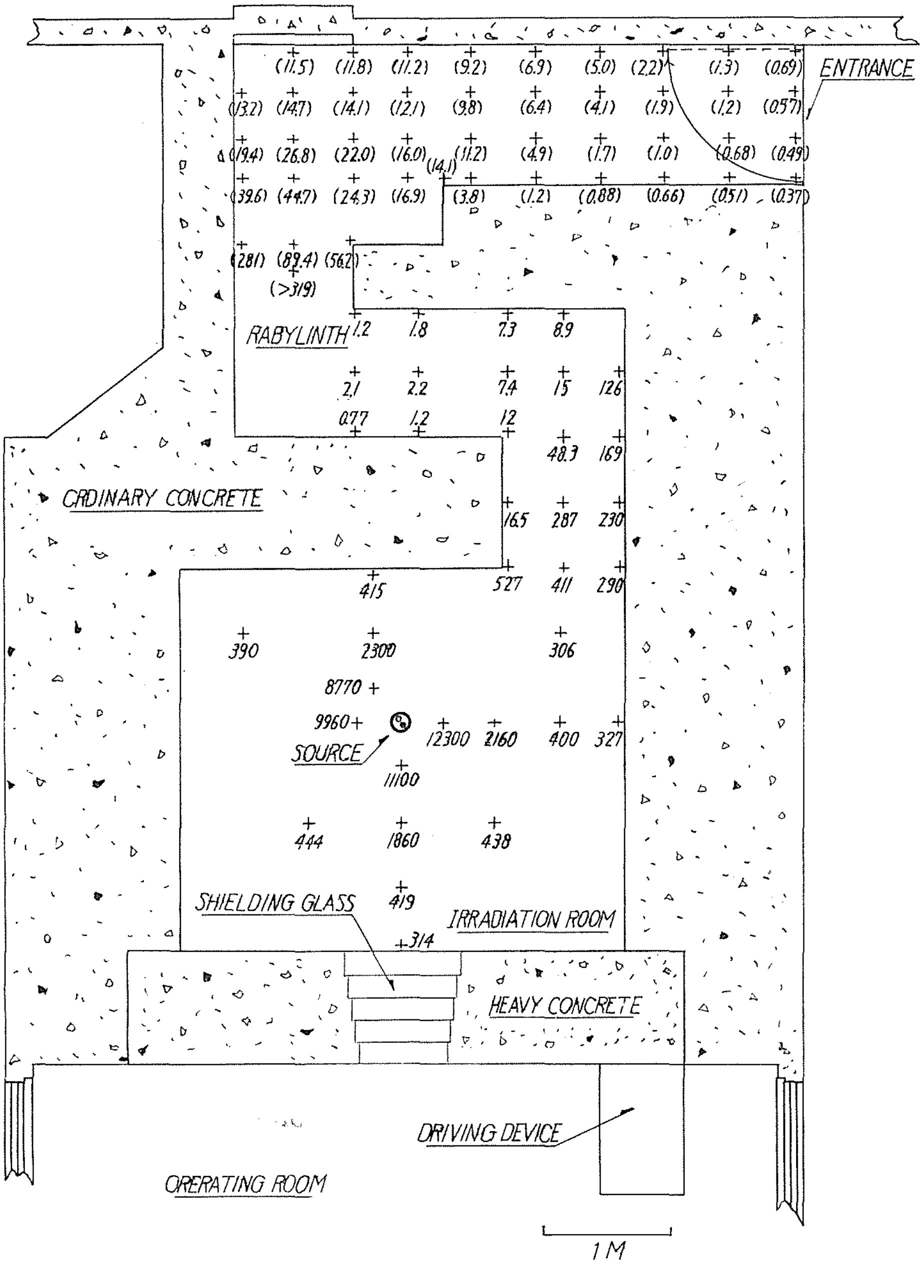

Fig. 7. Distribution of experimental does rates in the irradiation room and the labyrinth (Normalized to Febrary 15, 1961). The dose rates are given in units of r/hr, except those in parentheses in units of mr/hr.

t_2 = effective path of a photon in the sheaths.

In our case, the form of the source is axially symmetric, so the dose rate is only a function of distance from the axis. We calculated the dose rate on only three planes perpendicular to the central axis of the source pencil (l_2= 0.0, 2.4, 4.8 cm) and at 36 points with different distances from the central axis of source on each plane. The calculation was carried out by the electronic computer NEAC 2203 in our Laboratory. The results of our calculation are presented in Table 1 and graphically in Fig. 6.

As the dimension of this source is only about 10 cm high, the measured values of dose rates outside the source cage, shown in Fig. 6, were averaged ones over the level l_2. And, as the source and dosimeters were both arranged on the floor, the dose rates obtained experimentally would be overestimated due to the gamma radiation back-scattered from the floor. The discrepancy between experiment and theoretical values was found to be less than about 10 per cent.

DISTRIBUTION OF DOSE RATES IN THE IRRADIATION ROOM AND THE LABYRINTH

The dose rates in the irradiation room and labyrinth were measured to check the calculation for shielding and to prepare for the accidental exposure of the worker. In this work a Victoreen r-meter of Radocon type (Model 575A) and a r-meter of ionization chamber type (Kobe Kogyo Model DR-3) were employed according to the order of magnitude of dose rate. For the dose rate higher than 5×10^4 r/hr a prove of No. 603 type and for the field strength less than the value a prove of No. 607 were used. For the dose rate less than 250 mr/hr a r-meter of Kobe Kogyo Model DR-3 was used.

The results obtained is given in Fig. 7. In the present measurement the position of the centre of source pencil is selected to be 70 cm above the floor. The dose rate at the entrance of the labyrinth is about 0.5 mr/hr with the door being opened. In our calculations of shielding designs, a leak of less than 2 mr/hr was desired at the entrance for the source strength of 2 kilo-Curies of Co^{60}.

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