HIGH-INTENSITY X-RAY FACILITY

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RESUMEN

La distribución espacial de la dosis del haz de rayos X producido por el acelerador Van de Graaff de electrones del Instituto de Física, UNAM, ha sido determinada mediante el dosímetro solución acuosa de cloral hidratado. Los promedios de los coeficientes másicos de absorción para diversos materiales fueron también calculados para facilitar el uso de la unidad de irradiación en diversos campos de investigación.

ABSTRACT

The spatial dose distribution of the X-ray beam produced by the electron

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Van de Graaff accelerator at the Instituto de Física, UNAM, has been determined using the chloral-hydrate aqueous-solution dosimeter. Mean mass absorption coefficients for several materials were also calculated in order to use the facility for several experiments.

INTRODUCTION

A high-intensity X-ray facility attached to an electron Van de Graaff accelerator at the Instituto de Física, UNAM, has been under development as a source of ionizing radiation in research and large-scale experiments on radiation chemistry, food preservation by irradiation, surgical-materials sterilization, industrial radiography and radiobiology. The characteristics of the X-ray beam are required for this work and hence have been determined.

Figure 1 is a schematic representation of the facility and is self-explanatory. Figure 2 shows the bottom section of the accelerator, described in detail by Limón[1], and also the main area for experiments with a total volume of about 4 m^3. Controls for the accelerator and target are outside of the high-intensity radiation area, so operation exposure to radiation is considerably less than that permitted by radiological safety.

X-rays with energies of up to 1.5 MeV are produced by bombarding a HVEC gold target[2] with electrons from the Van de Graaff accelerator. The electron beam is handled with two focusing coils, shown in Figure 1, in order to produce different beam diameters at the insulated target where the beam current is measured.

In order to measure the X-ray intensity distribution at various distances from the target, the following requirements are necessary:

1) The measuring device must be able to obtain the point-to-point spatial distribution in a large area with a minimum of absorption of the radiation energy.
2) The response of the device must be essentially independent of the energy over a wide range of energies.
3) In the case of a dosimeter, a uniform, preferably linear, change in some property as a function of dose is necessary.

4) The device should provide instantaneous readings or at least not be affected by a lapse in time between irradiation and reading.

The 0.2 M chloral-hydrate aqueous-solution dosimeter was selected as a X-ray measuring device[3] in accordance with the above considerations:

1) The solution was contained in 2 cm^3 recipients, so that absorption is negligible.

2) Radiation-induced changes in the solution are independent of the energy[4].

3) The variation of the pH of the solution is linear between 100 to 700 rads and hence is suitable for use as a dosimeter in this interval.

4) Finally, the pH variation is not affected by a time lapse provided that the solution is not exposed to light.

Several experiments were also done with activated cobalt-borosilicate glass dosimeters[5], but the energy dependence of this dosimeter is not known.

EXPERIMENTS AND RESULTS

A wooden table with interchangeable legs was used to position the recipients with the solution. The table was positioned accurately under the target so that the center of the table corresponds to the center of the target. The dosimeter solution was prepared and dose readings were done following the method described in detail by Limón[1].

Dose rates varies with distances from the target according to the relations shown in Figure 3 for several energies of the electrons. The intensity of the radiation differs from the inverse-square distance relation, due to scattering of the photons caused by the shielding walls.

The spatial X-ray dose distribution, for an electron beam 4 mm in diameter, is shown in Figures 4 and 5, for several distances along axes perpendicular to the electron beam. It can be seen that the shape of the X-ray beam is considerably different from that of the parent electron beam. This results because the X-rays are emitted in a cone whose apex is the parent electron beam. Additional

evidence is that the X-ray beam length and width distributions are approximately the same at distances from the target greater than 60cm.

The shape of the electron beam at the position of the target has been determined for several conditions of the focusing coils, removing the target and using polyvinyl chloride plates (Johnston Industrial Plastics, 3070) and intensifying screens (par-speed, Du Pont). These shapes are shown in Figure 6.

DOSIMETRY AND SUGGESTED PROCEDURE FOR EXPERIMENTS.

The suggested procedure for experiments is as follows:

i) In the case of liquids or solids, in order to obtain uniformity of dose along the sample, it is necessary that size must be selected by taking in account the spatial dose distribution shown in Figures 4 and 5, because for several positions the variation of the point-to-point dose distribution is quite large.

ii) After selection of sample size and its most suitable position relative to the target, dose rate in the sample $(D.R.)_s$ can be derermined by use of the relation

$$(D.R.)_s = \frac{\overline{(\mu/\rho)}_s}{\overline{(\mu/\rho)}_d} (D.R.)_d \qquad (1)$$

where $(D.R.)_d$ is the dose for a dosimeter exposed in the same conditions as that of the sample. $\overline{(\mu/\rho)}_s$ and $\overline{(\mu/\rho)}_d$ are the mean mass energy absorption coefficients for the system and dosimeter, respectively.

The energy spectrum for the X-rays is known[6,7] (see Figure 7) so that the radiation beam can be considered as the sum of monoenergetic beams that are absorbed independently by the material. The mean coefficient is a function of the energies and the number of photons in each energy range and can be calculated by combining graphically the spectrum and the variation of the mass absorption coefficient with the energy and according to the relation

$$(\mu/\rho) = \sum_i w_i \, (\mu/\rho)_i \qquad (2)$$

where w_i is the weight fraction and $(\mu/\rho)_i$ the mass absorption coefficient for the ith element in the medium.

Mean coefficients have been calculated, at different electron beam energies, for several materials including some typical dosimeters (see Table 1).

It is recommended that for liquids the typical Fricke solution[8] be used as a secondary dosimeter.

For solids, some commercial dosimeters are available, such as cobalt-activated borosilicate glass, silver-activated phosphate glass, (Bausch and Lomb); lithium fluoride powder [9] (Harshaw, Controls for Radiation, or Madison Research).

ACKNOWLEDGMENTS

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	Mean mass absorption coefficients (cm^2/g)				
Maximum X-ray energy (MeV)	0.5	0.75	1.00	1.25	1.50
Water	0.2206	0.1557	0.1309	0.1224	0.1097
0.2 M chloral hydrate aqueous solution	0.6095	0.5070	0.3806	0.3498	0.2869
0.001 M ferrous ammonium sulfate, 0.001 M sodium chloride, 0.8N sulphuric acid (Fricke solution)	0.2259	0.1615	0.1590	0.1261	0.1126
Cobalt activated borosilicate glass dosimeter	0.2989	0.2551	0.2020	0.1875	0.1609
Polyvinyl chloride plates	0.5258	0.4431	0.3347	0.3079	0.2539

Table 1. Mean mass absorption coefficients, at different electron beam energies, for several materials, including some typical secondary dosimeters.

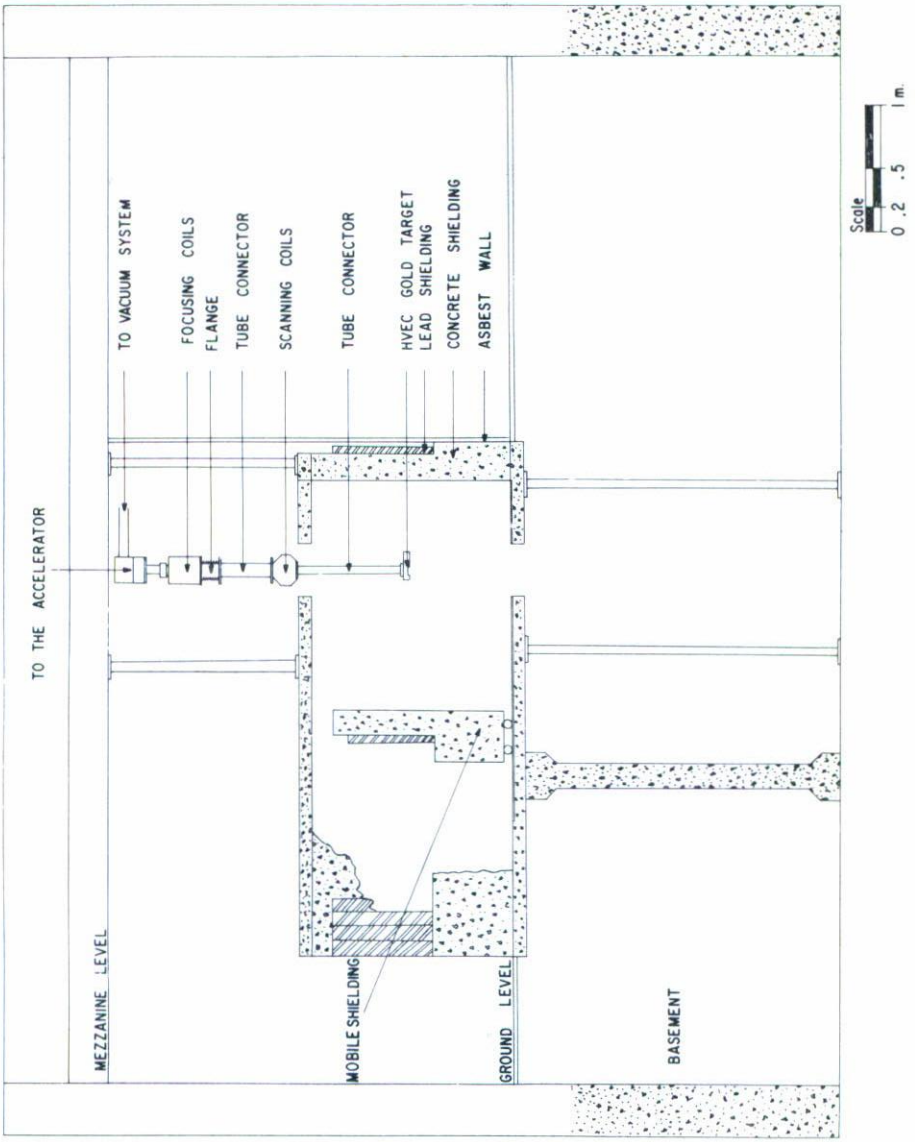

Fig. 1 A schematic representation of the facility, showing the position of the target in the shielding areas, localized at the electron Van de Graaff Accelerator, Instituto de Física, UNAM. The basement room can be used for large samples, provided that the target is mounted there by means of a connecting tube.

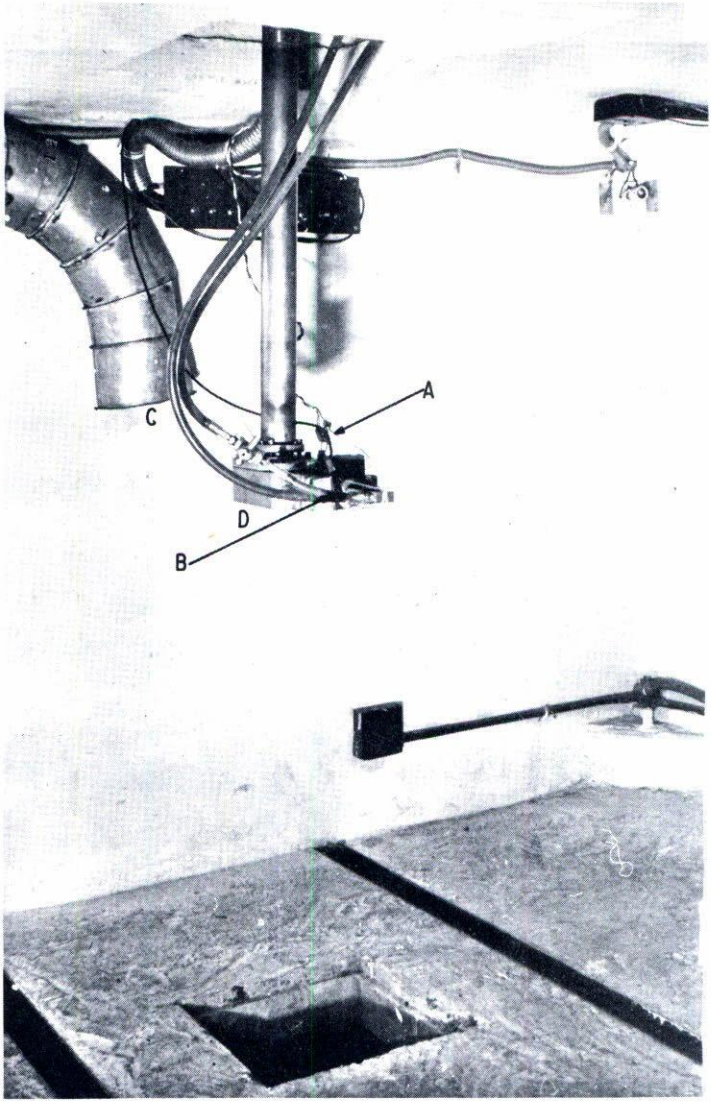

Fig. 2 The HVEC gold target array at the bottom of the accelerator, showing several details. A indicates the switch system connected to the safety interlocks in the control room outside of the high-level radiation area. B is the water cooling to prevent excessive overheating for electron beam currents of up to 250 μA. C indicates the output of the air conditioned system to minimize the presence of ozone produced by radiation. D shows the output window of radiation.

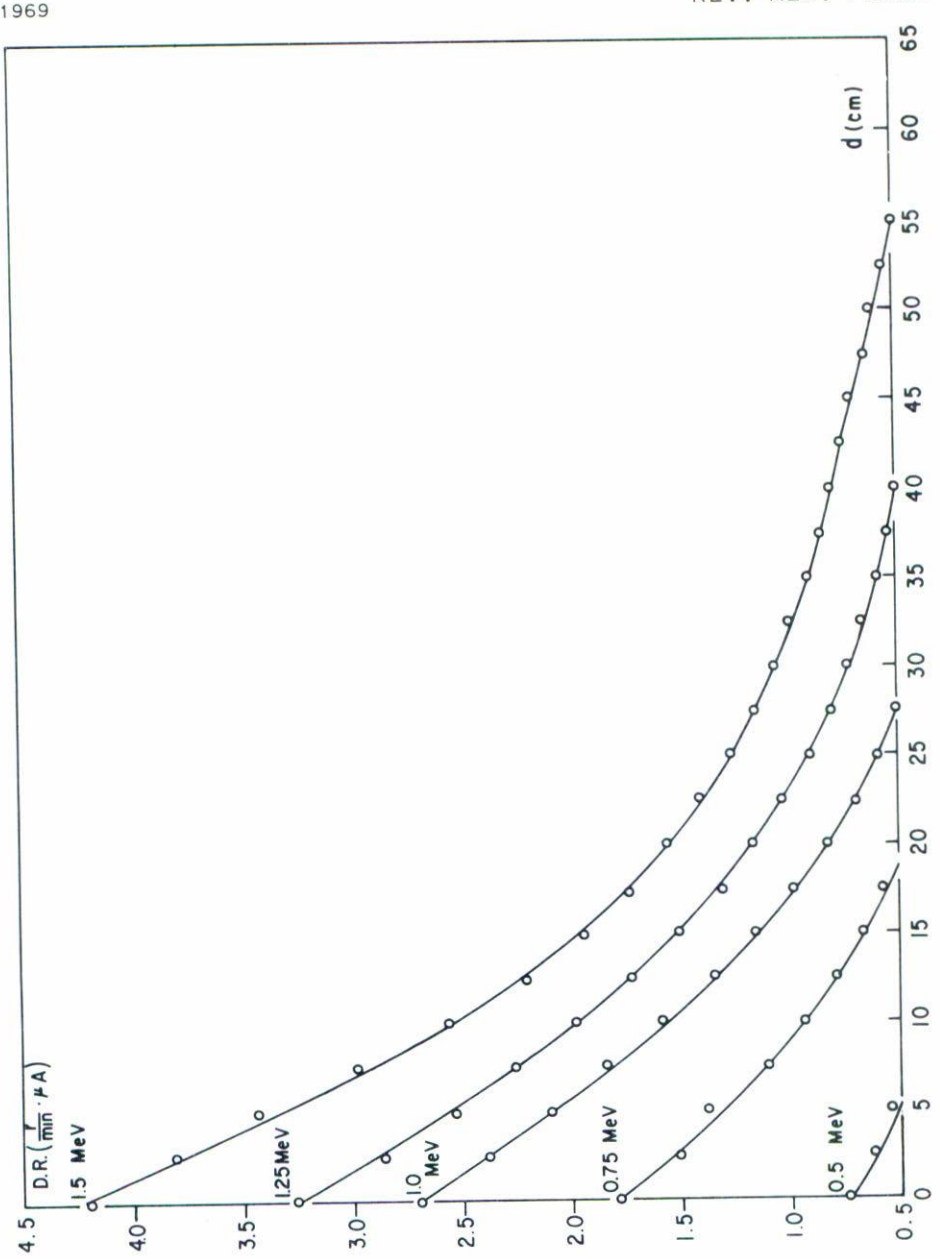

Fig. 3 Dose rate variation with distance from the target. The data are reported in terms of rads per minute per μA x MeV of the electron beam. This unit refers to an absorbed dose and is dependent on the material.

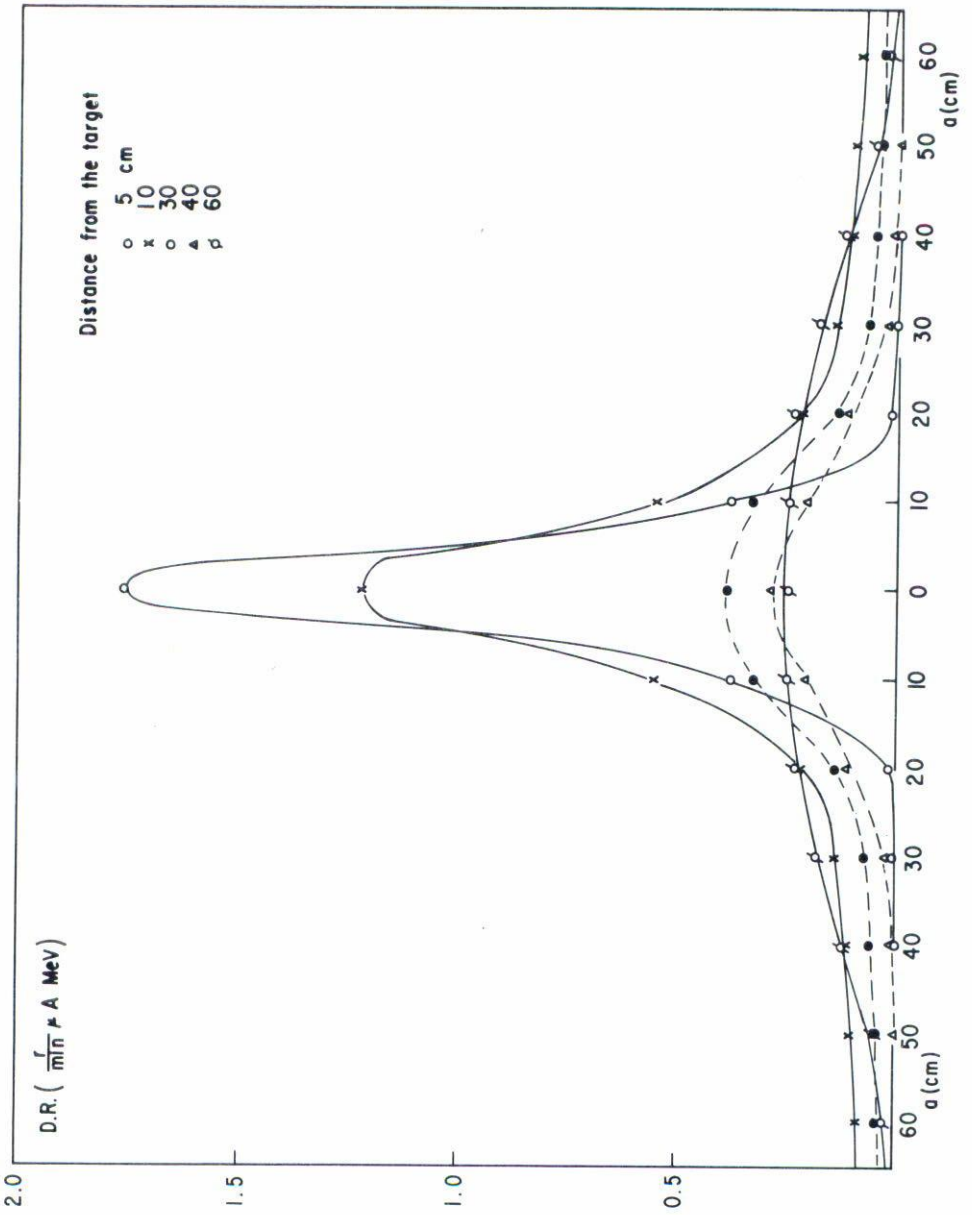

Fig. 4 Spatial X-rays dose distribution for several distances along the N-S axis perpendicular to the direction of the electron beam. The data are reported in terms of rads per minute per μA xMeV of the electron beam.

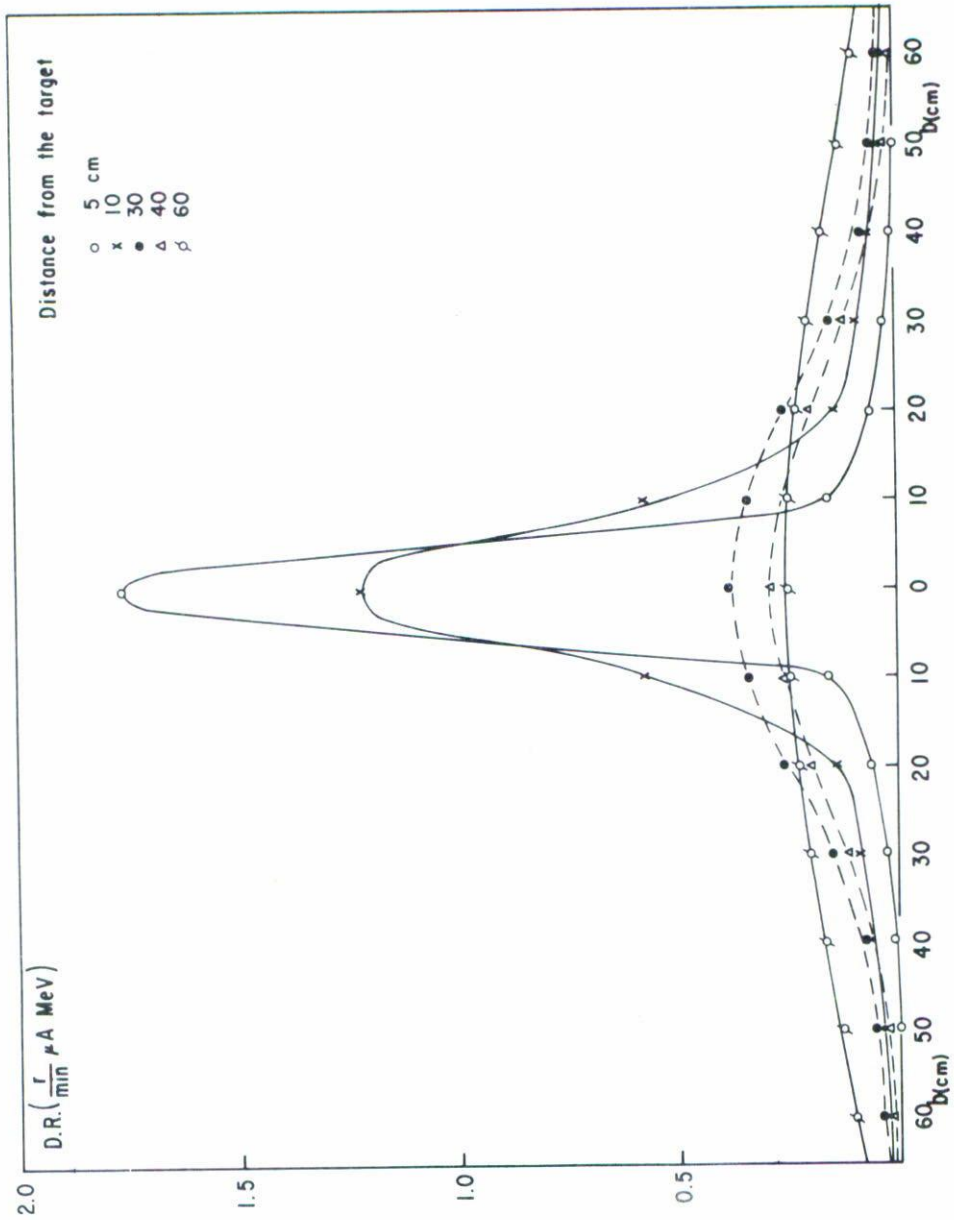

Fig. 5 Spatial X-rays dose distribution for several distances along the E-W axis perpendicular to the direction of the electron beam. The data are reported in terms of rads per minute per μA x MeV of the electron beam.

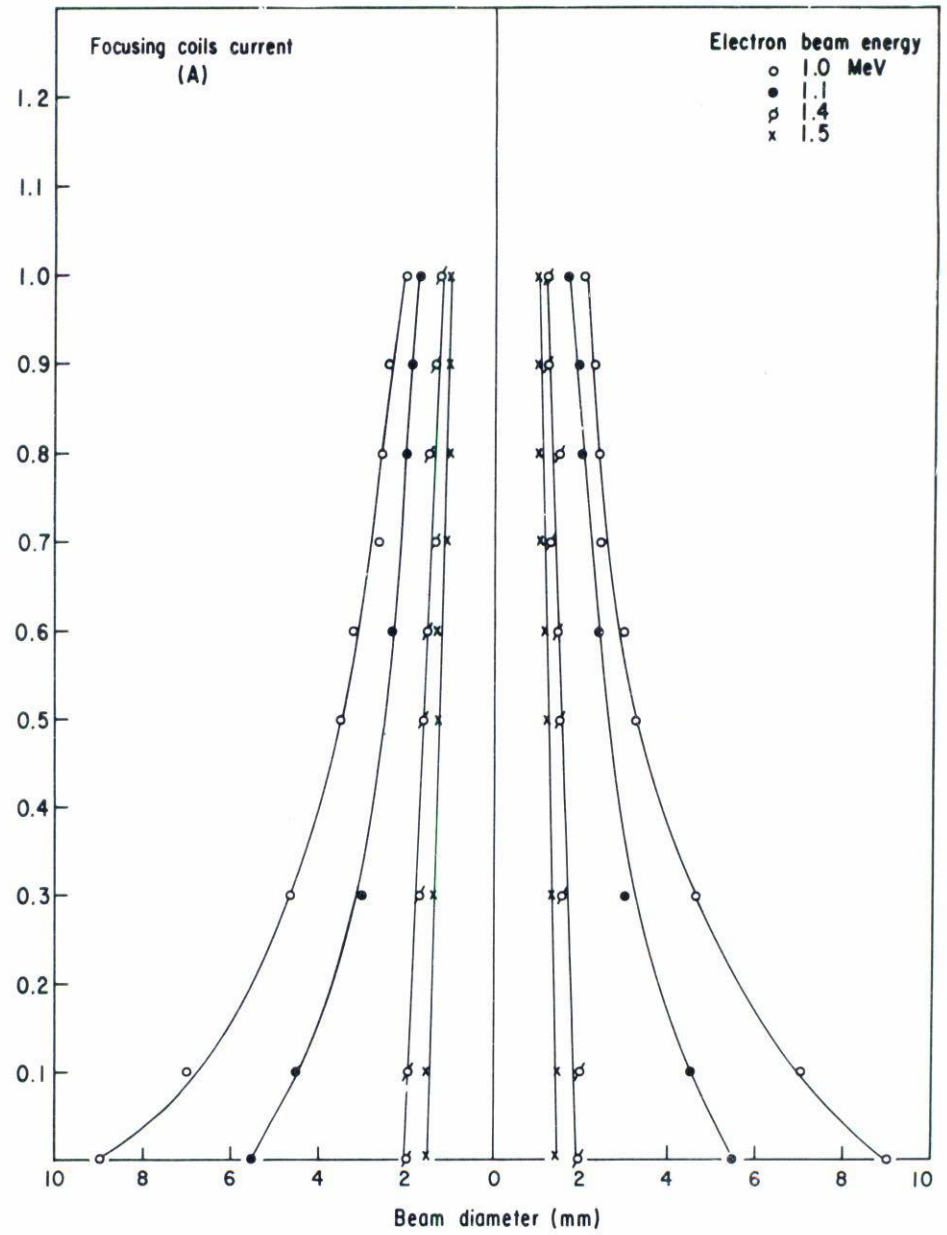

Fig. 6 Shapes of the electron beams at the target position for several currents and conditions of the focusing coils, determined by coloration of polyvinyl chloride plates and luminescence of par-speed intensifying screens.

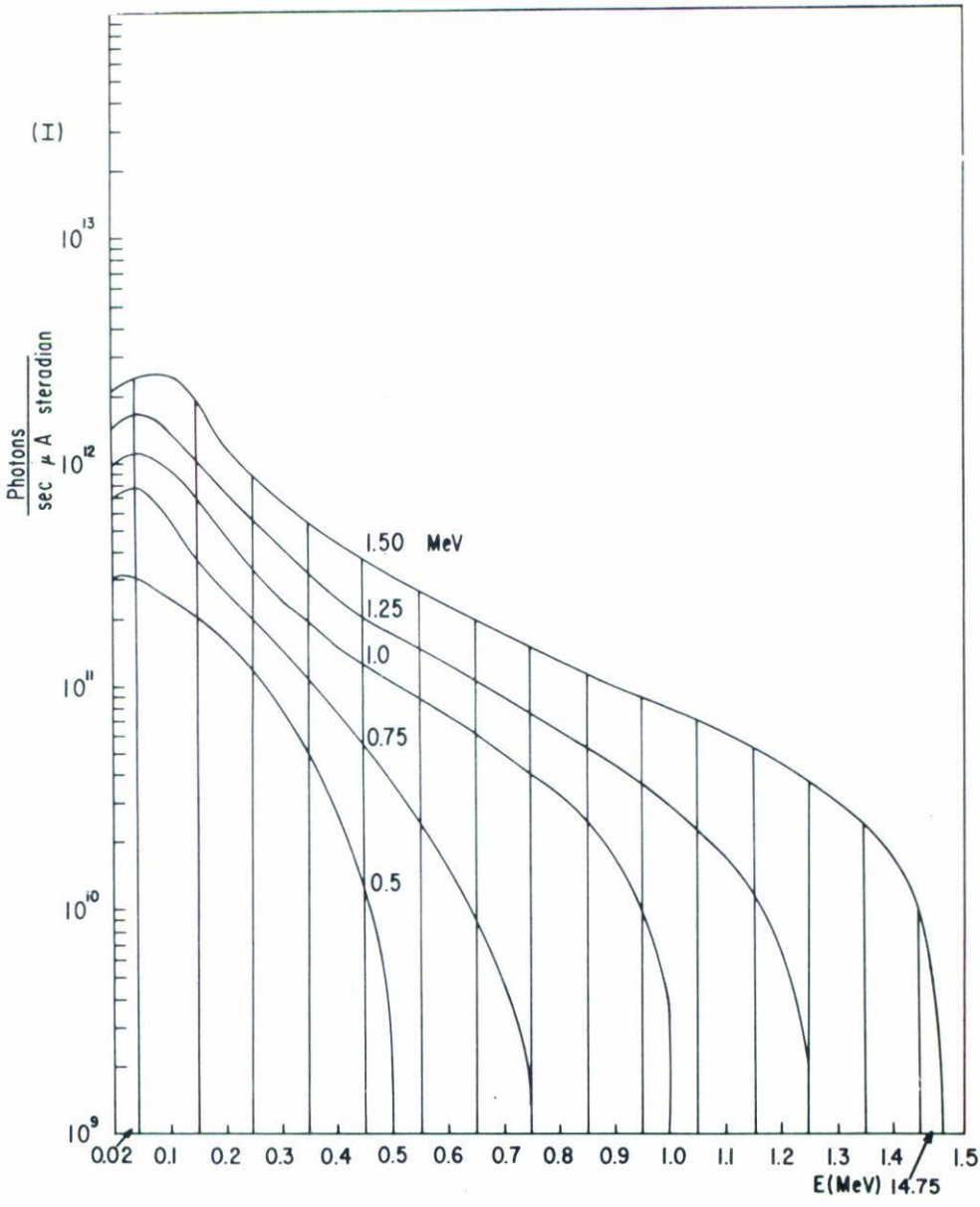

Fig. 7 Bremsstrahlung spectra of 0.5, 0.75, 1.0, 1.25 and 1.5 MeV electrons on a gold target. (I) represents the intensity of the X-rays beam in photons per sec x μA x steradian and was determined from the experimental data of Edelsack[6] and Dance[7]. The 0.1 MeV energy intervals plotted in the figure were used in the calculation of the variation of the mean coefficients with energy.