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A FILM TECHNIQUE FOR DOSIMETRY OF Am^{241}

LIVERMORE SITE

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A FILM TECHNIQUE FOR DOSIMETRY OF Am²⁴¹

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ABSTRACT

This report is a study of film response to Am^{241} radiation, using du Pont type 558 dosimeter film packets. On the basis of this response, an attempt was made to assign roentgen-values to given film densities.

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SCOPE

This report is a study of film response to Am^{241} radiation, using du Pont type 558 dosimeter film packets. On the basis of this response, an attempt was made to assign roentgen values to given film densities.

It should be noted here that the Am^{241} used as source material for this study was contained in aluminum slugs as described below. It is hoped that a workable quantity of completely unshielded Am^{241} will be available in the near future to provide data for a supplementary report on this material.

METHOD

The Chemistry Department supplied Am^{241} contained in aluminum slugs 4 inches long by 5/8 inch o.d., the walls being 1/16 inch thick. Eight slugs were supplied, four containing 500 mg and four containing 200 mg.

Irradiation of the film for each run was conducted in a relatively "scatter-free" condition as follows: The slugs and film were suspended by thin wires so that they were in the center of a 15 x 15 room, halfway between ceiling and floor. In this way, it was felt that scattering effects were minimal. The various exposures were made using this setup with appropriate critical distance and time measurements for each.

The du Pont type 558 dosimeter film packets were used throughout this experiment. This packet, containing its components (sensitive No. 508 and insensitive No. 1290 films), was exposed in the standard UCRL film

badge for absorption data. More refined absorption data were obtained through the method described below.

All the film were processed along with controls to provide a "base plus fog" background reading. They were developed in "Kodak Liquid X-ray Developer" for 5 minutes at 20°C., washed for 1 minute, fixed in "Kodak Liquid X-ray Fixer" for 10 minutes, followed by a 20-minute wash in a circulating water bath.

When dry, the film were read on a Macbeth-Ansco densitometer to provide the data used in the calculations. The method of treating density readings is described under "Calibration Procedures."

To obtain detailed absorption data, step-wedges were constructed of Al, Cu, Pb, and Lucite (see Fig. 1). These were affixed to the film packet surface with collodion, and provided a continuum of densities on the film in individual areas large enough to be read accurately on the densitometer. In this manner, the slope of an absorption curve could be established from data on a single film, insuring uniformity of exposure time and distance factors for that run.

CALIBRATION PROCEDURES

To estimate the accuracy of our energy-determination methods, film were exposed to an XMR medical x-ray unit set at 35 kvp. Calculation of the average energy of this machine and setting, using Kramers' method,¹ gave $\bar{E} = 16$ kv. An aluminum absorption curve from the film gave $\bar{E} = 18-20$ kv.

Again using Kramers' method of spectrum determination, a Norelco x-ray unit with a "150-kv head" set on 100 kvp was found to give an average energy of 49.9 kv, (see Fig. 2). This machine was then used to simulate the radiation from Am^{241} (60 kv) for purposes of these film studies (see Fig. 3).

Determination of dosage in roentgens from the Norelco was made using Landsverk chambers. The probable error of these chambers is $\pm 2\%$ down to 30 kv.

¹H. A. Kramers, "On the Theory of X-ray Absorption and of the Continuous X-ray Spectrum," Phil. Mag. 46, 836-871 (1923).

Fig. 1. Step wedges affixed to film packet, and typical film after development.

MUL-2605

Fig. 2. 100-kv spectrum from Norelco x-ray unit.

MUL - 2606

Fig. 3. 100-kv calibration curve used to assign roentgen-values to Am^{241} .

RESULTS

Figures 4 and 5 provide curves which represent the over-all response of the 508 and 1290 flm components to Am^{241} radiations.

There are a number of soft x-ray components ranging around 15 and 20 kv in the decay scheme of Am^{241} . Absorption coefficients suggest that the Al shell will reduce these soft components to a negligible percentage of the total radiation. The film response in our absorption curves shows this to be true in this experiment.

As will be seen later, the slugs can be considered in effect mono-energetic 60-kv sources. Lucite is commonly used as convenient shielding material by personnel working with these slugs. The half-value layer of Lucite for 60 kv is 1.33 inches.

To determine the energy of Am^{241} radiation from the curves, the following relationship was used:

$$\begin{aligned}
 I &= I_0 e^{-(\mu/\rho)\rho x} & \text{where } I &= \text{final intensity} \\
 \ln I &= \ln I_0 + (-\mu/\rho)\rho x & I_0 &= \text{original intensity} \\
 \ln I_0 - \ln I &= (\mu/\rho)\rho x & \mu/\rho &= \text{mass absorption coefficient} \\
 \frac{\ln I_0 - \ln I}{\rho x} &= \frac{\mu}{\rho} & \rho &= \text{density of absorber} \\
 & & x &= \text{thickness of absorber in cm.}
 \end{aligned}$$

Since the density of the film is a linear function of the exposure over a fixed range, then if we use only those densities that fall within this range, we can say:

$$\frac{\mu}{\rho} = \frac{\ln D_0 - \ln D_x}{\rho x}$$

Solving for μ/ρ , the corresponding energy can be found in various tables.²

²Gladys R. White, X-ray Attenuation Coefficients from 10 kev to 100 Mev, NBS-1003, May 1952.

Fig. 4. No. 508 film response to Am²⁴¹

MUL-2608

Fig. 5. No. 1290 film response to Am²⁴¹

Taking the data for aluminum from Fig. 6, for thicknesses 0 and 100 mils, we can calculate as follows:

$$\frac{\mu}{\rho} = \frac{0.56 - 0.39}{0.254 \times 2.7} = \frac{0.17}{0.686} = 0.248$$

$$\approx 63 \text{ kv.}$$

For copper,

$$\frac{\mu}{\rho} = \frac{0.66 - (-2.62)}{0.254 \times 8.9} = \frac{3.28}{2.26} = 1.45$$

$$\approx 63 \text{ kv.}$$

For lead, using 0 and 10 mils, we get:

$$\frac{\mu}{\rho} = \frac{0.90 - (-0.52)}{0.0254 \times 11.3} = \frac{1.42}{0.287} = 4.95$$

$$\approx 53 \text{ kv.}$$

For the Al and Cu, the determination gave 63 kv in both cases. For the Pb, the result was 53 kv. As seen from the Pb curve of Fig. 6, only 4 points fell within a usable range, providing an extremely steep and questionable slope. In view of this, it was felt justifiable to accept the 63-kv values as reflections of a monoenergetic 60-kv radiation.

With the Norelco set as previously described, film standards were run, using the aforementioned Landsverk dosimeters to obtain roentgen values. The curve in Fig. 3 represents the exposure-density correlation in this energy region.

This curve then provides a means of estimating the dose received from the Am^{241} in the slugs under consideration. A single 500-mg slug produced an average of 0.530 r/hr at 6 inches.

Film placed on the surface of one 500-mg slug gave a density equivalent to 22 r/hr under the shield. The value from the open window (14.8r) is not as accurate, since the density is in the saturation region of the film.

Slugs are handled singly or in mass in a glove box. In order to cover both cases, scattering and mass dose were determined. Using eight slugs (four 500 mg and four 200 mg) the total dose at 6 inches should be approximately 5.6 times the dose of one 500-mg slug (0.530 r). These eight slugs were placed on wood 2 inches thick and a film placed at 6 inches.

MUL-2609

Fig. 6. Absorption curves for Al, Cu, and Pb.

The result was 2.9 r/hr. The calculated value was 2.97 r/hr. Thus any backscattering that did occur was compensated for by loss in geometry of the outside slugs. These same conditions should prevail in an experiment.

DISCUSSION

Examination of the film-response curve for a fixed roentgen-value as the $\bar{E}$ is varied indicates that, while the response is changing in the region used in this experiment, the general change should not be more than 30%. This variation will give an r-value for the Am^{241} that is high. In future experiments this value can be determined more accurately since work is progressing on the determination of film vs energy response. Specifically, more monoenergetic beams can be obtained from our x-ray machines. When this work is finished we will be able to use a narrow 60-kv beam and not the broad 49.9 kv beam used here.

Inspection of the various curves in Figs. 2 and 3 shows that the total range of the film packet in terms of time is 0.1 minutes (minimum detectable) to 250,000 minutes (maximum density before saturation). At the rate of 0.530 r/hr, this represents a range of 10 mr on the open window of the sensitive film to 25,000 r on the Cd and Fe shield of the insensitive film. These are the extreme ranges and any calibration work for energy or accurate determination of r-values should be attempted in the range where density of the film will fall on the linear portion of the curve (0.75-2.25).

Handbook NBS-59³ states that "The Relative Biological Effectiveness for x-rays and gamma rays of any photon energy shall be considered to be one"

The maximum permissible total weekly doses stated in this handbook are:

1. whole body: 300 mr
2. hands : 1500 mr

³National Bureau of Standards, Permissible Dose from External Sources of Ionizing Radiation, NBS-59, September 1954.

Based on these limits, the experimental findings in this report indicate:

1. A weekly dose from hand contact with the slugs will be obtained in 4 minutes.
2. Whole body dose at one foot would be obtained in 2 hours 15 minutes.

SUMMARY

Film type du Pont packet 558 was exposed to Am²⁴¹ in an aluminum slug. Determination of the energy was 63 kv, which approaches the actual 60 kv. All the softer radiations were absorbed in the shell. The 60-kv portion of the radiation gave 0.530 r/hr at 6 inches. The surface dose was 22.8 r/hr. The dose at 1 foot was 0.132 r/hr. These values and NBS Handbook No. 59 recommendations give:

1. A weekly hand dose at contact in 4 minutes.
2. A weekly whole body dose at one foot in 2 hours 15 minutes.

/vet