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RESPONSE OF ION CHAMBERS AND DOSIMETERS TO A PULSED 7500-kVp X-RAY FIELD

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December 14, 1965

RESPONSE OF ION CHAMBERS AND DOSIMETERS TO A PULSED 7500-kVp X-RAY FIELD*

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ABSTRACT

Radiation-rate response of two types of ion chambers, and integrated dose of four types of dosimeters were measured in a variable, pulsed, 7500-kVp X-ray field produced inside the shield of an electron linear accelerator.

The indications of radiation rate as a function of beam-pulse rate and beam-current rate were measured.

Radiation doses were integrated with pocket dosimeters, film badges, and lithium fluoride thermoluminescent dosimeters while the radiation rate indication of the portable radiation-rate meters was being continuously observed.

Response errors of all devices were corrected with correction factors determined in this experiment. The correction factors are known to be valid only for the pulse rates, electron energies, and pulse durations used in this work.

INTRODUCTION

It is frequently necessary to use radiation-rate or charge-collecting instrumentation in the vicinity of pulsed sources of ionizing radiation. For those instances it is necessary to be able to correct for any difference between the indicated and true radiation rate or field. Various phenomena may occur that introduce errors in devices which depend upon electrical fields to separate charge. With use of the common film dosimeter and the lithium-fluoride thermoluminescent dosimeters, only the effective energy of the radiation need be known. The response errors have been established in this experiment for 7500-kVp X rays, measured inside the shielding enclosure of the accelerator. This experiment showed that these dosimeters can be used in the vicinity of pulsed radiation when the appropriate correction factor is established for each.

METHODS AND APPARATUS

Electron linear accelerator

The source of pulsed X rays was the Berkeley electron linear accelerator. The electrons were directed onto a tungsten-converter foil to produce the desired bremsstrahlung radiation.

The accelerator has a readily variable pulse-repetition rate ranging from 1 to 120 pulses per second. The beam current is variable up to 5.0×10^{17} electrons per pulse (80 mA/pulse) for long-term irradiations.

The energy is variable from 3 to 9 MeV. For this work 6.0- and 7.5-MeV energies were used for instrument linearity studies, but dose rates were established for 7.5-MeV studies only.

Detectors

The two ion chambers used were a Jordan Radgun (Model AGB-10KG-SR) with a range of 0.01 mR/hr to 10 000 R/hr, and a Victoreen Low Energy Survey Meter (Model 440) with a range of 0 to 300 mR/hr. The electroscopes were Bendix (model NS) with a range of 0 to 200 mR.

Two film-badge configurations were used--du Pont film package 558 in a plastic badge holder with a cadmium filter, and film package 556 in a plastic holder with open window and filters of plastic, copper, and cadmium. Variations of these filters were also tried.

The lithium fluoride (LiF) thermoluminescent dosimeter (TLD) contained 57 mg of TLD-100 powder (Harshaw Chemical Company) in polyethylene capsules. The LiF-TLD reader was designed, built, and tested at this Laboratory.[1] The system range is from 10 ± 3.5 mR to 100 000 ± 5000 R integrated dose.

Detector sensitivities and energy dependence

Various sources of information contain data regarding the sensitivity and energy dependence of the detectors used in this experiment.

The energy dependence of ion chambers and pocket dosimeters was studied in detail by McKown and Storm.[2] Curves of their measurements of the Model AGB-50B-SR and Model 440 instruments are shown in Figs. 1 and 2, respectively.[2] The AGB-50B-SR should be identical in energy dependence with the AGB-10KG-SR, as both units used chambers of identical construction. Figure 3 shows response curves of a Victoreen electroscope. Comparison among curves from other pocket dosimeters of this type indicate their energy dependence is similar.[3]

The sensitivities of film packets 556 and 558 are taken from the company's brochure.[4] Packet 556 contains film type 508 and 834, and packet

558 contains film type 508 and 1290. Response curves of the 508, 834, and 1290 film types are shown in Figs. 4, 5, and 6 respectively.

The energy-dependence curve of the TLD-100 powder, reproduced from data of Cameron et. al.,[5] is shown in Fig. 7 where the TLD-100 curve is compared to a film badge curve normalized to cobalt-60 gamma radiation.

Calibration of the detectors

The ionization chambers, films, pocket dosimeters, and LiF-TLD were calibrated at the Health Physics Department radium-calibration range. The fact that the effective energy of radium is not as low as that of the bremsstrahlung radiation spectrum measured was taken into account when the data were evaluated. The Radgun was calibrated while the ion-chamber and control unit were connected with a 25-ft chamber-extension cable. The radium calibration served as a firm reference from which correction factors could be generated with confidence.

Experimental setup

Figure 8 shows the physical layout of the control room and irradiation room at the electron linear accelerator.

The detectors were exposed to a very small current of electrons that were converted to bremsstrahlung radiation in a 0.030-in. tungsten foil. The distance from detectors to tungsten was 1 meter.

The Victoreen 440 was oriented so that the thin window pointed upwards with the aluminum cap left in place. This permitted use of first surface mirrors by which the meter face could be read with binoculars from the control room. The Jordan Radgun meter, and range controls were brought out to the control room. Other detectors were irradiated without the necessity of constant observation.

Each device was mounted on the median plane of the beam and was centered to ±2.5 mm. The electroscopes were checked for an upscale reading before irradiation. Prior to use, the LiF-TLD and film badges were stored in a low-radiation area in the control room.

The electroscopes were read immediately following irradiation. The LiF-TLD's were read out within an hour of irradiation.

DATA REDUCTION AND EVALUATION

The effective energy of the bremsstrahlung spectrum^6 was established with the filtered gamma film badge. The ratios of the densities under the plastic, copper, and cadmium filters were fitted to the calibration curves. The other film badges were then read on the basis of the established effective energy from the 7500 kVp X-rays.

The LiF-TLD dose data was compared with the corrected film-badge dose data. Data from these two dosimeters agreed well.

The dose indicated by the film badges and the dose indicated by the LiF-TLD dosimeters was compared with the indicated dose rate of the active detectors. The electroscope dosimeters were normalized to unit time and also compared.

The correction factors for the active detectors were obtained by dividing the indicated dose rate by the normalized dose rate from the passive detectors.

EXPERIMENTAL RESULTS

The results of the linearity tests of the rate-indicating ion chambers as a function of pulse-repetition rate and pulse duration are shown in Fig. 9 for the Victoreen 440 and Jordan Radgun for 6-MeV electrons (6000-kVp X rays) and a 6-μsec pulse duration.

Linearity information of the Radgun was observed across the second range scale (3 decades) for pulse rates of 7.5 to 120 pulses/second, and higher beam intensities for this purpose. The results are shown in Fig. 10.

Results for instrument response to various pulse-repetition rates with 7.5-MeV electrons (7500-kVp X rays) and 7 μsec pulse width for the Victoreen 440 and Radgun are shown in Fig. 11.

As is evident in all cases, the indicated rate linearity is within the limits specified by the manufacturer. As shown later, the indicated dose-rate average is not accurate at these pulse durations.

During intercomparison irradiations, special attention was necessarily paid to the stability of the accelerator and the steadiness of the rate output of the ion-chamber rate meters. The exposure area was limited to an area of normal angular divergence of the electron beam, with a constant bremsstrahlung energy pattern thus maintained over the detectors.

The irradiation was timed with a stopwatch and electric elapsed-time meter. Timing was accurate to better than 0.01%. The various dose and dose-rate measurements below are given within the limits of the readout systems and calibrations, and were time-normalized for all detectors exposed to 7500-kVp X rays.

Detector	Dose Rate (R/hr)
LiF-TLD	0.15 to 0.45
Film packet 558	0.18 to 0.54
Film packet 556	0.19 to 0.59
Electroscope	0.36
Model 440	0.215
Radgun	0.165

The effective X-ray energy, established from data acquired with the filtered film, was evaluated as 400 keV. With this information the dose-rate and integrated doses of the detectors could be better defined.

Shown below are the values calculated for each detector, with the response of each corrected to the measured effective X-ray energy.

Detector	Energy-corrected dose rate (R/hr)
LiF-TLD	0.38
Film packet 558	0.45
Film packet 556	0.48
Electroscope	0.36
Model 440	0.215
Radgun	0.130

DISCUSSION

Several factors account for the wide variations in the results and are discussed below. First to consider is the vast difference in the response of each type of detector. The passive dosimeters all agree within ±15% when an effective energy is established. With electrical-field-dependent devices, both the collection potential and wall thickness must be considered. The wall thickness affects the low-energy sensitivity; the collection potential is a controlling factor of the ion recombination in the ion chamber. This is somewhat important in light of the pulse durations and the duty cycles used during the experiment. Considering the instantaneous-radiation intensity rate, the several hundred percent error becomes more acceptable. Take, as an example, a true average dose rate of 100 mR per hour, a 6-μsec pulse duration, and 7.5 pulses per second--the instantaneous intensity rate would be 0.615 R per pulse. If this rate were maintained at its peak intensity, the steady-state field would be 1.66×10^4 R/hr.

The peak intensity per pulse as a function of pulse rate, and pulse duration for average dose rates of 100 and 300 mR/hr, have been calculated and are shown in Fig. 12. Remember that the correction factors of each instrument must be applied to the peak-intensity value to obtain an accurate peak intensity for the intercomparison levels between detectors.

Note that with the use of film badges in unfiltered X-ray or bremsstrahlung spectra, the soft (low-energy) component causes blackening at a rate exceeding 10 times that of photons in the region of a few tenths MeV. For a badge containing at least two kinds of filters, this blackening can be reduced somewhat, but the associated error in the dose evaluation increases.

Measurements of this sort are complicated by energy dependence, peak-intensity rates, and varieties of variables that must be accounted for in each detector. Uncertainties of this nature cause the adoption of large error limits to attempt to account for every system's shortcomings.

CONCLUSIONS

From the data, conclusions about detector response at the two energies experimentally observed here can be drawn. A final tabulation of correction factors to be applied directly to the indicated radiation dose or rate are given in Table 1 along with the error limits.

Because no measurable pulse-rate effects on the rate meters were observed in the regions studied, we conclude that the time-constant of the meter was long enough to overcome such effects.

Film badges are not recommended as continuous dosimeters with unshielded bremsstrahlung of the peak energies used here; however, if film is used, the use of filters facilitates dose evaluation when calibration data are adequate.

We believe that measurements outside the shield would yield results similar to these taken inside the shield, with the exception of a hardening of the bremsstrahlung spectrum and the related change in the response of all detectors used.

Table 1. Correction factors for dosimetric devices exposed directly to 7500-kVp bremsstrahlung radiation.

Detector	Correction factor	Error limits (%)
1. AGB-10KG-SR	3.0	± 30
2. Model 440	1.8	± 20
3. Mod. NS electro electroscopes	1.1	± 30
4. du Pont 508	0.83	± 20
5. du Pont 834	0.83	± 20
6. du Pont 1290	0.83	± 20
7. LiF-TLD-100	1.0	± 10

ACKNOWLEDGMENTS

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FOOTNOTE AND REFERENCES

[*] This work was done under the auspices of the U. S. Atomic Energy Commission.

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2. Donald McKown and Ellery Storm, The Photon Energy Response of Several Ionization Chamber Instruments, Los Alamos Report LA-2679, TID-4500, 17th Ed (February 1962).
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4. E. I. du Pont de Nemours, Photoproducts Department Brochure A-1009-a.
5. J. R. Cameron, F. Daniels, N. Johnson, and G. Kenney, Radiation Dosimetry Utilizing Thermoluminescence of Lithium Fluoride, Science 134, 33 (1961).
6. Malcolm MacGregor, Nucleonics 17, No. 2 (1959).

FIGURE CAPTIONS

Fig. 1. Typical response curves of rate meter Model AGB-50B-SR (The Victoreen Company). Position A: o———, shield closed; □----, shield open. Position B: Δ———. Sensitivity equals instrument reading divided by standard chamber reading. Correction factor is 1 over sensitivity. In the lower right corner, arrows indicate beam direction. This figure, taken from Ref. 2, is used with permission of that author.

Fig. 2. Typical response curves of rate meter Model 440 (The Victoreen Company). Position A: o———, shield on; □----, shield off. Position B: Δ———. Sensitivity, correction factor, arrows, and source same as Fig. 1.

Fig. 3. Typical response curves of dosimeter Model 656/A (0.5 R direct-reading pocket dosimeter, The Victoreen Company). Sensitivity correction factor, and source same as Fig. 1. Dosimeter 1 (o), 2 (□), and 3 (Δ).

Fig. 4. Typical response curves of film dosimeter type 508 (du Pont). Numbers on curves refer to effective wavelengths. These curves were supplied by the manufacturer and are used with permission.

Fig. 5. Typical response curves of film dosimeter type 834 (du Pont). Numbers on curves refer to effective wavelengths. Source same as Fig. 4.

Fig. 6. Typical response curves of film dosimeter type 1290 (du Pont). Numbers on curves refer to effective wavelengths. Source same as Fig. 4.

Fig. 7. Energy dependence of LiF and film-badge dosimeters relative to ^{60}Co. Data supplied by and used with permission of J. R. Cameron, University of Wisconsin Medical Center.

Fig. 8. Floor plan of electron linac.

Fig. 9. Meter readings [Victoreen 440 (o) and Jordan Radgun (□)] as a function of measured beam current and pulse repetition rate. Six-μsec pulse duration, 6000 kVp X rays. Numbers on curves are pulses per second.

Fig. 10. Jordan Radgun dose indication as a function of pulse rate with a constant beam current per pulse, for 6000 kVp X rays.

Fig. 11. See Fig. 9 caption. Seven-μsec pulse duration, 7.5-MeV electrons.

Fig. 12. Calculated average dose rate as a function of pulse rate, peak dose rate per pulse, and pulse duration. Pulse duration: Curves A and C, 6 μsec; Curves B and D, 7 μsec.

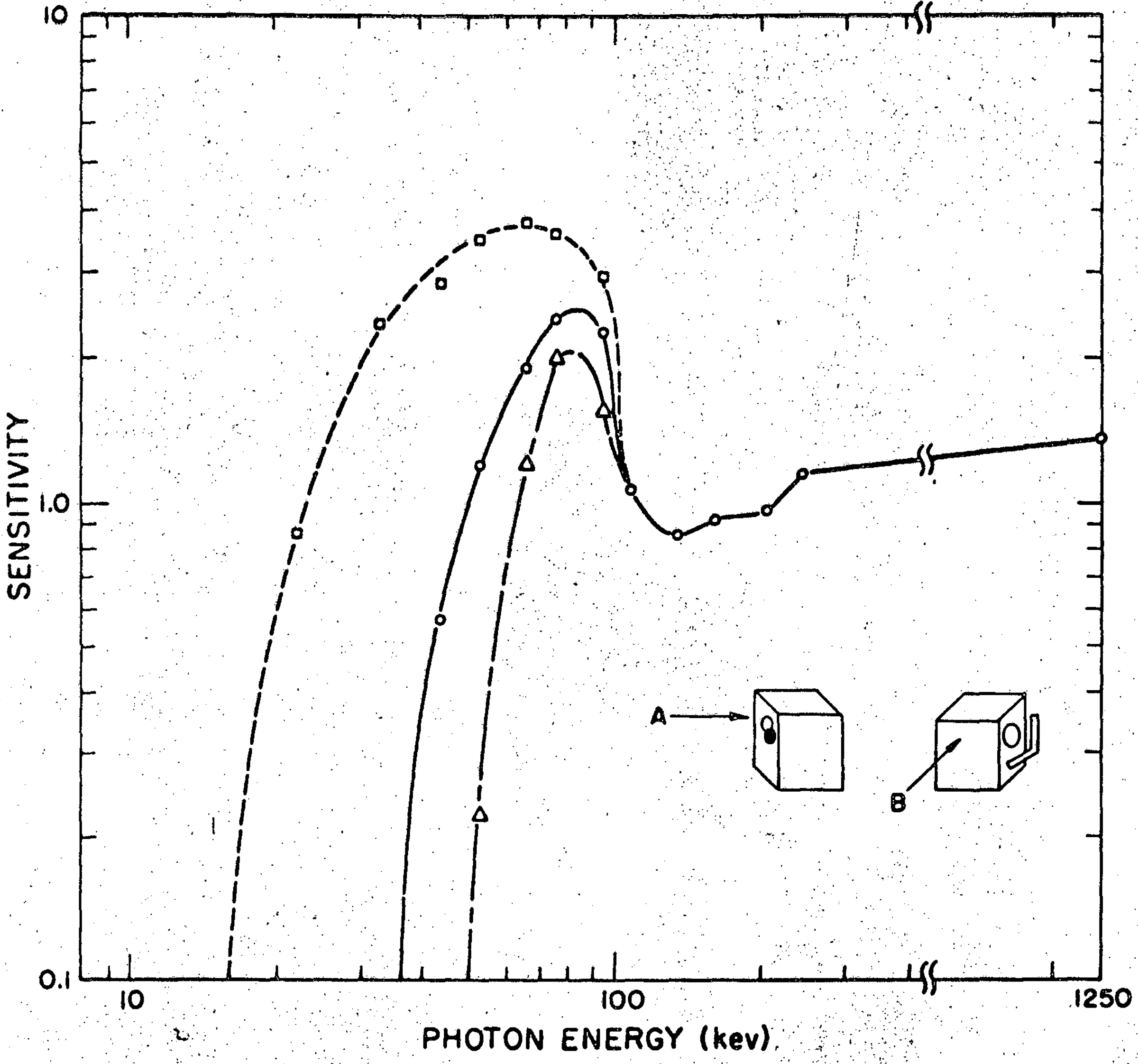

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Fig. 1

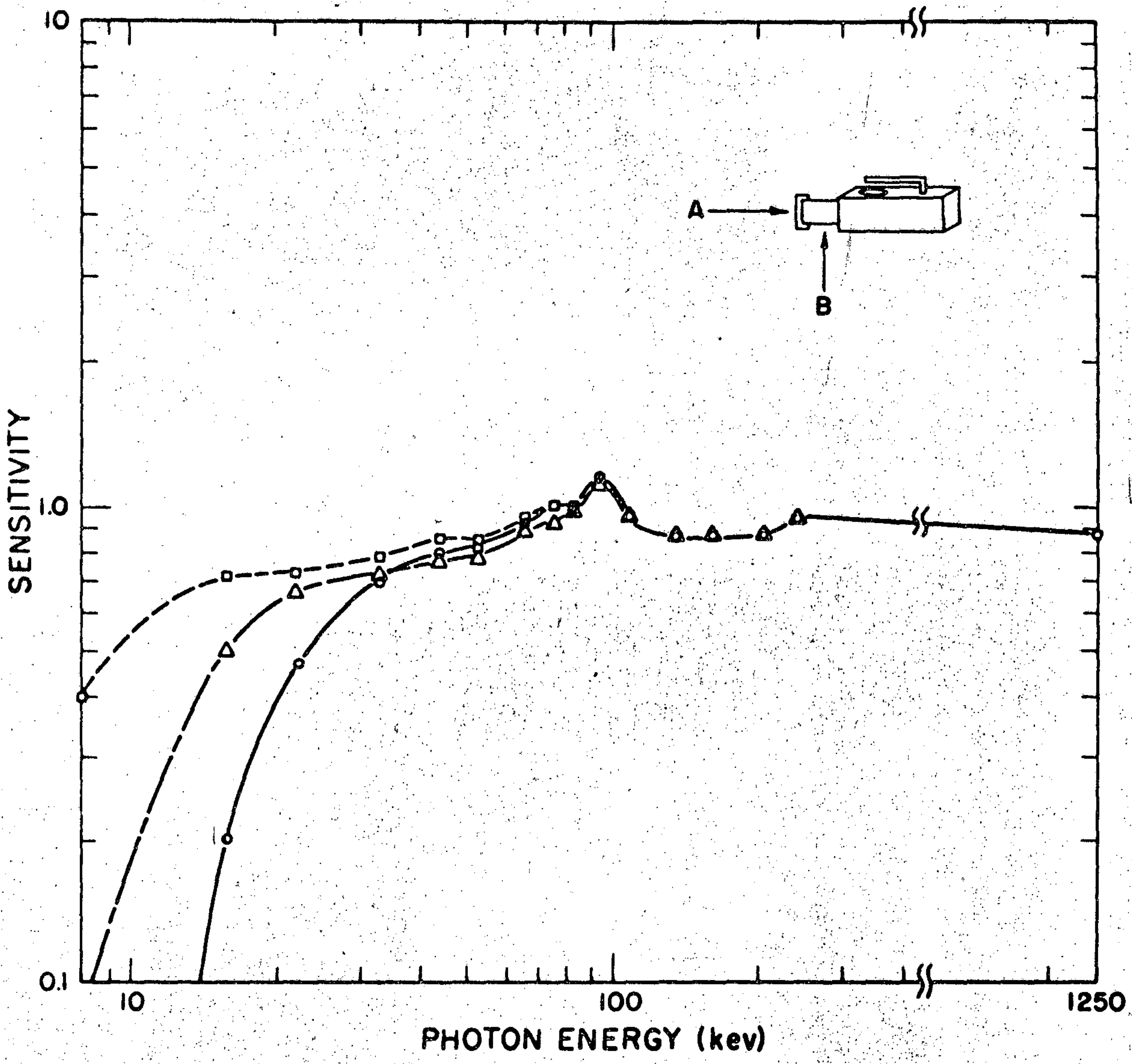

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Fig. 2

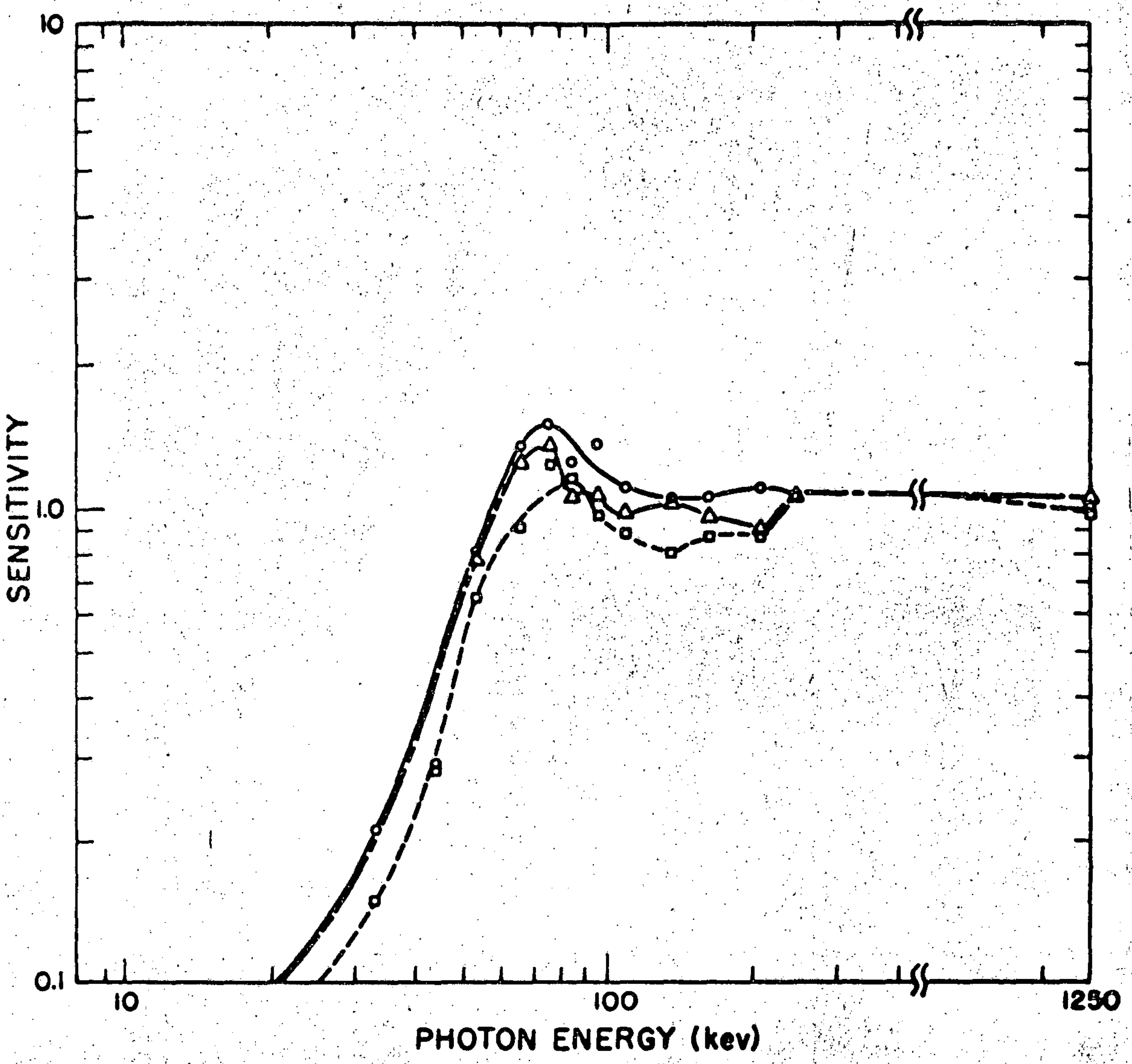

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Fig. 3

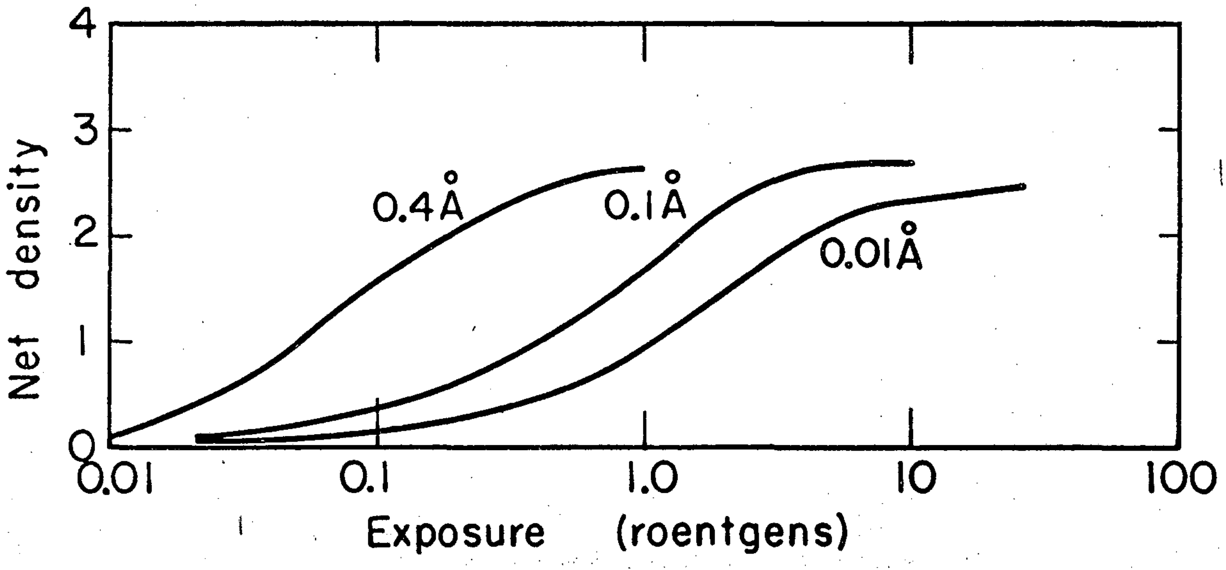

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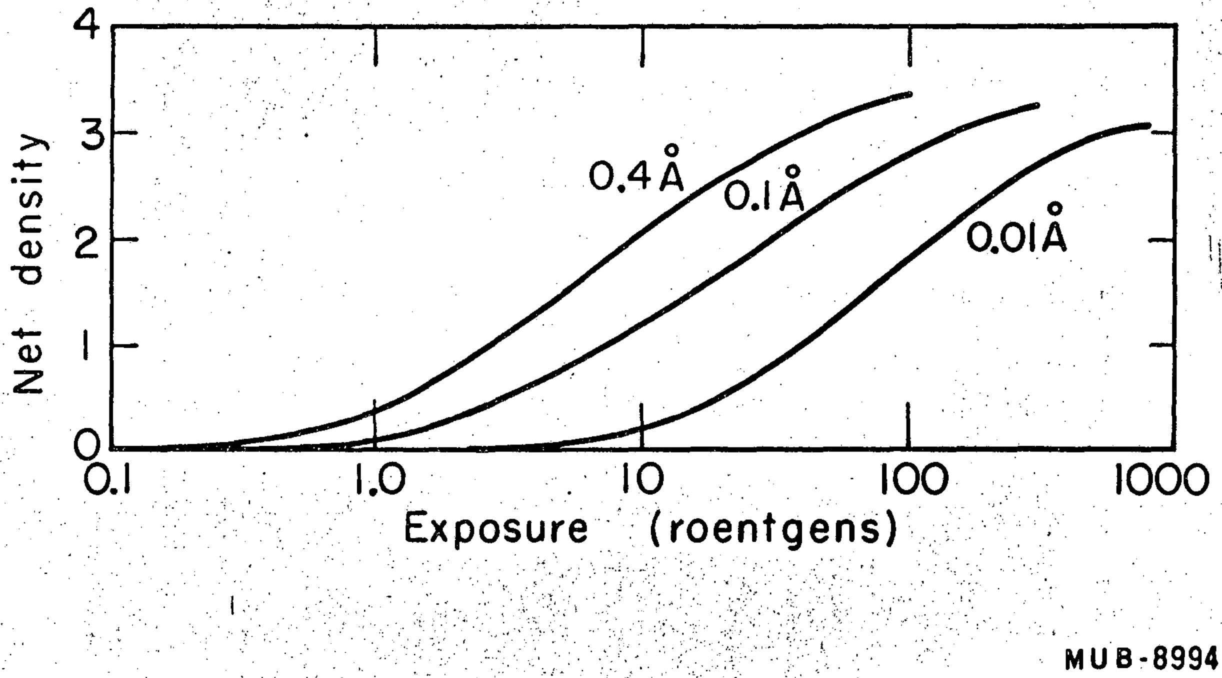
Fig. 4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3
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10
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0.01 Å
MUB-8994

Fig. 5

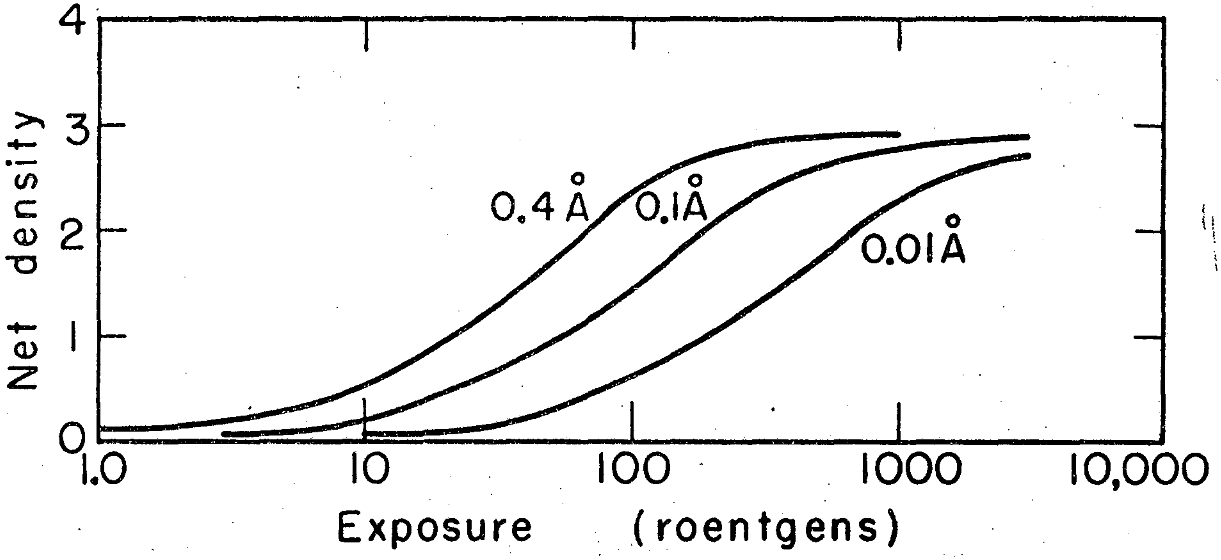

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Fig. 6

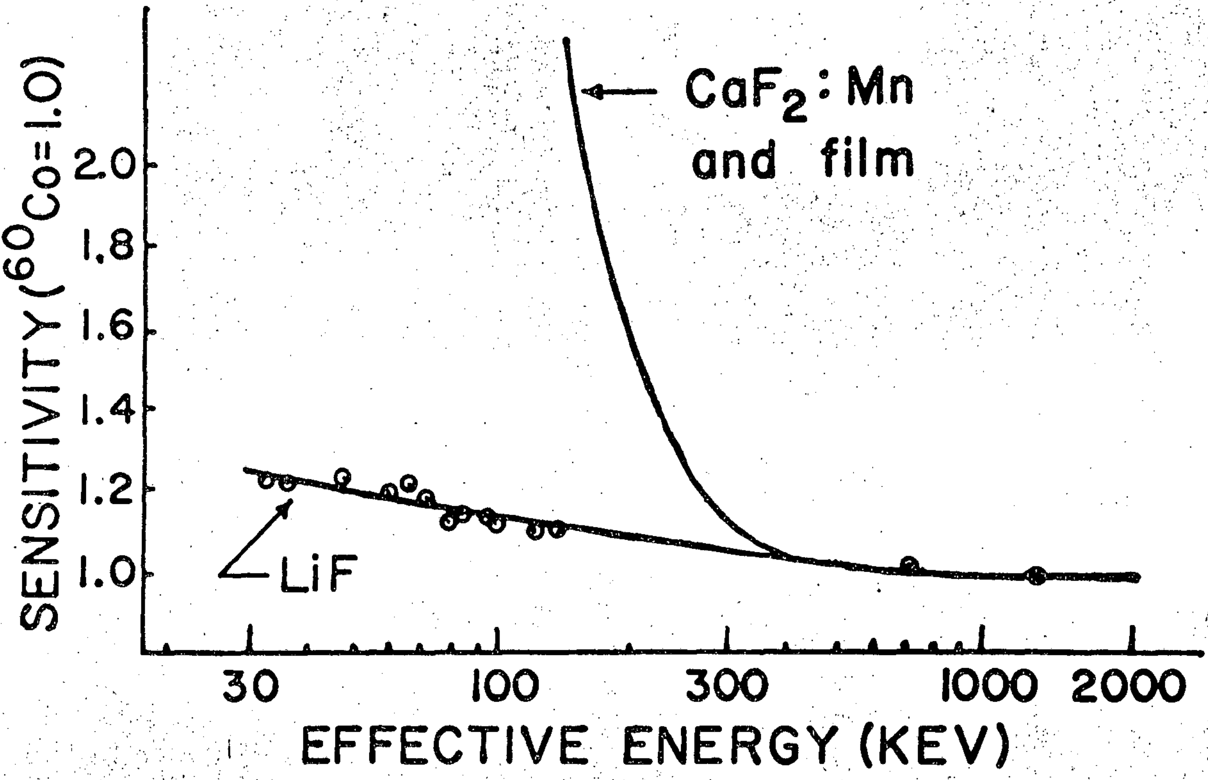

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Fig. 7

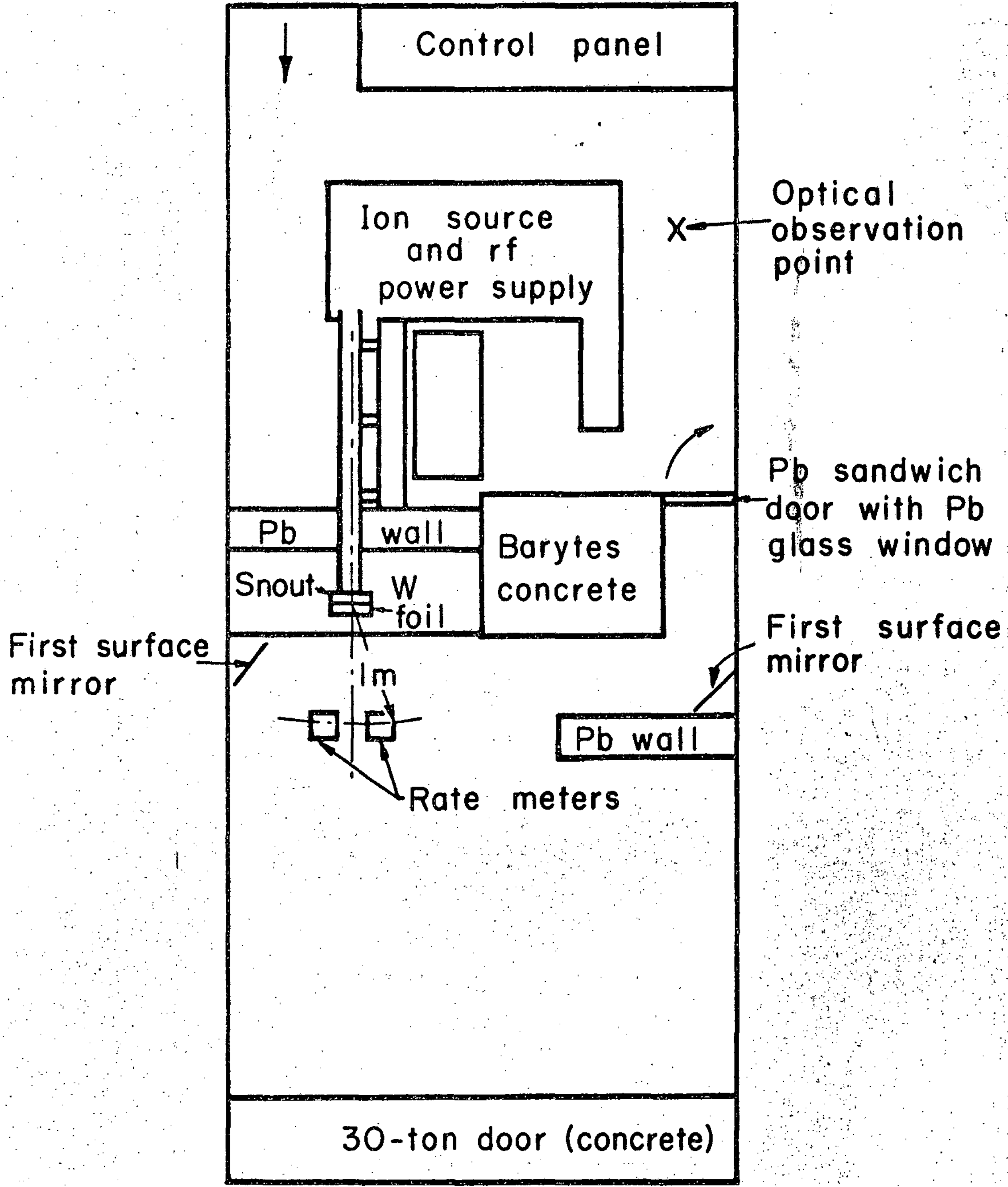

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Fig. 8

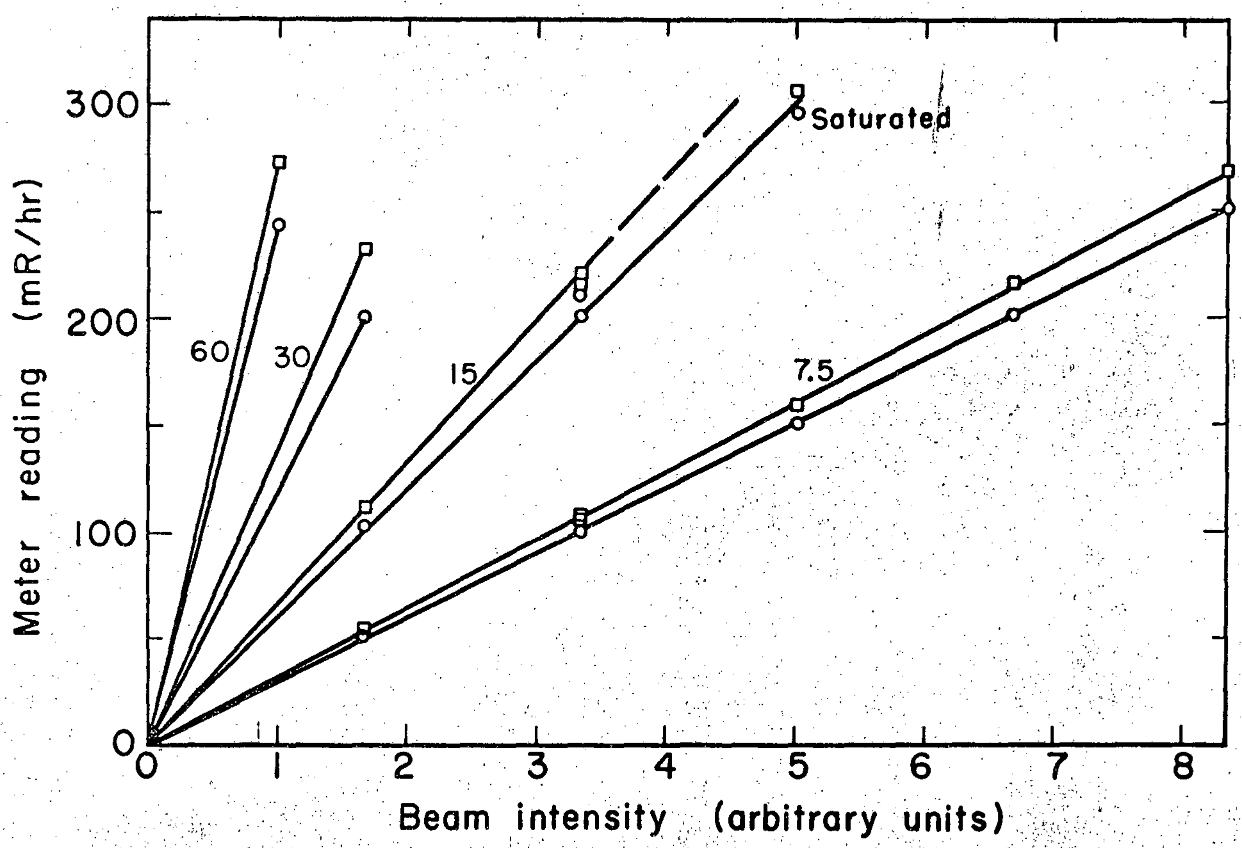

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Fig. 9

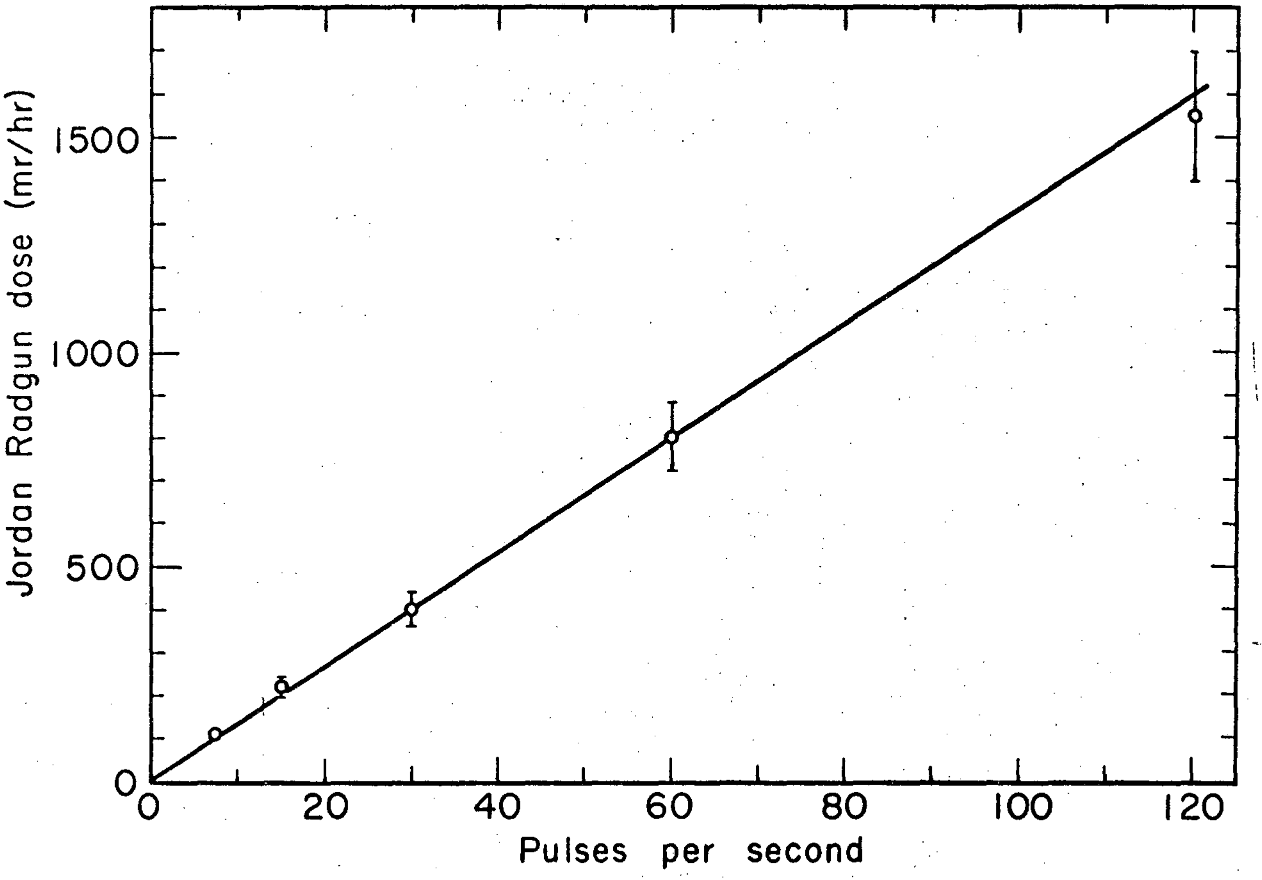

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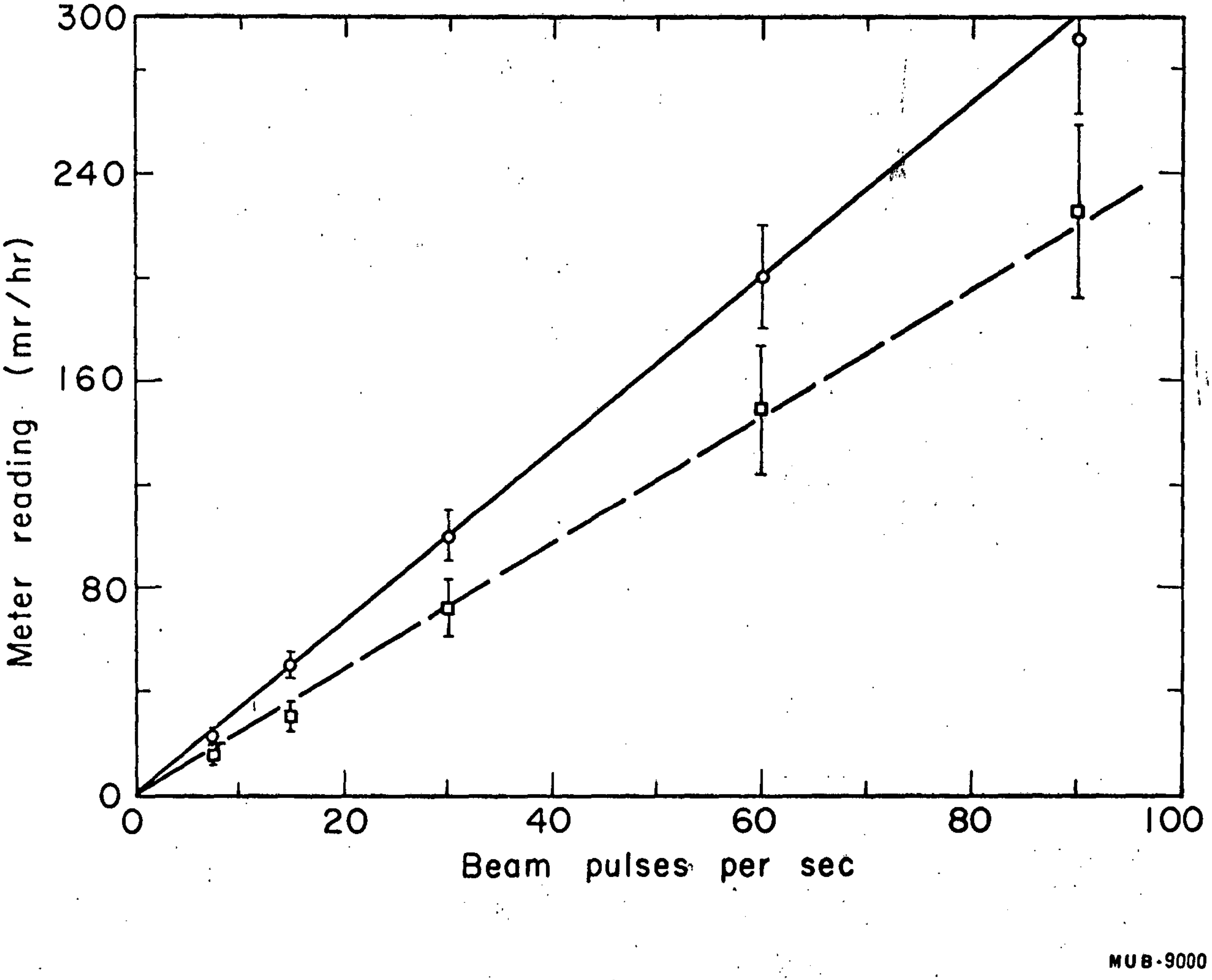
Fig. 10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Meter reading (mr/hr)
Beam pulses per sec
MUB-9000

Fig. 11

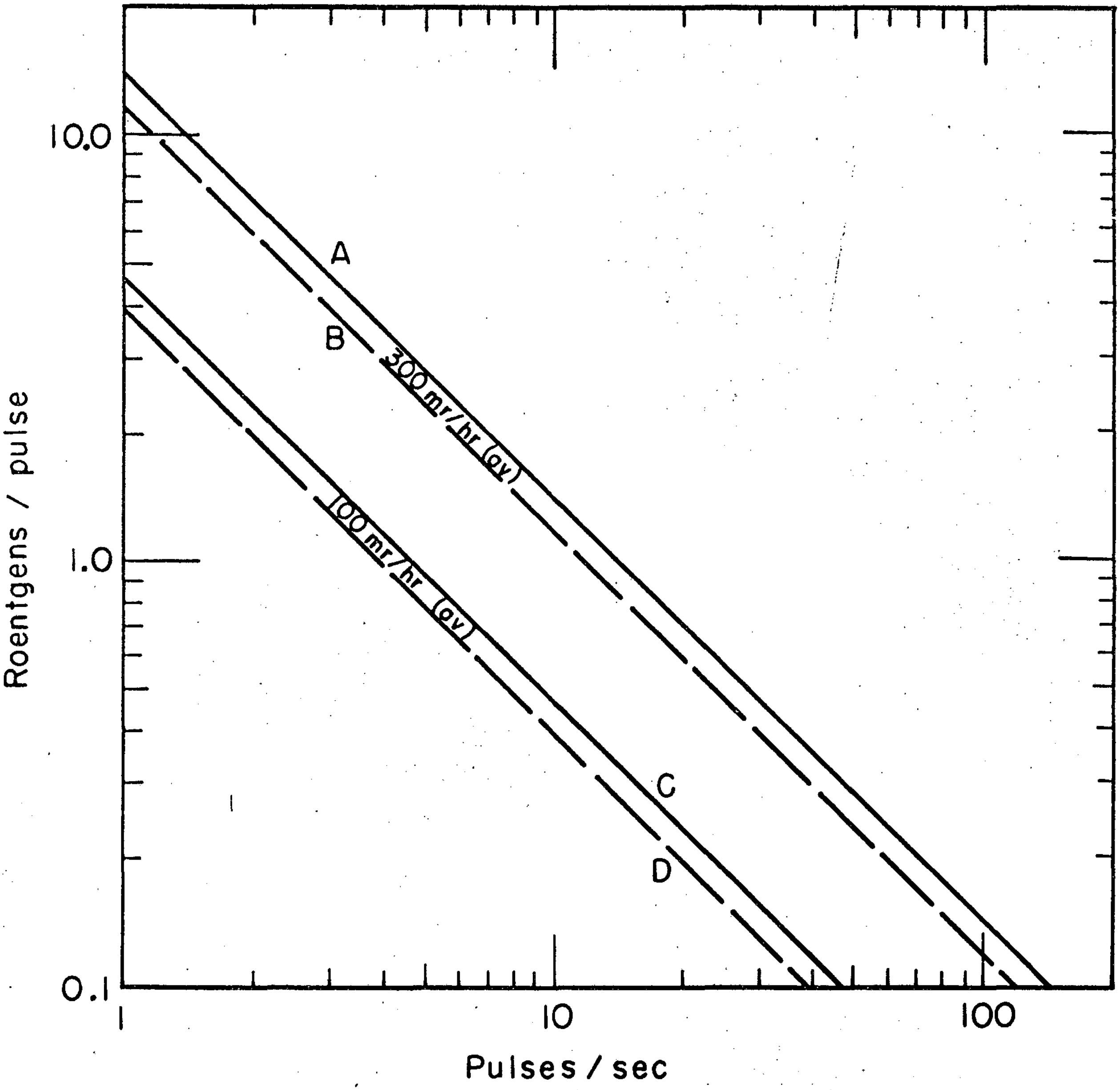

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Fig. 12

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