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The Photon Energy Response of Several Commercial Ionization Chambers, Geiger Counters, Scintillators, and Thermoluminescent Detectors

UNITED STATES
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LOS ALAMOS SCIENTIFIC LABORATORY
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THE PHOTON ENERGY RESPONSE OF SEVERAL COMMERCIAL IONIZATION CHAMBERS, GEIGER COUNTERS, AND THERMOLUMINESCENT DETECTORS

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ABSTRACT

The photon energy response of 15 commercial ionization chambers, six Geiger counters, and two thermoluminescent dosimeters was measured from 8 to 1250 keV. Only those commercial instruments in routine or special use at Los Alamos were tested.

INTRODUCTION

The photon energy responses of 20 different models of radiation survey meters and two types of thermoluminescent detectors are presented. Only one survey meter apiece for six models and two apiece for the remaining fourteen models were measured. Similar measurements made on 10 survey instruments and two pocket dosimeters in 1962 were reported in LA-2679.[1] The instruments selected for these measurements are those in routine or special use at the Los Alamos Scientific Laboratory.

The response was measured over an energy range of 8 to 1250 keV, using sources as monochromatic as possible. Where convenient, the measurements were taken with the instruments in different orientations and with open and closed shields. The results are presented in plots of sensitivity as a function of energy in kilovolts. The sensitivity is defined as the ratio of the radiation survey meter reading to that of a standard instrument. A free-air ionization chamber and a Victoreen thimble chamber calibrated by the National Bureau of Standards were used as standards.

SOURCES

Three types of sources were used to cover the energy range. Fluorescent sources were used from 8 to about 100 keV, heavily-filtered direct x-ray beams from 100 to 240 keV, and isotope gamma rays from above 240 to 1250 keV.

A 300-kV constant potential Norelco x-ray unit was the primary source for the 8- to 250-keV region. The x-ray tube was mounted vertically and except for the exit window was completely encased in a 1-in.-thick lead shield. A lead diaphragm with a tapered conical hole in it was placed over the exit

TABLE I. FLUORESCENT SOURCES

Atomic Number	Radiator Material	Radiator Thickness[a] (g/cm^2)	Weighted Average Energy (keV)	Aluminum L-Line Filter Thickness (g/cm^2)	Scattered Radiation in Fluorescent Source (%)	Exposure Rate at 50 cm[b] (mR/min)
29	Cu	0.014	8.14	0.006	30	21
35	Br	0.032	12.09	0.055	20	25
42	Mo	0.052	17.78	0.055	3	52
47	Ag	0.074	22.59	0.103	2	56
56	Ba	0.13	32.98	0.103	4	55
64	Gd_2O_3	0.23	44.13	0.103	4	42
70	Yb_2O_3	0.35	53.80	0.441	7	23
77	Ir	0.55	66.66	0.441	12	17
82	Pb	0.72	77.00	0.441	13	17
90	Th	1.50	95.79	1.446	15	12

[a]Only the mass of the rare earth is included in the oxides.
[b]Primary x-ray source at 270 kV and 10 mA.

window to reduce the size of the x-ray beam. The tube, shielding, and supporting structure were mounted on a ball-bearing turntable so that both the fluorescent and direct beams could be directed down an instrument table.

A. Fluorescent Sources

Fluorescent x rays were produced by placing foils of different atomic number in the direct x-ray beam.

A lead-lined brass cylinder was placed against the exit window diaphragm to provide a mount for the radiator foils and to catch the primary beam and scattered radiation. The foils were put into the primary beam through a slit in the top of the cylinder. The center of the radiator was 15 cm from the x-ray target and at a 45° angle to the central ray of the primary x rays. The fluorescent beam passed through a 0.75-in.-diam exit hole in the brass cylinder. An electronically actuated shutter in front of the exit hole permitted the fluorescent beam to be shut off without shutting off the power to the x-ray tube. The fluorescent beam then passed through a second 0.75-in.-diam diaphragm over which were placed aluminum filters to absorb fluorescent L x rays and soft scattered radiation. Table I describes the radiator foils.

The spectrum purity of the fluorescent sources was determined by both absorption and spectrometer measurements. The absorption measurements were also used to determine the aluminum thickness required to remove the L x rays. The exposure rates were measured with a free-air ionization chamber. When the source-to-detector distance was measured from the diaphragm in the brass cylinder to the diaphragm in the free-air chamber, the inverse-square law held within 2% beyond a distance of 25 cm. Measurements were made with photographic film at several distances along the instrument table to determine the uniformity of the fluorescent beam. The beam was approximately circular, and the diameter of the uniform region was 4, 8, and 12 cm at 25, 50, and 100 cm, respectively, from the fluorescent sources. The beam was considered uniform when the film exposure varied by no more than 2%.

B. Heavily Filtered Direct X-Ray Sources

For the direct beam measurements, a lead diaphragm with a somewhat smaller tapered conical hole than that used for the fluorescent sources was placed over the exit window to limit the size of the beam. A rectangular steel box was mounted to the diaphragm to hold the thick filters. An electronically actuated shutter was mounted inside the diaphragm so that the beam could be shut off without shutting off the power to the x-ray tube. The x-ray voltage was varied, and large amounts of filtration were employed to obtain as narrow a spectrum band as possible. The amount of filtration, or the degree of monochromaticity achieved was limited by the practical necessity of obtaining intensities large enough to calibrate the instruments.

Table II gives the details of the direct beam sources. The effective energy was determined by absorption measurements, and the spectral peak and half-height width by spectrometer measurements. The exposure rates were measured with the free-air ionization chamber. When the source-to-detector distance was measured from the x-ray target to the chamber diaphragm, the inverse-square law held within 2% beyond 20 cm from the target. The beam uniformity was measured with photographic film. The beam was approximately circular, and the diameter of the uniform

TABLE II. DIRECT BEAM SOURCES

Exciting Potential (kV)	X-Ray Current (mA)	Primary Filter[a] (g/cm²)	Effective Energy (keV)	Spectral Peak (keV)	Spectral Width at Half-Height (keV)	Exposure Rate at 50 cm (mR/min)
130	15	4.0 Mo	108	108	30	68
170	15	8.0 Mo	135	140	36	90
200	15	9.0 Sn	162	164	39	70
250	10	15.0 Sn	205	205	46	70
290	10	21.0 Sn	242	240	60	68

[a]Filters placed between two 1/32-in.-thick aluminum sheets.

(2%) region was 2, 4, and 12 cm at 25, 50, 100, and 150 cm, respectively, from the target.

C. Radioisotope Sources

The gamma rays from three isotopes were used to obtain the higher energies. The 411-keV line in ^{198}Au, the 661-keV line in ^{137}Cs, and the 1170- and 1330-keV lines in ^{60}Co were used to calibrate the instruments. Since the two lines in ^{60}Co are nearly equal in intensity, it was taken to be a 1250-keV source. The gold was enclosed in an aluminum capsule and irradiated in the Omega West reactor a few days before the instruments were calibrated. Exposure rates were measured with a "high energy" Victoreen R-chamber which had been calibrated by the National Bureau of Standards.

METHOD OF MEASUREMENT

The health physics instruments were obtained from the instrument depot where they are issued to monitors. They had been serviced by a commercial instrument company in Santa Fe. Group P-6 had then calibrated the instruments to ^{60}Co after checking the batteries, zeroing the meters, and setting the sensitivity if required. The center of each Geiger tube and ionization chamber was determined and then marked on the outside cover of the instrument. All instruments were operational when obtained, but four had to be replaced due to malfunctions before the calibration was completed.

Because of the variety of instruments, no set formula was used to check out each meter before use. All were given at least 5 minutes warmup. Instruments with zero adjustments were zeroed. If an internal source was provided, the instrument reading was checked.

Two sets of tracks were mounted on the instrument table of the x-ray unit, one set for the fluorescent beam and the other for the direct beam. The x-ray tube was positioned so that each beam was directed above and along the center of its set of tracks. A pointer that moved along the tracks was adjusted to the beam center as a reference for lateral and vertical positioning of the instruments. The instruments were placed on an aluminum scissors-type laboratory jack between the tracks to adjust their height. We attempted to obtain near midscale meter deflections by varying the source-to-instrument distance. Instruments were placed as close as 50 cm and as far as 600 cm from the source, but care was taken to ensure that the entire portion of the sensitive chamber of each device was within the uniform portion of the beam. The instruments were measured in different orientations and with open and closed shields. The meter deflection was read from about 6 meters away with the aid of 7 x 50 Navy binoculars mounted on a tripod. A small mirror held by a ringstand clamp was also necessary in order to see the meter deflection of some of the instruments.

The isotope exposures were performed in a different manner. The source was placed in a Lucite holder mounted on a table. The instruments were placed on stands and tables at various distances from the source, depending on their sensitivity. No instrument was closer than 2 meters or further than 8 meters from the source. The meter deflection was read directly without aid of optical devices.

RESULTS

A. Radiation Survey Meters

Table III lists the radiation survey meters whose energy response was measured. Only those instruments now in use by Group H-1 were measured.

The results of the energy response measurements are given in Figs. 1 through 35,

TABLE III. DESCRIPTION OF RADIATION SURVEY METERS

Instrument Model	Manufacturer	Scale	Scale Range	Type	Chamber or Counter Dimensions	Window and Shield	Number Measured
440	The Victoreen Instrument Co.	linear	0 to 3,10,30,100, and 300 mR/h	ionization chamber	3.5 in. diam 2.5 in. long	Mylar window aluminum shield	1
440 RF	The Victoreen Instrument Co.	linear	0 to 3,10,30,100, and 300 mR/h	ionization chamber	3.5 in. diam 2.5 in. long	aluminum window	2
444	The Victoreen Instrument Co.	linear	0 to 3,10,30,100, and 300 mR/h and R/h and integrating mR	ionization chamber	3.5 in. diam 2.5 in. long	Mylar window	1
666	The Victoreen Instrument Co.	linear	0 to 3,10,30,100, and 300 mR/h 0 to 300 and 30,000 R/h	external ionization chamber probes	4 in. diam 1.5 in. long 1.5 in diam 0.5 in. long	plastic probe	1
AGB-50B-SR	The Victoreen Instrument Co.	log	0.05 to 50 mR/h 0.05 to 50 R/h	pressurized ionization chamber	1 in. diam 2.5 in. long	aluminum window steel shield	2
AGB-500B-SR	The Victoreen Instrument Co.	log	0.5 to 500 mR/h 0.05 to 500 R/h	pressurized ionization chamber	1 in. diam 2.5 in. long	aluminum window steel shield	2
2025 Radector III	The Victoreen Instrument Co.	log	0.1 to 100 mR/h 0.1 to 100 R/h 0.1 to 1000 R/h	pressurized ionization chamber	2 in. diam 3 in. long	aluminum window	2
M-100 Minirad	The Victoreen Instrument Co.	log	0.01 to 100 R/h	pressurized ionization chamber	1 x 1 x 2 in.	steel-walled case	2
SU-10	Tracerlab, Inc.	linear	0 to 5,50,500, 5000, and 50,000 mR/h	ionization chamber	5 in. long 3 in. wide 2.5 in. high	steel-walled case	2
AGB-10KG-SR	Jordon Electronics Co.	log	0.01 to 10 mR/h 0.01 to 10 R/h 0.01 to 10,000 R/h	pressurized ionization chamber	3.5 in. diam 4 in. long	aluminum window steel shield	2
414	Baird Atomic, Inc.	log	0 to 3000 mR/h	ionization chamber	3 in. diam 6 in. long	Mylar window aluminum shield	2
AEC-7A	Sylvania Electric Products, Inc.	linear	0 to ∿10 R/h	ionization chamber	3 in. diam 6 in. long	Mylar window aluminum shield	2
2588	Nuclear Chicago Corporation	linear	0 to 25,250,and 2500 mR/h	ionization chamber	3 in. diam 6 in. long	Mylar window polyethylene shield	1
CEA 1025 DGET Trop System	Thomson Co.	linear	0 to 10 mR/h 0 to 100 mR/h 0 to 1 R/h 0 to 10 R/h	ionization chamber	3 in. diam 6 in. tall	Tissue equivalent chamber, polyethylene shield	1
6112 B	TOTAL KOM.-Ges. Foerstner & Co.	log	0.1 to 2 mR/h 1 to 50 mR/h 50 to 2000 mR/h 1 to 50 R/h 10 to 1000 R/h	2 Geiger-Mueller tubes in extendable probe	0.75 in. diam 4 in. long	Chromium plated brass tube screened window	1
12	Ludlum Measurements, Inc.	linear	0 to 0.05 mR/h 0 to 0.5 mR/h 0 to 5 mR/h 0 to 50 mR/h	end window Geiger-Mueller tube	1.5 in. diam 5 in. long	plastic window	2
14	Ludlum Measurements, Inc.	linear	0 to 20 mR/h	Geiger-Mueller tube	0.75 in. diam 3 in. long	Chromium plated brass tube screened window	2
E-112B-1	Eberline Instrument Co.	linear	0 to 20 mR/h	Geiger-Mueller tube	0.75 in. diam 3 in. long	Chromium plated brass tube screened window	2
E-400	Eberline Instrument Co.	linear	0 to 200 mR/h	Geiger-Mueller tube	0.75 in. diam 3 in. long	Chromium plated brass tube screened window	2
E-500A	Eberline Instrument	linear	0 to 200 mR/h	Geiger-Mueller tube	0.75 in. diam 3 in. long	Chromium plated brass tube screened window	2

in which the sensitivity is plotted versus the energy in keV. Sensitivity is defined as the ratio of the health physics survey instrument reading to the standard (free-air or thimble) chamber readings.

When the response of each instrument to each of the sources had been measured the response was again measured using the first source employed. With four exceptions, the readings agreed with the earlier measurement within 10%. When all possible sources of error, such as stability of x-ray voltage and current, alignment of source and detector, zeroing of the instrument, and parallax in meter deflection reading are taken into account, the accuracy of any point on the curves can be considered to be no better than 30%.

Only one instrument (Victoreen Model 666 with the small probe) showed severe extracameral effects. Two or three instruments with the same model number showed large differences in their energy response.

B. Thermoluminescent Detectors

The energy response of two types of commercial thermoluminescent dosimeters in special use at LASL was also measured. The EG&G mini dosimeters consist of LiF powder hermetically sealed in cylindrical glass tubes 1.4-mm in diameter and 12-mm long. They were placed upright on foam plastic when exposed. Ten dosimeters were exposed for each energy up to 100 keV, and five at each energy above 100 keV. The photon energy response of the EG&G dosimeter is given in Fig. 36. At each energy the maximum, minimum, and average readings are shown.

The Controls for Radiation, Inc., TLD dosimeters consist of a mixture of LiF phosphor and Teflon in the form of a disc 0.02-in. thick and 0.5-in. in diameter. Three to four of these dosimeters were exposed at each energy while placed upright on foam plastic. The dosimeters were exposed both in air and in plastic finger rings. The photon energy responses of the ConRad dosimeters exposed in air and in rings are given in Figs. 37 and 38, respectively. The reading of each dosimeter is plotted at each energy.

ACKNOWLEDGMENTS

The authors thank Allen M. Valentine for preparing and reading the thermoluminescent dosimeters and Dean D. Meyer for requesting the measurements and suggesting which instruments to measure.

REFERENCE

1. D. A. McKown and E. Storm, "The Photon Energy Response of Several Ionization Chamber Instruments," Los Alamos Scientific Laboratory report LA-2679, 1962.

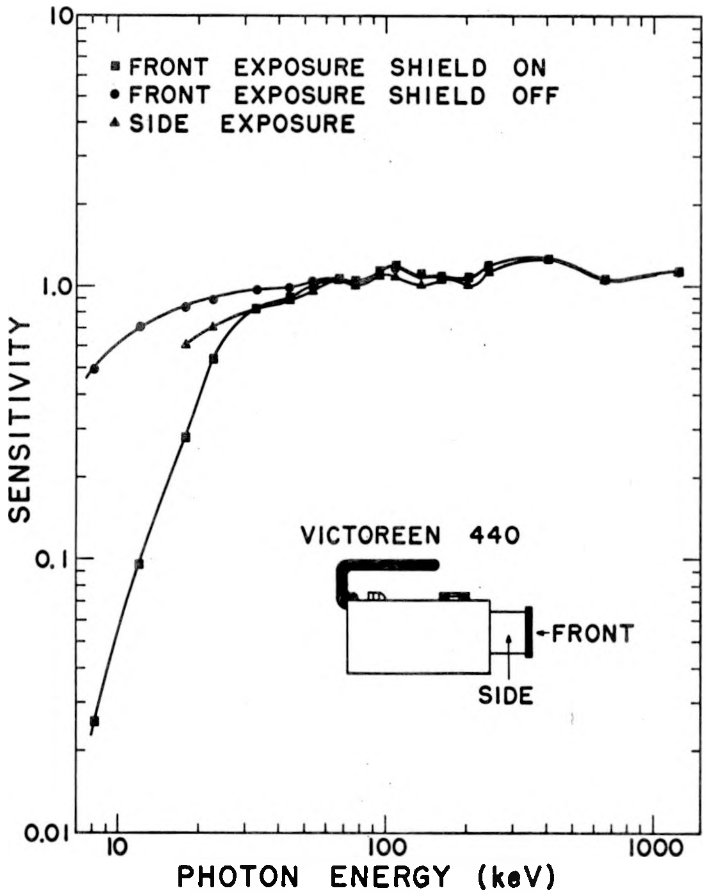

Fig. 1. Victoreen Instrument Company survey meter Model 440 Serial No. 521.

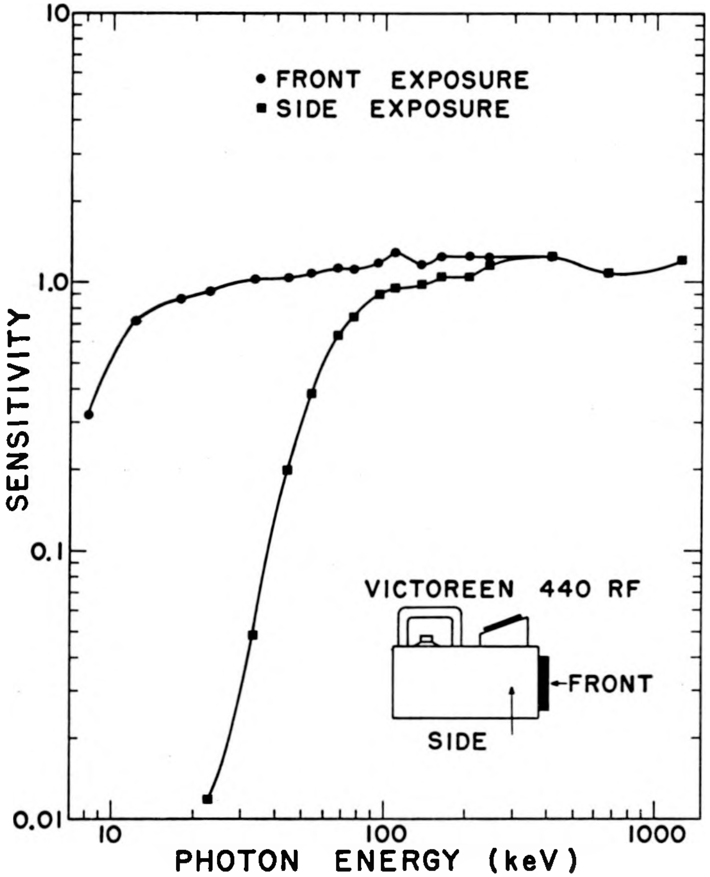

Fig. 2. Victoreen Instrument Company survey meter Model 440 RF Serial No. 214.

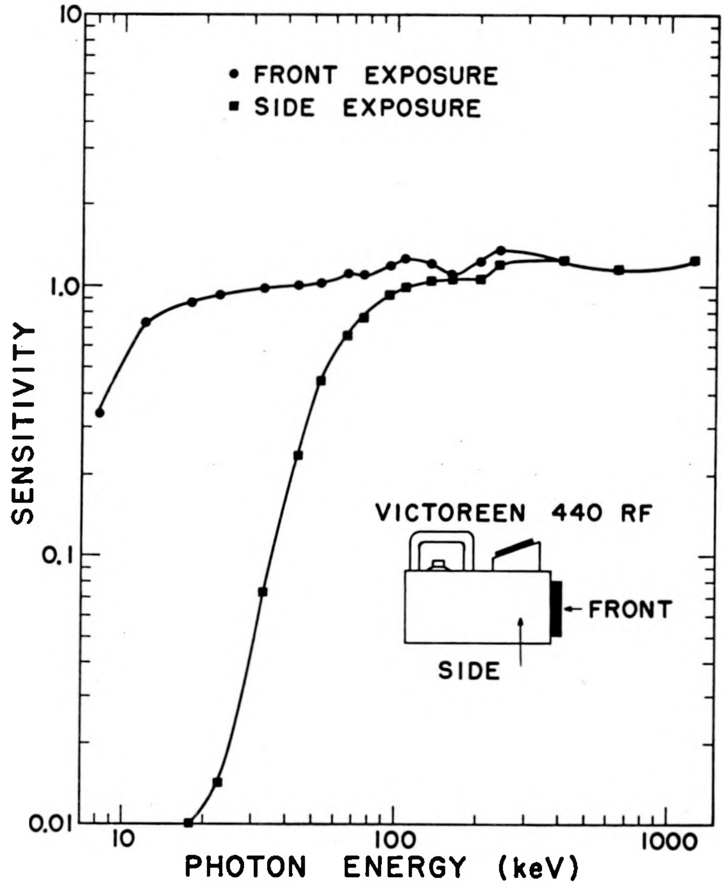

Fig. 3. Victoreen Instrument Company survey meter Model 440 RF Serial No. 213.

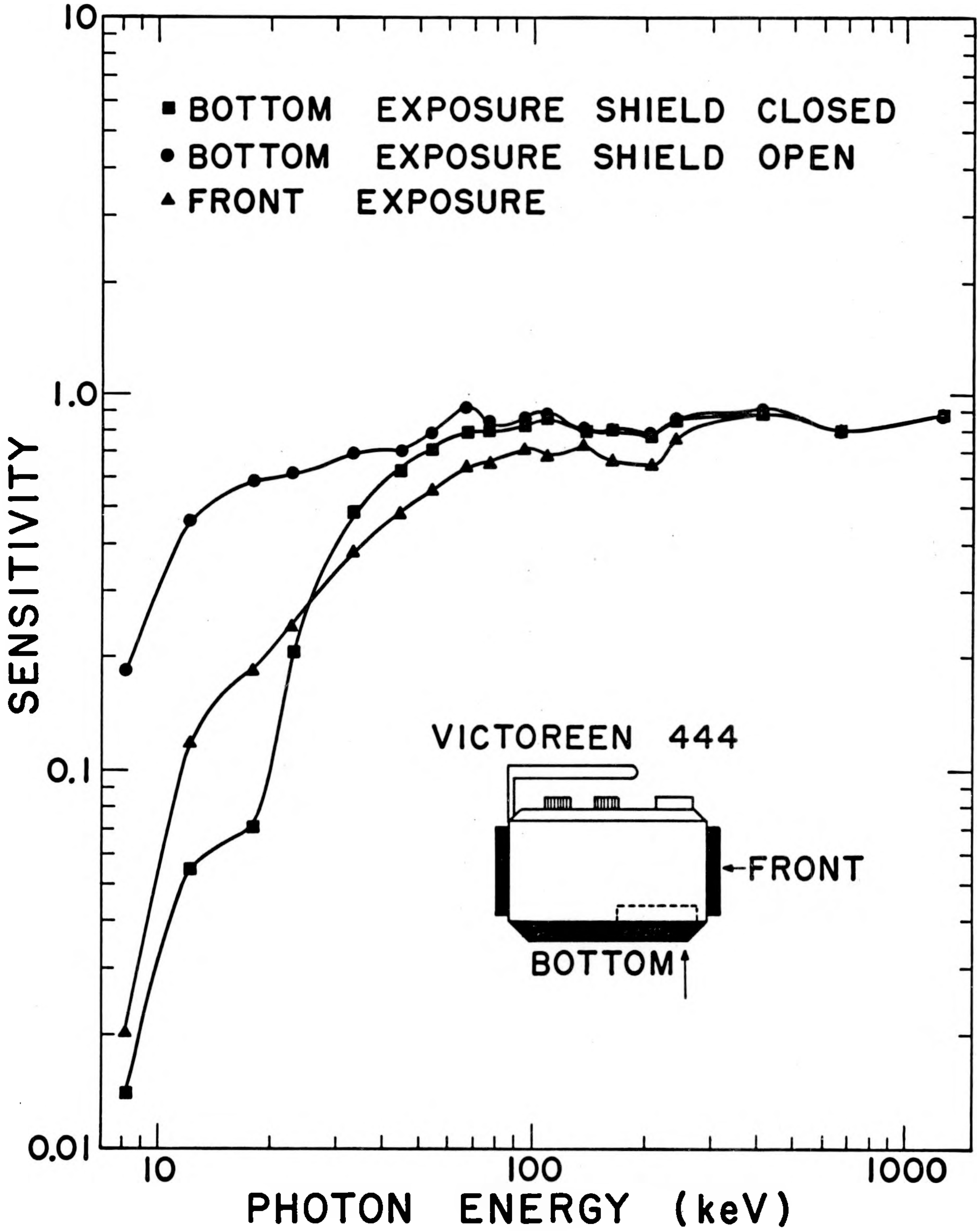

Fig. 4. Victoreen Instrument Company survey meter Model 444 Serial No. 130.

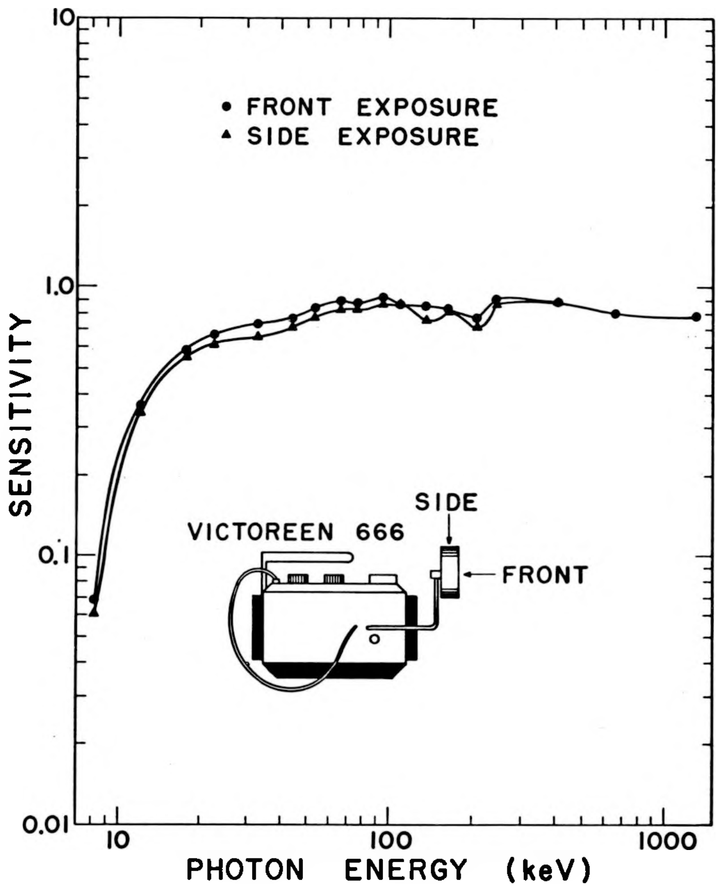

Fig. 5. Victoreen Instrument Company survey meter Model 666 Serial No. 113, 4-in. probe.

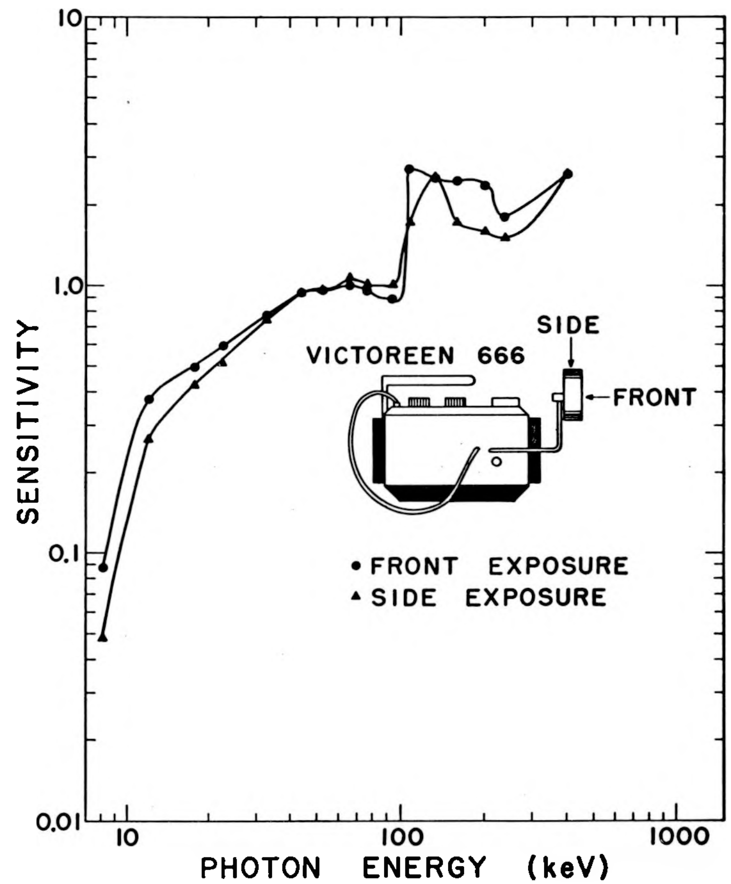

Fig. 6. Victoreen Instrument Company survey meter Model 666 Serial No. 113, 1-1/4-in. probe.

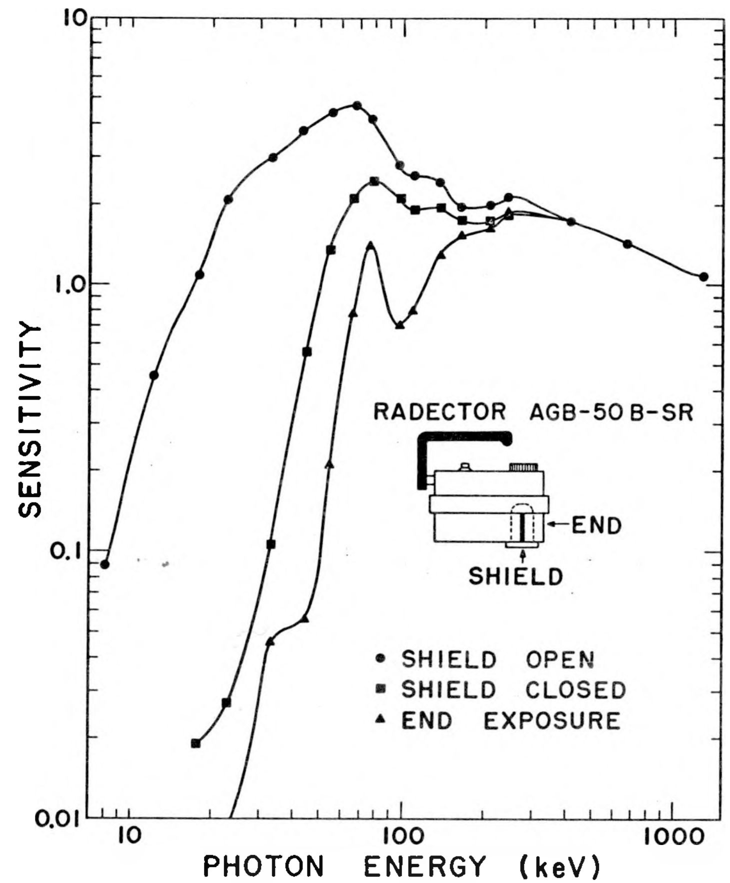

Fig. 7. Victoreen Instrument Company Radector Model AGB-50B-SR Serial No. 2437.

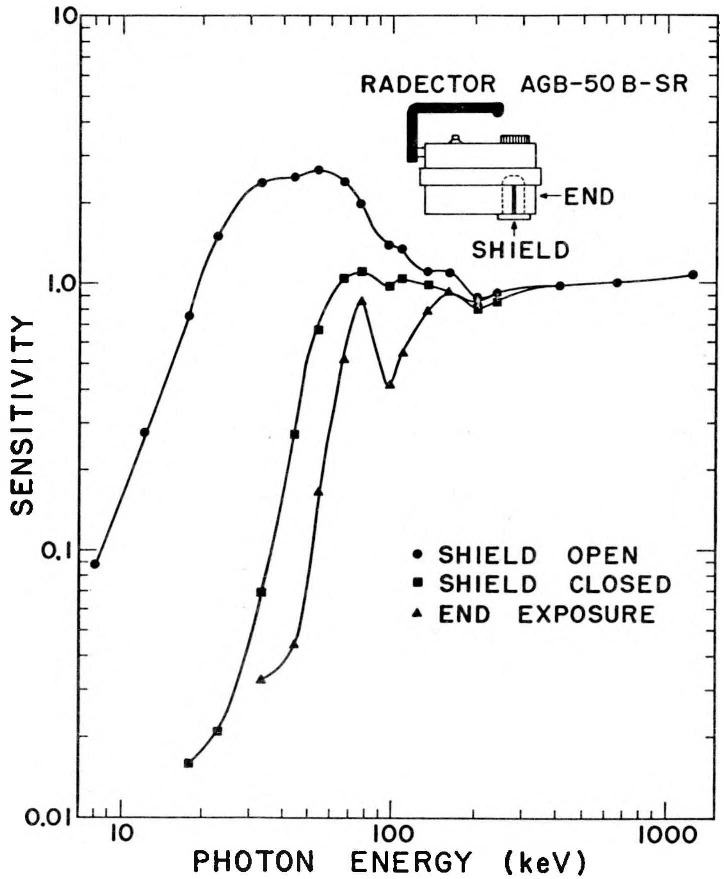

Fig. 8. Victoreen Instrument Company Radector Model AGB-50B-SR Serial No. 1206.

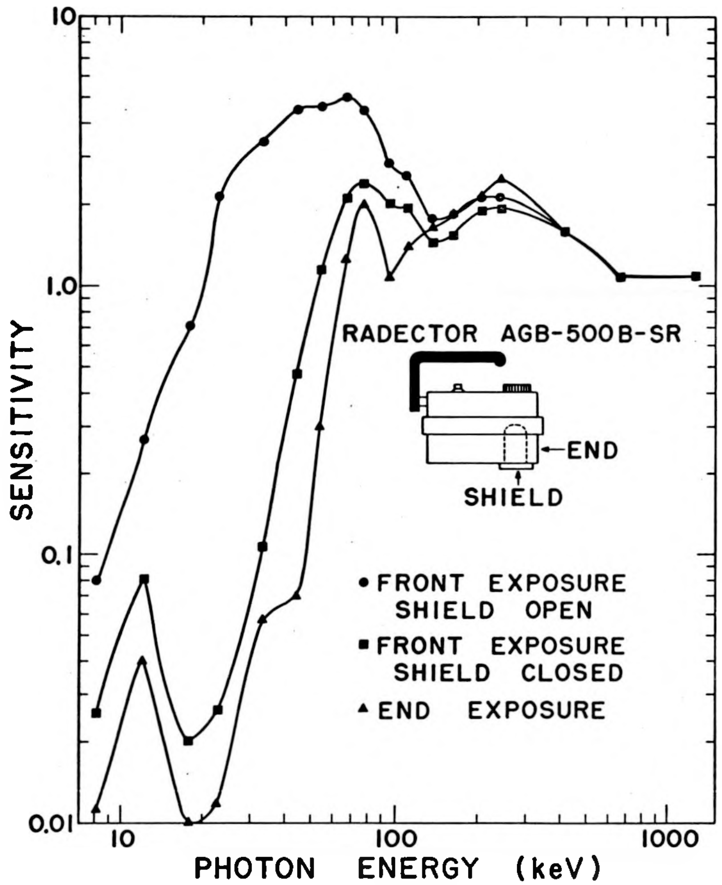

Fig. 9. Victoreen Instrument Company Radector Model AGB-500B-SR Serial No. 2647.

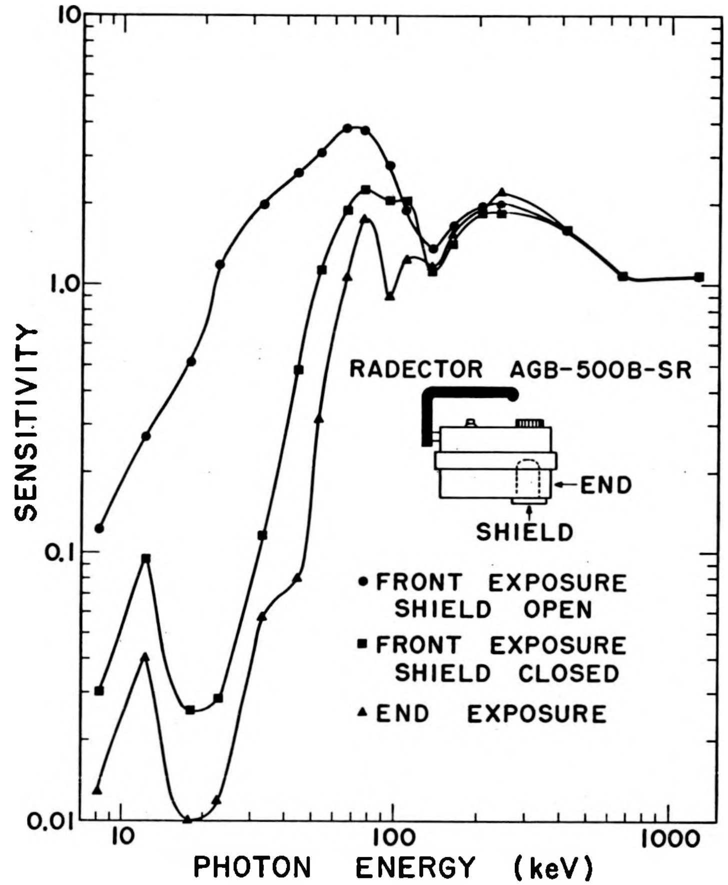

Fig. 10. Victoreen Instrument Company Radector Model AGB-500B-SR Serial No. 2644.

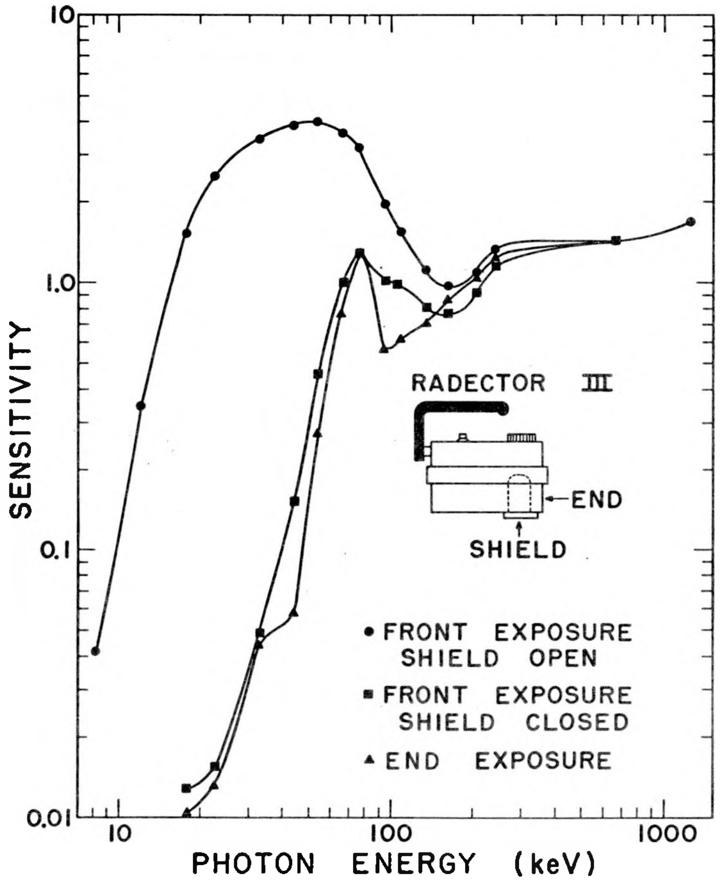

Fig. 11. Victoreen Instrument Company Radector III survey meter Model 2025 Serial No. 353.

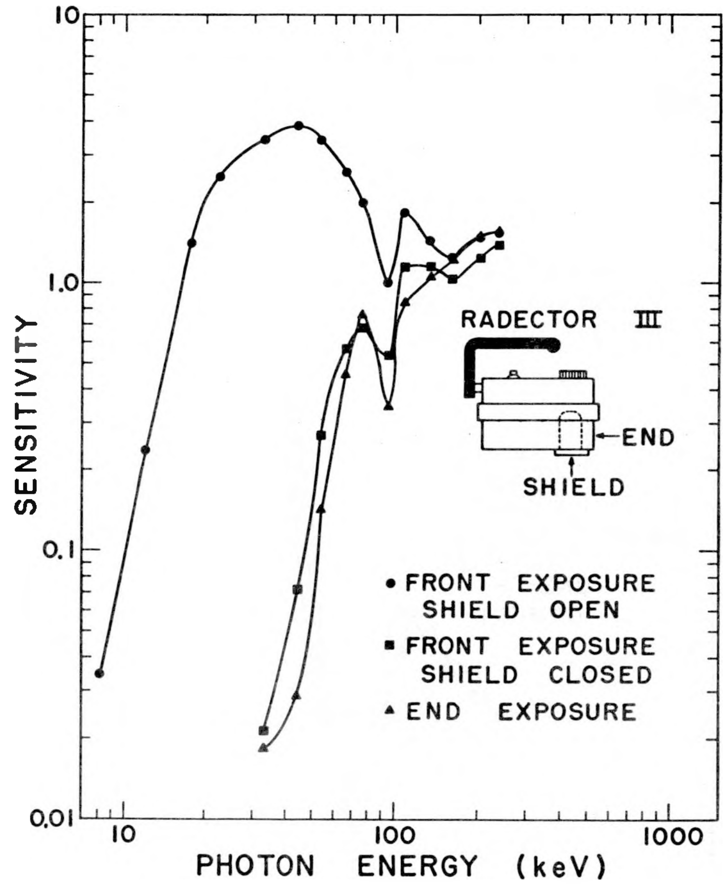

Fig. 12. Victoreen Instrument Company Radector III survey meter Model 2025 Serial No. 364.

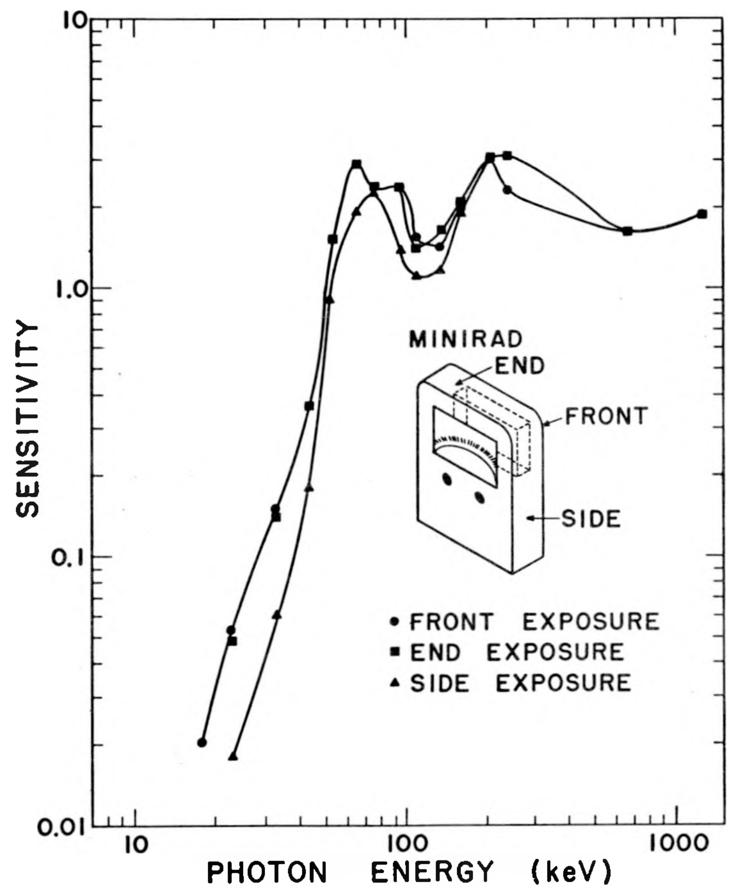

Fig. 13. Victoreen Instrument Company Minirad gamma survey meter Model M-100 Serial No. 0296.

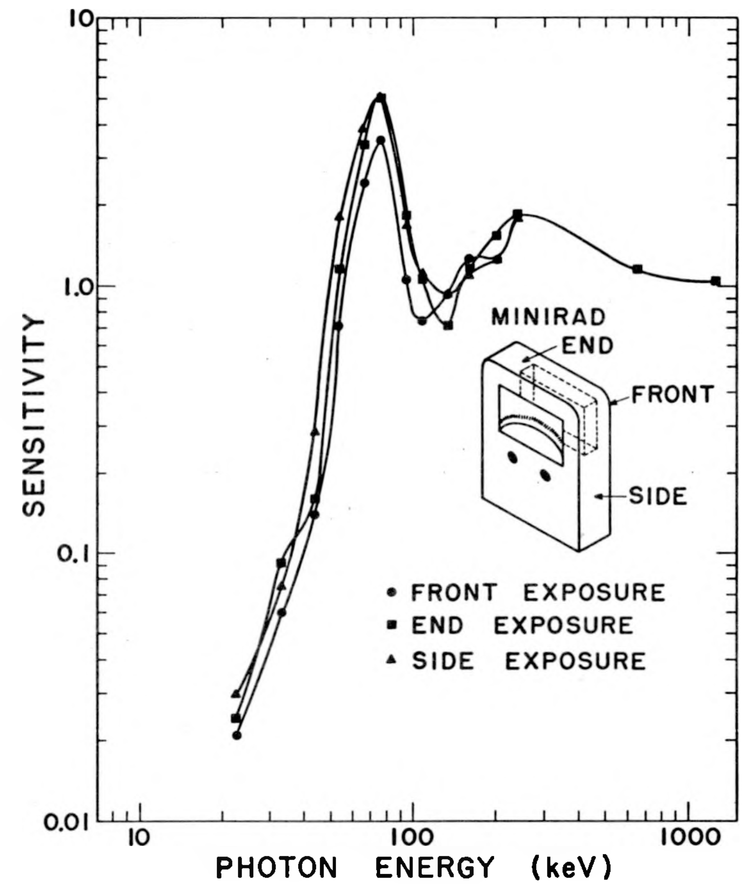

Fig. 14. Victoreen Instrument Company Minirad gamma survey meter Model M-100 Serial No. 0301.

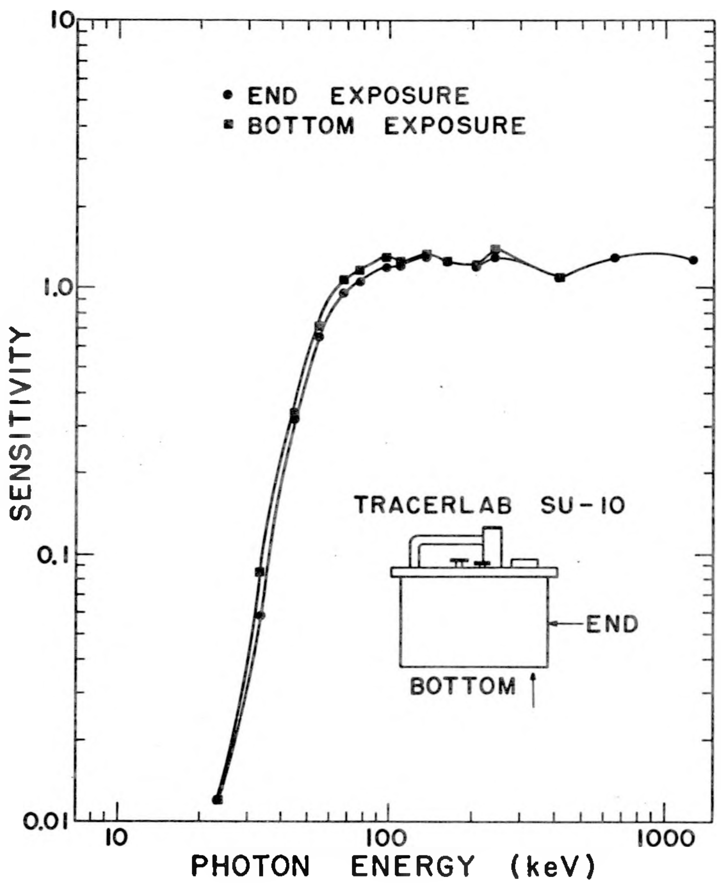

Fig. 15. Tracerlab, Inc. Model SU-10 Radiac (AN/PDR T-1B) Serial No. 5698.

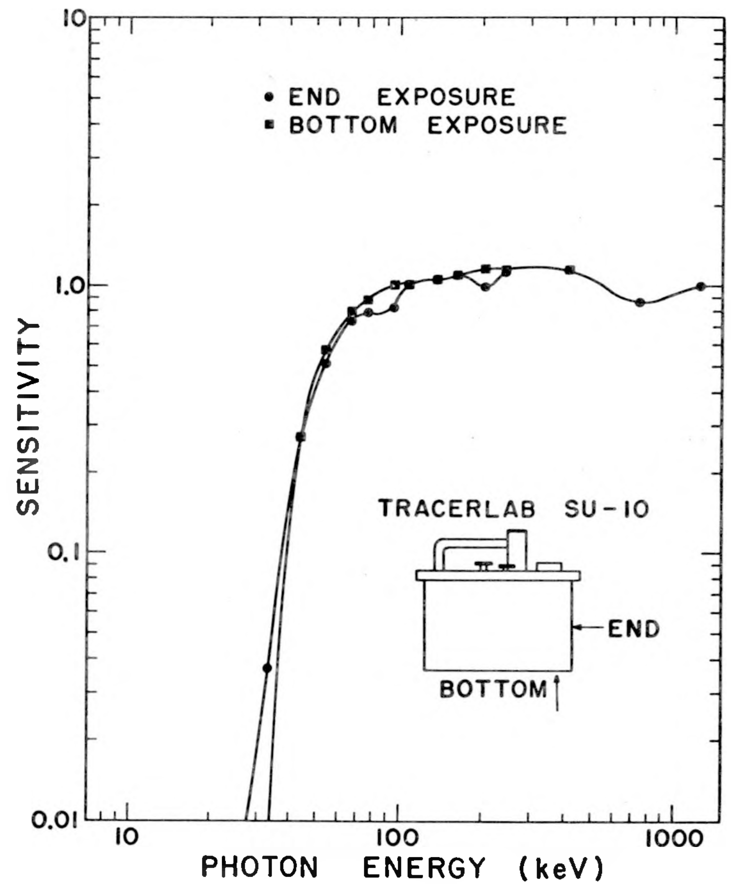

Fig. 16. Tracerlab, Inc. Model SU-10 Radiac (AN/PDR T-1B) Serial No. 5806.

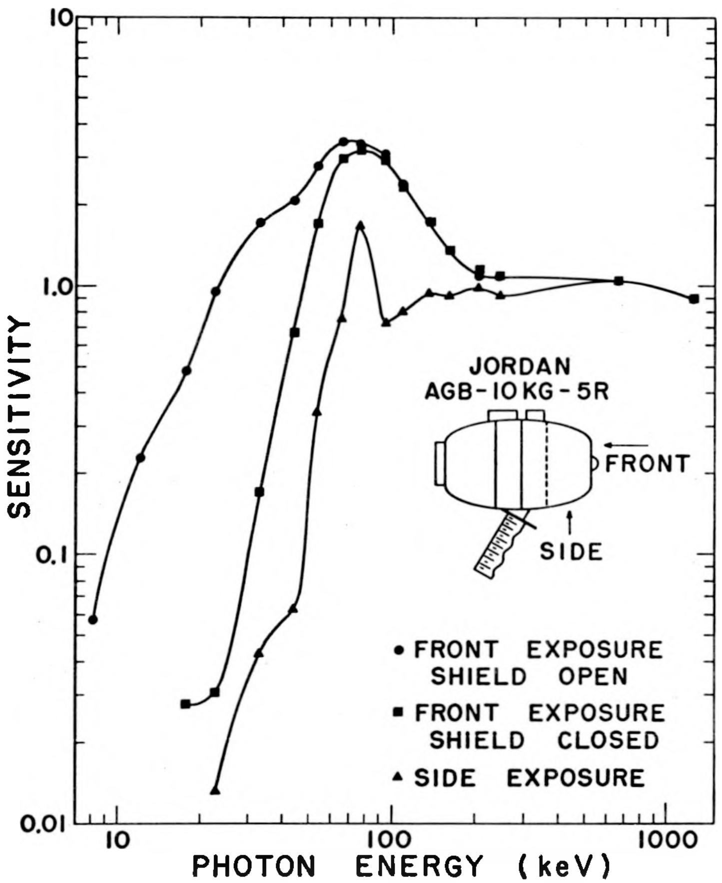

Fig. 17. Jordan Electronics Co. Model AGB-10KG-SR Serial No. 1554.

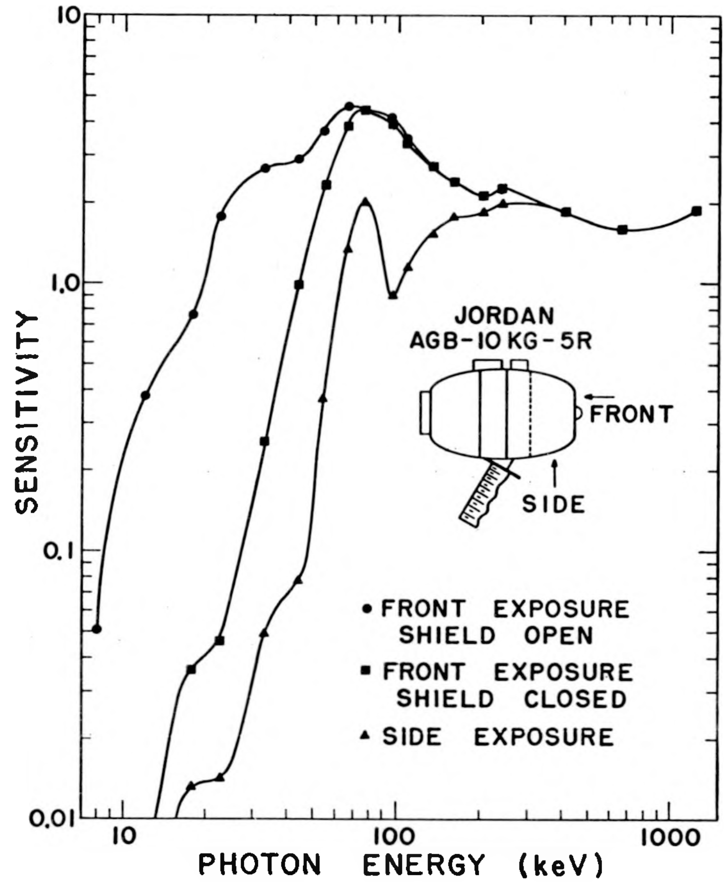

Fig. 18. Jordan Electronics Co. Model AGB-10KG-SR Serial No. 1556.

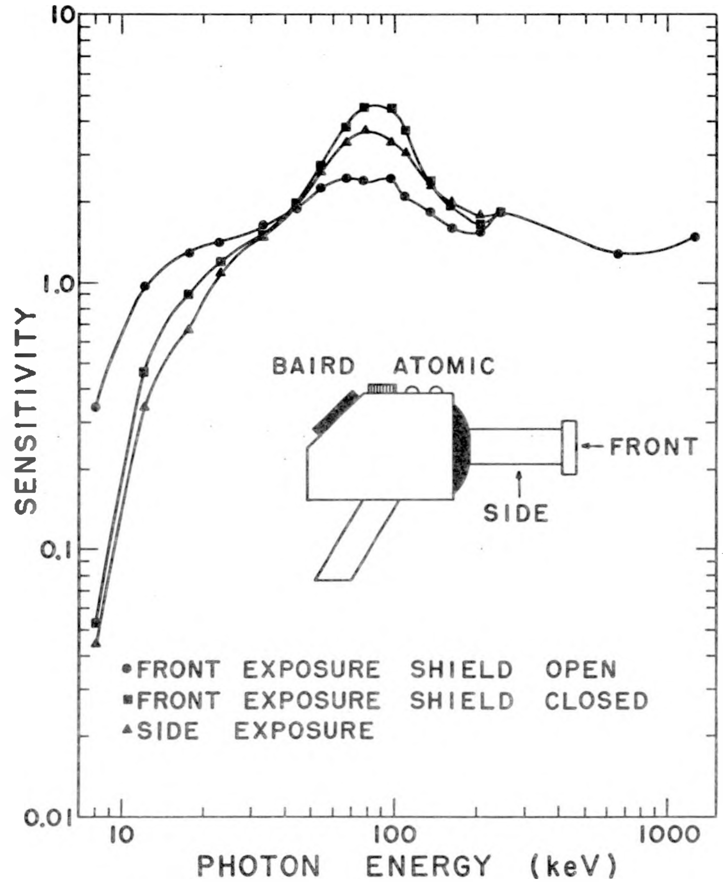

Fig. 19. Baird Atomic, Inc. logarithmic survey meter Model 414 Serial No. 464.

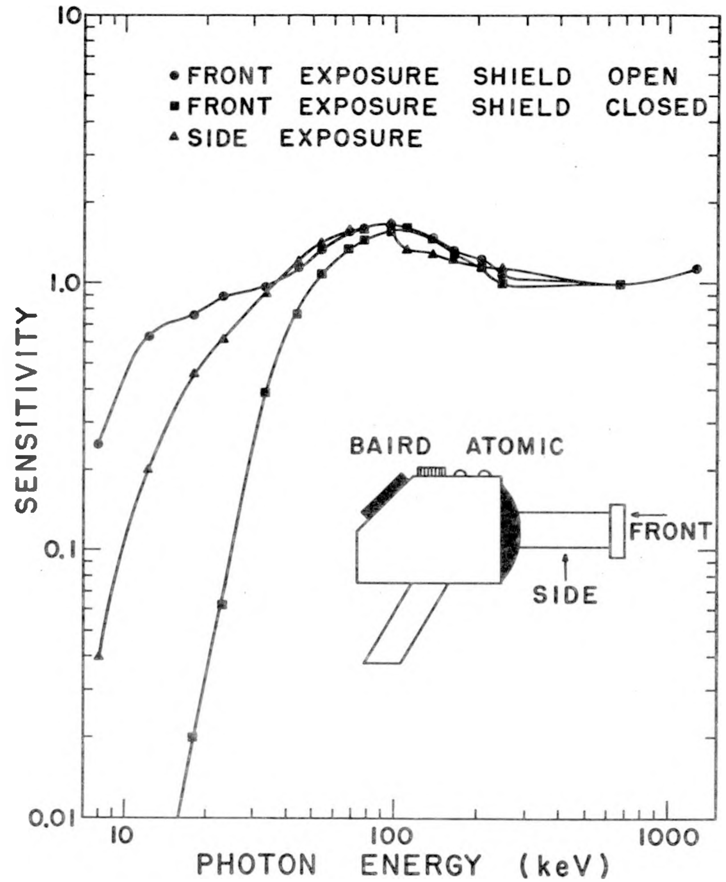

Fig. 20. Baird Atomic, Inc. logarithmic survey meter Model 414 Serial No. 465.

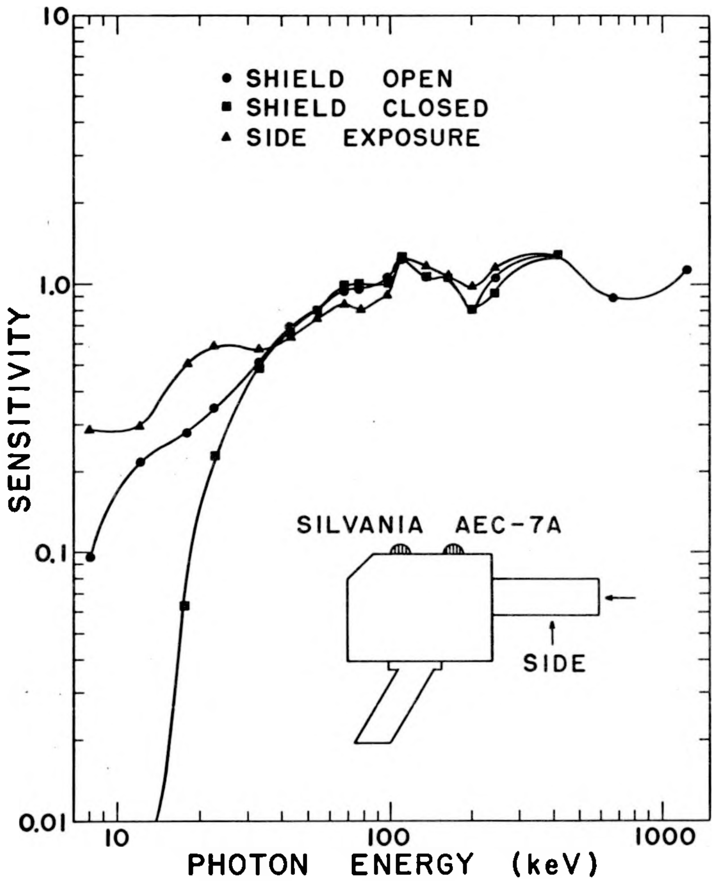

Fig. 21. Sylvania Electric Products, Inc. beta-gamma survey meter AEC-7A type RD-316 Serial No. 7.

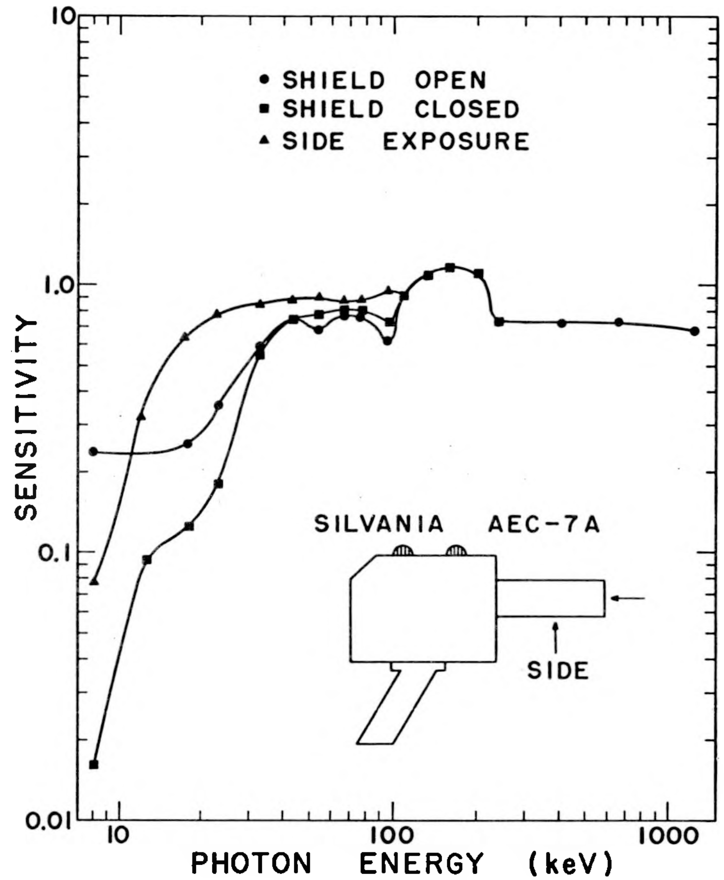

Fig. 22. Sylvania Electric Products, Inc. beta-gamma survey meter AEC #Sic-7A Serial No. 129.

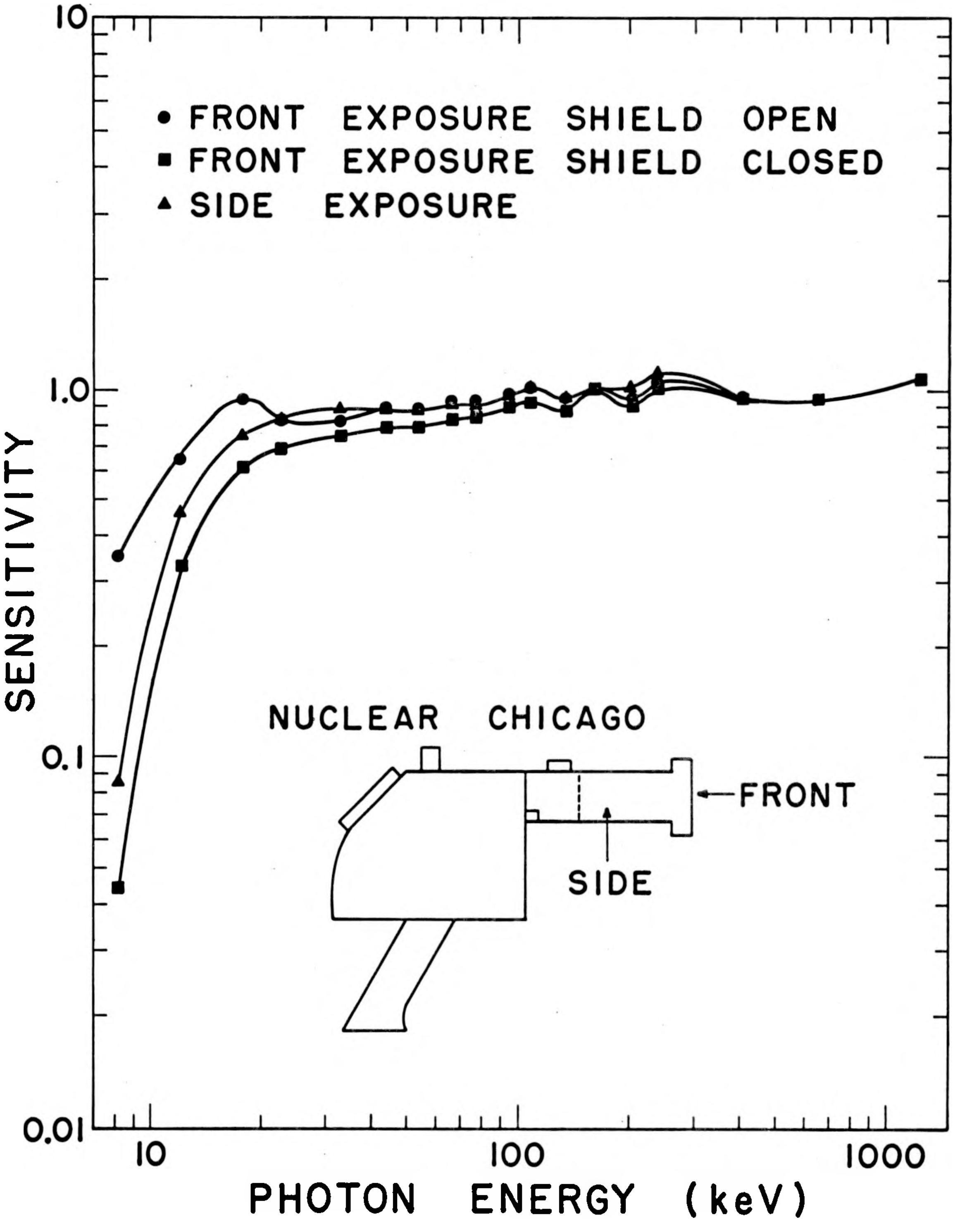

Fig. 23. Nuclear-Chicago Corp. Model 2588 Serial No. 012 (chamber Model 2526).

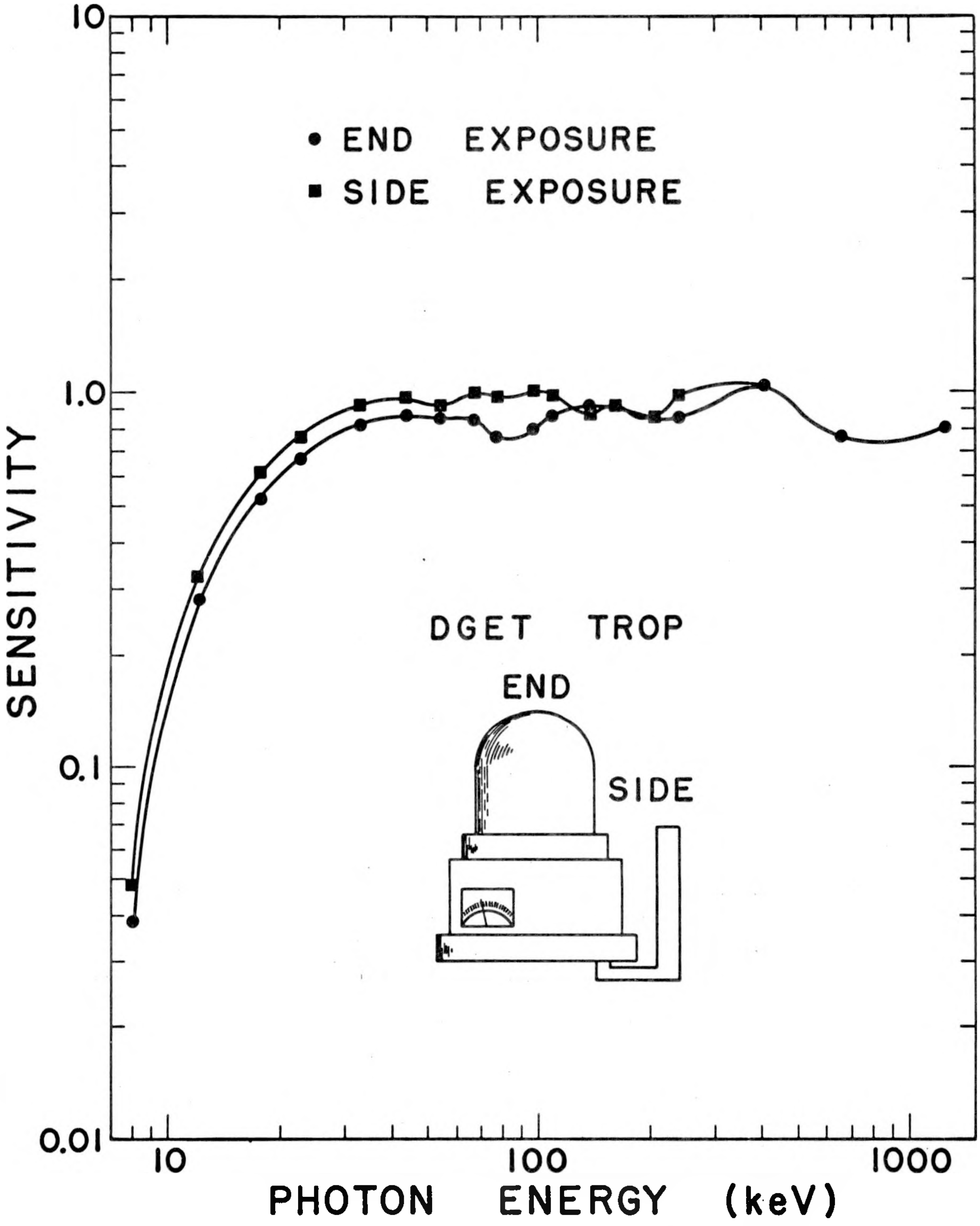

Fig. 24. Thomson Co. DGET Trop System CEA 1025.

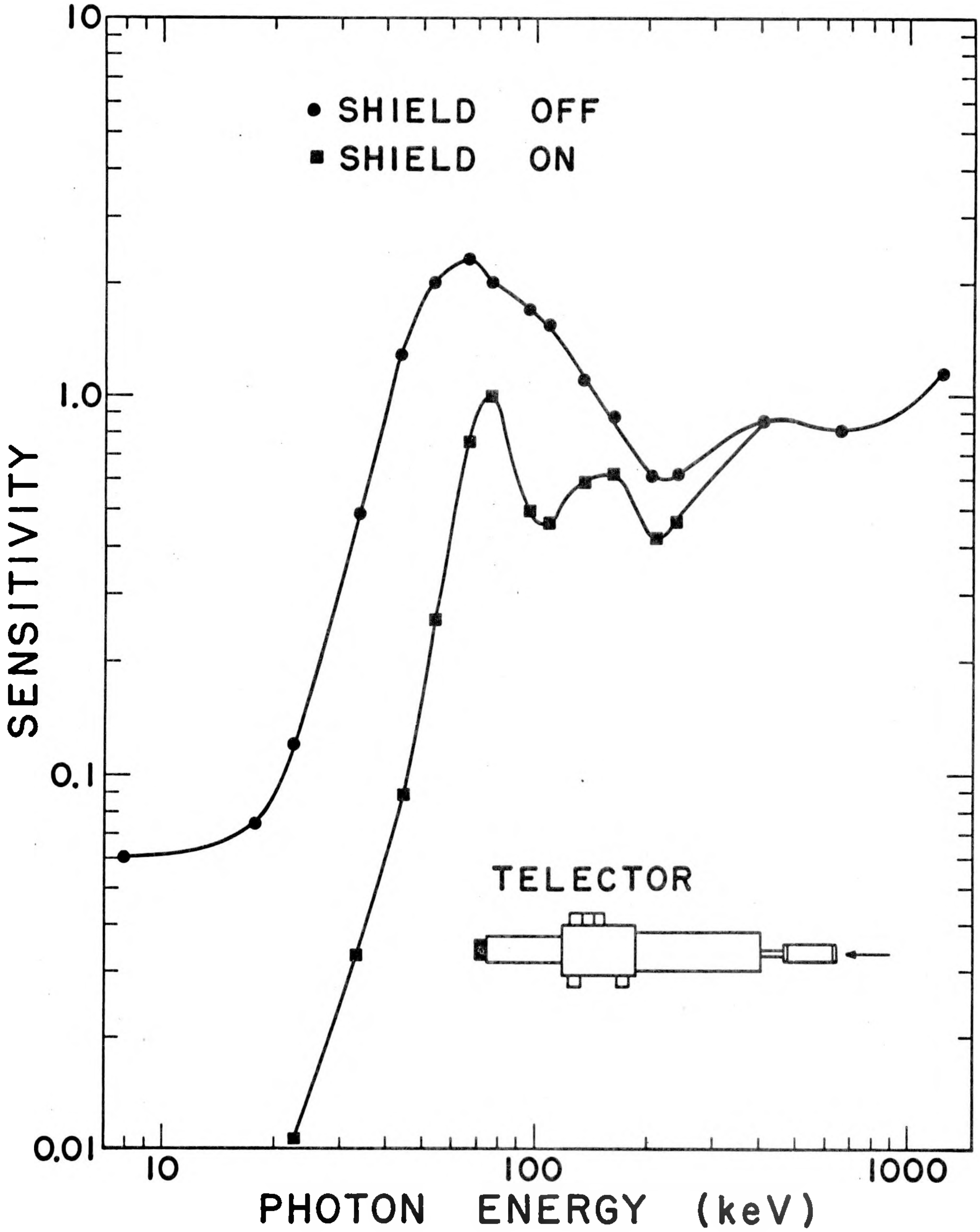

Fig. 25. TOTAL KOM,-Ges. Foerstner & Co. Telector total 6112B.

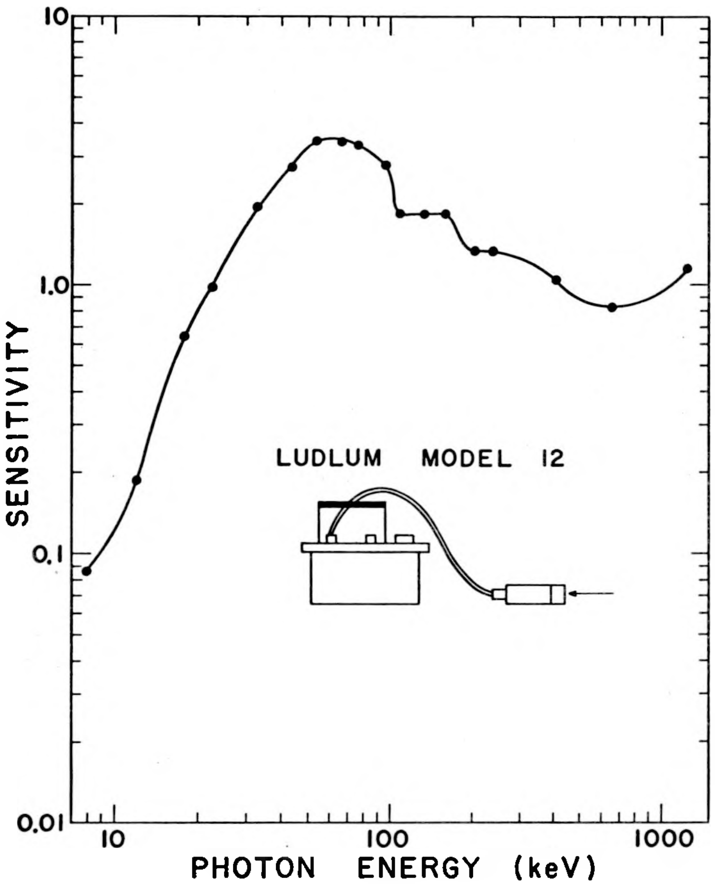

Fig. 26. Ludlum Measurements, Inc. count rate meter Model 12 Serial No. 667.

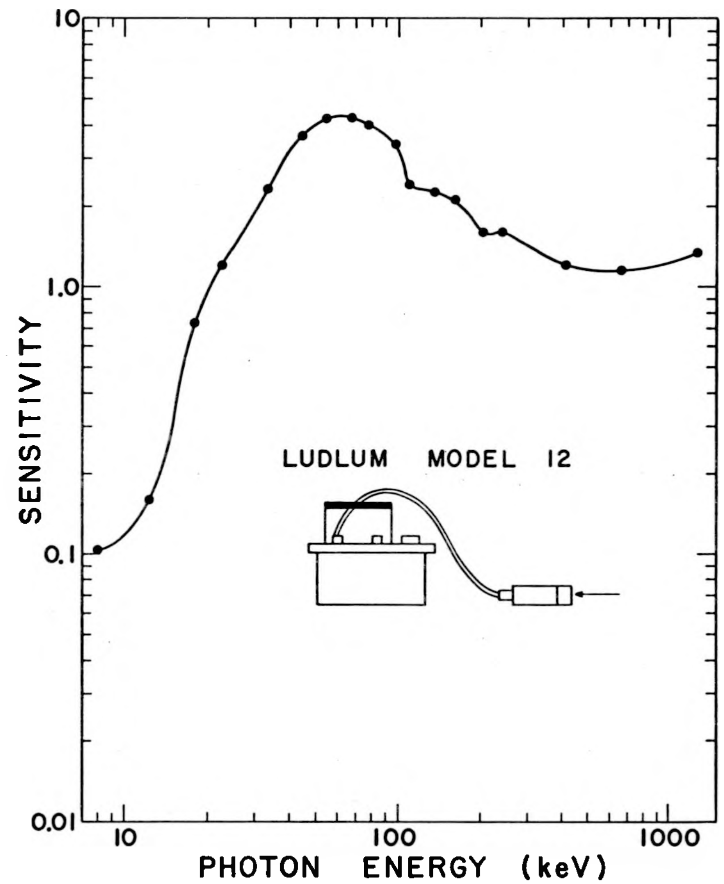

Fig. 27. Ludlum Measurements, Inc. count rate meter Model 12 Serial No. 691.

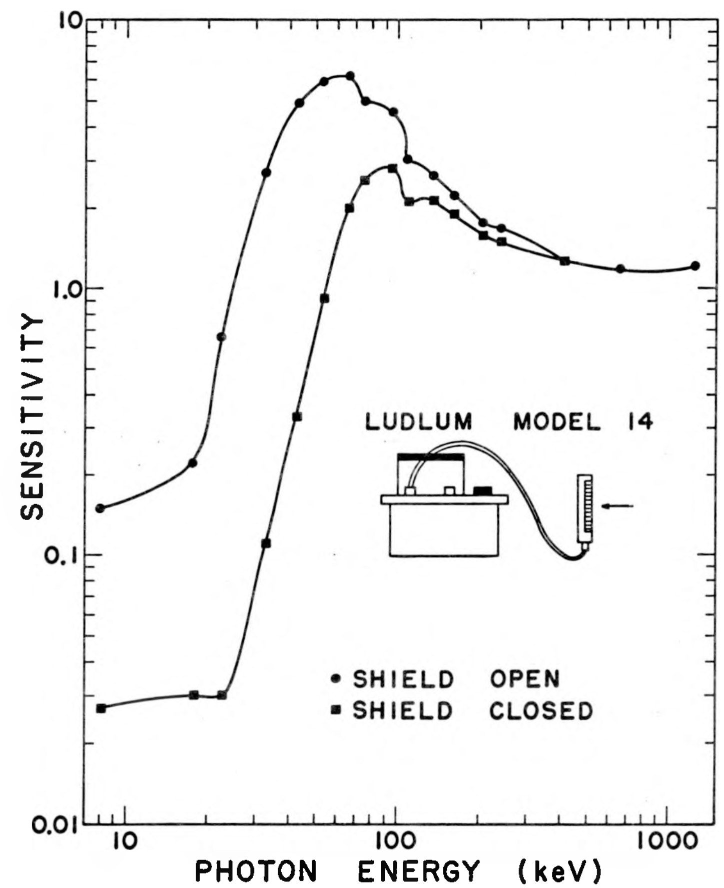

Fig. 28. Ludlum Measurements, Inc. Geiger counter Model 14 Serial No. 85.

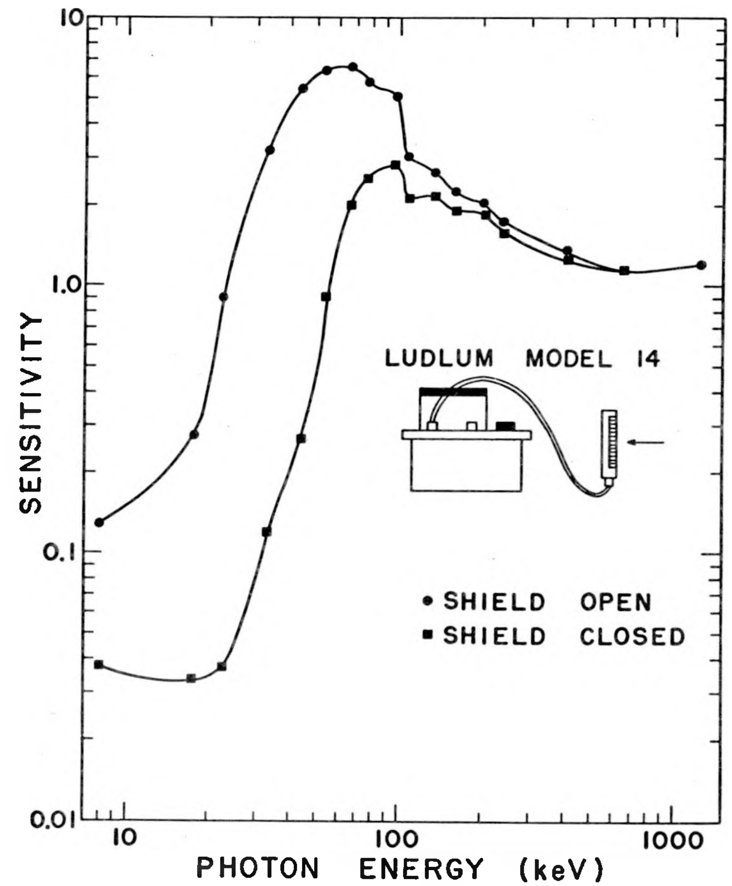

Fig. 29. Ludlum Measurements, Inc. Geiger counter Model 14 Serial No. 117.

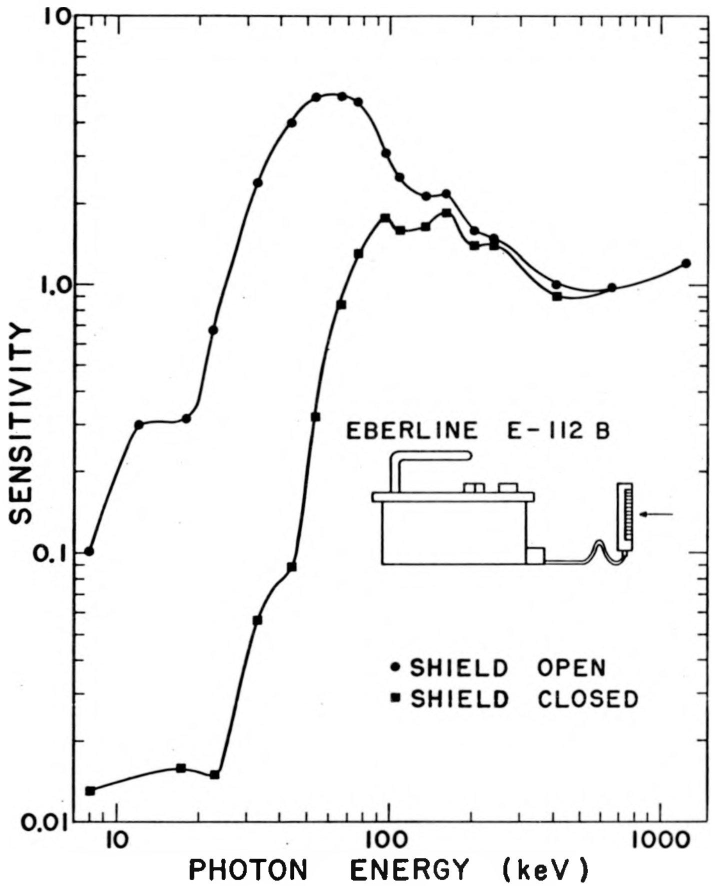

Fig. 30. Eberline Instrument Corporation Geiger counter Model E-112B-1 Serial No. 1182.

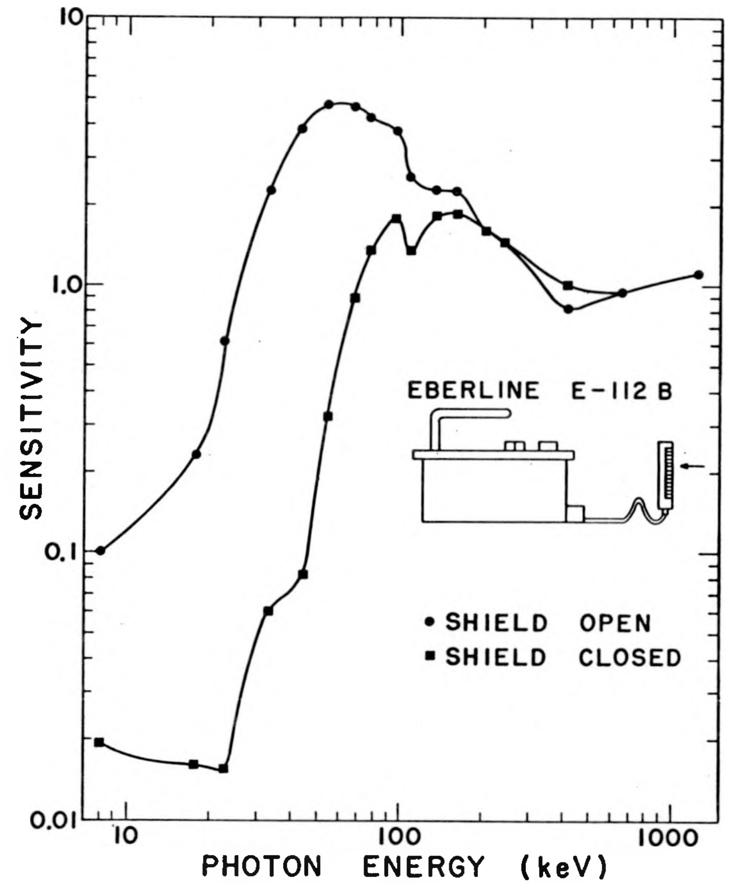

Fig. 31. Eberline Instrument Corporation Geiger counter Model E-112B-1 Serial No. 1107.

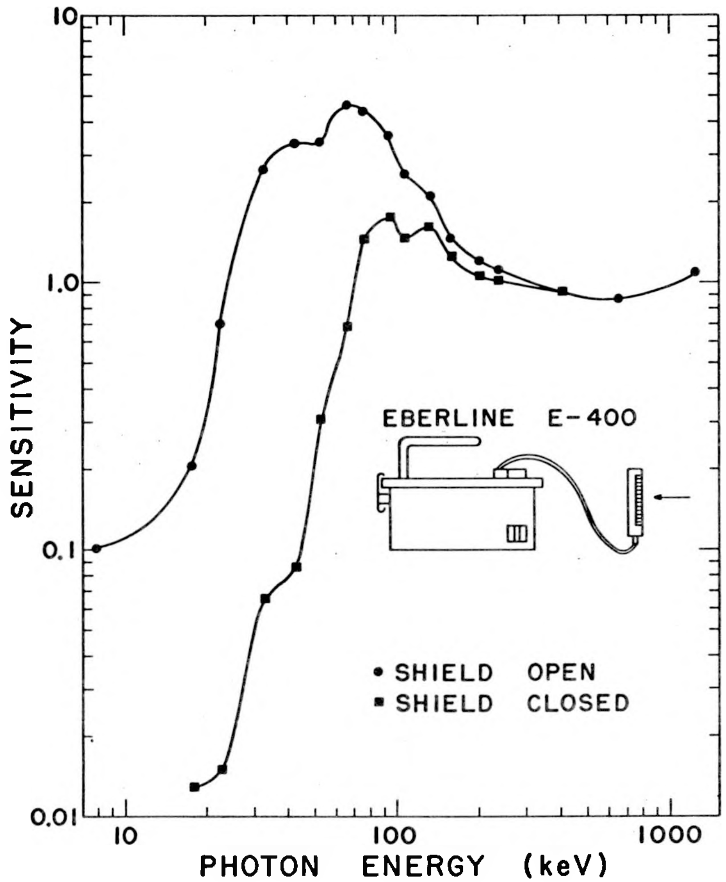

Fig. 32. Eberline Instrument Corporation Geiger counter Model E-400 Serial No. 389.

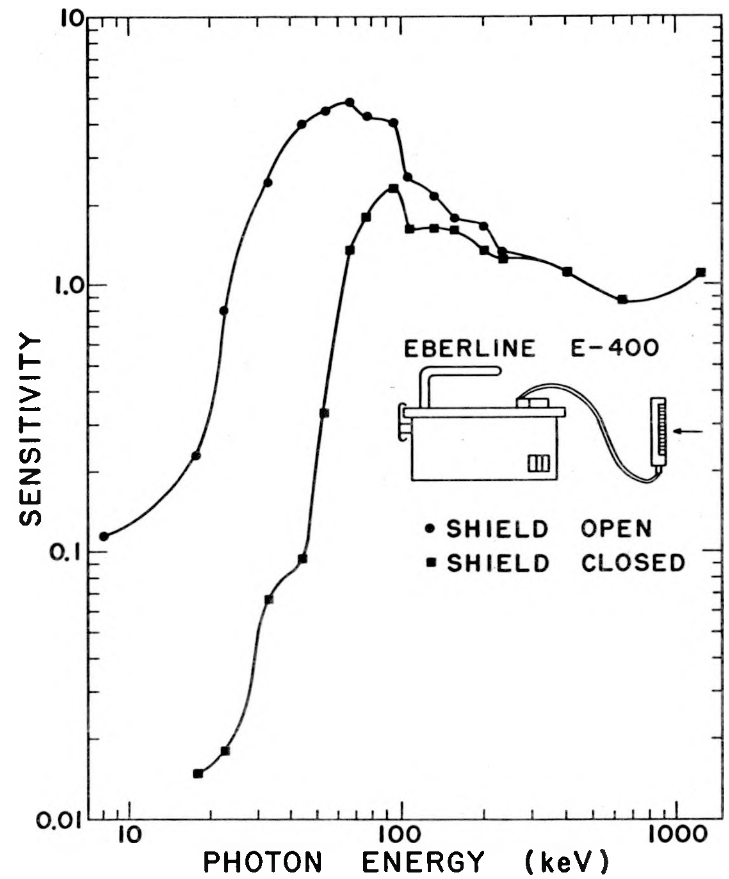

Fig. 33. Eberline Instrument Corporation Geiger counter Model E-400 Serial No. 380.

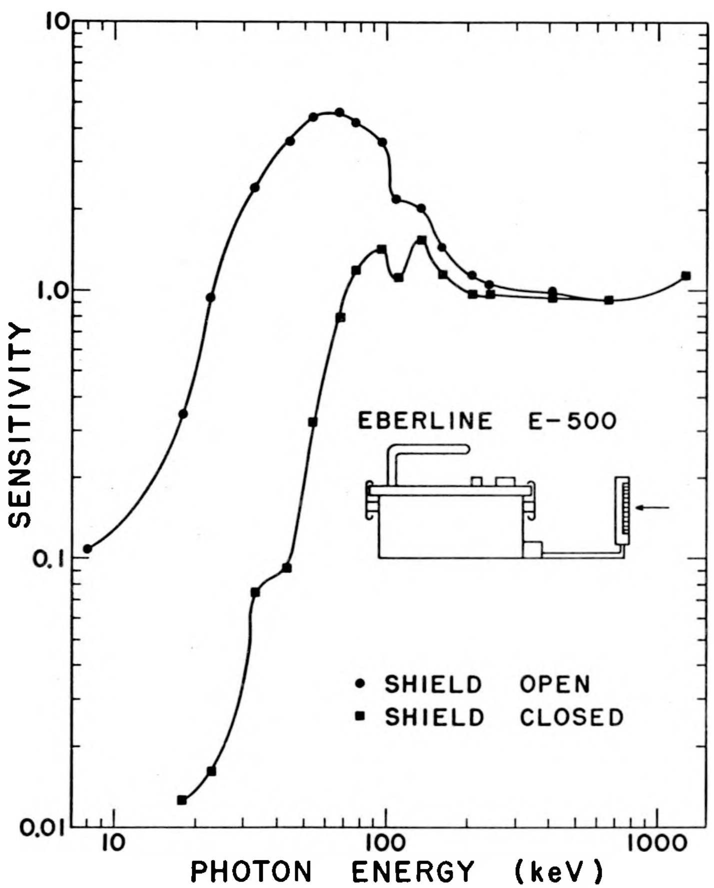

Fig. 34. Eberline Instrument Corporation Geiger counter Model E-500A Serial No. 185.

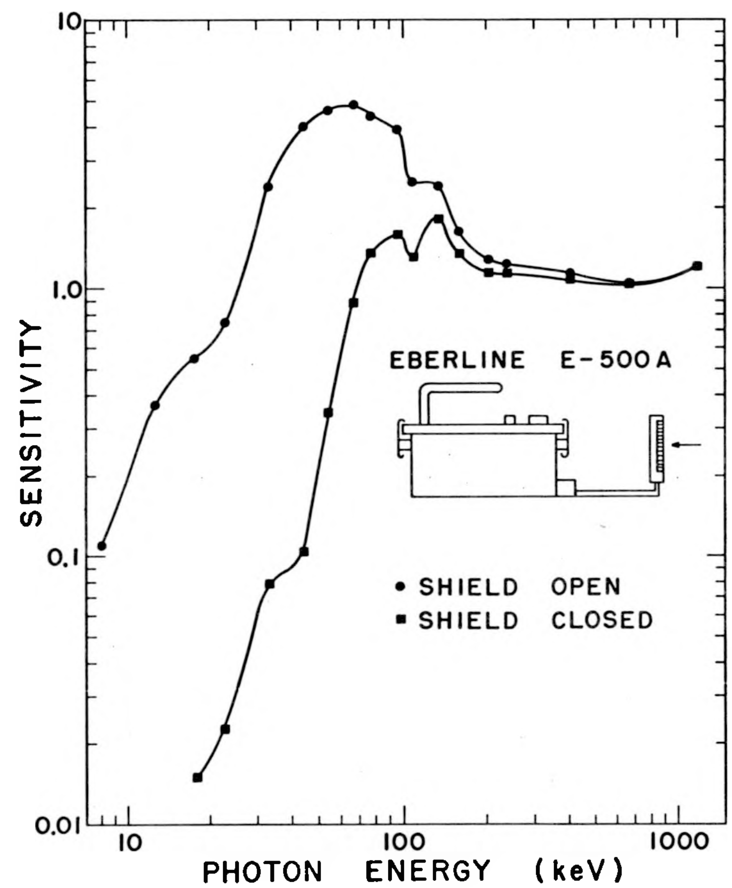

Fig. 35. Eberline Instrument Corporation Geiger counter Model E-500A Serial No. 182.

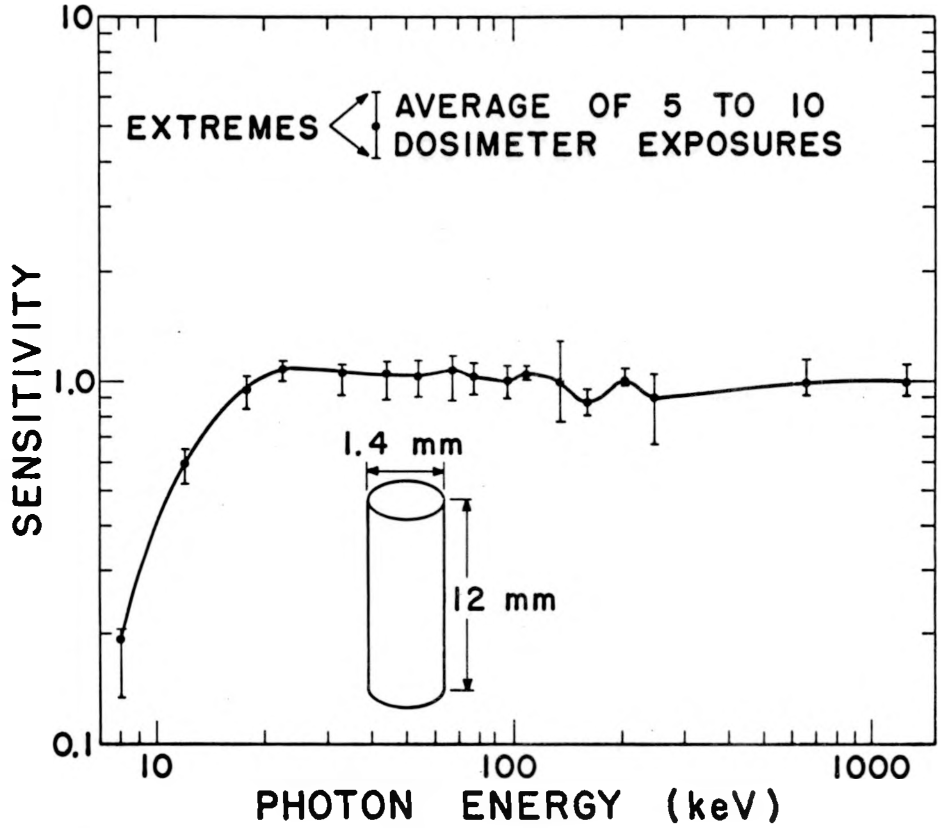

Fig. 36. EG&G, Inc. mini LiF thermoluminescent dosimeters.

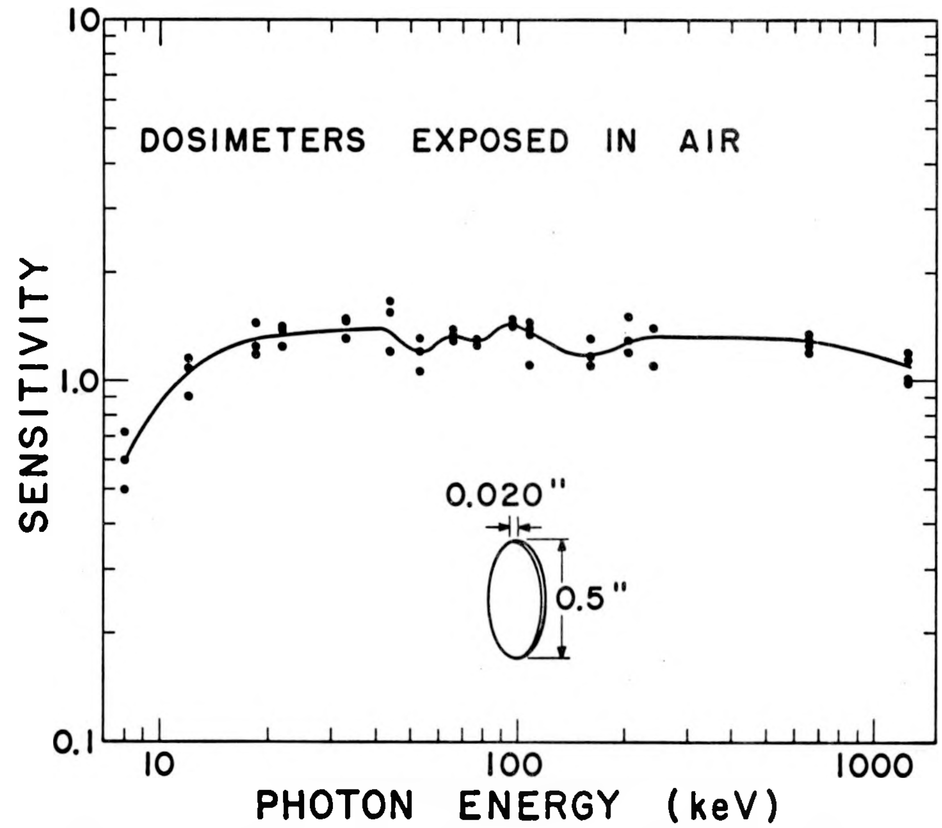

Fig. 37. Controls for Radiation 20-mil LiF Teflon disc thermoluminescent dosimeter.

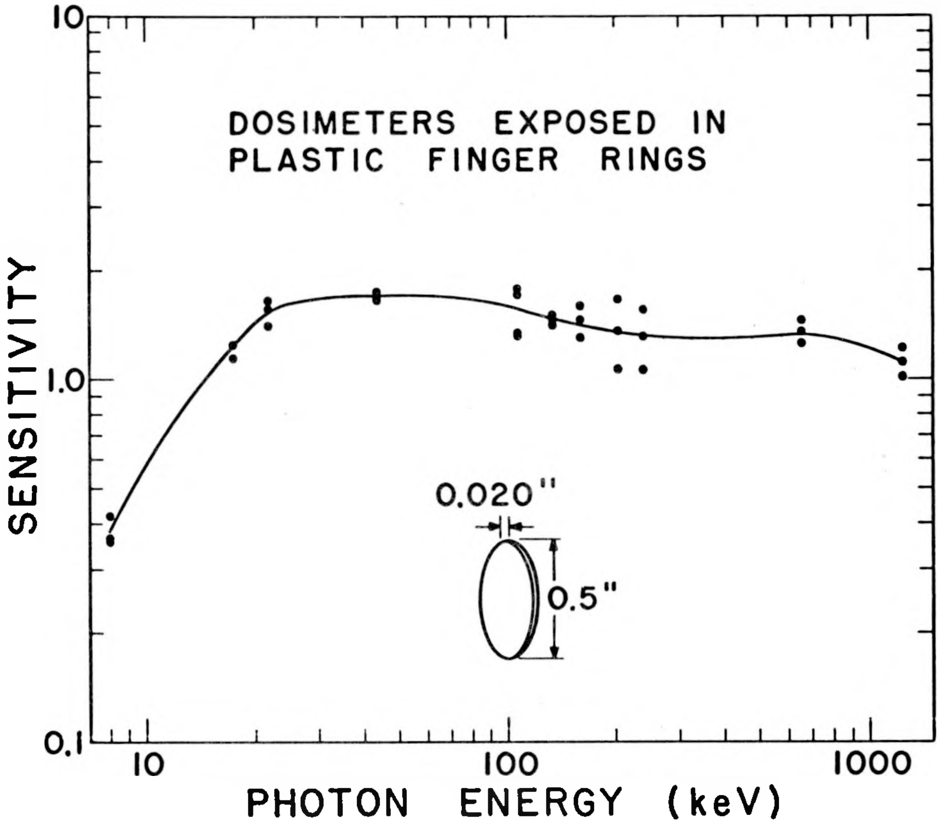

Fig. 38. Controls for Radiation 20-mil LiF Teflon disc thermoluminescent dosimeter.