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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

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RADIATION AND TEMPERATURE TESTS OF CADMIUM TELLURIDE DETECTORS

OCKLE E. JOHNSON
COMBAT SURVEILLANCE & TARGET ACQUISITION LABORATORY

NOVEMBER 1981

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This report describes the testing of CdTe sensors together with front end electronics developed by Radiation Monitoring Devices, Inc for Radiac Division CS&TA Laboratory, Fort Monmouth, NJ. These new solid state sensors show promise, in terms of miniature size and sensitivity, toward the development goal of wrist watch-sized military radiac. The unit was to operate from 10^{-2} mR/h to 10^{6} mR/h using the least number of sensors.

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To cover such a wide range of exposure - eight decades - two detectors were used. The larger and more sensitive sensor is 16mm in diameter by 2mm thick. The second detector which was made very small, to function at the higher radiation levels, was only 2mm x 2mm x 0.25mm.

X-ray energy dependence using unshielded sensors varied from 120 at 85 keV to 14 at 222 keV compared to 1250 keV; this requires additional work toward compensation and more uniform response.

Using temperature compensating electronics, gamma radiation rates varied by a maximum of 14% between -34°C and 52°C.

Preliminary results from one test show that CdTe crystals are damaged and their pulse response degraded when exposed to even small doses (such as 57 rads tissue) of neutron radiation. Above all, and before all other considerations and improvements, work must be accomplished to demonstrate that adequate nuclear hardening of CdTe detectors (including neutron radiation) is feasible and attainable.

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I. INTRODUCTION

This report describes the testing to date of CdTe sensors together with front end electronics developed by Radiation Monitoring Devices, Inc., for Radiac Division, Combat Surveillance and Target Acquisition Laboratory, Fort Monmouth, NJ (Contract DAAK 20-80-C-0008). These new solid state sensors show promise, in terms of miniature size and sensitivity, toward the development goal of wrist-watch-size military radiac. Radiation Monitoring Devices, Inc. (RMD) was contracted to produce CdTe detectors with preamplifiers, investigate temperature performance, and deliver sample devices. The design objective was the development of a sensor prototype which had a maximum variation in sensitivity of $\pm 10\%$ for Cs^{137} gamma radiation over the temperature range of -46°C to 52°C. In addition, the unit was to operate from 10^{-2} milli rads per hour (mR/h) to 10^6 mR/h using the least number of sensors.

To cover such a wide range, eight decades of exposure, two detectors were used. The larger and more sensitive sensor is 16mm in diameter by 2mm thick. It was used with the temperature compensating electronics developed under the present program. The compensation is carried out by raising the detector bias voltage 33% and reducing the lower level threshold approximately 67% for the very low temperature region. This compensation is required by the reduction in charge collection at these low temperatures.

The second detector which was made very small to function at the higher radiation levels was only 2mm x 2mm x 0.25mm. Even with this miniature detector the count rate was over 50,000 counts per second at 100 rads per hour (R/h). With a detector of such small area and thickness, it was possible to apply enough electric field to overcome the decrease in charge mobility at low temperatures. Thus, it was found that the sensitivity of this detector remained within $\pm 20\%$ with no electronic temperature compensation.

One of each size detector, along with its associated laboratory prototype electronics, was delivered to Fort Monmouth for testing. The electronics is physically housed in two boxes, one for power supply (including bias voltage), the other to accommodate the charge-sensitive preamplifier and pulse discriminator/shaper (Fig. 1A). The output of the pulse discriminator/shaper consists of trains of square pulses about three volts amplitude and about two microseconds in duration (Fig. 1B). The preamplifier output pulse-spectrum is also photographed in Fig. 1B. This report details the testing of the two units.

Data was obtained by connecting either the high flux unit or the low flux unit to the Mech-tronics Nuclear Model 702 Scaler-Timer and exposing the unit to gamma radiation and x-rays. A typical measurement was 10,000 counts per minute.

A Tracor Northern TN-1705 Pulse Height Analyzer (PHA) was used to obtain preliminary gamma-ray spectra with the Cadmium Telluride crystals being used as sensors (see Fig. 1C). To enable coupling of the negative pulse spectrum from the RMD preamplifier with the PHA, a linear, inverting pulse amplifier had to be designed. Further work with PHA will be required in connection with investigation of energy dependence and pulse height spectra for various gamma/x-ray energies.

2. CALIBRATION LINEARITY OF THE HIGH FLUX UNIT

The calibration linearity of the high flux unit was checked with a Cs^{137} gamma radiation source (AN/UDM-1A). Table 1 and Figure 1D show the results with the source plug out and the source open, that is, with no shielding in the radiation path between the source and the detector. Column 4 shows rate dependence. At 400 R/h the relative counting rate is only 33.3% of the counting rate at 4 R/h. Counting rate versus counting efficiency is plotted in Figure 2. A smaller CdTe crystal would be desirable since it would tend to increase the linearity. However, it also seems that some form of electronic compensation is required in order to yield a rate-proportional response at high dose rates.

Table 2 and Figure 3 show the calibration linearity of the high flux unit with Cs^{137} using the AN/UDM-1A in its three source modes. The AN/UDM-1A is a collimated source with or without shielding between the source and the detector. In the "plug out-source open" configuration there is no shielding between the source and the detector. In the "plug in-source open" configuration there is a lead plug in the collimation hole between the source and the detector. In the "plug out-source closed" configuration there is no lead plug in the collimation hole, but the source is in a hole in the lead pig and not aligned with the collimation hole. The lower response, shown in Figure 3, in the "plug out-source closed" configuration is probably due to energy dependence. This assumption is corroborated by the considerable energy dependence observed with x-rays (para. 5 below).

Table 3 and Figure 4 show the calibration linearity of the high flux unit with Co^{60} (AN/UDM-1). It is to be noted that the count rate on 9 Dec 80 decreased about 13% compared to the count rate on 25 Nov 80. The response shift of approximately 13% may be attributable to an inadvertent slight bumping of the CdTe detector by the source plug.

3. TEMPERATURE TESTS

The original high flux unit was susceptible to noise, which proved particularly troublesome in the temperature chamber (noise pick-up). This problem prevented temperature data from being obtained from this detector. The manufacturer found that there was a poor ground connection and replaced the crystal. Temperature data was then collected on this replacement CdTe device.

Table 5 shows the results of the temperature test of the new high flux unit. At -51°C the count rate is only 17% less than at room temperature. At 52°C the count rate was the same as at room temperature.

Table 6 shows the results of the temperature test of the low flux unit. At 52°C the count rate was only 4% lower than at room temperature. At -34°C the count rate ratio was only 14% higher than at room temperature.

4. CALIBRATION LINEARITY OF THE LOW FLUX UNIT

Background count of the low flux unit was approximately 90 counts per minute or 1.5 counts per second. At a radiation rate of 0.2 mR/h, the count rate was 2,423 counts per minute. This translates to about 4 counts per second at 0.02 mR/h. This sensitivity compares favorably with the Geiger tube presently being used in Radiacmeter AN/VDR-1.

Table 7 and Figure 6 show the calibration linearity of the low flux unit with Cs^{137} using the low level calibration range. Table 8 and Figures 7 and 8 show the calibration linearity of the low flux unit with Cs^{137} using the AN/UDM-1A. Figure 8 shows saturation at about 3 R/h. Figure 8A shows the counting rate versus counting efficiency of the low flux unit. Table 9 and Figures 9 and 10 show the calibration linearity of the low flux unit with Co^{60}. Table 10 shows the non-linearity of the low flux unit above 100 mR/h. Since the high flux unit operates linearly in the 100 mR/h region, the low flux unit would not be required to function in this range.

5. X-RAY ENERGY DEPENDENCE OF THE HIGH FLUX UNIT

The characteristics of the x-rays used in the energy dependence tests, are shown in the Appendix. A computer print-out showing the energy distribution at each effective energy is shown in Figures 11 and 12.

The high flux unit was exposed to highly filtered x-rays at a rate of 10 R/h. The effective energies ranged from 56 keV to 222 keV. In addition, the high flux unit was exposed to Cs^{137} with an energy of 662 keV and Co^{60} with an energy of 1.25 MeV. Results are presented in Table 4 and Figure 5. Saturation occurred at high count rates leading to the use of the counting efficiency factor used in Table 4 and taken from Figure 2 and Table 1. Since the maximum exposure available from Co^{60} was 3 R/h, Figure 5A was used to derive the Cs^{137} to Co^{60} ratio of 1.82. Count rate ratios compared to 1,250 keV varied from 120 at 85 keV to 14.0 at 222 keV. An extremely enhanced low energy response (by a factor of 40 at 85 keV, with lead shield; by a factor of 120 without lead shield) is evident.

6. COUNT STABILITY OF THE LOW FLUX UNIT

The low flux unit was exposed in fixed geometry to a radium source. The average count rate was approximately 18,000 counts per minute or about 2 mR/h. Table 11 shows that the count rate did not vary between 10 Dec 80 and 6 Jan 81.

Samples were taken on a random, intermittent basis, with power (bias voltage) applied only during periods of counting. The detector remained exposed to radiation continuously over the observation period.

In a second stability test, the activated (bias voltage applied) low flux unit was exposed continuously to Co^{60} at a rate of 1 R/h, 24 hours per day, beginning 2 Mar 81 and concluding 24 Mar 81, for a total of 508 R. See Table 12. Count rates were checked throughout the period and did not vary measurably over the entire interval.

7. NUCLEAR HARDENING

Preliminary results from one test show that CdTe crystals are damaged and their pulse response degraded when exposed to even small doses (such as 57 rads tissue) of neutron radiation. This observation resulted from rather recent tests (by Electronics Technology and Devices Laboratory) at a Fast Burst Reactor facility, and a review of all relevent data was still in progress at the time of this writing. Damaged crystals will be examined further and additional experiments will be proposed to more fully evaluate the degree of vulnerability to neutron exposure.

8. CONCLUSIONS AND RECOMMENDATIONS

The key to developing the generation of wrist-watch-size and other miniature military radiacs rests on the size, sensitivity, and power demand of available nuclear radiation detectors. The effort discussed here represents an initial phase to investigate the feasibility of using the new miniature solid-state Cadmium Telluride (CdTe) radiation detector for this application. The test results demonstrate that CdTe detectors basically show promise and could, indeed, be used over most of the desired radiation exposure range and environmental temperature conditions required for military field use. In particular, the operational prototype hardware with electronics, which was developed and delivered to Ft. Monmouth, maintains detector sensitivity to within ±14% over the temperature range of -46°C to 52°C in radiation fields of 10^{-2} mR/h to 10^5 mR/h. It is necessary, though, to reduce the size of the high level detector or otherwise to reduce its maximum count rate, so that it will respond with acceptable linearity to the upper limit of dose-rate measurement (10^6mR/h).

X-ray energy dependence of the high flux unit compared to 1,250 keV varied from a factor of 120 at 85 keV to 14.0 at 220 keV. Effort must be directed toward compensating for this unusually high energy dependence. Above all and before all other considerations and improvements, work must be accomplished to demonstrate that adequate nuclear hardening of CdTe detectors (including neutron radiation) is feasible and attainable.

9. ACKNOWLEDGEMENTS

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APPENDIX

CHARACTERISTICS OF X-RAYS USED IN ENERGY DEPENDENT TESTS

The x-ray machine used in the energy dependence tests is a 250 kV Westinghouse Quadracondex. The beam is heavily filtered using ERADCOM filters. Exposures were made at 10 R/h with a filament current of 10 mA. The inherent filtration is equivalent to 3mm of aluminum. The x-ray machine was calibrated using NBS certified R-meters. The CdTe units were exposed to x-rays of 56 keV, 85 keV, 129 keV, 178 keV, and 222 keV effective energy.

Following are the specific characteristics of each effective energy. A computer print-out showing the energy distribution at each effective energy is shown in Figures 11 and 12.

Effective Energy: 56 keV

Tube Potential: 70kV
Filtration: 0.89mm Copper
Distance from Target: 69.7cm

Effective Energy: 85 keV

Tube Potential: 100 kV
Filtration: 1.04mm Tin
Distance from Target: 43.7cm

Effective Energy: 129 keV

Tube Potential: 150 kV
Filtration: 4.13mm Tin
Distance from Target: 3[illegible].7cm

Effective Energy: 178 keV

Tube Potential: 200 kV
Filtration: 2.07mm Tin plus 1.94mm Lead
Distance from Target: 26.7cm

Effective Energy: 222 keV

Tube Potential: 250 kV
Filtration: 2.07mm Tin plus 3.88mm Lead
Distance from Target: 32.7cm

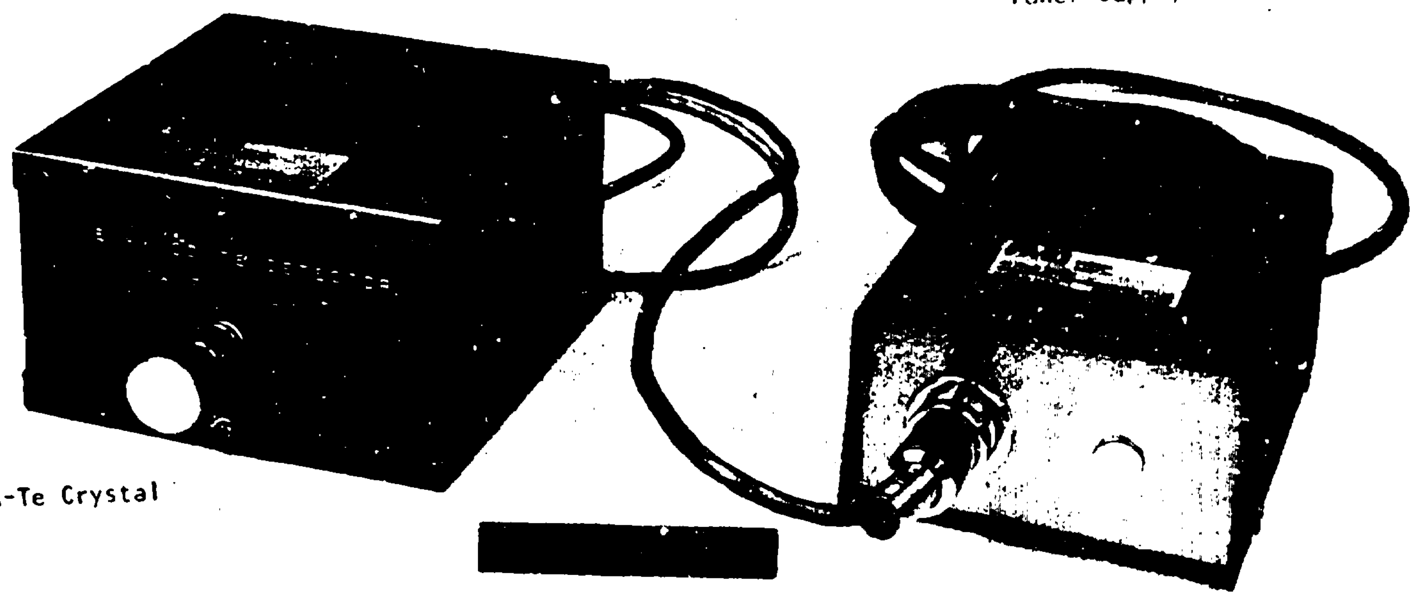

Figure 1A - Prototype Radiac System with CdTe Detector

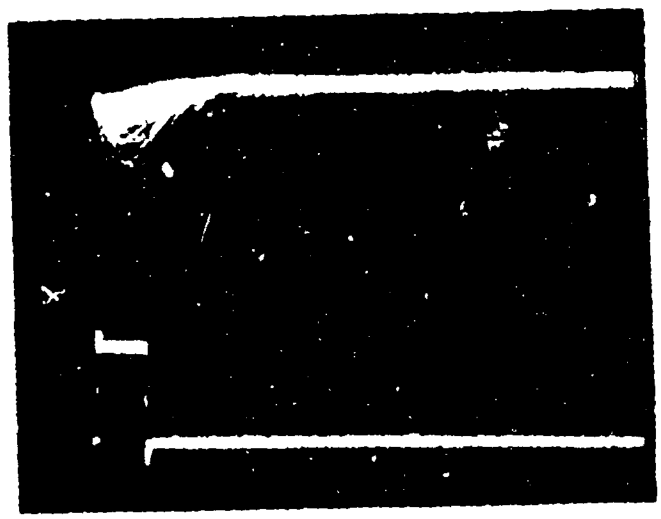

Figure 18 - Low Flux Unit Pulse Output.
Lower Trace: Pulse Shaper Output, 2.0 Volts/CM
Upper Trace: Preamplifier Output, 0.2 Volts/CM
2.0 Microseconds/CM

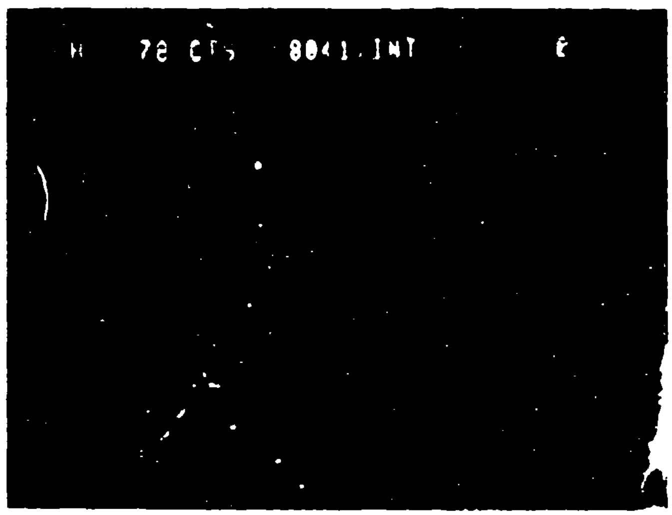

Figure 1C - Spectrum from High Flux Crystal Exposed to Co^{57} (122 keV Peak)

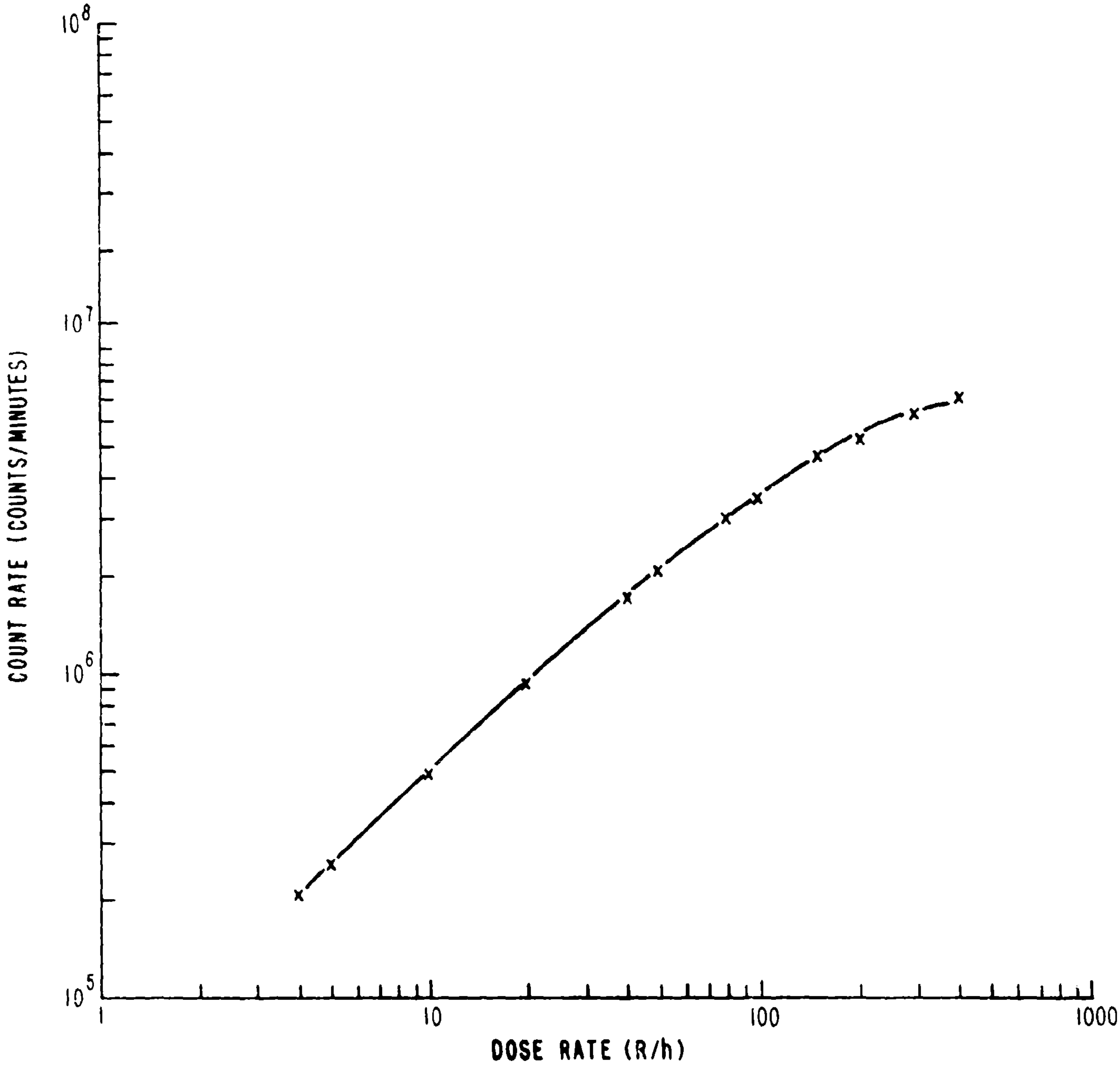

FIGURE 1D. CALIBRATION LINEARITY OF HIGH FLUX UNIT WITH Cs^{137}
(AN/UDM-1A WITH PLUG OUT - SOURCE OPEN)

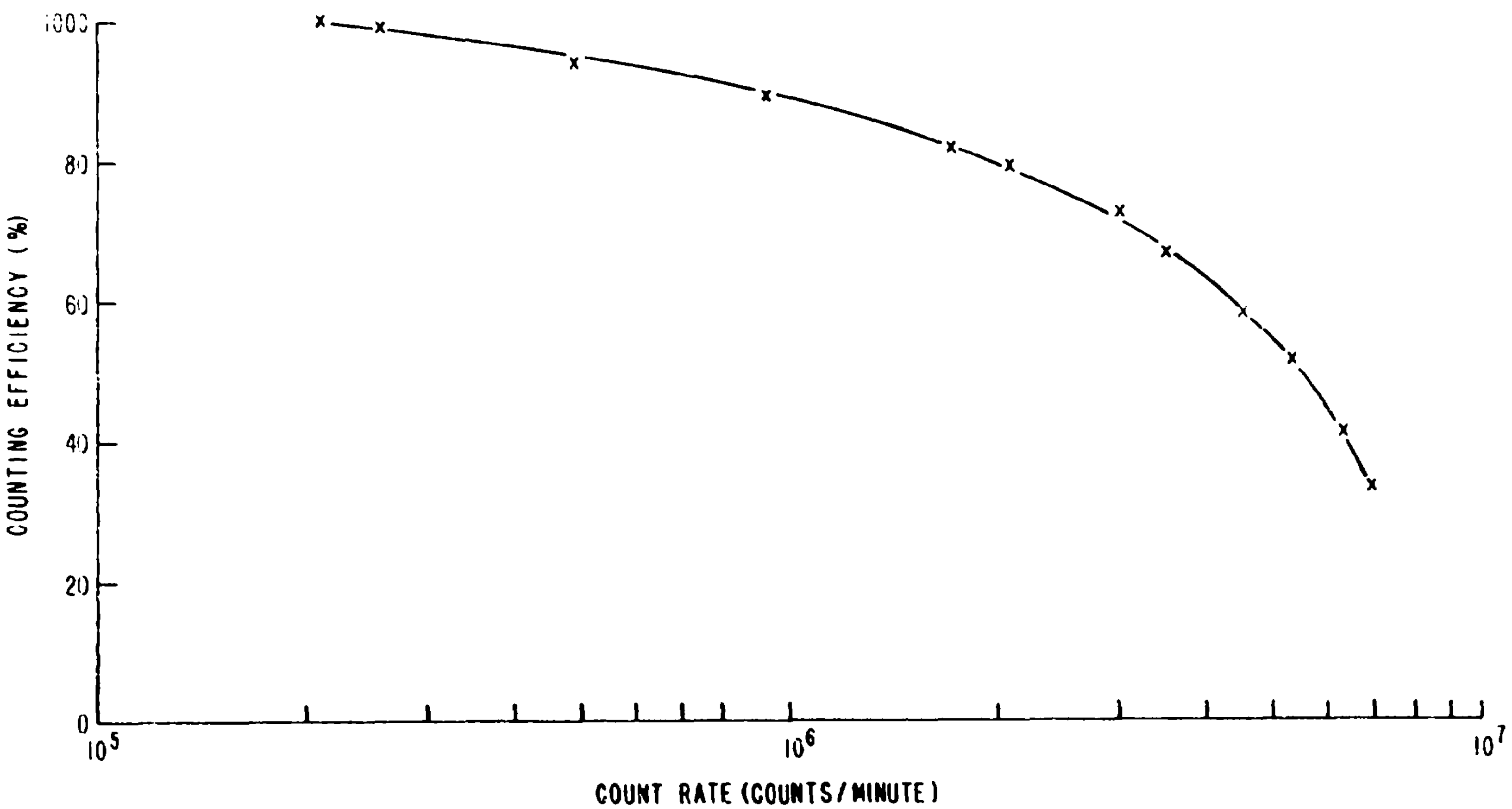

FIGURE 2. COUNTING RATE VERSUS COUNTING EFFICIENCY OF HIGH FLUX UNIT

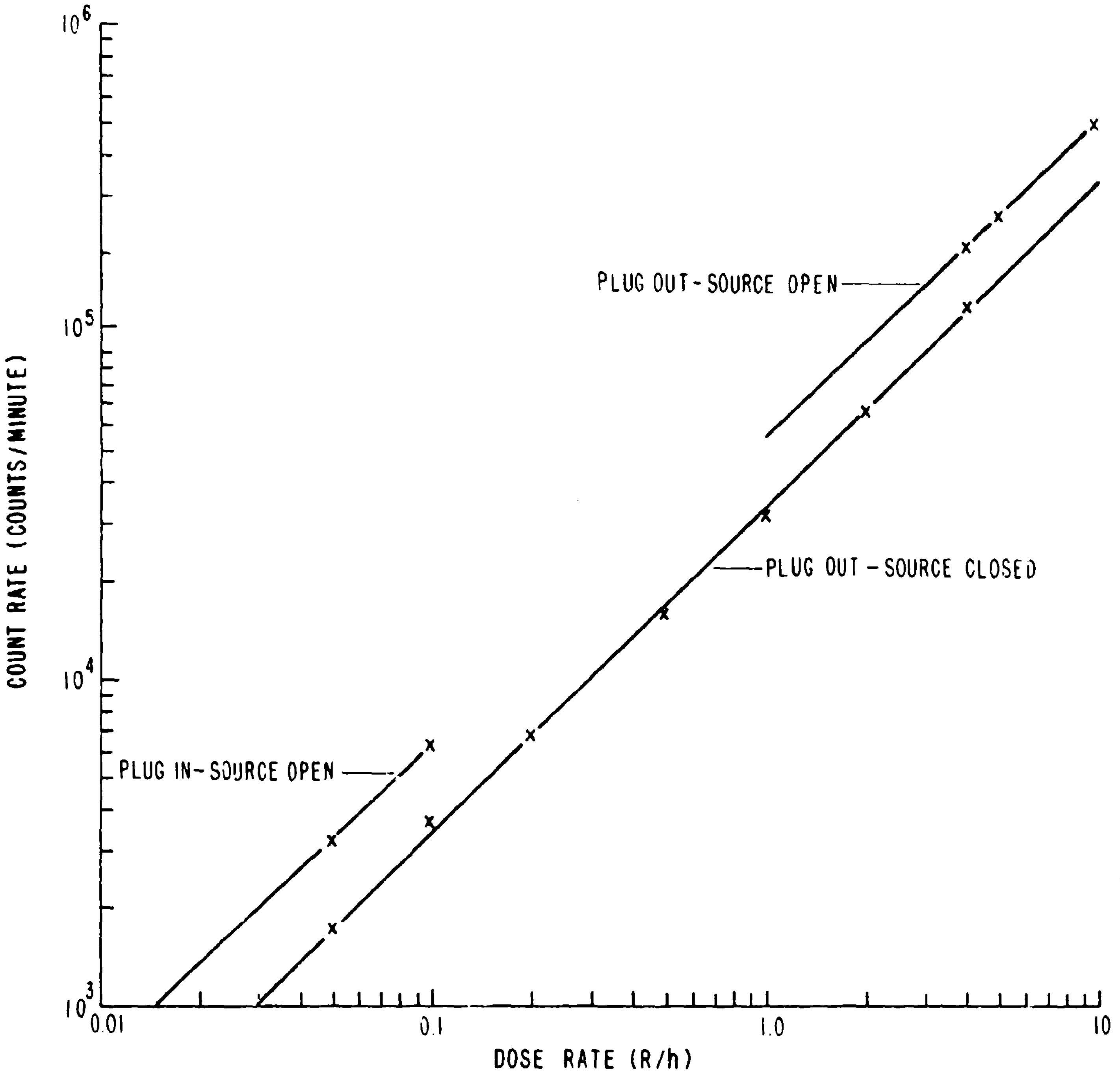

FIGURE 3. CALIBRATION LINEARITY OF HIGH FLUX UNIT WITH Cs^{137} (AN/UDM-1A)

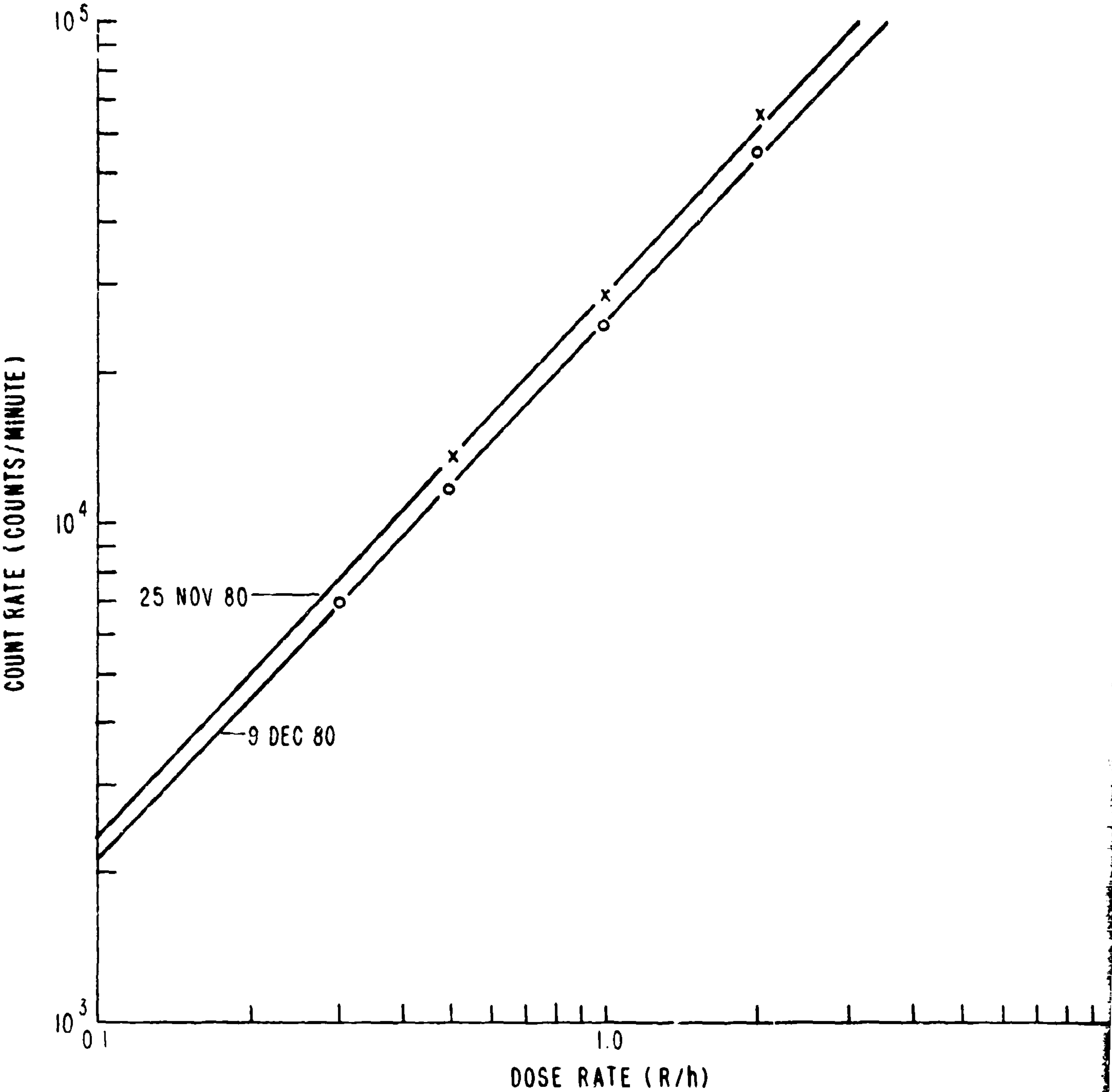

FIGURE 4. CALIBRATION LINEARITY OF HIGH FLUX UNIT WITH Co^{60}
(AN/UDM-1 WITH NO PLUG)

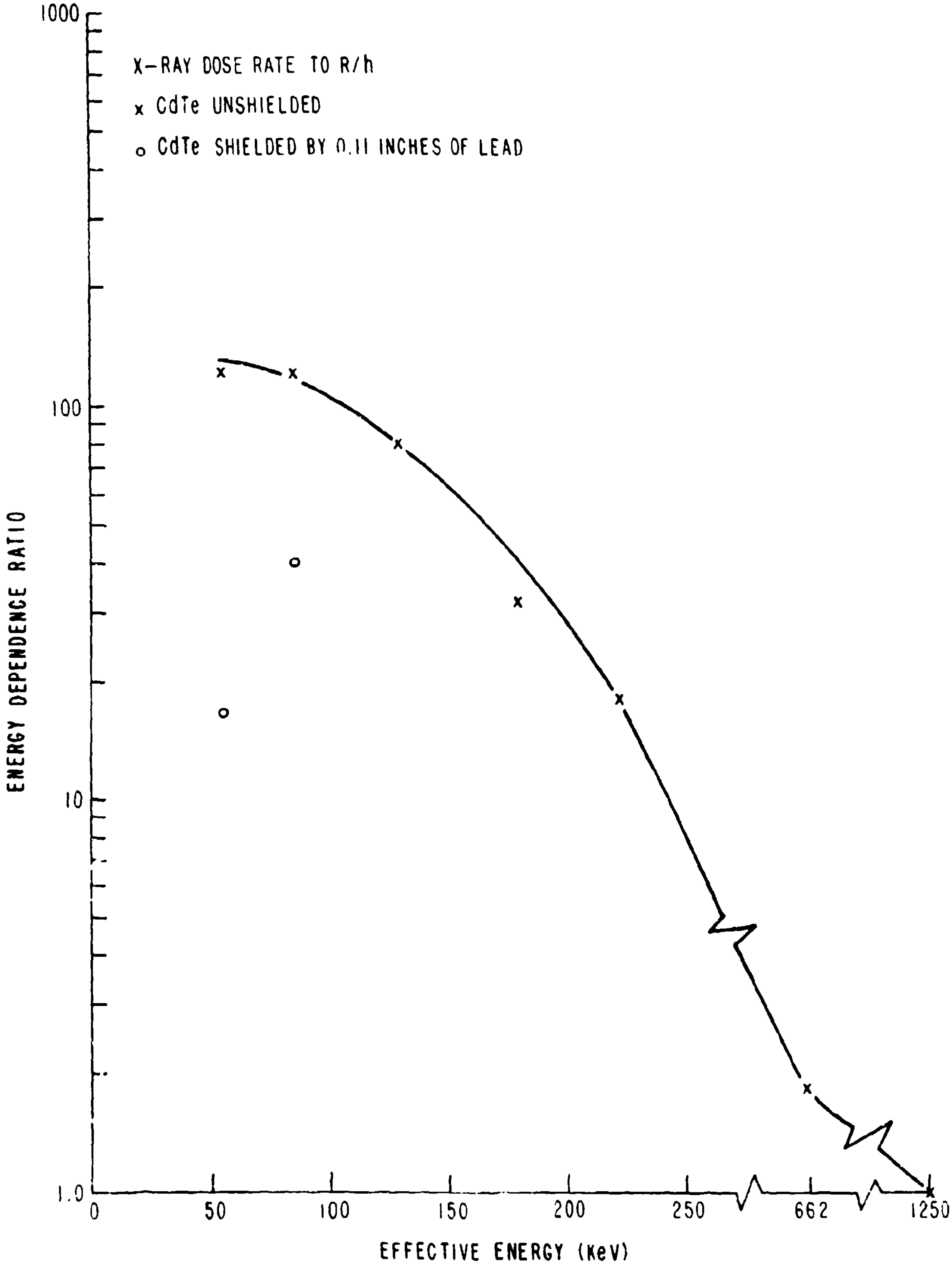

FIGURE 5. X-RAY ENERGY DEPENDENCE OF HIGH FLUX UNIT

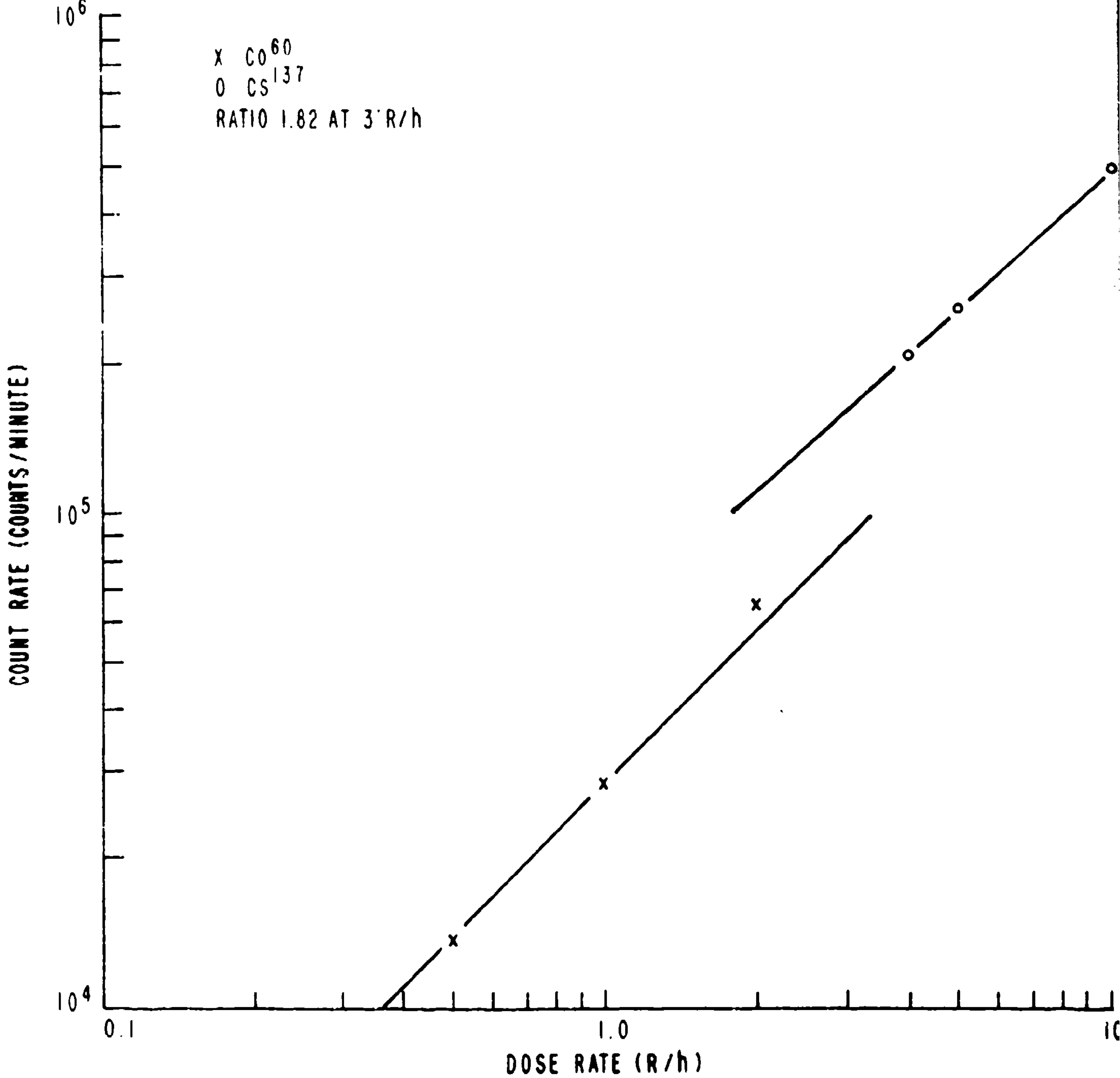

FIGURE 5A. ENERGY DEPENDENCE OF Cs^{137} COMPARED TO Co^{60} (SOURCES UNSHIELDED)

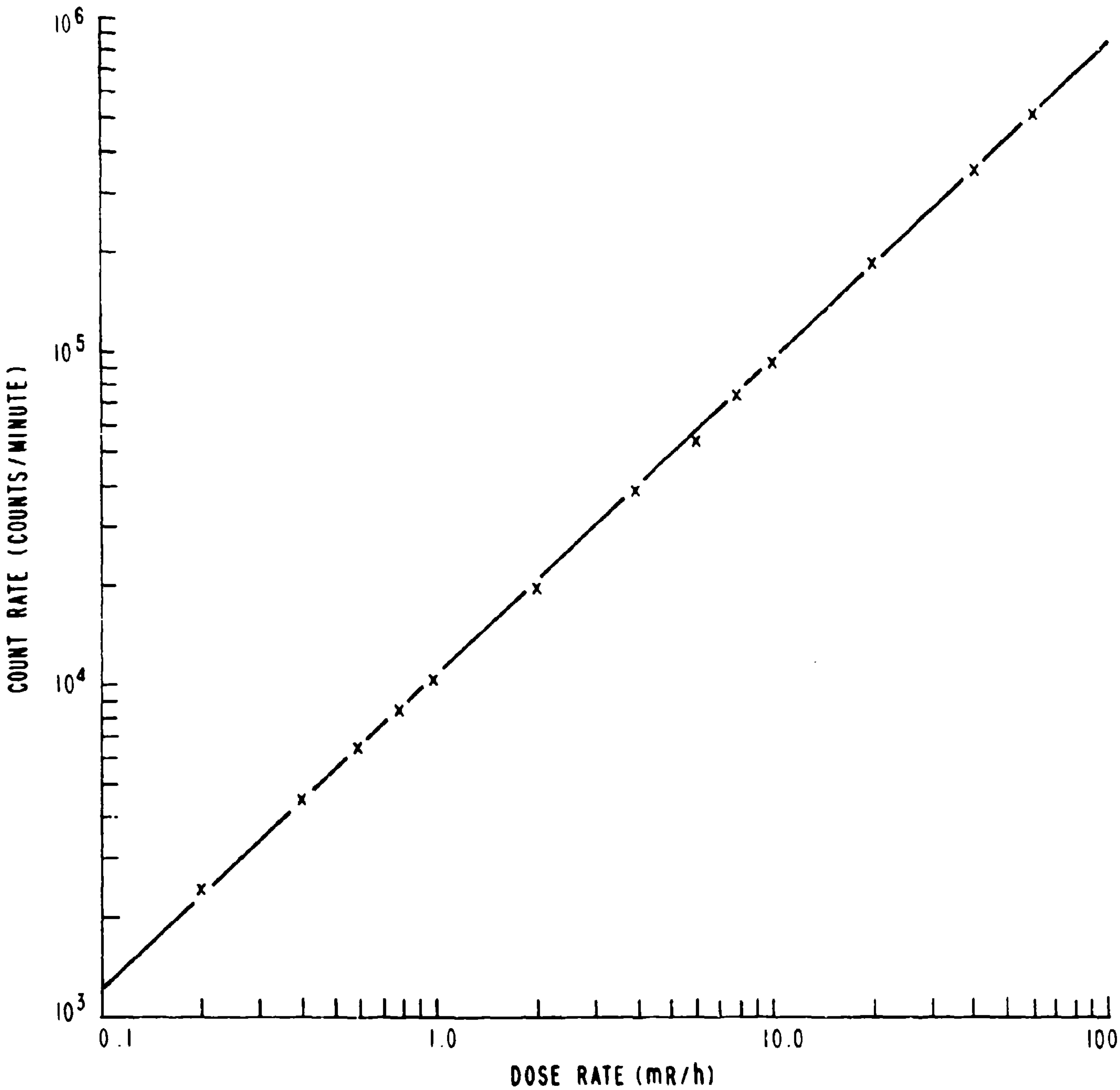

FIGURE 6. CALIBRATION LINEARITY OF LOW FLUX UNIT WITH Cs^{137}
(LOW LEVEL CALIBRATION RANGE)

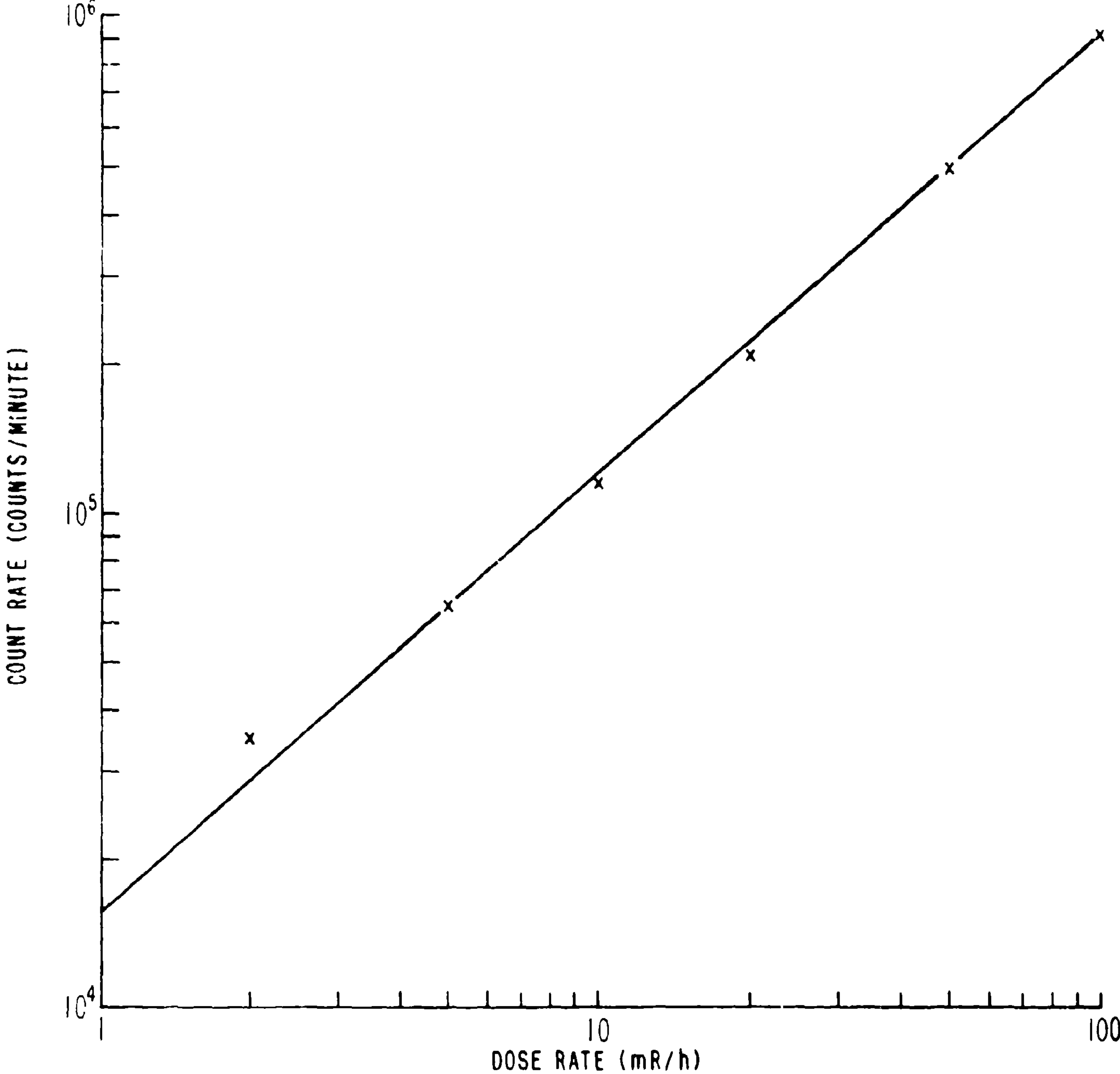

FIGURE 7. CALIBRATION LINEARITY OF LOW FLUX UNIT WITH Cs^{137}
(AN/UDM-1A, LOW RANGE)

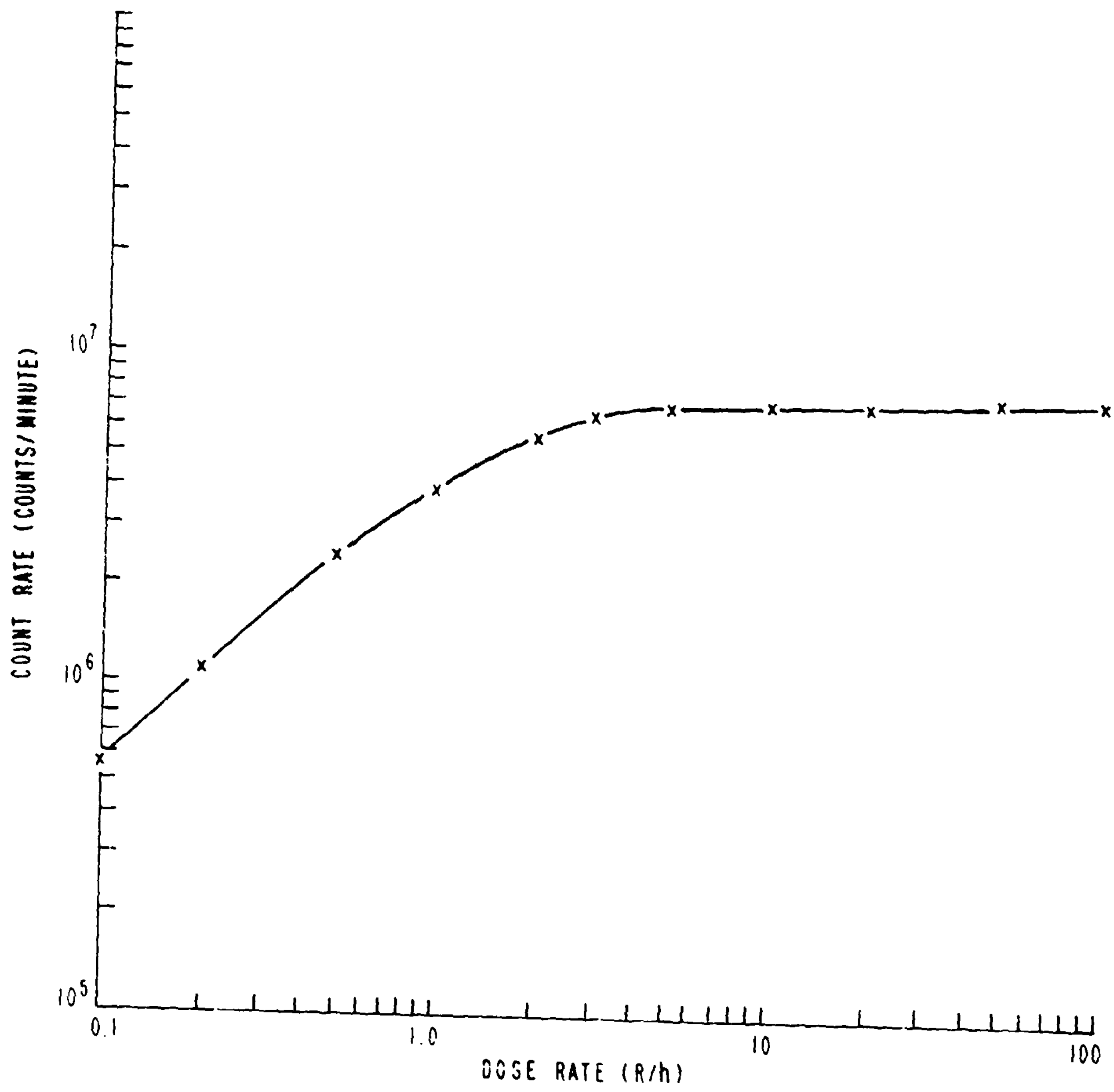

FIGURE 8. CALIBRATION LINEARITY OF LOW FLUX UNIT WITH Cs^{137}
(AN/UDM-1A, HIGH RANGES)

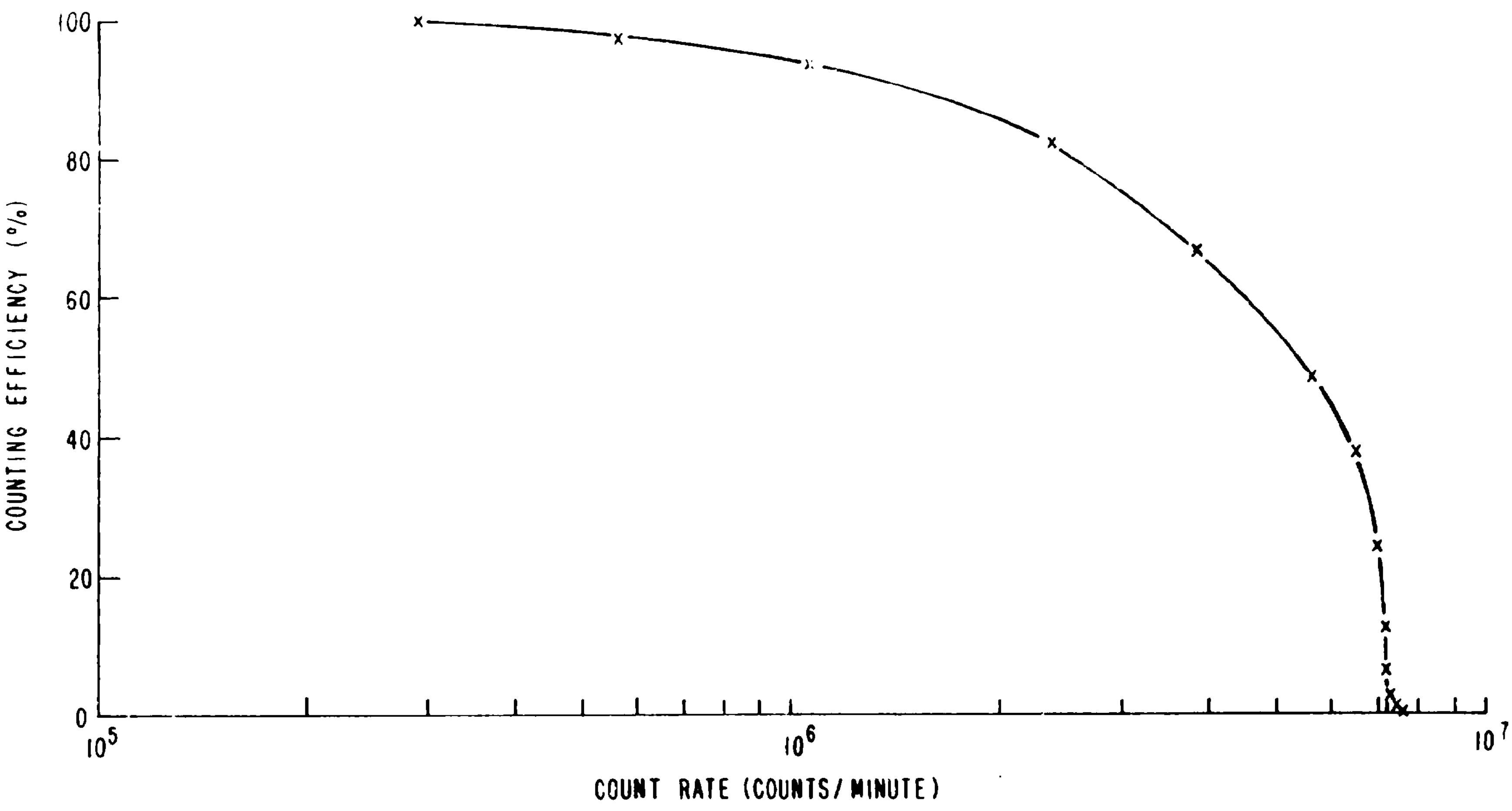

FIGURE 8A. COUNTING RATE VERSUS COUNTING EFFICIENCY OF LOW FLUX UNIT

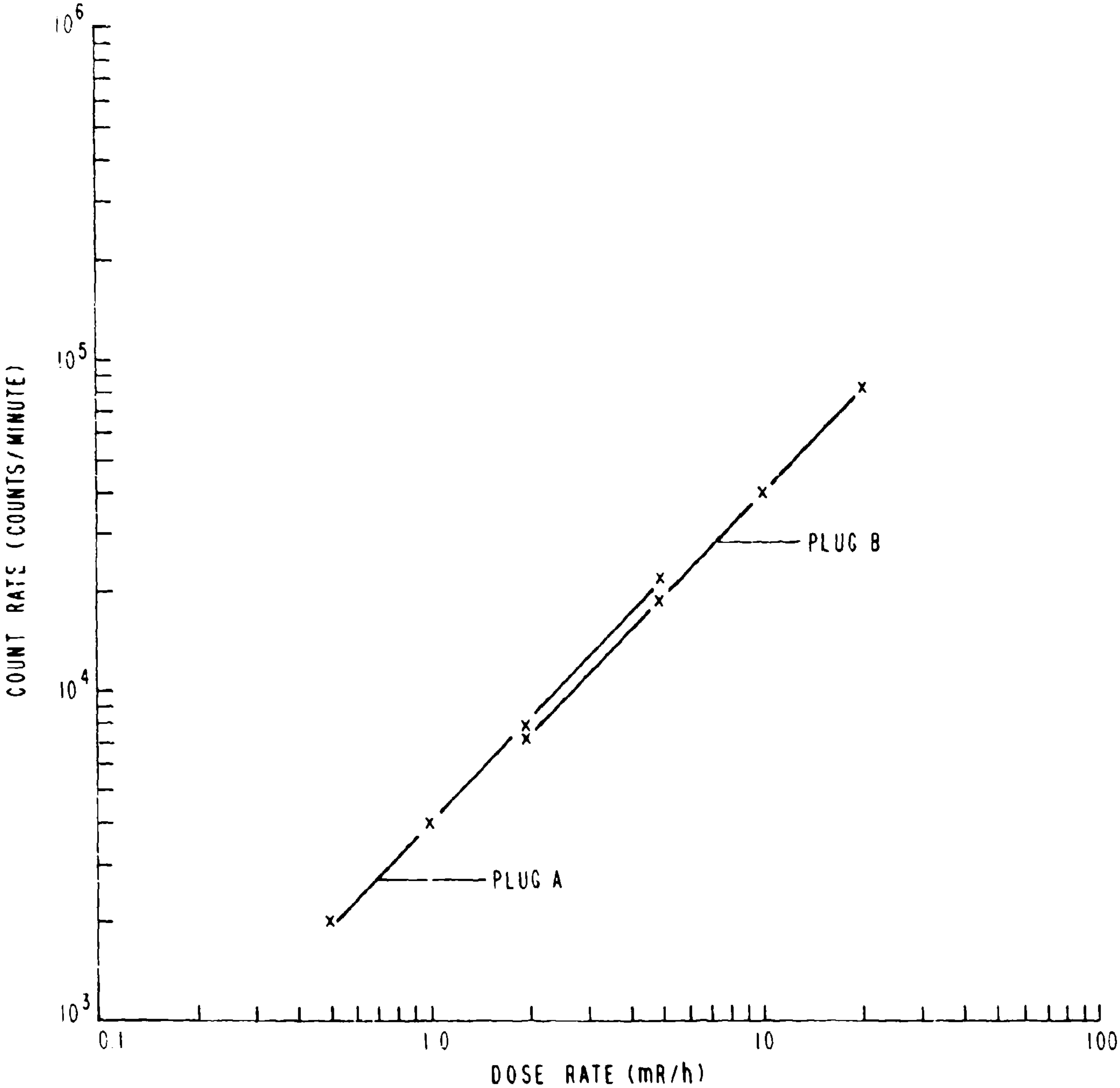

FIGURE 9. CALIBRATION LINEARITY OF LOW FLUX UNIT WITH Co^{60}
(AN/UDM-1, LOW RANGES)

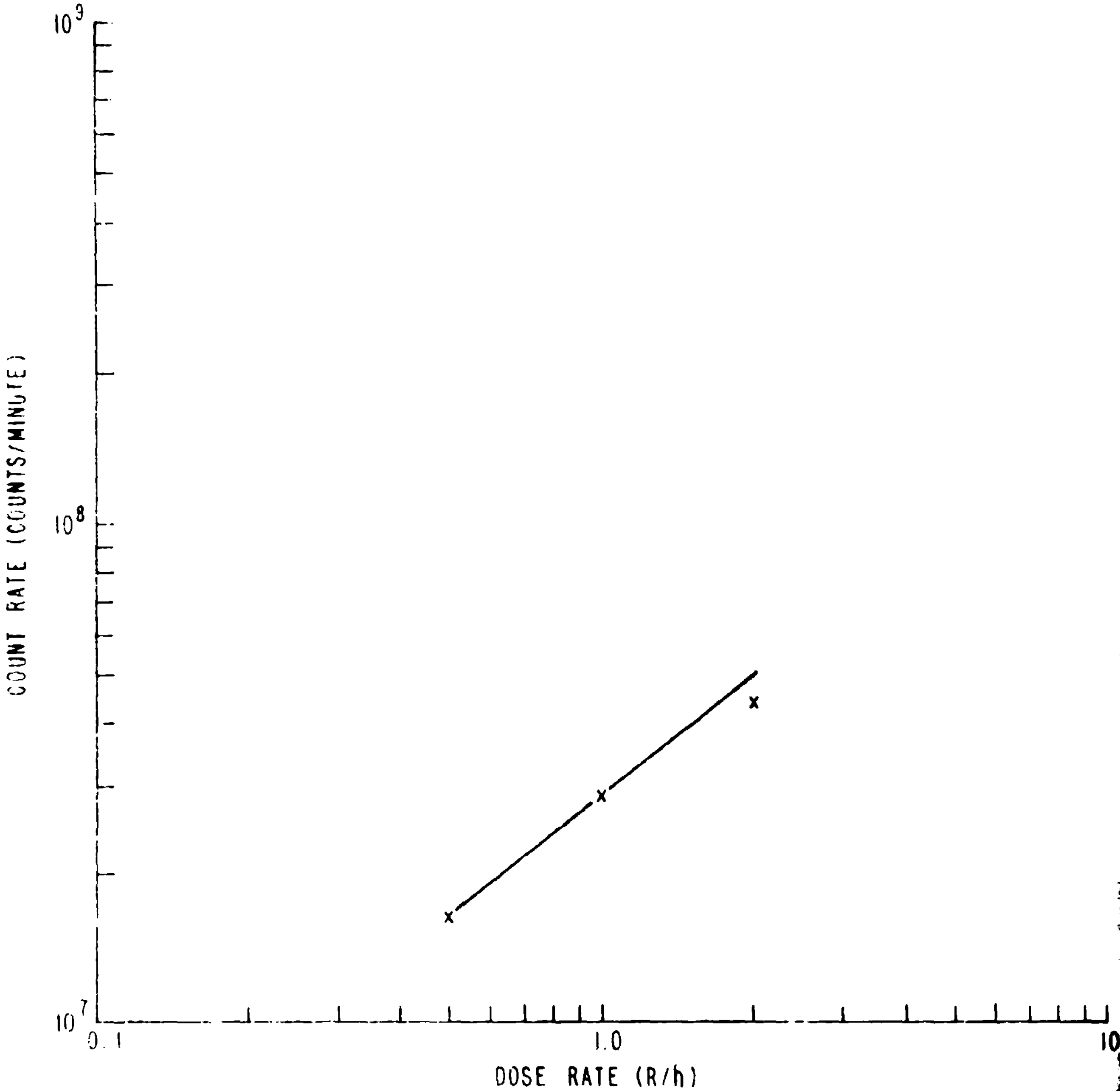

FIGURE 10. CALIBRATION LINEARITY OF LOW FLUX UNIT WITH Co^{60}
(AN/UDM-1, HIGH RANGE)

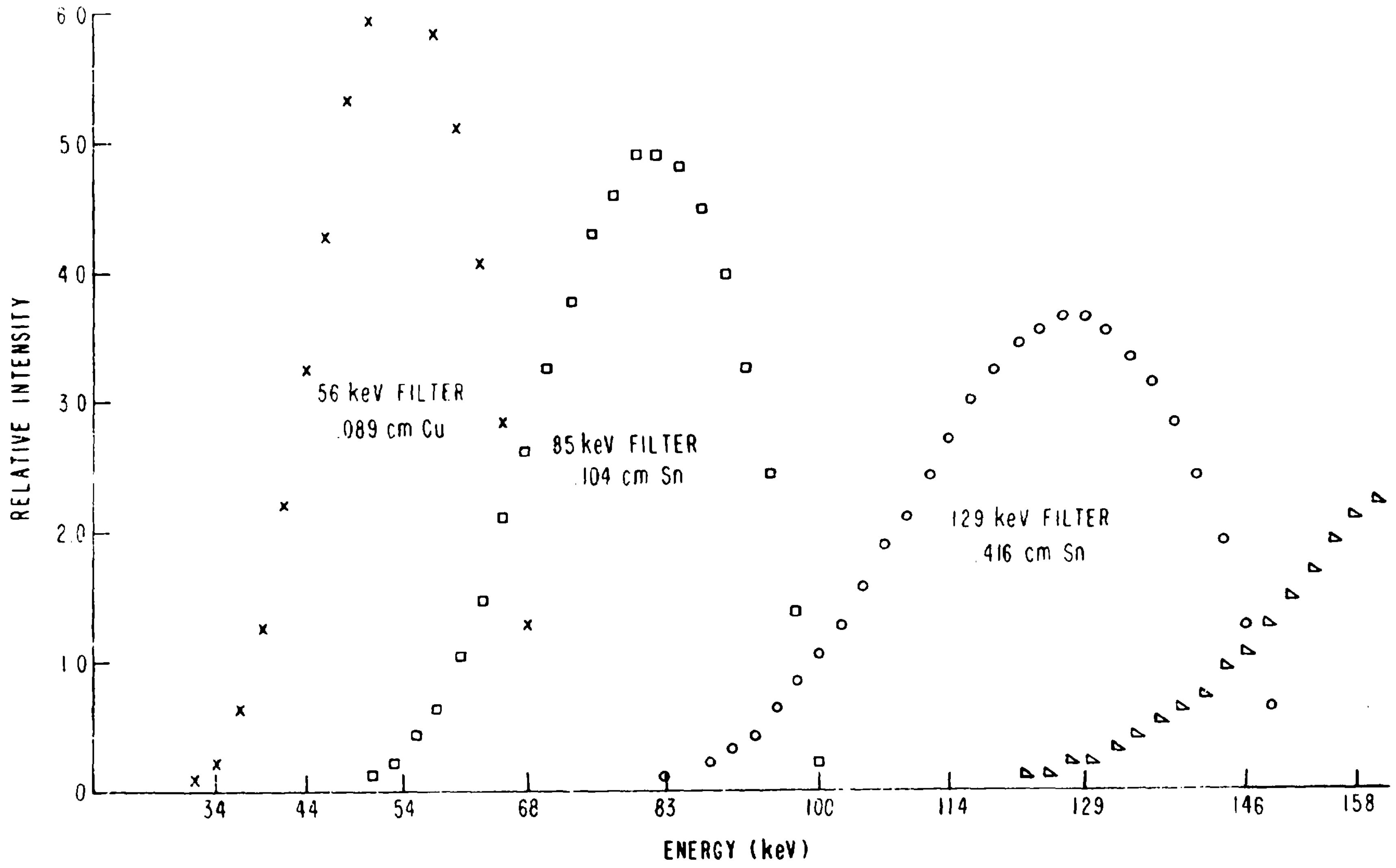

FIGURE 11. ENERGY DISTRIBUTION OF X-RAYS AT EFFECTIVE ENERGIES OF 56 keV, 85 keV AND 129 keV

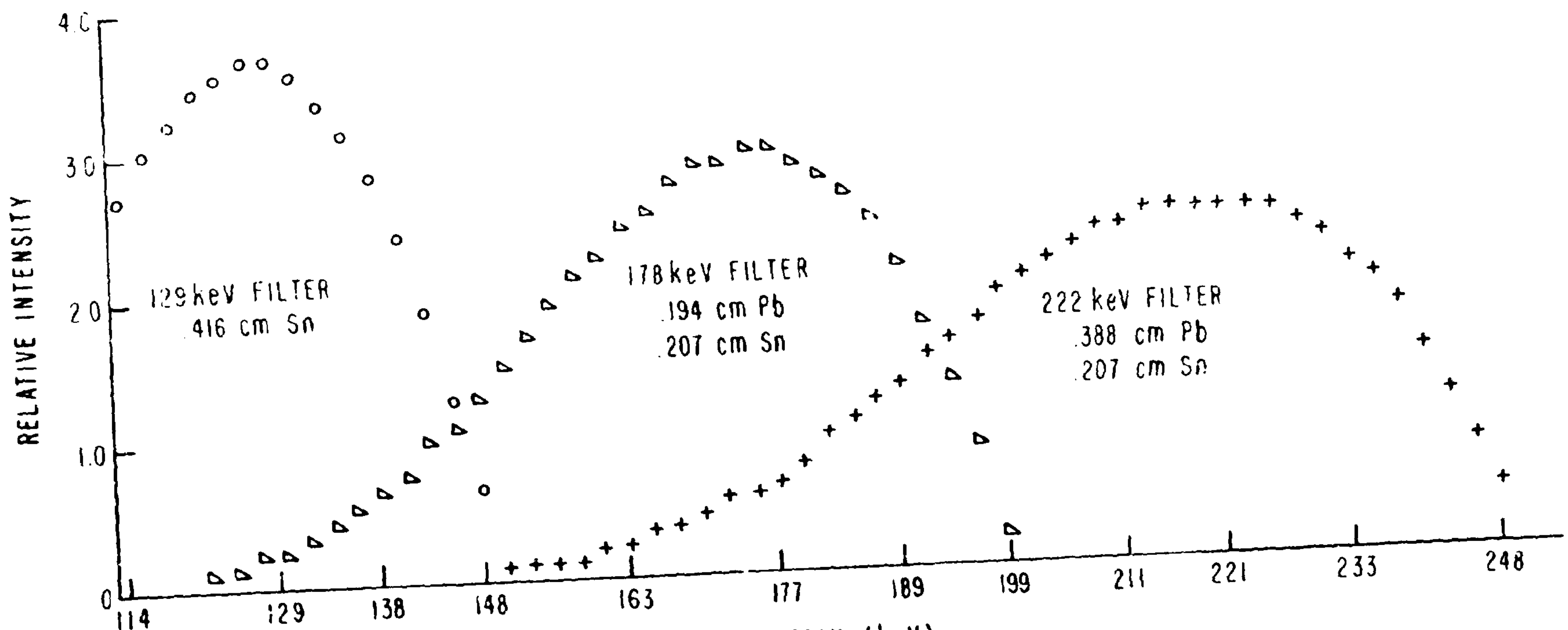

FIGURE 12. ENERGY DISTRIBUTION OF X-RAYS AT EFFECTIVE ENERGIES OF 129 keV, 178 keV AND 222 keV

TABLE 1. CALIBRATION LINEARITY OF HIGH FLUX UNIT WITH Cs^{137}
(AN/UDM-1A WITH PLUG OUT-SOURCE OPEN)

Radiation Rate R/h	Count Rate Counts/Minute	C/m/R/h	%(4R/h)
4	209,900	52.5	100.0
5	259,400	51.9	98.9
10	492,600	49.3	93.9
20	932,200	46.6	88.8
40	1,722,000	43.1	82.1
50	2,081,000	41.6	79.2
80	3,010,000	37.9	72.2
100	3,524,000	35.2	67.0
150	4,578,000	30.5	58.1
200	5,346,000	26.7	50.9
300	6,336,000	21.7	41.3
400	6,999,000	17.5	33.3

TABLE 2. CALIBRATION LINEARITY OF HIGH FLUX UNIT WITH Cs^{137} (AN/UDM-1A)

Radiation Rate mR/h	Count Rate Counts/Minute	Source Mode
50	1,754	Plug Out-Source Closed
100	3,586	Plug Out-Source Closed
200	6,666	Plug Out-Source Closed
500	15,910	Plug Out-Source Closed
1,000	32,152	Plug Out-Source Closed
2,000	65,849	Plug Out-Source Closed
4,000	136,828	Plug Out-Source Closed
50	3,231	Plug Out-Source Open
100	6,325	Plug Out-Source Open
4,000	209,966	Plug Out-Source Open
5,000	259,400	Plug Out-Source Open
10,000	492,600	Plug Out-Source Open

TABLE 3. CALIBRATION LINEARITY OF HIGH FLUX UNIT WITH Co^{60} (AN/UDM-1 WITH NO PLUG)

Radiation Rate R/h	Count Rate 25 Nov 80 Counts/Minute	Count Rate 9 Dec 80 Counts/Minute	Ratio
0.3		6,957	
0.5	13,732	11,852	0.86
1.0	28,372	25,178	0.89
2.0	65,188	56,029	0.86

TABLE 4. X-RAY ENERGY DEPENDENCE OF HIGH FLUX UNIT AT 10 R/h

Effective Energy keV	Count Rate Counts/Minute	Counting Efficiency Factor	Normalized Count Rate Counts/Minute	Energy Dependence Ratio*
56	7,857,000	4.55	35,700,000	124.3
85	7,792,000	4.44	34,600,000	120.3
129	7,117,000	3.22	22,900,000	79.5
178	5,028,000	1.82	9,150,000	31.8
222	2,907,000	1.39	4,040,000	14.0
662	492,700	1.06	523,000	1.82
1250	287,000	1.00	287,000**	1.00
56***	3,318,000	1.46	4,844,000	17.9
85***	5,972,000	1.82	10,867,000	40.1

* Compared to 1250 keV
** Derived from Figure 5
*** CdTe covered with 0.0156 inches of lead

TABLE 5. TEMPERATURE TEST OF HIGH FLUX UNIT

Temperature °C	Count Rate Counts/Minute	Ratio*
23	2,617	1.00
52	2,615	1.00
-51	2,582	0.99

* Compared to Room Temperature Reading

TABLE 6. TEMPERATURE TEST OF LOW FLUX UNIT

Temperature °C	Count Rate Counts/Minute	Ratio*
21	6,932	1.00
52	6,672	0.96
-34	7,920	1.14

* Compared to Room Temperature Reading

TABLE 7. CALIBRATION LINEARITY OF LOW FLUX UNIT WITH Cs^{137}
(LOW LEVEL CALIBRATION RANGE)

Radiation Rate mR/h	Count Rate Counts/Minute
0.2	2,423
0.4	4,422
0.6	6,449
0.8	8,453
1.0	10,591
2.0	19,681
4.0	38,158
6.0	54,451
8.0	74,447
10.0	93,740
20.0	184,681
40.0	356,933
60.0	509,995

TABLE 8. CALIBRATION LINEARITY OF LOW FLUX UNIT WITH Cs^{137} (AN/UDM-1A WITH PLUG OUT-SOURCE CLOSED)

Radiation Rate mR/h	Count Rate Counts/Minute	Source Mode
2	34,850	Plug in-Source Open
5	65,142	Plug in-Source Open
10	114,100	Plug in-Source Open
20	209,200	Plug in-Source Open
50	494,300	Plug in-Source Open
100	934,800	Plug in-Source Open
50	291,000	Plug Out-Source Closed
100	564,000	Plug Out-Source Closed
200	1,087,000	Plug Out-Source Closed
500	2,391,000	Plug Out-Source Closed
1,000	3,880,000	Plug Out-Source Closed
2,000	5,650,000	Plug Out-Source Closed
3,000	6,565,000	Plug Out-Source Open
5,000	6,997,000	Plug Out-Source Open
10,000	7,198,000	Plug Out-Source Open
20,000	7,184,000	Plug Out-Source Open
50,000	7,304,000	Plug Out-Source Open
100,000	7,425,000	Plug Out-Source Open
200,000	7,521,000	Plug Out-Source Open

TABLE 9. CALIBRATION LINEARITY OF LOW FLUX UNIT WITH Co^{60} (AN/UDM-1)

Radiation Rate mR/h	Count Rate Counts/Minute	Source Mode
0.5	2,041	Plug A
1.0	3,989	Plug A
2.0	7,839	Plug A
5.0	22,053	Plug A
2	7,324	Plug B
5	18,834	Plug B
10	39,873	Plug B
20	83,357	Plug B
500	1,641,000	No Plug
1,000	2,847,000	No Plug
2,000	4,354,000	No Plug

TABLE 10. CALIBRATION LINEARITY OF LOW FLUX UNIT WITH Cs^{137} (AN/UDM-1A)

Radiation Rate mR/h	Counts/Minute	C/M/mR/h	% (50mR/h)
50	291,000	5,820	100.0
100	564,000	5,640	96.9
200	1,087,000	5,435	93.4
500	2,391,000	4,782	82.2
1,000	3,880,000	3,880	66.7
2,000	5,650,000	2,825	48.5
3,000	6,565,000	2,188	37.6
5,000	6,997,000	1,399	24.0
10,000	7,198,000	720	12.4
20,000	7,184,000	359	6.2
50,000	7,304,000	146	2.5
100,000	7,425,000	74	1.3
200,000	7,521,000	38	0.6

TABLE 11. COUNT STABILITY OF LOW FLUX UNIT

Date	Average Counts 10 Minutes ($\bar{x}$)	Standard Deviation (σ)	$\frac{\sigma}{\bar{x}}$ %	Number of Samples
10 Dec 80	179,873	279	0.155	7
11 Dec 80	179,862	822	0.457	21
12 Dec 80	180,398	1,187	0.658	10
16 Dec 80	179,959	938	0.521	13
17 Dec 80	179,783	679	0.378	16
18 Dec 80	180,569	898	0.497	8
19 Dec 80	180,357	797	0.442	14
22 Dec 80	180,563	980	0.543	16
23 Dec 80	180,582	687	0.380	11
24 Dec 80	181,020	978	0.540	7
5 Jan 81	180,357	848	0.470	14
6 Jan 81	180,016	1,203	0.668	9

TABLE 12. COUNT STABILITY OF LOW FLUX UNIT AT 1 R/h (3 SAMPLES, 1 MINUTE SAMPLE TIME)*

Date	Average Counts Per Minute
3 March 81	2,893,000
4 March 81	2,885,000
6 March 81	2,874,000
9 March 81	2,873,000
13 March 81	2,871,000
20 March 81	2,881,000
23 March 81	2,887,000
24 March 81	2,872,000

*Note: Detector voltage and Co^{60} radiation was applied continuously over entire period (3-24 Mar 81).