Radiation Physics Note 52

A STUDY OF NTA FILM BADGE RESPONSE TO X-RAYS

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Introduction

At Fermilab there are a number of sources of X-rays to which personnel might be exposed. These sources include X-ray machines in both the neutron therapy facility (NTF) and Lab D, and various accelerator devices and beam components located in accelerator areas.

This study includes measurements of the integral dose response of Landauer P1 (NTA) film badges,[1] pocket ionization chamber dosimeters,[2] and a Victoreen 555[3,4] ion chamber to X-rays from several representative X-ray sources. A dose rate comparison was made between an Elron GM Survey Meter and the V555 ion chamber in one case. The sources selected for measurement were the X-ray devices at NTF and Lab D, and an electrostatic septum under test at Enclosure B-12.

This study is intended to augment the laboratory's film badge testing (quality assurance) program as recommended in a recent DOE health physics audit.[5] The study also provides useful intercomparison data for the detection devices used.

The Victoreen 555 Ionization Chamber

Descriptions and a separate experiment using this ionization chamber are described elsewhere.[3,4] A response curve from Reference 4 is included here as Fig. 1.

The 0.1 DAS probe used in these measurements is rated for 20-250 keV. The chamber wall is made of C. Propionate of thickness 46 mg/cm^2. It is noted for future reference that the probe has a beta cutoff of 0.215 MeV energy electrons.[3]

The response of the V555 ion chamber to X-rays in the energy range of these measurements is nearly constant. The dashed line of Fig. 1 which is based on three calibration points suggests a 3% over response, although the calibration point in the energy range of these measurements indicates about a 3% under response. This apparent uncertainty in response falls within the manufacturer's ± 6% error for this instrument.[3] Note that the ion chamber dose data was not adjusted for an air density correction of 1.01.

It is believed that the V555 ionization chamber response is closely proportional to X-ray exposure dose (see Fig. 3) and that the data are accurate to ± 6% in the range of these measurements.

NTF X-Ray Measurements

Most of the measurements in this study were made using the NTF diagnostic X-ray unit.[7] The NTF X-ray beam cross section is broad and uniform, and the dose can be carefully controlled with a timer. Also, the tube voltages and hence photon energy (E_{max}) can be varied. The maximum photon intensity of typical diagnostic X-ray tubes occurs at approximately one-half the end-point energy corresponding to the tube high voltage setting.[6]

This study was conducted over a six month period. Three separate sets of NTF X-ray data were taken and sent separately for analysis. The first two sets of measurements were made with the V555 ionization chamber and three film badges exposed simultaneously. For the third set the V555 was not used, and the dose delivered was based on Figure 2. The chamber and films were placed at the point of intersection of the alignment lasers 168 cm from the X-ray source during irradiation. The data are tabulated in Tables 1A, 2A and 3. All exposures were at a broad focus current setting of 150 mA and at the voltage indicated.

In Tables 1A and 2A, column 3 contains the doses of the Victoreen 555 ionization chamber measured in the integral mode. Columns 4 and 5 contain average deep and shallow (skin) doses and standard deviations based on the three film badges exposed simultaneously at each position. The last column is the average V555 ion chamber dose rates computed from Columns 2 and 3. This number was calculated as a check for consistency in the data.

In Table 3 the dose expected based on the dose rate (58 mR/sec) and exposure time are listed in column 2. Columns 3 and 4 contain reported NTA deep and shallow doses, respectively.

Tables 1B and 2B contain pocket dosimeter[2] data for comparison with the ion chamber. In each case the dose represents an average of four readings together with the standard deviation.

Figure 2 contains a plot of the V555 ion chamber dose rate (Tables 1A and 2A, Col. 6) versus the X-ray units high voltage setting. This graph may prove useful for future film badge tests, keeping in mind that the tube output characteristics may change gradually with time.

In Fig. 3 the V555 ion chamber and NTA film response data taken from the three data sets at 70 kV have been plotted versus exposure time. The ion chamber data is highly linear, and it was analyzed by least squares which yielded a slope of 58 mR/sec. The film data, however, deviates from linearity. The film appears to under respond at low doses and over respond at higher doses compared to the ion chamber.

The NTA film results include both a shallow (skin) dose and a deep dose reading.[1] The deep dose is the dose delivered at 1 cm depth in a 30 cm diameter tissue equivalent sphere. The shallow dose is defined as the dose delivered to this sphere at a depth of 0.007 cm, which corresponds closely to the thickness of the epidermis of skin. The dose measured with the V555 ion chamber corresponds to deep dose.

Ratios of the NTA shallow-and deep-dose values were calculated and the averages at each tube voltage were plotted in Figure 4. Ratios for the Lab D and septum data at their respective operating high voltages were included as well. The error bars are standard deviations. The dose ratio appears to diminish with increasing tube voltage (photon energy) at constant tube current, possibly following a gradually sloping tail of an exponential-type function.

As an exercise, the shallow/deep dose ratios were fit to a line which extrapolates to a ratio 1 at about 160 kV, predicting that deep and shallow dose values will be reported equal for X-rays with endpoint energies above about 160 keV. The ratio of shallow dose to deep dose is expected to rise sharply at very low voltages corresponding to low photon energies. The dashed line represents one speculated possibility.

The NTA film and V555 ion chamber dose data are compared in Fig. 5. The NTA deep dose values of Table 2A at different high voltages were averaged for the ion chamber nominal doses of 50, 100, 250 and 500 mR and were plotted as the four shaded circles. The six open circles represent the data from Table 1A, and the triangles were used for the data of Table 3. The dashed line shows where the points would lie if the film and ion chamber dose (or expected) values were equal.

According to Fig. 5, the film under responds by the factor 0.7 at ion chamber doses below 150 mR and over responds by a factor of about 1.15 above 150 mR over the range of doses measured. The two solid lines were fit by eye to the data of the low-and high-range groups.

Two sets of measurements were made with pocket dosimeters and the V555 ion chamber and recorded in Tables 1B and 2B. In each case four dosimeters were measured simultaneously with the chamber probe in integral mode. They under responded by an average factor of 0.77. This under response is consistent with the response curves for the dosimeters at the peak intensity supplied by the manufacturer.[2] Therefore, a correction factor of 1/(0.77) = 1.3 must be applied to pocket dosimeter readings at 70 kV high voltage. This corresponds to an average photon energy of about 35 keV.

Lab D X-Ray Measurements

The X-ray dose was measured at two selected locations near the Lab D X-ray unit.[9] Measurements were made at both 120 kV and 140 kV. The data from these measurements are recorded in Table 4. Each of the data sets consisted of a simultaneous measurement with the V555 ion chamber, two or more NTA film badges, and in the case of data set 4 a pocket dosimeter. The devices were placed side by side in front of the X-ray beam port with the ion chamber in the center.

The measured values of data set No. 1 shown in columns 3 and 4 are 1680-, 1000-, and 230- mR, indicating a high degree of nonuniformity in the field. Data sets 2, 3, and 4 were measured in the same manner at an opening in the back of the X-ray unit. One film badge in each of data sets

2 and 3 were reported defective (and hence unread) by the vendor. The three entries in columns 4 and 5 of data set 4, represent three films with identical readings. A pocket dosimeter reading was included in column 6.

Because of the highly nonuniform fields measured in this case, no attempt was made to correlate the NTA film and ion chamber measurements. However, the average 120 kV shallow/deep dose ratio was computed and displayed in Figure 4.

These measurements were useful for a number of reasons. An important discovery was that the dose rate near this device can have large variations locally over a short range of a few centimeters. It points out the need for careful area surveys and for appropriate controls to prevent needless exposures to personnel.

Electrostatic Septum

An electrostatic septum undergoing tests at Enclosure B-12 was used as a source of X-rays. The septum was operated at 140 kV during the test measurements. An attempt was made to find a location of uniform field near the surface of the septum with only limited success. The data are listed in Tables 5A and 5B.

Data set No. 1 is comprised of an average of four pocket dosimeter readings plus a V555 ion chamber reading, all made simultaneously. For some unexplained reason the pocket dosimeters read 25% higher (rather than lower) than the V555 ion chamber. This is in contrast to the Lab D measurements in Table 4. It is also inconsistent with similar measurements recorded in Tables 1B and 2B for the NTF data. Possibly, the electrostatic field was strong enough to affect the ion chamber reading.

Data set 2 included simultaneous measurements with the V555 ion chamber, two film badges, and two pocket dosimeters. The location was not the same as for data set 1. The devices were aligned side by side in the order listed, with the V555 ion chamber in the center. The data indicate that the field was not uniform over the approximately 10 cm x 4 cm area where the measurements were made. The average NTA shallow/deep dose ratio at 140 kV was included in Fig. 4.

A comparison of dose rates was made at a particular location between the V555 ion chamber and an Elron GM survey meter. The results are listed in Table 4B. The ion chamber response is flat for low energy X-rays, according to Fig. 1. GM devices are known to over respond at low energies.[8] The over response factor is 1.7 requiring a correction of 1/1.7 = 0.6 for GM meter readings when measuring X-rays near septa and similar devices.

Summary

Dose measurements made with the NTF diagnostic X-ray unit could be done reliably because of good field uniformity and accurate control of exposures. Field measurements at the Lab D X-ray unit and at the electrostatic septum produced poorer results, primarily because of the lack of field uniformity.

The V555 ionization chamber was shown to be a convenient and accurate device for measuring X-ray doses.

Measurements of Landauer P1 (NTA) film badge responses to NTF X-rays showed a nonlinear effect. Below 150 mR, the badges under responded by a factor 0.7. Above 150 mR the badges over responded by a factor of about 1.15.

Pocket ion chamber dosimeters under responded to X-rays. The correction factor for pocket dosimeter readings was determined to be 1.3 at 70 kV.

A comparison of dose rate for the V555 ionization and an Elron GM survey meter near an electrostatic septum showed that the Elron over responded as was expected. The Elron correction factor was determined to be 0.6.

Acknowledgement

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References

1. Film Badge Type P1 supplied by R. S. Landauer, Jr. & Company, Glenwood, IL. 60425.

2. Dosimeter Corporation of America, Model 862-200 MR.

3. Instruction Manual for Model 555 Radocon II Integrating Ratemeter. Victoreen Instrument Division, 10101 Woodland Avenue, Cleveland, Ohio 44104. A copy of this manual is kept in the IMAC file of the Safety Section.

4. Couch, J., Fermilab Radiation Physics Note 50: A Comparison of the Victoreen Model 555 Ionization Chamber and NTA Film Responses to ^{137}Cs Gamma Rays. February 1985.

5. Department of Energy Health Physics Appraisal Report, July 16-24, 1984.

6. Johns, H. E. and J. R. Cunningham. The Physics of Radiology, 4th ed (1983) C. C. Thomas, publisher. See Figures 2-13.

7. Easymatic Super 325 diagnostic X-ray unit with molybdenum - tungsten target. The operation manual is kept in the Neutron Therapy Department Files.

8. Knoll, G. F. Radiation Detection and Measurement. John Wiley and Sons, New York 1979. See Chapter 7, especially pp 234-35.

9. This is an industrial radiography unit which is used by Experiment 653 to make fiducial marks on their detector emulsions.

TABLE 1A NTF Data Set No. 1 - NTA Film Response

High Voltage kV	Exposure Time (Sec)	Ion Chamber Dose (mR)	NTA Deep Dose (mR)	NTA Shallow Dose (mR)	Ion Chamber Dose Rate mR/sec
70	0.5	29	15±7	20	58
	0.65	38	25±7	25±7	58
	1.0	60	40	50	60
	3.0	177	225±21	240±14	59
96	1.0	120	78±5	88±5	120
	2.0	243	335±19	358±22	122

TABLE 1B NTF Data Set No. 1 - Pocket Dosimeter Response

High Voltage kV	Exposure Time (sec)	Ion Chamber Dose (mR)	Pocket Dosimeter (mR)	Ion Chamber Dose Rate mR/sec	Dose Ratio
70	3.0	177	140±4	59	0.79

TABLE 2A NTF Data Set No. 2 - NTA Film Response

High Voltage kV	Exposure Time (sec)	Ion Chamber Dose (mR)	NTA Deep Dose (mR)	NTA Shallow Dose (mR)	Ion Chamber Dose Rate mR/sec
96	0.50	58	30 ± 0	33 ± 6	116
	0.90	104	60 ± 10	73 ± 12	116
	2.2	250	353 ± 25	393 ± 42	114
		500	607 ± 35	637 ± 31	
81	0.60	48	30 ± 10	33 ± 6	80
	1.2	95	57 ± 6	63 ± 6	79
	3.2	247	357 ± 25	433 ± 60	77
	6.45	500	600 ± 20	647 ± 32	78
70	0.80	45	20 ± 0	30 ± 0	56
	2.0	112	70 ± 10	83 ± 15	56
	4.5	252	347 ± 15	407 ± 42	56
	9.0	510	620 ± 69	683 ± 93	57

TABLE 2A (cont.)

High Voltage kV	Exposure Time (Sec)	Ion Chamber Dose (mR)	NTA Deep Dose (mR)	NTA Shallow Dose (mR)	Ion Chamber Dose Rate mR/Sec
56	2.0	62	40 ±10	50 ±10	31
	3.4	105	67 ±15	83 ±21	31
	8.0	247	357 ±15	453 ±25	31
	16.0	490	563 ±25	607 ± 38	31
42	5.0	54	50 ±0	60 ±0	11
	10.0	107	80 ±0	100 ±0	11
	23.0	250	343 ±25	465 ±64	11

TABLE 2B NTF Data Set No. 2 - Pocket Dosimeter Response

High Voltage kV	Exposure Time (sec)	Ion Chamber Dose (mR)	Pocket Dosimeter (mR)	Ion Chamber Dose Rate mR/sec	Dose Ratio
70	2.4	136	102 ±4	57	0.75

TABLE 3 NTF Data Set No. 3 - NTA Film Response

Exposure Time (Sec)	Expected Dose (mR)	NTA Deep Dose (mR)	NTA Shallow Dose (mR)
1.4	81	57 ± 6	63 ± 6
1.7	99	53 ± 12	57 ± 6
2.1	122	83 ± 23	97 ± 29
2.4	139	83 ± 23	97 ± 21
2.7	157	247 ± 74	263 ± 85
3.1	180	213 ± 6	227 ± 6
3.5	203	213 ± 25	227 ± 25
4.3	249	287 ± 32	297 ± 35
5.2	302	327 ± 35	343 ± 31
7.0	406	437 ± 25	457 ± 15

HV = 70 kV

I = 150 mA

$\dot{D}$ = 58 mR/sec

TABLE 4 Lab D Data

Data Set No.	High Voltage kV	Ion Chamber Dose (mR)	NTA Deep Dose (mR)	NTA Shallow Dose (mR)	Pocket Chamber Dose (mR)
1	120	1000	1680	1790	—
			230	230	—
2	120	213	130	150	—
3	120	115	80	90	—
4	140	80	30	30	25
			30	30	
			30	30	

TABLE 5A NTA Film Response to Septum

Data Set No.	High Voltage kV	Ion Chamber Dose (mR)	NTA Deep Dose (mR)	NTA Shallow Dose (mR)	Pocket Chamber Dose (mR)
1	140	96	—	—	120 ± 18
2	140	152	—	—	85
			130	140	—
			210	210	—
			—	—	117

TABLE 5B Instrument Responses to Septum

Instrument	Dose Rate R/hr	Ratio
Elron	1.5	1.7
V555	0.9	

FIGURE 1

Calibration curve for V555 Ion Chamber. Circles are calibration points. Solid line is a "Typical" curve from Reference 1. Dashed line is an adjusted average calibration curve based on three calibration points.

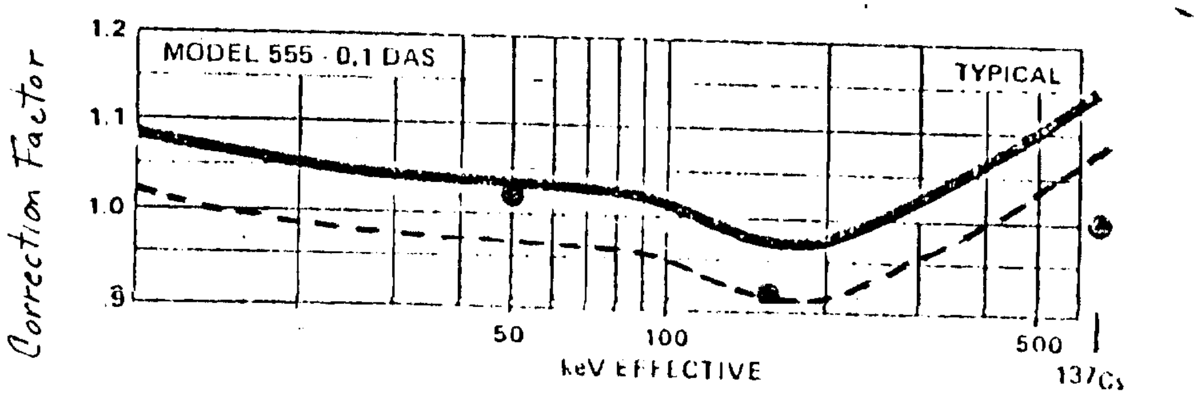


FIGURE 2

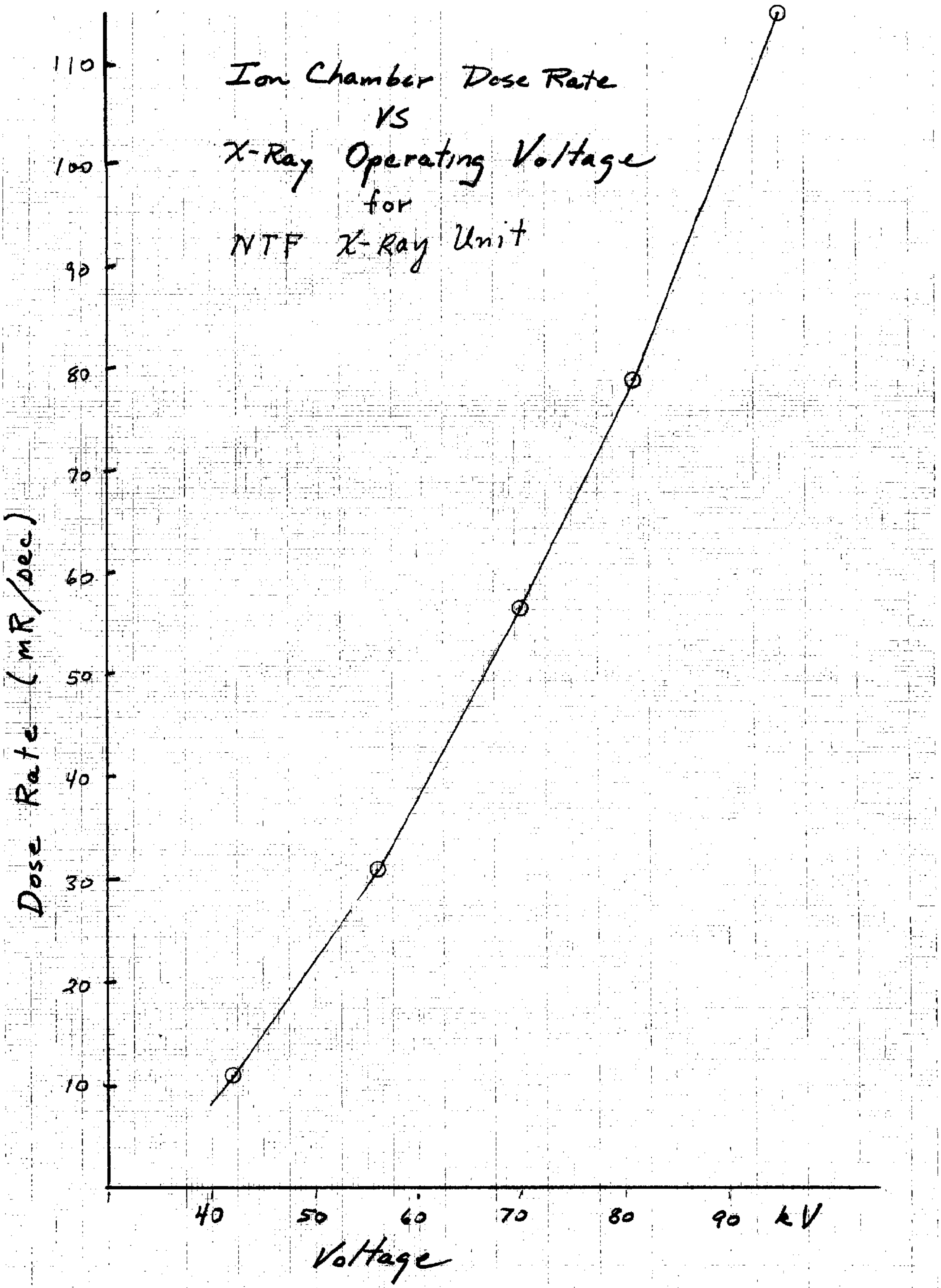

Ion Chamber Dose Rate
VS
X-Ray Operating Voltage
for
NTF X-Ray Unit
Dose Rate (mR/sec)
110
100
90
80
70
60
50
40
30
20
10
40
50
60
70
80
90
kV
Voltage

FIGURE 3

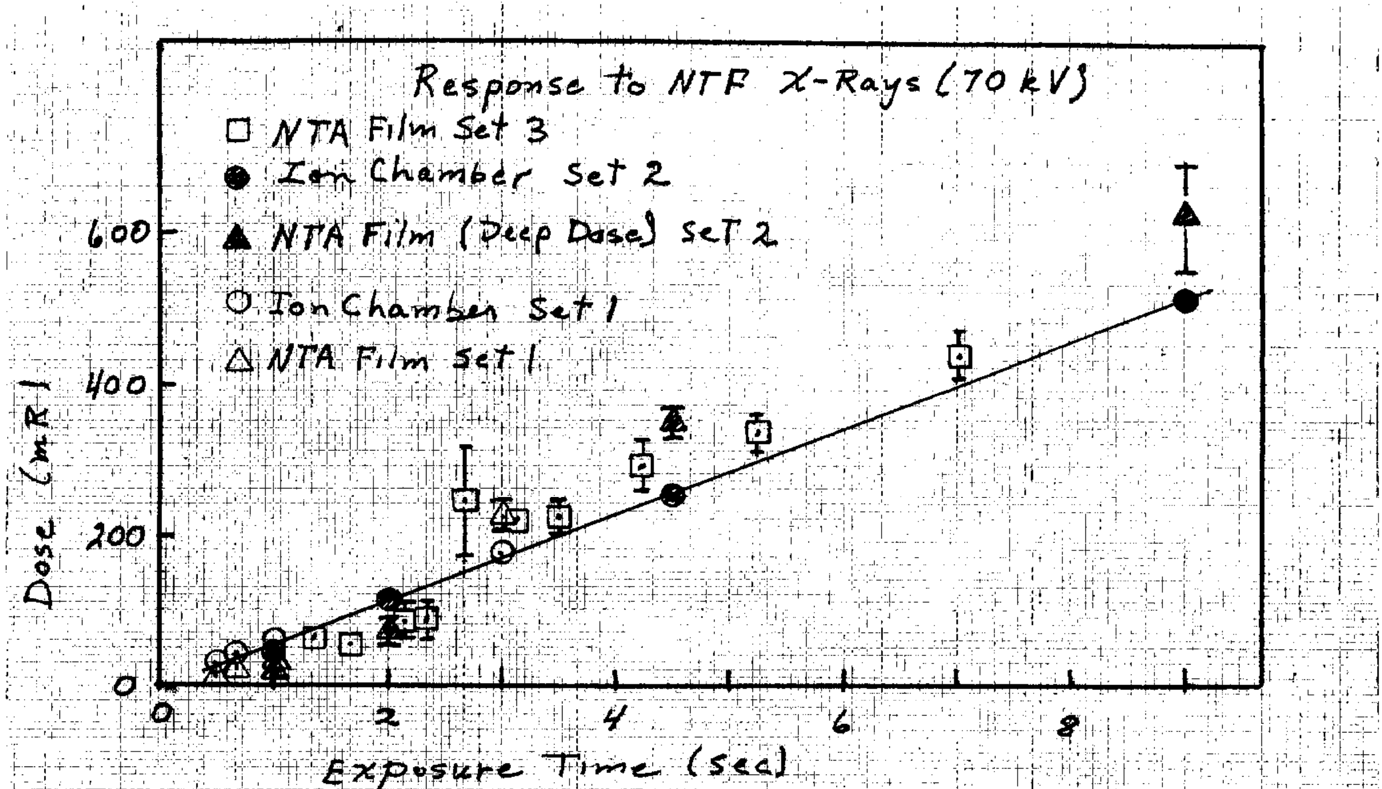


FIGURE 4

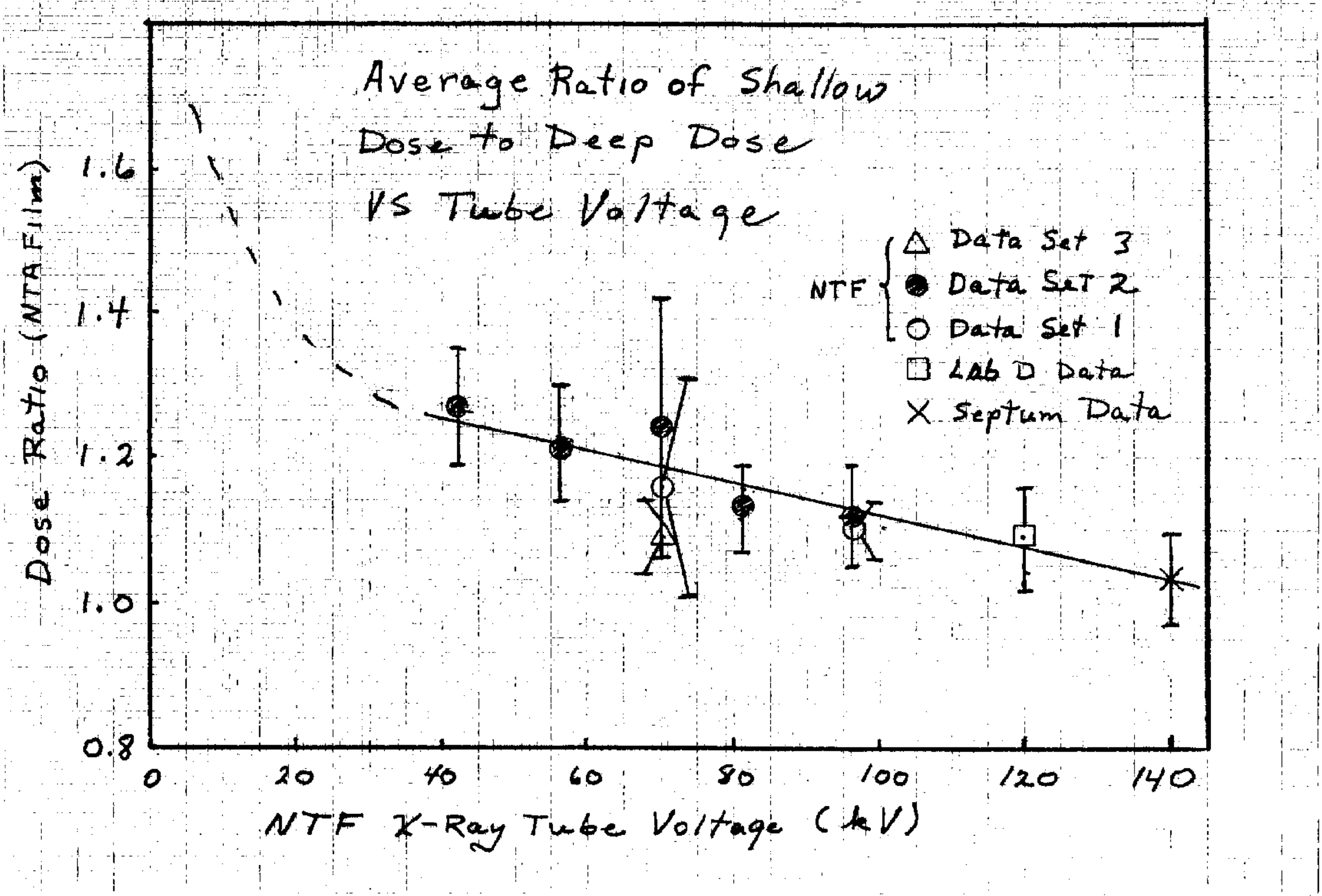
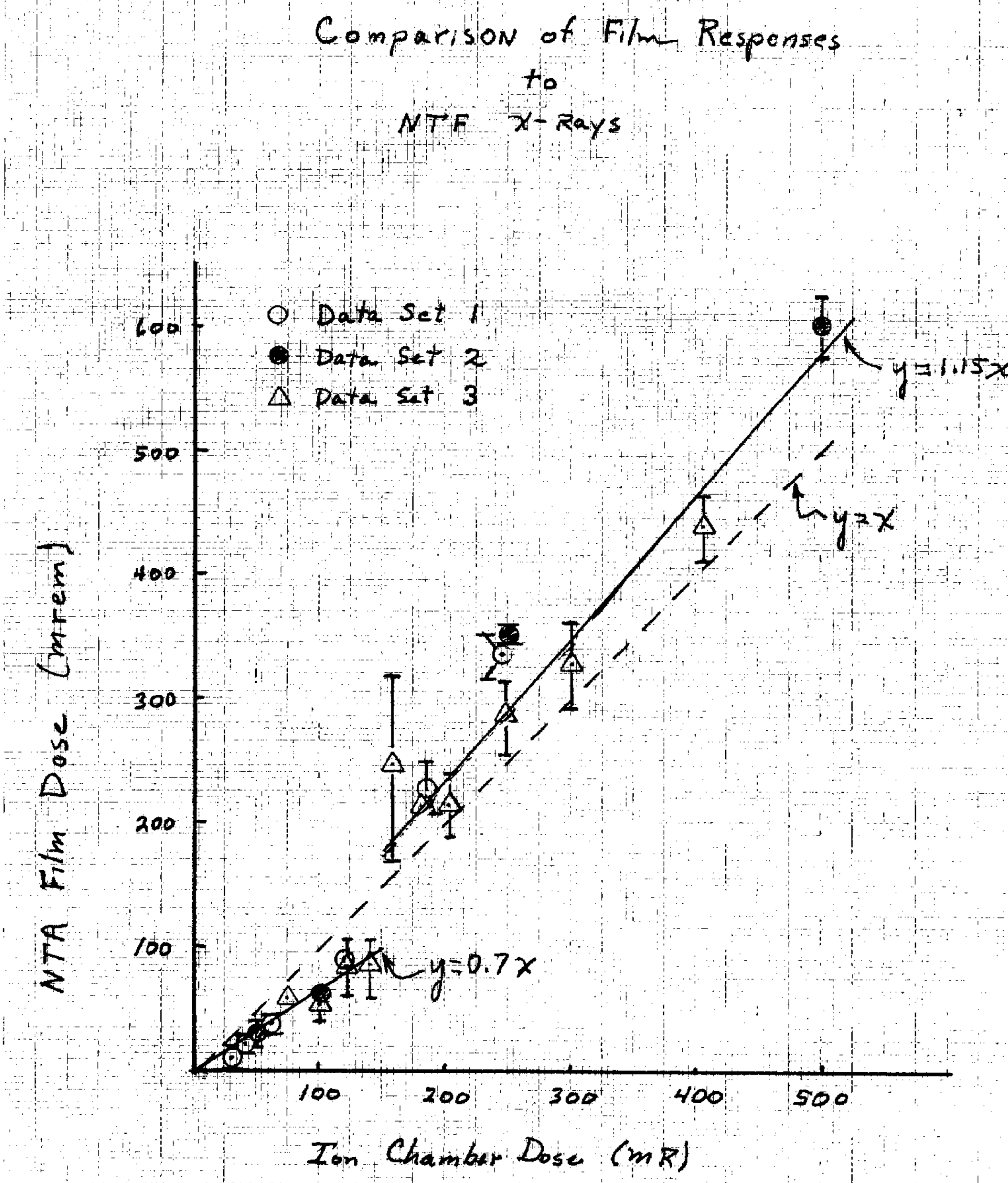


FIGURE 5


Comparison of Film Responses
to
NTF X-Rays
Data Set 1
Data Set 2
Data Set 3
y=1.15x
y=x
y=0.7x
600
500
400
300
200
100
100
200
300
400
500
NTA Film Dose (mrem)
Ion Chamber Dose (mR)