WHITE PAPER

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MGP INSTRUMENTS MODEL DMC 2000S ELECTRONIC DOSIMETER RESPONSE CHARACTERISTICS

INTRODUCTION

The purpose of this paper is to document a study by Columbia Generating Station (CGS) of the MGP Instruments (MGPI) Model DMC 2000S Electronic Dosimeter (ED) response characteristics to dose rate measurements. Specifically, the study focused on how the dosimeter reacts and triggers an alarm when the measured value reaches the corresponding dose rate alarm threshold value, as well as possible influences on audible and visual alarms. It is intended to provide CGS Radiation Protection personnel, or other interested CGS staff, with an enhanced general understanding of this concept. The level of detail in the paper assumes the reader already has some familiarity with the basic principles of radiation detection and measurement. A description section is included to describe the DMC 2000S, and give the reader a better understanding of how the ED functions.

This study was limited in scope to only dose rate measurement and alarm function since Battelle's Pacific Northwest Division extensively tested the performance of the DMC 2000S ED, and documented the evaluation in report No.PNWD-3040, Evaluation of the Model DMC 2000S Electronic Dosimeter. The scope of that test evaluated the dosimeters against the criteria of various national and international standards. It included performance areas such as Response Time, Measurement Range, Background Response, Dose Linearity, Dose Rate Linearity, and Response to Transient High Dose Rates, Photon Energy Dependence, Angular Response, Dose Alarm Accuracy, and Dose Rate Alarm Accuracy. It was not the intent of this study to duplicate or reproduce any of those tests since they have been covered in sufficient detail. If an individual would like to review the Battelle Report in addition to this white paper, an electronic copy of PNWD-3040 can be found in the EN Radiation Protection groups' folder on the S: Drive (S:\Radiation Protection\Radiological Support\Cal Lab\Instrument Info\DMC2000S Dosimeter). A hard copy is also maintained by Radiological Support, HP Staff Advisor - Instrument Specialist.

The dose rate alarm accuracy was previously tested as part of Battelle test (PNWD-3040, Section 3.17). The results of that test concluded that the DMC 2000S met both the criteria for dose rate alarm accuracy as defined ANSI 42.20, Section 5.3.11. Specifically, whereas the dose rate alarm activated within 5 seconds, and the dose delivered before the rate alarm activated was less than 1 mrem. The additional testing at CGS was conducted to determine what occurs during short duration exposures (e.g., < 5 seconds), the delay before, and length of time that audible and visual alarm signals were triggered. In addition, tests were also conducted to investigate the role of the instantaneous dose rate feature.

DMC 2000S DESCRIPTION

The DMC 2000S is an integrating alarming electronic dosimeter. The DMC 2000S uses a lithium drifted silicon diode detector to measure deep dose equivalent from penetrating radiation. The charge produced in the detector by ionizing radiation is converted by the ED electronic circuitry to dose equivalent in mrem through a dosimeter specific calibration factor. When gamma radiation interacts with the mass in the vicinity of the interaction zone of the detector, charged particles are created in the empty region. A small charge is created and collected by the polarization voltage, thus producing a small pulse across the diode. This pulse is fed "downstream" to a discriminator / preamplifier circuit and eventually to the amplifier.

The preamplifier converts the charge to an electrical pulse and the discriminator eliminates signals due to electrical noise. The amplifier then produces a pulse of significant amplitude for the microprocessor to register a count. The number of particles generated in the detector is proportional to the incident radiation and the mass of the material in close proximity of the detector. Additionally, the detector shielding is one of the reasons why the dosimeter is accurate. It ensures that the response of the detector (that is, number of pulses per mrem/hour of exposure rate of a given energy) is approximately constant.

The DMC 2000S is designed for integrating dose. It is not a dose rate instrument; it increments every so many pulses (typically about 300 pulses per mrem) and it does have an additional capability where an instantaneous dose rate can be calculated, displayed, and trigger an alarm if a preset rate threshold is exceeded. The algorithm used to make this determination is proprietary information but basically it can be explained as a dose rate indication that comes from a rolling calculation of pulses counted in each second, and then averaged over the integration time. The longer the integration time the more accurate the value will be. The behavior is somewhat like the electronic time constant in a GM instrument. The DMC 2000S will alarm on a quick spike of the time. It is dependent on the integration time (the default is a rolling 6-seconds) and the magnitude of that spike.

However, there is also an alarm trigger (for instantaneous rate increase) that deals with a prompt jump in pulse rate (from one second to the next). The down side would be if the elevated dose rate is less than the integration time, the maximum recorded dose rate in the ED may not be the same as the incident dose rate. In every instance during the testing it was found that this instantaneous rate is very conservative initially until several seconds of data (testing showed typically 2-3 seconds) are accumulated and integration time is considered into the dose rate determination. One more reason the value is conservative, it's the maximum of the all the instantaneous sampled rates in the register of the entire time frame that the dosimeter was in use.

METHODOLOGY

For the purposes of this testing, three dosimeters were selected at random from the CGS general population of dosimeters. The DMC-2000 dosimeters are calibrated on a six month frequency using the MGP CDM-21 Automated Dosimeter Calibrator, which is traceable to National Institute of Standards and Technology (NIST). HPI 7.53, Operation and Characterization of MGPI CDM-21 Dosimeter Calibrator and Calibration of the DMC 2000S Electronic Dosimeter provides instructions for the calibration of the DMC 2000S.

A series of exposures were performed on those dosimeters in the Kootenai Building HP Portable Instrument Calibration Lab using the Shepherd Model 28 beam irradiator and Model 150 Track System with an adjustable table. The Shepherd 28 contains a nominal 1.5 Ci Cs-137 source and has calibrated dose rates from 0.5 mR/hr up to 3000 mR/hr. Since varying dose rates were desired, including one test where the dosimeter is moving on the rolling table into an increasing dose rate field, the decision was made to perform the exposures "free in air" rather than using a polymethyl methacrylate (PMMA) phantom.

The measurements were made with the center of the detector as the reference point. When the phantom is used in dosimeter irradiations it is placed in a preset location at 100 cm directly on the track. It was determined the phantom is too large and heavy to safely place on the rolling table and it could also damage the delicate precision in the table or track drive system. Additionally, it would avoid any potential bias due to variations from the presence of the phantom in the radiation beam. Close to the source, the phantom may not be uniformly irradiated and, consequently, backscatter may be different than when the phantom is further from the source. Although the contribution of such differences would likely be small it was also considered in the decision not to use the phantom.

Since the exposures were not performed on a phantom, delivered dose rates were not converted to deep dose equivalent rates (e.g., exposure rates were not multiplied by the 1.06 quality factor), nor was any correction made for the +15% Geometry Coefficient Factor (GCF) applied to the dosimeters during calibration. The purpose of the correction factor is primarily to enhance the dosimeter response so the ED estimated dose more closely matches the Dosimeter of Legal Record (DLR).

DATA ANALYSIS

Measurement deviation tests

The first series of testing included a review of the dosimeter calculated dose rate response data. This analysis of dose rate data is shown on the tables in Attachment B. The information was obtained from calibration records from a random population of dosimeter calibrations using results from the CDM-21 Automated Dosimeter Calibrator. It should be noted that although the calibrator data is in mrem/hr it is a calculated dose rate value from the dosimeter using integrated dose data from timed measurements. It is not based on the instantaneous rate function.

This data demonstrates there is an obvious variation in measured values, and these values randomly fluctuate around a mean. This is considered normal in any set of radiation measurements. Any one value can easily approach $\pm$ 20% of the reference value due to normal statistical deviation. This is demonstrated in the column labeled percent difference from mean.

Note that the standard deviation and statistical analysis on the data indicates these numbers are very good. Even on the low rates where there is greater error propagation, the coefficient of variation is below 10% and on the high rates it is less than 5%. It is especially remarkable that the difference between mean of the numbers in each set and the reference values are found to be approximately 2.5 to 3.5 percent. This further demonstrates that when the dosimeter has a sufficient time interval (i.e., 10 seconds) to integrate into the algorithm, the calculated dose rate values are quite accurate.

This test did not observe instantaneous dose rate function since it is common knowledge with DMC 2000S users, and the manufacturer, that the values fluctuate considerably. At times the rates may be observed as high as 150 to 170% of the actual true value of a particular radiation field. These over estimations of dose rates are clearly demonstrated in the next section. Therefore, some forbearance must be shown when reviewing or analyzing the instantaneous/max dose rate values. Consider that the displayed (or stored) dose rate is only a "quick estimate", or a prediction, of the true radiation dose rate field. It is the maximum of the instantaneous sampled rates in the time frame that the dosimeter was used. This function is, by design, conservative in the estimated rate and is easily influenced by many factors such as dosimeter motion, or rapidly increasing radiation field intensity.

Dose Rate Alarm Testing

This test consisted of a series of measurements to determine how the dosimeter responds to short duration exposures (e.g., 4 seconds or less). The test was used to demonstrate at what point the dosimeter will consistently register and trigger audible and visual alarms. Additionally a test was conducted to try to replicate the effect of movement of the dosimeter in a radiation field. This was done by placing the dosimeter on a movable track and advancing the dosimeter from one dose rate into a higher field. Attachment C contains tables with the results those tests. During testing it became apparent that spikes in the instantaneous dose rate measurement do occur. When these brief spikes in dose rate take place, the dose rate threshold is exceeded and then recorded in the register as an alarm triggered. This likely does frequently occur even though an actual radiation field of that dose rate was never entered. This is demonstrated in Attachment C where a dose rate of 1390 mrem/hr is recorded as an instantaneous maximum rate although the maximum true radiation field was never greater than 1000 mR/hr.

CONCLUSIONS

Testing confirms evaluations documented in the Battelle Report PNWD-3040, and what has been observed in operational experience at CGS. Due to the normal design characteristics the typical linear response of the dosimeter for dose and dose rate increases as the radiation field dose rates and accumulated dose (time in those fields) increase. The result will be a higher indicated response than the actual delivered, or incident, radiation in these higher radiation fields. See Attachment A for energy response curves. For comparison, the relatively flat response curve of an ion chamber dose rate instrument is included.

A 15% geometry coefficient factor (GCF) is applied during calibration to enhance the dosimeter response and correct for varying energy dependence of the dosimeter that does result in close agreement with the DLR over long monitoring periods. This creates a desirable DRD/DLR ratio in exposure monitoring reports. However, the consequence of that calibration adjustment factor is the dosimeter will respond to an incident radiation field, as measured with a HP survey meter, by as much as 15% high. Additionally, there is a designed tendency for the dosimeter to respond higher as radiation field dose rates increase. This is evident in the linearity curve shown on Attachment A, Figure 3.2a. All these factors influence how the dosimeter responds in a radiation field and why the measured dose rates will be higher than the true radiation levels. This is a very conservative, but desirable, approach for an electronic alarming dosimeter.

Although the dosimeter is designed to integrate dose, an algorithm is used to approximate a dose rate by dividing incurred dose over a short sample time (found to be around three seconds). While this works fairly well in moderate to high dose rate fields, in low dose rate situations the short sample time coupled with the random nature of decay introduces significant low radiation counting statistical errors and instantaneous rate spikes which can result in erroneous (false) alarms. Even when using long sample times, such as during calibration, those deviations can be observed. Refer to Attachment B in the column showing the percent difference from the mean. It is evident as well that the deviations are much greater at low dose rates.

The testing confirmed that the DMC 2000S consistently triggers an alarm in every instance that the preset dose rate alarm threshold is exceeded and that alarm condition is recorded in the dosimeters' internal register. However, depending on the intensity and duration of the incident radiation, the audible and visual alarms may not always be activated although an alarm condition is recorded in the register. This is especially true if the duration of the incident radiation is less than two seconds. Furthermore, if the duration is short and the length of time the dosimeter is in an alarm condition (such as a spike in the instantaneous maximum rate), audible and visual alarm conditions may be so short in duration they are indistinguishable before the alarm condition clears. This was confirmed in the ED Rate Alarm Testing Attachment C, as well as Attachment D in the histogram text that when the dosimeter is in a radiation field on the "edge" of the alarm set point then the rate alarms will begin and end alarm anywhere from 1 to 6 seconds in duration.

Alternatively, for durations that are sufficient in length (typically 4 seconds or more) to allow for an accumulation of dose to be recorded, there can be little doubt that the alarm condition existed. In these instances, audible and visual alarm indicators are clearly evident and should be easily recognized by the wearer. Also, a review of the histogram could be used to calculate an average dose rate simply by multiplying the integrated dose in the one minute history period by 60 (min per hour) to derive the mrem/hr value for the integration period. Again refer to Attachment D Histogram text that shows as the dosimeter was moved into a delivered dose rate of 1000 mR/hr. When a one minute period is reviewed the total dose for that period is recorded in the histogram and can be multiplied by 60 (sec/hr). This would give the average rate in mrem/hr. In this instance 18.8 mrem was recorded in one min. The average calculated rate would be 18.8 x 60 = 1128 mrem/hr. That averaged value is very close to what would be expected to have been exposed to and would include the approximately 1.15 correction factor applied, in other words estimated 1150 mrem/hr. As discussed earlier, the instantaneous maximal rate for this this test was recorded in the register at 1390 mrem/hr.

Through the extensive empirical testing during the development of this white paper it is the authors opinion that dose rate set points < 50 mR/hr are of little to no value due to high false alarm rates. To ensure low to no false alarms, minimum set point values for rate alarms at or above 75 mR/hr work very well and would provide early indication of impending dose rates near100 mrem/hr. Selection of alarm set points to close to actual dose rates measured in the field using typical survey meters does not allow adequate margin for the ED to account for normal statistical variation in the measured values. With this limited margin and the typical variations evident in test measurement results, the probability is very high that at least one measured value will trigger a dose rate alarm threshold. This is due to statistical variation alone, even if the ED is stationary in a radiation field. The issue can be compounded when the ED is in motion such as when moving toward a radiation source, or when the dosimeter is swinging on a lanyard.

RECOMMENDATIONS

1) With the current CGS calibration adjustment (e.g., the GCF) of 15% and current CGS policy and procedural recommendation for dose rate alarm set points not to exceed 125% of anticipated area dose rates (150% for lower dose rates), a less than adequate margin exists to allow for normal statistical variation in the EDs measured values. There are two options recommended:

    a. Do not set rate alarm set points below 135% anticipated dose rates as measured by portable survey meters and recorded on survey documents; or,

    b. Add a 10% or 15% correction factor to the survey results to “normalize” the readings equivalent to the expected ED response for those actual area dose rates. This factor would be applied to survey results prior to setting rate alarm set points at 125% of the anticipated conditions.

2) The ED dose rate alarm set points should be established with consideration of maintaining a sufficient margin to allow for normal statistical variations in measured values. This is especially true in very low dose rate fields (e.g., <50 mR/hr) where error rate is much more pronounced due to the normal oscillation of radiation exposure at very low levels and the typical variations in indicated (measured) radiation readings.
   For this reason Dose Rate Alarm set points below 75 mR/hr should be avoided. Otherwise, false alarms would be likely resulting in significant time and resources investigating and recording the alarms. And ultimately when a false alarm is determined the cause, a loss of trust and confidence by the workers in the equipment, and its reliability.

3) When work involves worker positions such as leaning over, or working above a source where the dosimeter is not close against the body (such as it is when in a standing or seated position). A dosimeter swinging into a radiation field or toward a radiation source will have a difficult time responding to the percent change and predicting an accurate dose rate. In such instances dose rate alarms may be anticipated and considered during worker briefings.

   To minimize the potential for dose rate alarms consideration should be given to securing the dosimeter and/or lanyard to the individual such as an additional "badge clip" to clip the lanyard to clothing. The use of tape or a dosimetry belt could also be used to keep the dosimeter close to the body and prevent swinging. This might also be helpful for baggy protective clothing to keep the pocket of the PCs close to the body and near the DLR.

4) When working in tight locations such as squeezing between pipes when the dosimeter is in direct contact with a surface emitting radiation, consideration should be given to differences in geometry of the ED detector. The smaller size of the device compared to that of a survey instrument (i.e., RO2/2A), can cause the dosimeter response to be higher than what was measured with a survey meter. This higher indicated ED response along with the known statistical variations in measured values may cause rate alarm thresholds to be exceeded, and rate alarms triggered based on statistical probabilities alone. In these instances dose rate alarms may be anticipated and considered during worker briefings.

REFERENCES

1. DMC 2000S Electronic Dosimeter User's Manual

2. PPM 11.2.9.31, Operation of the MG DMC-2000 Electronic Dosimeter

3. PNWD-3040, Evaluation of the MGP Instruments Model DMC 2000S Electronic Dosimeter. January 2001

4. American National Standards Institute (ANSI) N13.27, 1997. American National Standard for Dosimetry – Performance Requirements for Pocket-sized Alarm Dosimeters and Alarm Ratemeters.

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ATTACHMENTS

Attachment A – DMC 2000S Response Curves from Battelle Report PNWD-3040.

Attachment B – Dose Rate Measurement Deviation Test

Attachment C – ED Rate Alarm Test

Attachment D – ED Alarm Test Dosimeter Histogram Text

Energy Response Curve from Battelle Report PNWD-3040

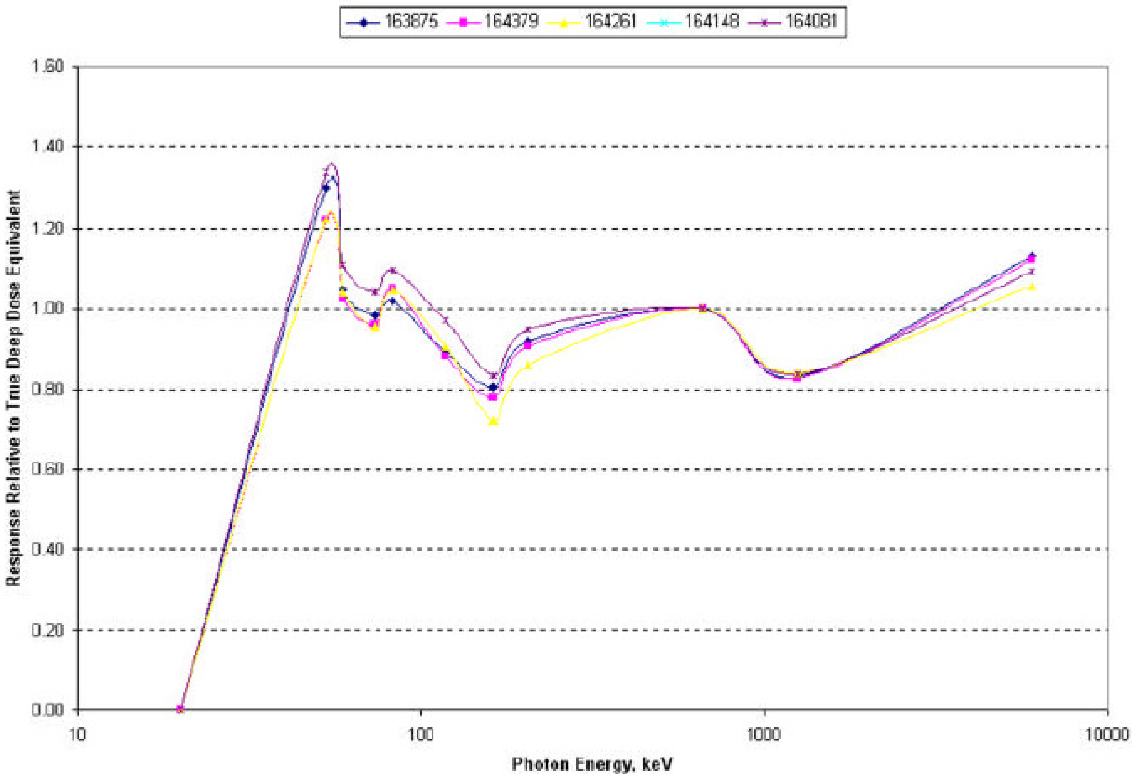

Figure 3.5. MGPI DMC 2000S Photon Energy Dependence Normalized to ^{137}Cs

Table 3.13. Results of Test of MGPI DMC 2000S Photon Energy Dependence Showing Response of Each Dosimeter Relative to True Deep Dose Equivalent (Results Normalized to ^{137}Cs)

Beam Code	Energy, keV	DMC 2000S Serial Number					Average
		163875	164379	164261	164148	164081	
M30	20	-99.9%	-99.9%	-99.9%	-99.9%	-99.9%	-99.9%
M100	53	+30%	+22%	+22%	+29%	+34%	+27%
^{241}Am	59	+5%	+3%	+4%	+1%	+11%	+5%
M150	73	-1%	-4%	-5%	-5%	+4%	-2%
H100	83	+2%	+5%	+5%	-2%	+10%	+4%
H150	118	-11%	-12%	-9%	-11%	-3%	-9%
H200	162	-20%	-22%	-28%	-29%	-17%	-23%
H250	204	-8%	-9%	-14%	-16%	-5%	-11%
^{137}Cs	662	0%	0%	0%	0%	0%	0%
^{60}Co	1250	-17%	-17%	-16%	-16%	-16%	-16%
$^{16}N^{(a)}$	6129	+13%	+6%	+6%	+8%	+9%	+9%

(a) Values listed are calculated as (Indicated Dose – True Deep Dose Equivalent)/(True Deep Dose Equivalent).

DMC 2000S Dose Rate Linearity Curve

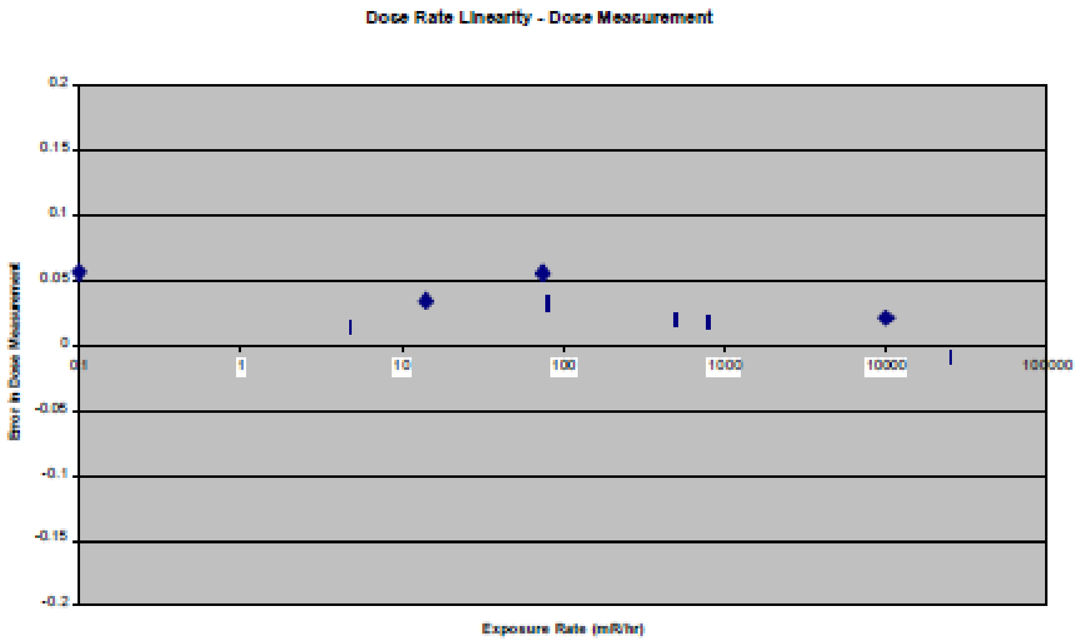

Figure 3.2a. MGP DMC 2000S Dose Equivalent Response as a Function of Dose Equivalent Rate

Typical Response Curve for an Ion Chamber Dose Rate Instrument

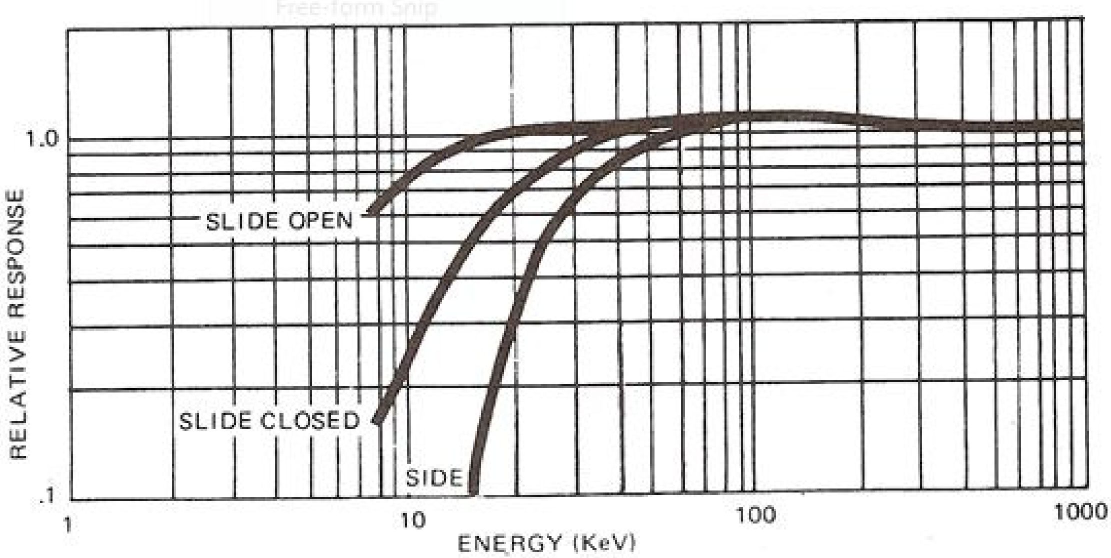

Figure 1-2. Nominal Photon Energy Response

Attachment A

<u>Dose Rate Measurement Deviation Test</u>

The following tables represent a demonstration and test of variation in the dosimeter's indicated (displayed) response to a stationary dose rate field. Data was gathered from population of dosimeter calibrations using results from the CDM-21 Automated Dosimeter Calibrator.

<u>Low Filter Exposure Data</u>

Title Reference 41 mrem/hr

	Standard Deviation (s)
	3.82
	Coefficient of Variation (CV)
	9.10
	+-' 1 Sigma
-1' Sigma	38.1
+1' Sigma	45.8
	+-' 2 Sigma
-2' Sigma	34.3
+2' Sigma	49.6

No.	Input Data	% Diff from (X)
1	44.0	4.9%
2	49.0	16.8%
3	49.0	16.8%
4	39.0	-7.0%
5	36.0	-14.2%
6	43.0	2.5%
7	44.0	4.9%
8	39.0	-7.0%
9	40.0	-4.6%
10	38.0	-9.4%
11	43.0	2.5%
12	48.0	14.4%
13	37.0	-11.8%
14	42.0	0.1%
15	40.0	-4.6%
16	42.0	0.1%
17	39.0	-7.0%
18	41.0	-2.3%
19	40.0	-4.6%
20	46.0	9.7%
	SUM	
	839	
	Mean (x)	
	41.95	

Comments:
None

Medium Filter Exposure Data

Title Reference 355 mrem/hr

Standard Deviation (s)	23.60
Coefficient of Variation (CV)	6.50
+-' 1 Sigma	
-1' Sigma	339.3
+1' Sigma	386.5
+-' 2 Sigma	
-2' Sigma	315.7
+2' Sigma	410.1

No.	Input Data	% Diff from (X)
1	372.0	2.5%
2	387.0	6.6%
3	366.0	0.9%
4	316.0	-12.9%
5	331.0	-8.8%
6	400.0	10.2%
7	355.0	-2.2%
8	348.0	-4.1%
9	376.0	3.6%
10	380.0	4.7%
11	387.0	6.6%
12	372.0	2.5%
13	344.0	-5.2%
14	380.0	4.7%
15	374.0	3.1%
16	395.0	8.8%
17	340.0	-6.3%
18	344.0	-5.2%
19	328.0	-9.6%
20	363.0	0.0%
	SUM	
	7258	
	Mean (x)	
	362.90	

Comments:
None

High Filter Exposure Data

Title: Reference 5350 mrem/hr

	Standard Deviation (s)
	187.23

	Coefficient of Variation (CV)
	3.38

	+-' 1 Sigma
-1' Sigma	5359.3
+1' Sigma	5733.7

	+-' 2 Sigma
-2' Sigma	5172.0
+2' Sigma	5921.0

No.	Input Data	% Diff from (X)
1	5770.0	4.0%
2	5430.0	-2.1%
3	5580.0	0.6%
4	5370.0	-3.2%
5	5610.0	1.1%
6	5580.0	0.6%
7	5280.0	-4.8%
8	5500.0	-0.8%
9	5270.0	-5.0%
10	5480.0	-1.2%
11	5320.0	-4.1%
12	5870.0	5.8%
13	5820.0	4.9%
14	5320.0	-4.1%
15	5450.0	-1.7%
16	5660.0	2.0%
17	5820.0	4.9%
18	5630.0	1.5%
19	5690.0	2.6%
20	5480.0	-1.2%
	SUM	
	110930	
	Mean (x)	
	5546.50	

Comments:
None

ED Rate Alarm Test

Dosimeters Tested (selected from general population)

1) 665632
2) 242319
3) 660615

Source Used: Shepherd 28 Beam Irradiator

Stationary field - Flash exposure alarm test

Time (sec)	Rate (mR/h)	Alarm Set	Audible Alarm	Visual Alarm	Alarm Triggered in register	Indicated max rate (Dosimeter	Comments
1	50	50	No	No	No	39 / 12 / 13	10 sec intervals. Then read via Dosimass
1	50	50	No	No			
1	50	50	No	No			
2	50	50	No	Yes	Yes (except on 1)	43 / 54 / 53	
2	50	50	No	No	Yes (except on 3)	51 / 54 / 42	
2	50	50	Yes	No	Yes (only on 3)	46 / 48 / 50	
1	80	80	No	No	No	62 / 28 / 33	
1	80	80	No	No			
1	80	80	No	No			
3	80	80	Yes	Yes	Yes	86 / 101 / 98	
3	80	80	Yes	Yes	Yes	92 / 90 / 96	
2	100	100	No	Yes	Yes	100 / 78 / 56	
2	100	100	Yes	No			
2	100	100	No	No			
3	100	100	Yes	Yes	Yes	143 / 113 /120	
3	100	100	Yes	Yes	Yes		
3	100	100	Yes	Yes	Yes		

Comments

The short duration flash exposures result in what appear to be an alarm in such a short duration that it is indistinguishable before it clears. It may consist of a quick flash or beep. Durations of 3 or more seconds tend to result in clear audible and visual alarm triggers.

Following this test dosimeter numbers were reduced from 3 to 2 as it became difficult to discern which dosimeter was in alarm condition.

Moving field - Alarm test

Time (sec)	From Rate (mR/h)	To Rate (mR/h)	Alarm Set point	Audible Alarm	Visual Alarm	Alarm Triggered in register (Dosimass)	Indicated max rate (Dosimeter #1 / 2)	Comments
5	500	1000	1500	No	No	No	1250 / 1290	
*	500	1000	1200	Yes	Yes	Yes	1320 / 1350	* exposed dosimeter 1.5 min then moved from 500 to 1000
15	500	1000	1250	Yes*	Yes*	Yes	1390 / 1360	* Intermittent/sporadic alarm
*	500	1000	1250	Yes*	Yes*	Yes	1340 / 1310	Slow increase pausing at 700 and 900 for approx. 30
5	20	40	50	Yes	Yes	Yes	58	
5	20	40	50	Yes	Yes	Yes	67	

Comments

At alarm set points 125% above the reference radiation field, alarms were sporadic. Intermittent alarms would range in duration from 6 to 10 seconds with pauses or delays between alarm triggers from only 1-2 seconds. See Attachment D.

Note that the dosimeters were stationary most all of the mesurement period except during the advancement.

Calculated dose rates from integrated dose, as taken from histogram text (Attachment D) more closely matched dose rates and were typically 9-12% higher. Whereas the max rate taken from the dosimeter register was as high has 140%, and for low dose rates in one instance up to 170%.

Dosimeter n°242319 "DMC2000S"

History period : 1 mn
Start date & time : Thu 09 Feb 2012 12:10:03

```
                        ------ Measurement alarms & anomalies
                        |  --------- DM events & faults
                        |  |  ------------ Tracking events
                        |  |  |   ------------ Dose increments (primary)
                        |  |  |   |
                        v  v  v   v
Thu 09 Feb 2012 12:15:03 :   dosimeter deactivation (PAUSE)
                         :            3.1 mrem
                12:14:03 :           18.2 mrem
                12:13:54 : rate alarm ends
                12:13:52 : rate alarm !
                12:13:49 : rate alarm ends
                12:13:48 : rate alarm !
                12:13:46 : rate alarm ends
                12:13:45 : rate alarm !
                12:13:43 : rate alarm ends
                12:13:42 : rate alarm !
                12:13:40 : rate alarm ends
                12:13:38 : rate alarm !
                12:13:28 : rate alarm ends
                12:13:25 : rate alarm !
                12:13:23 : rate alarm ends
                12:13:22 : rate alarm !
                12:13:17 : rate alarm ends
                12:13:15 : rate alarm !
                12:13:13 : rate alarm ends
                12:13:12 : rate alarm !
                12:13:11 : rate alarm ends
                12:13:10 : rate alarm !
                12:13:05 : rate alarm ends
                12:13:03 : rate alarm !
                         :           13.4 mrem
                12:12:59 : rate alarm ends
                12:12:58 : rate alarm !
                12:12:57 : rate alarm ends
                12:12:56 : rate alarm !
                12:12:54 : rate alarm ends
                12:12:53 : rate alarm !
                12:12:52 : rate alarm ends
                12:12:51 : rate alarm !
                12:12:49 : rate alarm ends
                12:12:46 : rate alarm !
                12:12:45 : rate alarm ends
                12:12:44 : rate alarm !
                12:12:03 :            6.1 mrem
                12:10:05 :   primary dose & time preset ends
                12:10:04 :   dosimeter activation (RUN)
                         :   primary dose & time preset
```

Dosimeter n°665632 "DMC2000S"

History period : 1 mn
Start date & time : Thu 09 Feb 2012 12:38:16

```
                          ------ Measurement alarms & anomalies
                          |  --------- DM events & faults
                          |  |  ------------ Tracking events
                          |  |  |   ------------ Dose increments (primary)
                          |  |  |   |
                          v  v  v   v
Thu 09 Feb 2012 13:15:16 :    dosimeter deactivation (PAUSE)
                13:13:16 :          13.5 mrem
                13:12:57 : rate alarm ends
                13:12:56 : rate alarm !
                13:12:51 : rate alarm ends
                13:12:49 : rate alarm !
                13:12:47 : rate alarm ends
                13:12:46 : rate alarm !
                13:12:44 : rate alarm ends
                13:12:43 : rate alarm !
                13:12:42 : rate alarm ends
                13:12:41 : rate alarm !
                13:12:33 : rate alarm ends
                13:12:32 : rate alarm !
                13:12:16 :          18.8 mrem   1128 mR/hr.
                13:12:15 : rate alarm ends
                13:12:14 : rate alarm !
                13:12:08 : rate alarm ends
                13:12:07 : rate alarm !
                13:12:06 : rate alarm ends
                13:12:05 : rate alarm !
                13:12:02 : dose alarm !
                13:11:38 : rate alarm ends
                13:11:37 : rate alarm !
                13:11:36 : rate alarm ends
                13:11:35 : rate alarm !
                13:11:28 : rate alarm ends
                13:11:27 : rate alarm !
                13:11:22 : rate alarm ends
                13:11:21 : rate alarm !
                13:11:17 : rate alarm ends
                13:11:16 : rate alarm !
                         :          16.6 mrem
                13:11:09 : rate alarm ends
                13:11:08 : rate alarm !
                13:11:07 : rate alarm ends
                13:11:06 : rate alarm !
                13:11:05 : rate alarm ends
                13:11:04 : rate alarm !
                13:11:02 : rate alarm ends
                13:11:01 : rate alarm !
                13:10:51 : rate alarm ends
                13:10:50 : rate alarm !
                13:10:16 :          9.2 mrem
                12:38:18 :    primary dose & time preset ends
                12:38:17 :    dosimeter activation (RUN)
                         :    primary dose & time preset
```

Attachment D