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Panasonic Dosimetry System Performance Testing and Results at Nuclear Accident Dose Levels

500 RAD to 10,000 RAD

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Overview:

Title 10 Code of Federal Regulations Part 835.1304, Nuclear Accident Dosimetry, states “

- a) Installations possessing sufficient quantities of fissile material to potentially constitute a critical mass, such that the excessive exposure of personnel to radiation from a nuclear accident is possible, shall provide nuclear accident dosimetry for those personnel.
- b) Nuclear accident dosimetry shall include the following:
 - (1) A method to conduct initial screening of personnel involved in a nuclear accident to determine whether significant exposures to radiation occurred;
 - (2) Methods and equipment for analysis of biological materials;
 - (3) A system of fixed nuclear accident dosimeter units; and
 - (4) Personal nuclear accident dosimeters worn by all personnel who enter locations in which criticality alarm systems are required.”

Panasonic thermoluminescent dosimeters (TLDs) are used as the **photon** dose assessment part of the personal nuclear accident dosimeter (PNAD) and may be used for the same purpose with the fixed nuclear accident dosimeter (FNAD).

To demonstrate compliance with 10CFR835.1304 (and, its predecessor, DOE Order 5480.11), several sets of dosimeters were irradiated to photon doses above the upper limit of the DOELAP testing standard, DOE/EH-0026 and DOE/EH-0027. The upper range of the test was 10,000 rads, using both low energy (70 keV) and high energy (662 keV and 1332 keV) sources. The testing indicated that the Panasonic TLD system is capable of meeting the requirements of 10CFR835.1304 and DOE Order 5480.11.

Procedure:

Initially five standard Rocky Flats personal dosimeters were prepared for each dose level / photon energy with ten transit dosimeters. The photon energies chosen were the two energies specified in DOE/EH-0026, Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems: low energy: NIST technique M150 (70 keV) and high energy: ¹³⁷Cs (662 keV). The TLDs used in the dosimeters were Panasonic UD-802AS and UD-809AS TLDs.

The test dose levels for the PNAD dosimeters were 500 rads, the upper limit of the DOELAP testing, 750 rads, and 1000 rads, the upper limit formerly specified for PNAD dosimeters in DOE Order 5480.11. The PNAD testing was performed January 1998.

The test dose levels for the FNAD dosimeters were 3,000 rads, 6,000 rads, and 10,000 rads, the upper limit formerly specified for FNAD dosimeters in DOE Order 5480.11. The FNAD testing was performed in March 1998.

The dosimeters were sent to Battelle Pacific Northwest National Laboratories (PNNL) for irradiation. The irradiation protocol used by PNNL followed the DOELAP requirements, with the exception of using a ⁶⁰Co source for the irradiations for the high energy photons to dose levels greater than 1,000 rads. The dosimeters were irradiated on PMMA phantoms, however, no testing was performed at this time to quantify the difference between “free-in-air” and phantom response.

The PNAD test dosimeters were irradiated to the photon energies originally specified. However, after the FNAD test dosimeters were received by the PNNL staff, it was determined that dose rate of the ^{137}Cs (662 keV) source was too low to permit timely irradiation of the dosimeters to doses above 1,000 rads.. We decided to use the ^{60}Co (1173 and 1332 keV) source since this source has a much higher dose rate. The number of dosimeters irradiated using the ^{60}Co source in each of the dose categories stated above was reduced from five dosimeters per category to four dosimeters per category. The number of transit dosimeters was reduced from ten to eight dosimeters. The extra five dosimeters were irradiated to 5 rem using the ^{60}Co source. (The average response of element 3 of the UD-802 (E3) of these five dosimeters was compared to the 5 rem calibration dosimeters' average response irradiated using the ^{137}Cs source. The average response was 20% below the delivered dose, compared with the 10% low response of the ^{137}Cs source.)

The test TLD readings were processed through the ELEM module of the ISA dose processing software to correct the element readings with Element Correction Factors (ECFs) and to subtract the transit dosimeter readings.

The net element readings were processed through the standard site dose equivalent algorithm to calculate a dose for each UD-802/UD-809 TLD pair. (The standard site dose equivalent algorithm contains an Accident Category branch.) A performance quotient, P_i , was calculated for each dosimeter, using the following equation:

$$P_i = \frac{(\text{Reported})_i - (\text{Delivered})_i}{(\text{Delivered})_i}$$

The bias, B , defined as the average of the performance quotients, P_i , for n dosimeters, for a specific group of dosimeters, was computed using the following equation:

$$B = \frac{1}{n} \sum_{i=1}^n P_i$$

The standard deviation, s , of the performance quotients, P_i , was computed for each specific group bias, B , using the following equation:

$$s = \left[\frac{\sum_{i=1}^n (P_i - B)^2}{n - 1} \right]^{1/2}$$

Each of the equations above may be found in DOE/EH-0026, section 4.2.

A bias, B , and standard deviation, s , were computed for each group of dosimeters, and for all dosimeters per photon energy, and for all dosimeters. The tabular results and graphs for the bias of each group by photon energy are contained in Appendix 1.

Quality Assurance:

Prior to reading the PNAD test TLDs in Reader 1, calibration dosimeters, irradiated at Battelle on Dec. 16-17, 1997, were read to determine the condition of Reader 1. The results of the calibration dosimeters were:

Battelle Calibration TLDs

Battelle Irradiation Date: Dec. 16-17, 1997

Reader 1 Read Date: Jan. 19, 1998

Photon Counter Ratios				Freq. Counter Ratios
E2	E3	E5	E7	E3
0.998	1.006	0.956	1.025	1.038

Each read file contained two On-Line Quality Control (QC) TLDs. Each QC TLD was within the allowed limits. Using both the calibration TLD data and the On-Line QC TLD data, the reader appeared to be within calibration limits. Therefore, no correction to the data for reader performance was required.

For the FNAD test TLDs, calibration dosimeters, irradiated at Battelle on March 4-5, 1998, were read to determine the condition of Reader 2 before and after the test TLDs. The results of the calibration dosimeters were:

Battelle Calibration TLDs					
	Battelle Irradiation Date:		March 4-5-, 1998		
	Reader 2	Read Date:		March 25, 1998	
	Photon Counter Ratios				Freq. Counter Ratios
	E2	E3	E5	E7	E3
Before	1.023	1.021	1.017	1.044	1.031
After	1.017	1.029	1.065	1.084	0.908

The "before" calibration TLD ratios indicated that the TLD reader was working properly, however, the "after" calibration TLD ratios indicated that the TLD reader's response had shifted during the processing of the test TLDs. The 5 rem ⁶⁰Co group TLDs had a response on element 3 (E3) that was 20% below the delivered dose, indicating that the shift was in the frequency counter. Since all the test TLD readings were from the frequency counter, the TLD responses were adjusted using the "after" Frequency Counter ratio. The adjusted TLD responses were processed through the algorithm to obtain the final doses that are contained in Appendix 1.

Conclusion:

PNAD Test TLDs: Each dosimeter was within $\pm 20\%$ of the delivered dose, and the bias, B, for all dosimeters was 0.071, with a standard deviation, s, of 0.039. The Panasonic dosimetry system meets the requirements of 10CFR835.1304 and DOE Order 5480.11 for use in a PNAD in determining the Gamma dose portion of the dose from a Nuclear Accident.

FNAD Test TLDs: Two dosimeters were not within $\pm 20\%$ of the delivered dose, however, the bias, B, for all dosimeters was 0.017, with a standard deviation, s, of 0.103. The Panasonic dosimetry system meets the requirements of 10CFR835.1304 and DOE Order 5480.11 for use in a FNAD in determining the Gamma dose portion of the dose from a Nuclear Accident.

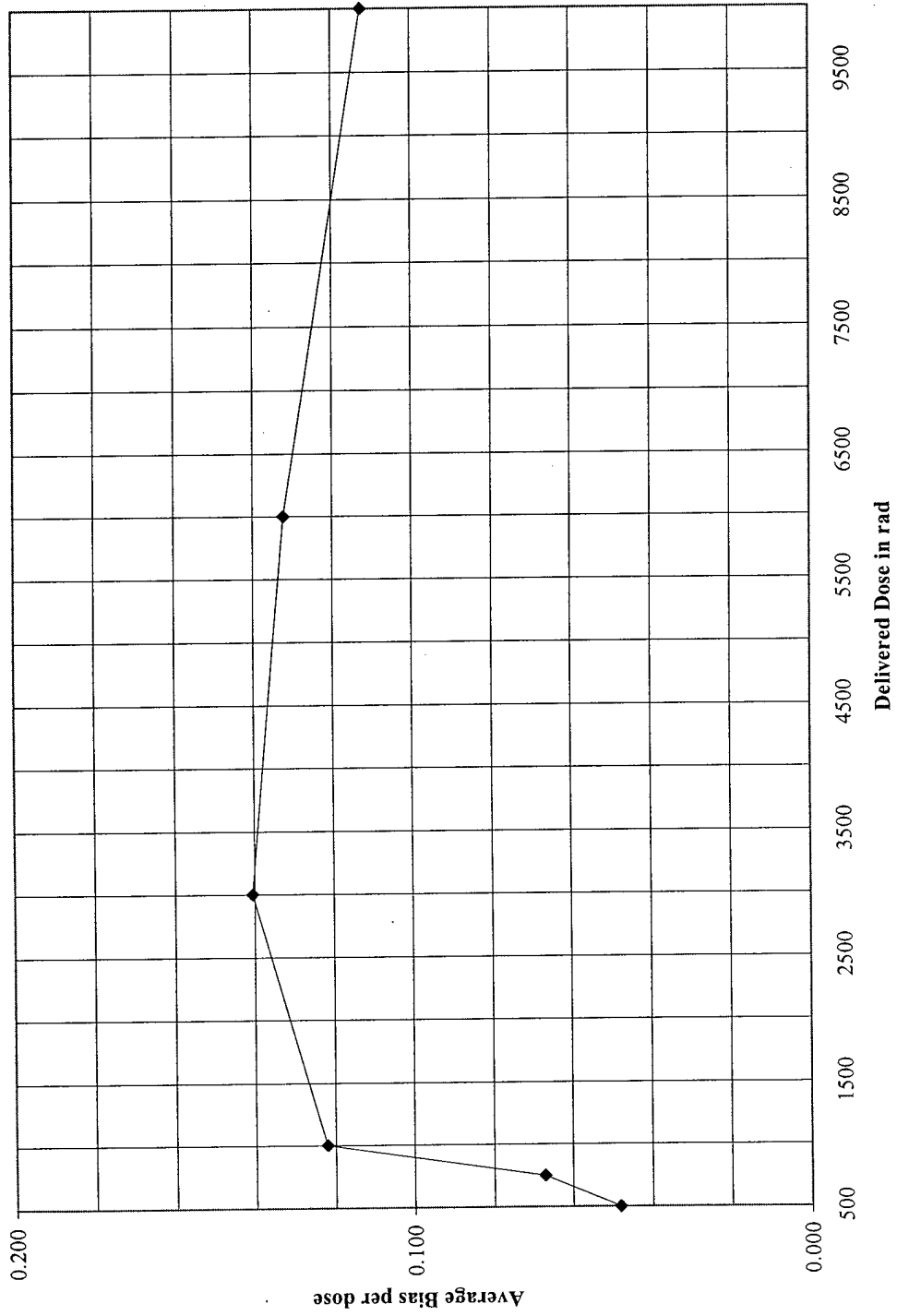
Appendix 1
Panasonic Dosimetry System
Nuclear Accident Level Performance Results
Low Energy Photon Testing

	Reported Deep Dose rad	Delivered Deep Dose rad	Performance (Rep- Del)/Del	Outside +/- 0.20	Subgroup Performance	
	491.314	500.065	-0.017			
M150	538.021	500.065	0.076			
500 rem	532.913	500.065	0.066			
	532.996	500.065	0.066	Bias	0.048	
	525.365	500.021	0.051	St. Dev.	0.038	
	803.111	750.023	0.071			
M150	813.046	750.053	0.084			
750 rem	825.140	750.053	0.100			
	781.492	750.053	0.042	Bias	0.067	
	779.080	750.053	0.039	St. Dev.	0.027	
	1140.766	1000.056	0.141			
M150	1167.807	1000.056	0.168			
1000 rem	1080.129	1000.056	0.080			
	1115.750	1000.056	0.116	Bias	0.122	
	1106.382	1000.056	0.106	St. Dev.	0.033	
	3877.597	2999.932	0.293	0.293		
M150	3567.268	2999.932	0.189			
3000 rem	3171.857	2999.932	0.057			
	3180.312	2999.932	0.060	Bias	0.140	
	3309.525	2999.932	0.103	St. Dev.	0.100	
	6975.635	6000.099	0.163			
M150	6890.161	6000.099	0.148			
6000 rem	7027.201	6000.099	0.171			
	6681.547	6000.099	0.114	Bias	0.132	
	6393.408	5999.952	0.066	St. Dev.	0.043	
	10418.701	9999.881	0.042			
M150	11624.980	9999.881	0.163			M150
10000 rem	12269.676	9999.999	0.227			group
	10707.717	9999.881	0.071	Bias	0.113	0.104
	10604.702	9999.881	0.060	St. Dev.	0.079	0.037

High Energy Photon Testing

	Reported Deep Dose rem	Delivered Deep Dose rem	Performance (Rep- Del)/Del	Outside +/- 0.20	Subgroup Performance	
¹³⁷ Cs	524.621	500.003	0.049			
500 rem	520.997	500.003	0.042			
	498.650	500.003	-0.003	Bias	0.026	
	507.384	500.003	0.015	St. Dev.	0.021	
	802.712	749.984	0.070			
¹³⁷ Cs	782.753	749.984	0.044			
750 rem	819.361	749.984	0.093			
	770.687	749.984	0.028	Bias	0.063	
	811.836	750.005	0.082	St. Dev.	0.027	
	1082.217	999.996	0.082			
¹³⁷ Cs	1066.142	999.996	0.066			
1000 rem	1068.189	1000.017	0.068			
	1087.436	999.996	0.087	Bias	0.074	
	1064.948	1000.017	0.065	St. Dev.	0.010	
	4.451	5.003	-0.110			
⁶⁰ Co	4.556	5.003	-0.089			
5 rem	4.427	5.003	-0.115			
	4.530	5.003	-0.095	Bias	-0.095	
	4.664	5.003	-0.068	St. Dev.	0.019	
	3029.112	2999.757	0.010			
⁶⁰ Co	2969.987	2999.757	-0.010			
3000 rem	3039.857	2999.757	0.013	Bias	0.031	
	3330.565	2999.757	0.110	St. Dev.	0.054	
	6229.744	6000.208	0.038			
⁶⁰ Co	6663.536	6000.208	0.111			
6000 rem	5987.726	6000.208	-0.002	Bias	0.050	
	6312.353	6000.208	0.052	St. Dev.	0.047	
	10442.843	10000.082	0.044			⁶⁰ Co & ¹³⁷ Cs
⁶⁰ Co	8733.459	10000.082	-0.127			group
10000 rem	8546.286	10000.082	-0.145	Bias	-0.084	0.027
	8910.012	10000.082	-0.109	St. Dev.	0.087	0.057
All Dosimeters		Bias	0.056			
	Tested	St. Dev.	0.085			
# outside +/-0.20			2			

Accident Dose Level Performance
Low Energy Combined Testing
(NIST M150) (70 keV)



Accident Dose Level Performance
High Energy Photon Combined Testing
(Cs-137 & Co-60)

