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Evaluation of the Neutron Dosimeter Used by Martin Marietta Energy Systems, Inc., Ability to Meet the Requirements of the American National Standard for Personnel Neutron Dosimeters (Neutron Energies Less Than 20 MeV) ANSI N319-1976

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MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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EVALUATION OF THE NEUTRON DOSIMETER USED BY MARTIN MARIETTA ENERGY SYSTEMS, INC., ABILITY TO MEET THE REQUIREMENTS OF THE AMERICAN NATIONAL STANDARD FOR PERSONNEL NEUTRON DOSIMETERS (NEUTRON ENERGIES LESS THAN 20 MeV) ANSI N319-1976

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ABSTRACT

An evaluation of the neutron dosimeter used by the Centralized External Dosimetry System of Martin Marietta Energy Systems, Inc., was performed, and the dosimeter was shown to meet the requirements of the American National Standard for Personnel Neutron Dosimeters, ANSI N319-1976. This report details the requirements of the Standard, describes the tests performed, and evaluates the results of testing.

To demonstrate compliance with the Standard, dosimeters were irradiated with a ^{252}Cf source while mounted on a standard phantom. Dose was measured using the routine methodology employed by the Centralized External Dosimetry System for neutron dosimetry. The ability to accurately measure neutron dose was compared to specific performance criteria from the Standard. This includes testing the lower limit of detection, upper limit of detection, precision of results, and the capability to detect neutrons in a high gamma dose environment. In addition to neutron exposure, the dosimeters were required to be exposed to environmental factors including temperature extremes, high humidity, exposure to room light, and a drop to a hard surface. Only after exposure to these conditions were the dosimeters read, with results compared to the requirements of the Standard. Normal use factors of routine neutron dosimetry influencing the accuracy, sensitivity, or precision of the dosimetry system were also evaluated to measure their impact on dosimeter response.

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1. INTRODUCTION

The Standard (ANSI N319-1976) has been established to provide guidance for routine personnel neutron dosimetry. The Standard applies to devices worn by individuals, as contrasted with hand-held or fixed-area instrumentation. It does not apply to dosimetry necessary for criticality accidents.[1] This evaluation will determine whether the neutron dosimeter used by the Centralized External Dosimetry System (CEDS) at sites managed by Martin Marietta Energy Systems, Inc., for the Department of Energy, meets the performance and use requirements described in the Standard. A bare ^{252}Cf source was used to provide neutrons for exposure. Bare ^{252}Cf undergoes spontaneous fission providing neutrons with energies up to 10 MeV, with a significant peak between 0.5 and 1.0 MeV.[2] The CEDS methodology assumes the exposure conditions relating to the neutron energy distribution for bare ^{252}Cf have been characterized, allowing for accurate measurement of neutron dose equivalent from the dosimeter response. It is assumed that fields with neutron energies in the range of the Standard can be characterized.

2. THE NEUTRON DOSIMETRY PROGRAM

2.1 DESCRIPTION OF DOSIMETERS

The neutron dosimeter used by Martin Marietta Energy Systems, Inc., (Harshaw/Bicron Technologies model 8806) contains four thermoluminescent elements. Elements 1 and 4 are composed of TLD-600 (neutron and photon sensitive), and elements 2 and 3 are composed of TLD-700 (photon sensitive only) material. Each element is 0.015" thick. The elements are contained within a housing which provides physical integrity for the element assembly and filtration of incident radiation. The filtration allows for comparison of albedo and incident neutron contribution by shielding incident radiation. Elements 1 and 2 are shielded by 0.026" ABS plastic and 0.018" cadmium. Elements 3 and 4 are shielded by 0.113" ABS plastic. Figure 1 provides an illustration of the dosimeter.

2.2 SYSTEM CALIBRATION

Proper calibration of the dosimeter is essential for providing accurate neutron dosimetry. The Standard recommends: "The neutron spectra used for calibration should simulate the spectra expected in the area where personnel neutron dosimeters are

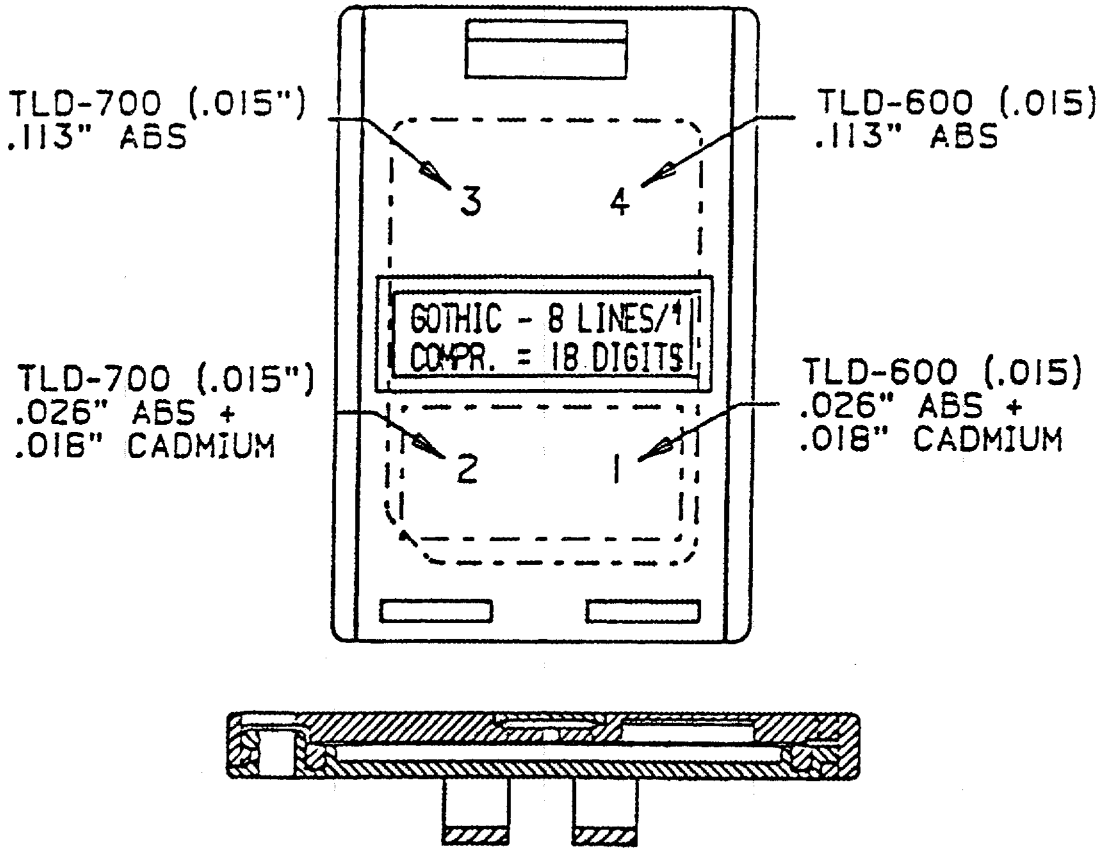

Fig. 1. CEDS neutron dosimeter assembly configuration. *Source*: "Technical Basis for the Centralized External Dosimetry System," CEDS, Martin Marietta Energy Systems, Inc., Oak Ridge, Tenn., p. 4-12, Oct. 4, 1991.

required."[1] CEDS Standard Operating Procedures call for calibration of neutron dosimeters in the areas where each is used for neutron dose assessment.[3]

The calibration procedure compares dosimeter element response to dose equivalent calculations based on neutron spectra measurements at the location of use.[4] The comparison allows for determination of correction factors relating the response of elements 1 and 4 to the neutron dose equivalent. Correction factors are specific to the location the procedure was performed. Correction factors for a given area are assigned a neutron correction code which is then assigned to individuals who work in that location. For individuals working in more than one location, the correction code is a weighted average of area correction factors based on occupancy times. Communication is maintained with area Health Physics' personnel to stay informed of changes that may affect the neutron energy spectra and the associated correction factors in each area. If the neutron correction code is appropriate for the spectra, the corrected response of elements 1 and 4 should be nearly identical.

2.3 DESCRIPTION OF THE DOSE ASSESSMENT ALGORITHM

Upon reading for dose, individual element response is tabulated and the response is corrected for background and photon-induced signal.* The dosimeter response is then converted to dose equivalent by choosing the neutron correction code and applying the associated correction factors. Signal fading is accounted for and a reported neutron dose equivalent is indicated.

The amount of background radiation subtracted is based on the number of days between anneal and reading of the dosimeter. Photon-induced signal is removed by subtracting element 2 response from element 1, and element 3 response from element 4. This leaves a net neutron response on elements 1 and 4. The correction factors are applied to elements 1 and 4 and their corrected response is averaged.

A test is performed in the algorithm to determine if an appropriate neutron correction code was applied. If so, the corrected element 1 response should be within 20% of the average of elements 1 and 4. If not, the results will be identified for investigation. Finally, a fade correction is applied to the average response, yielding the neutron dose equivalent.

3. TESTING AND USE REQUIREMENTS

3.1 DOSIMETER IRRADIATIONS

Dosimeters were divided into groups and irradiated based on the specific performance criteria to be assessed. Forty-five dosimeters were mounted on a 30 cm x 30 cm x 15 cm PMMA phantom and exposed to radiation as described in Table 1.

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*Each element reading has element correction factors applied to the raw signal. These factors compensate for deviations in response between individual elements and dosimeter readers.

Table 1. Irradiation Protocols

Performance Criteria (number of dosimeters)	Delivered Neutron Dose Bare ^{252}Cf (mrem)	Delivered Photon Dose ^{137}Cs (mrem)
Lower Limit of Detection (10)	100	0
Upper Limit of Detection (5)	10,000	0
Determine Neutron Dose in the Presence of Photons (10)	1,000	3,000
Fade Determination (10)	1,000	0
Standard Deviation of Reported Dose and Fade (10)	1,000	0

3.2 ENVIRONMENTAL FACTORS

Once irradiated, the dosimeters were exposed to the following environmental factors:

(1) Temperature extremes of 0°C and 45°C for 1 week.

(2) A relative humidity of 90% for 1 week.

(3) Artificial fluorescent room light for the extent of the dosimetry period (one calendar quarter).

(4) A drop to a hard surface from a height of 1.5 meters.

Temperature and humidity conditions were controlled at the Y-12 Temperature Laboratory. The drop test was conducted on a concrete slab. To save time and expense, all environmental factors were applied to each dosimeter group with one exception. A group of 10 dosimeters irradiated to 1,000 mrem neutron exposure was processed after exposure to all environmental factors with the exception of light exposure for the extent of the dosimetry period. These dosimeters were used to determine the amount of signal fading (see: section 3.3, number 2).

3.3 USE FACTORS

CEDS Use Factors were evaluated to determine whether they adversely affect the dosimeter response. The Standard defines Use Factors as "those factors involved in the issue and wearing of personnel dosimeters that influence the accuracy, sensitivity, or precision of the neutron dosimetry system."[1]

The Standard gives the following guidance on Use Factors which should be considered when developing procedures for issuing neutron dosimeters:[1]

1) The normal position for wearing the dosimeter shall be prescribed by the facility personnel responsible for management of the radiation protection program. For unique or unusual potential exposure conditions, additional dosimeters whose placement will reflect the maximum hazard to the trunk section of the body may be provided.

2) Selection of the dosimetry period shall be made so that the loss of dosimeter response or fading over the entire dosimetry period is not more than 50% at a nominal dose equivalent in excess of 0.5 rem.

3) The dosimeter response shall be corrected for fading such that the estimated dose equivalent is not in error due to fading by more than 40%.

The above concerns are addressed as follows:

1) The normal position for wearing the CEDS neutron dosimeter is on an individual's belt at the waist.[5] To address the possibility that an unusual exposure condition may occur, CEDS Standard Operating Procedures provide guidance for issue and use of multiple whole-body dosimeters.[6]

2) The dosimetry period is one calendar quarter. Results of testing for dosimeter fade indicate this period is acceptable. Testing results are

presented in Table 2. A neutron dose equivalent of 1.0 rem was used for the determination of fade.

Table 2. Evaluation of Dosimeter Fading (One Calendar Quarter)

	Non-Faded (mR)*	Faded (mR)*	% Fading
Element 1 Average Response	597	572	-4.10
Element 4 Average Response	719	725	+ 0.08

3) Dosimeter signal fading is corrected when dosimeters are read for dose. The correction is based on the number of days between annealing and reading the cards. Data supporting compliance with this requirement is found in Table 3 (the fade correction is applied to these results) and in the Results of Testing section of this report. This data is labeled "Environmentally and Light Exposed Dosimeters."

3.4 PERFORMANCE REQUIREMENTS

After irradiation and exposure to the environmental stresses and Use Factors, the dosimeters were read for dose. The neutron dose equivalent results were compared to the following performance requirements:[1]

(1) Detect a minimum quarterly dose equivalent of 300 mrem divided by the number of dosimetry periods in each quarter. The Standard defines the lower limit of detection to be that value of neutron dose equivalent for which the neutron responses of a set of 10 or more dosimeters identically exposed will have a standard deviation of no greater than 50% (to be

*Element response has the element correction coefficient (ECC) and reader calibration factor (RCF) applied.

conservative, and to demonstrate compliance for monthly processing, a lower limit of detection of 100 mrem was tested).

(2) Determine dose equivalent up to 10 rem.

(3) Detect a neutron dose equivalent of 1 rem in the presence of a dose equivalent of 3 rem of gamma rays having energies in excess of 500 keV.

(4) Detect dose with a precision such that when a set of at least 10 dosimeters is exposed under identical conditions to a neutron source at a dose equivalent of approximately 1 rem, the standard deviation of measured neutron responses from the dosimeter set shall be less than or equal to 10%.

4. RESULTS OF TESTING

A complete listing of all dosimeter processing results used in this study can be found in Appendix A. The appendix tabulates the delivered dose, reported dose, and each element response. To provide a statistic to measure dosimeter performance, a Performance Quotient (PQ) is calculated. The PQ is defined as the difference between the reported and delivered dose, divided by the delivered dose.

Table 3 lists average PQs and the standard deviation of the dosimeter group assigned to each performance test. Also indicated is whether these results pass or fail to meet the performance objectives. In addition to the performance requirements, the Standard also defines Use Factors which should be evaluated. Use Factor 2 requires "the selection of the dosimetry period shall be made so that the loss of dosimeter response or fading over the entire dosimetry period is not more than 50% at a nominal dose equivalent in excess of 0.5 rem."[1] To demonstrate compliance with this requirement, one group of ten dosimeters was irradiated and subjected to all environmental factors except fade, and exposure to light for the duration of the dosimetry period. Table 2 compares the response of these dosimeters to those used for the determination of

Standard Deviation of Reported Dose. The dosimeters used in the standard deviation test were subjected to fading and light exposure for the length of the dosimetry period. Since for this test we are only interested in neutron response, comparisons were made using background and photon dose corrected element 1 and element 4 response. The dosimeter met the fade criteria.

Table 3. Performance Testing Results

Performance Test	Average PQ	Standard Deviation	Pass/Fail
Lower Limit of Detection	0.042	5.7%	Pass
Upper Limit of Detection	-0.116	0.9%	Pass
Detect Neutron Dose in High Photon Dose	-0.200	13.3%	Pass
Standard Deviation of Reported Dose	-0.104	3.2%	Pass

The Use Factor 3 required the dosimeter response to be corrected such that the estimated dose equivalent is not in error due to fading by more than 40%. The results listed in Table 3 have a fade correction applied. A review of these results will indicate that no group had an error in excess of 40% (performance quotient greater than 0.40 or less than -0.40).

5. CONCLUSIONS

Based on the results of testing, the Harshaw/Bicron neutron dosimeter model 8806 as used by CEDS meets the requirements of ANSI N319-1976. This test exposed dosimeters to a bare ^{252}Cf neutron source, but there is little reason to believe similar results would not be produced with other neutron sources. Proper calibration and use is essential for accurately reporting neutron dose and achieving performance requirements. To compensate for the large variation of dosimeter response as the neutron energy spectrum changes, CEDS Procedure 2-1-60, "Dose Equivalent Determination," requires an appropriate neutron correction code be developed for dose equivalent determination in each area neutron dosimetry is required.

The low standard deviation of the dosimeter response as tested in this study indicates that when properly calibrated, a multi-element TLD can provide excellent neutron dosimetry. As recommended in the Standard, our procedures call for calibration of the dosimeter on phantoms in areas where dosimeters are provided for neutron dose assessment. Dosimeter response is compared to neutron energy spectra measurements in the area tested and correction factors are determined. The correction factors are assigned to an area specific neutron correction code. The neutron correction code is referenced when determining the neutron dose equivalent from dosimeters assigned in the location of interest.

The Standard does not give guidance for accuracy of dosimetry, it is concerned with the precision of reported doses. Further guidance on reporting accuracy can be found in applicable accreditation standards.[7,8]

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APPENDIX A

ANSI N319-1976 PERFORMANCE DATA

APPENDIX A: ANSI N319-1976 Performance Data

Dosimeter Exposure Conditions - Testing Parameter

Environmentally Exposed Dosimeters

Cf-252 (Bare), 1000 mrem neutron dose - Fade Determination

Card #	L1	L2	L3	L4	Bkg L1&4	Bkg L2&3	Reported DOSE	Delivered Dose	Performance Quotient
902137	578	57	60	766	10.5	9	799	1000	-0.201
901155	558	57	58	750	10.5	9	776	1000	-0.224
902240	570	58	58	744	10.5	9	780	1000	-0.220
902964	640	60	61	726	10.5	9	820	1000	-0.180
903599	599	58	59	686	10.5	9	767	1000	-0.233
903327	599	59	59	694	10.5	9	772	1000	-0.228
903160	634	59	58	706	10.5	9	806	1000	-0.194
902149	579	59	58	745	10.5	9	787	1000	-0.213
903513	578	57	62	711	10.5	9	766	1000	-0.234
903498	634	58	60	666	10.5	9	782	1000	-0.218
								Average	-0.215
								Standard Deviation	0.018

Environmentally and Light Exposed Dosimeters

Cf-252 (Bare), 100 mrem neutron dose - Lower Limit of Detection

Card #	L1	L2	L3	L4	Bkg L1&4	Bkg L2&3	Reported DOSE	Delivered Dose	Performance Quotient
902322	79	20	21	106	24.5	23	104	100	0.040
901733	86	20	20	121	24.5	23	119	100	0.190
902752	81	21	21	101	24.5	23	102	100	0.020
900747	81	21	20	101	24.5	23	102	100	0.020
902486	83	21	20	101	24.5	23	103	100	0.030
902497	80	21	21	97	24.5	23	98	100	-0.020
902285	87	21	21	96	24.5	23	104	100	0.040
903164	81	21	21	98	24.5	23	100	100	0.000
903287	86	21	21	100	24.5	23	106	100	0.060
903118	79	21	22	106	24.5	23	104	100	0.040
								Average	0.042
								Standard Deviation	0.057

APPENDIX A: ANSI N319-1976 Performance Data

Environmentally and Light Exposed Dosimeters

Cf-252 (Bare), 1000 mrem neutron dose - Standard Deviation of Response and Fade Determination

Card #	L1	L2	L3	L4	Bkg L1&4	Bkg L2&3	Reported DOSE	Delivered Dose	Performance Quotient
901311	557	62	64	714	24.5	23	876	1000	-0.124
900249	565	62	61	662	24.5	23	849	1000	-0.151
901564	578	64	67	702	24.5	23	882	1000	-0.118
902490	582	64	61	692	24.5	23	883	1000	-0.117
901437	586	66	62	791	24.5	23	952	1000	-0.048
903511	558	66	66	748	25.5	24	913	1000	-0.087
902429	558	66	61	720	24.5	23	879	1000	-0.121
903256	552	66	68	735	24.5	23	879	1000	-0.121
903295	589	66	65	729	24.5	23	910	1000	-0.090
903235	602	68	70	764	24.5	23	941	1000	-0.059
								Average	-0.104
								Standard Deviation	0.032

Cf-252 (Bare), 10,000 mrem neutron dose - Upper Limit of Detection

Card #	L1	L2	L3	L4	Bkg L1&4	Bkg L2&3	Reported DOSE	Delivered Dose	Performance Quotient
902729	6048	503	516	6463	24.5	23	8920	10000	-0.108
903496	5395	507	526	7033	24.5	23	8727	10000	-0.127
902435	5498	515	511	7078	24.5	23	8852	10000	-0.115
902475	5624	523	495	6814	24.5	23	8786	10000	-0.121
903586	5729	532	515	6925	24.5	23	8932	10000	-0.107
								Average	-0.116
								Standard Deviation	0.009

Mixture: Cf-252 (Bare) - 1000 mrem; & Cs-137 - 3000 mrem; - Detection of Neutron Dose in the Presence of Photons

Card #	L1	L2	L3	L4	Bkg L1&4	Bkg L2&3	Reported DOSE	Delivered Dose	Performance Quotient
900247	2918	2342	2378	3094	24.5	23	992	1000	-0.008
900364	3009	2390	2545	3073	24.5	23	901	1000	-0.099
903450	2869	2407	2689	3160	24.5	23	724	1000	-0.276
903458	2920	2411	2618	3116	24.5	23	784	1000	-0.216
901319	2901	2430	2569	3158	24.5	23	813	1000	-0.187
900977	2925	2468	2483	3139	24.5	23	847	1000	-0.153
902772	2972	2503	2777	3095	24.5	23	626	1000	-0.374
902452	2812	2516	2668	3103	24.5	23	554	1000	-0.446
902289	3016	2541	2440	3152	24.5	23	900	1000	-0.100
902037	3071	2558	2490	3096	24.5	23	861	1000	-0.139
								Average	-0.200
								Standard Deviation	0.133

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