

LITHIUM FLUORIDE TLD DOSE QUALITY *

E. C. Ormond[‡], D. R. Bozman, S. R. Cordova, D. R. Mitchell and B. V. Oliver
Sandia National Laboratories
Albuquerque, NM 87185-1193 USA

D. E. Good, D. J. Henderson, K. Hogge, R. A. Howe, S. R. Huber, M. L. Larsen, S. E. Mitchell, C. V. Mitton, I. Molina and D. S. Nelson
National Security Technologies, LLC
North Las Vegas, NV 89030 USA

Abstract

Lithium Fluoride (LiF) Thermoluminescent Dosimeters (TLD's) have been used extensively as a diagnostic in radiographic facilities. For over three years we have used precision-calibrated TLD's in our facility. Said facility consists of two radiographic sources, each with a dose rating of 4-Rad at 1 m. The calibration and fielding of TLD's will be examined for accuracy and long term stability. TLD's will be evaluated in single point measurements and multi-point arrays. Overlaying three-chip TLD measurements will be compared to single chip TLD measurements. TLD results will also be compared to Pin Diodes for routine shot diagnosis and evaluation of shielding around the sources.

I. DOSE MEASUREMENTS- LITHIUM FLOURIDE TLD'S

A. Equipment Used

The TLD reader used is a Harshaw Model 3500 TLD System. The annealing oven is a Radiation Products Division, Model 186-001. It has two temperature probes, one feeding an analog gage and the other feeding a digital gage. The thermoluminescent dosimeters are the TLD-100 model with the five percent tolerance specification from Radiation Products Design, Inc. The TLD's were individually calibrated to improve their accuracy to less than five percent.

The settings for the Harshaw 3500 TLD system are detailed in Table 1.

Table 1. Harshaw 3500 TLD System Settings.

Function	Setting
Integrate Time	30 seconds
Max. Temperature	245°C
Integration Temperature	100°C
Temperature Rate	20°C per second
High Voltage	-500 V

B. Pre-Annealing

As recommended by the manufacturer, the lithium fluoride thermoluminescent dosimeters were annealed for one hour at 400°C before use. Immediately following they were cooled for five minutes in a brass quenching block, followed by two hours at 100°C and an additional five minutes in the quenching block.

Post-exposure annealing is completed as detailed above. We use this annealing process between exposures to remove residual dose equivalence signal.

C. Calibration

Consistency of dose measurements is the most important metric of Source performance [1]. To this end we investigated fading which is the loss of signal in thermoluminescent materials over time. The results of our own fading experiments have shown that LiF TLD's show no statistically significant fading in signal from ½ hour to 36 hours after irradiation. Our measurements are normally taken approximately 45 minutes after exposure.

TLD accuracy was measured by placing three adjacent TLD's in a single holder. System accuracy was measured

* Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

[‡] email: eormond@sandia.gov

at 1.56%, which is an improvement over the manufactures tolerance value of 15% for standard TLD's and 5% for high precision TLD's.

The TLD's were individually calibrated by exposure to a Cesium 137 source (National Institute of Standards and Technology traceable). Normally 100 chips are exposed in a batch. As an example of calibration procedure, for the latest calibration (December of 2012) the exposure time was 145.2 minutes for 20 Rads and 290.5 minutes for 40 Rads. A unique calibration factor is calculated and tracked for each chip.

A sample of the calibration data for nine batches of 100 LiF chips is shown in Table 2. The number after the Batch letter indicates calibration cycle (i.e. A3 is the third calibration of Batch A). Batch exposures were 20, 40, or 70 Rads. Variations in calibration factors were minimal in batches calibrated to the same dose. These variations scaled as the TLD exposure was increased. The lowest batch standard deviation measured for the chips used in this work was 0.93%, and the highest was 2.66%.

Table 2. LiF TLD Calibration Data.

TLD Reader Harshaw Model # 3500		
Cs Exposure (Rads)	Batch Name (100 TLDs)	Calibration Factor 100 TLDs (Rad/nC)
40	A3	1.48 ± 0.05
20	A4	1.46 ± 0.07
20	B1	1.43 ± 0.05
20	C1	1.42 ± 0.06
20	A7	1.40 ± 0.05
20	B3	1.34 ± 0.04
20	C3	1.31 ± 0.04
70	D3	1.36 ± 0.04
70	E3	1.34 ± 0.04

II. LONG TERM AVERAGE STANDARD DEVIATION IN DOSE

A. Hardware Setup

A standard fielding block was used for single point dose measurements. This hardware consisted of three side-by-side LiF TLD's shielded by one inch of aluminum on all sides (Fig. 1). The one inch aluminum shielding is defined as a standard for the class of radiography tests executed in our facility. In some cases the standard fielding block is subject to an additional one inch of tungsten shielding. These are cited as "hard spectrum dose measurements".

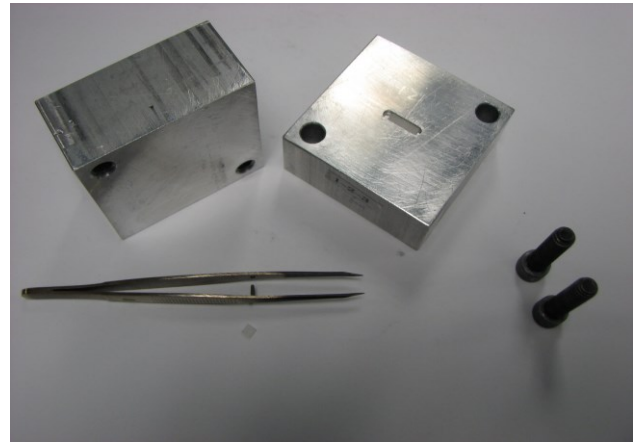


Figure 1. Standard TLD Hardware.

Review of the data has shown the Lithium Fluoride TLD's have maintained a low standard deviation. The average deviation over a 784 shot series is 1.56% and active replacement of TLD outliers has slowly lowered the standard deviation of the sets (Planchets) of TLD's. All 36 Planchets used in this series have been analyzed and are included in the average. A sample data set of Planchets is detailed in Table 3.

Table 3. LiF TLD Standard Deviation Averages.

Shot Numbers (PLANCHET)	AVG (% Std Dev Dose)
1186-1204 (A)	1.00
1206-1238 (B)	1.41
1239-1270 (C)	1.74
1271-1302 (A)	2.66
1304-1332 (C)	1.98
1333-1365 (A)	1.75
1879-1894 (A)	1.41
1895-1910 (B)	1.51
1911-1926 (C)	1.47
1927-1942 (A)	1.44
1944-1958 (B)	1.35
1960-1970 (C)	1.36
Overall AVG	1.56% (784 Shots)

III. 100-POINT ARRAY MEASUREMNTS

100-point TLD array measurements have been performed to measure x-ray spatial variations. The hardware is shown in Fig. 2. The array is shielded by one inch aluminum, and is positioned on the source axis at a distance of 29.2 cm. A single TLD is located at each point, with a vertical spacing of 10.9 mm, and a horizontal spacing of 11.4 mm.

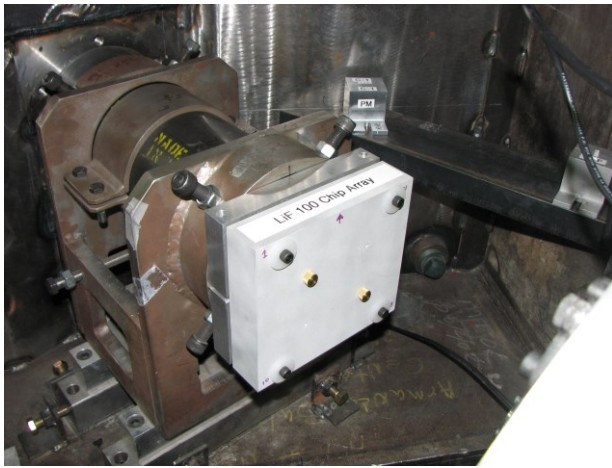


Figure 2. 100-Point Array Hardware.

A series of four shots fielding the 100-point array was evaluated. The first shot completed on Source 1 is shown in Fig. 3. The legend units are Rads. This shot indicated minor dose asymmetry. The low doses measured in the upper left and lower right quadrants are caused by mounting hardware (bolts). This gives a convenient fiducial for verification of the radiograph orientation.

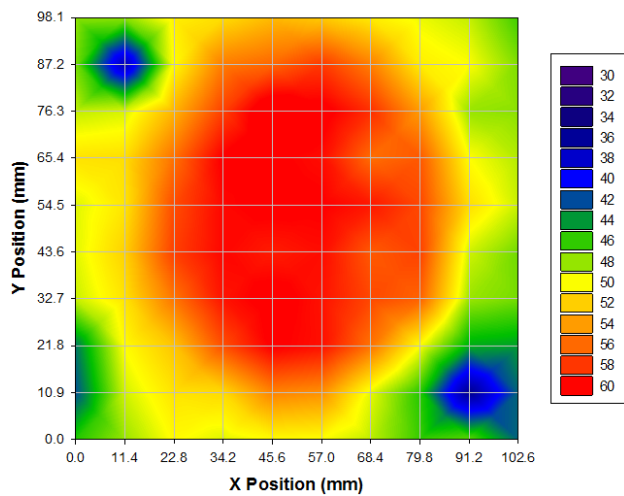


Figure 3. 100-Point Array (Source 1, Shot 1457).

A subsequent shot was completed on Source 2 and indicated more distinct asymmetric dose distribution (Fig. 4).

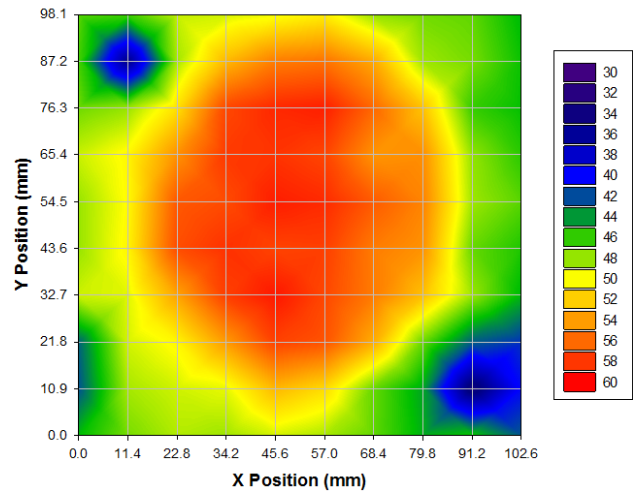


Figure 4. 100-Point Array (Source 2, Shot 1500).

An additional two shots were completed to explore dose distribution variation from shot-to-shot (Figs. 5 and 6).

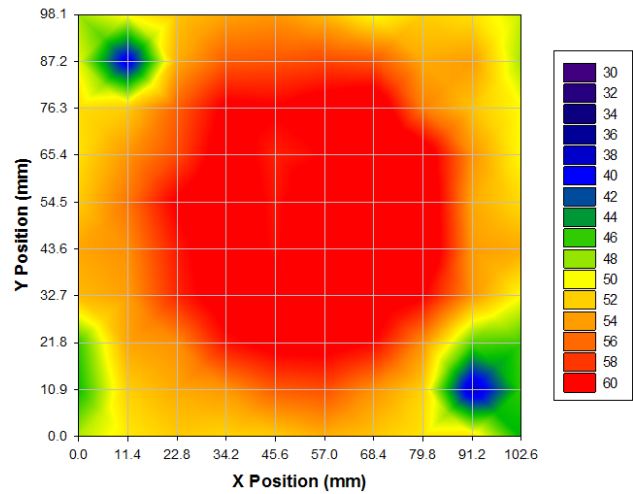


Figure 5. 100-Point Array (Source 1, Shot 1537).

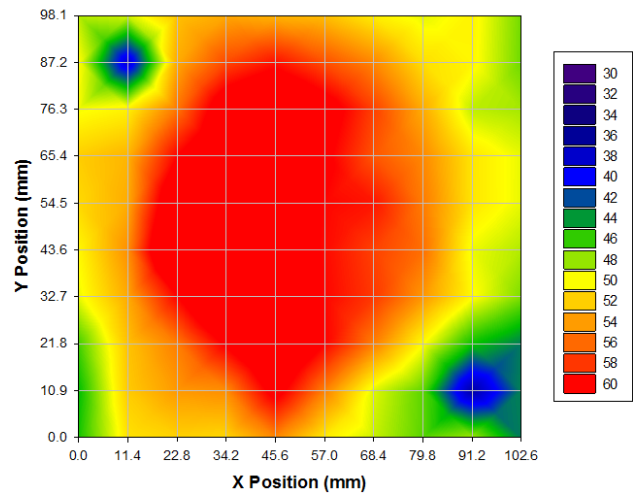


Figure 6. 100-Point Array (Source 2, Shot 1538).

In these cases the LiF TLD measurements indicate variation in dose distribution, once again more significant on Source 2. When evaluating the dose distribution in the center four points, the deviation was highest on Source 1.

IV. 32-POINT ARRAY MEASUREMENTS

32-point TLD array measurements have been performed to measure x-ray spatial variations. Three TLD's are located at each point, with a vertical and horizontal spacing of 5.8 mm (Fig. 7). The three TLD's are averaged to obtain the point dose value and obtain the distribution. The three TLD/point feature gives better precision than the one TLD/point used in the 100-Point array. Also the 32-Point array has a denser spacing which permits improved dose gradient measurements.

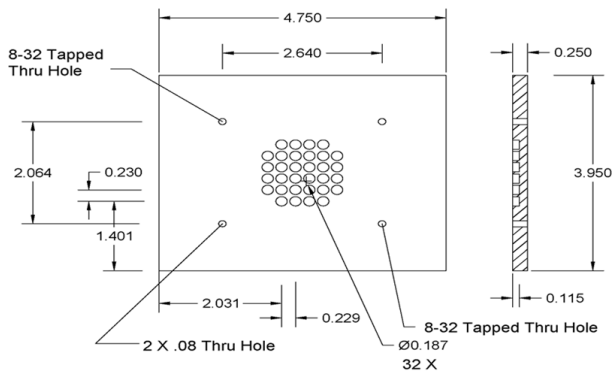


Figure 7. 32-Point Array Hardware.

A series of four shots fielding the 32-point array was evaluated. The first shot completed on Source 1 is shown in Fig. 8. This shot indicated no measurable dose asymmetry.

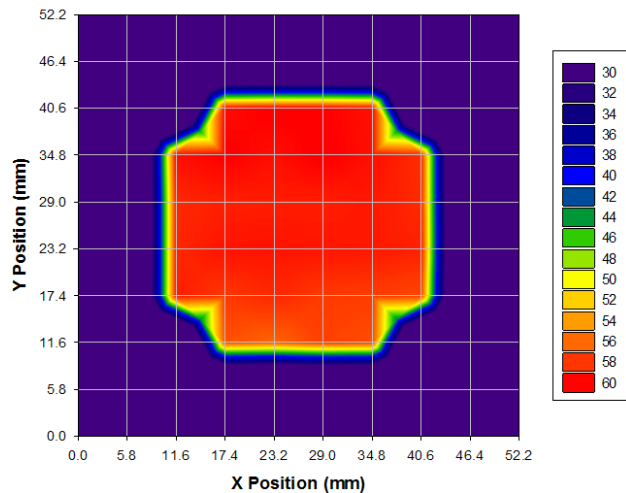


Figure 8. 32-Point Array (Source 1, Shot 1859).

The shape of the array causes the outer shape of the array to look squared as shown in Fig. 8. The purpose of the array is to accurately measure variation of dose going down line and the array is slightly larger than the collimation input to the imaging system.

A subsequent shot was completed on Source 2 and indicated symmetric dose distribution (Fig. 9). A total of seven shots have been completed to date with the 32 point array and the standard deviation of the 12 central points is between 0.51% and 0.92%.

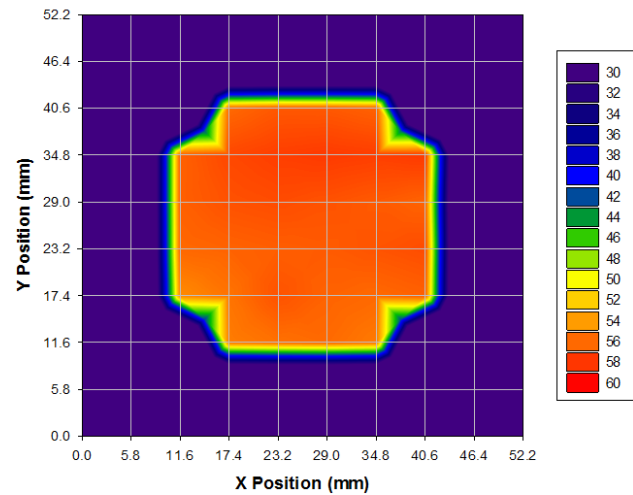


Figure 9. 32-Point Array (Source 2, Shot 1860).

An additional two shots were completed to verify minimal dose distribution from shot to shot (Figs. 10-11).

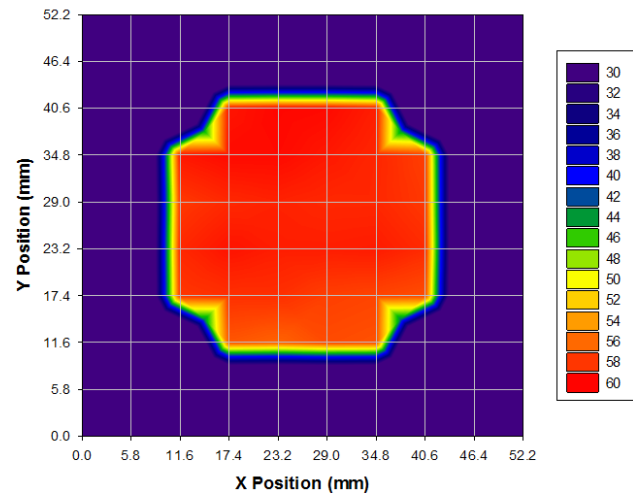


Figure 10. 32-Point Array (Source 1, Shot 1861).

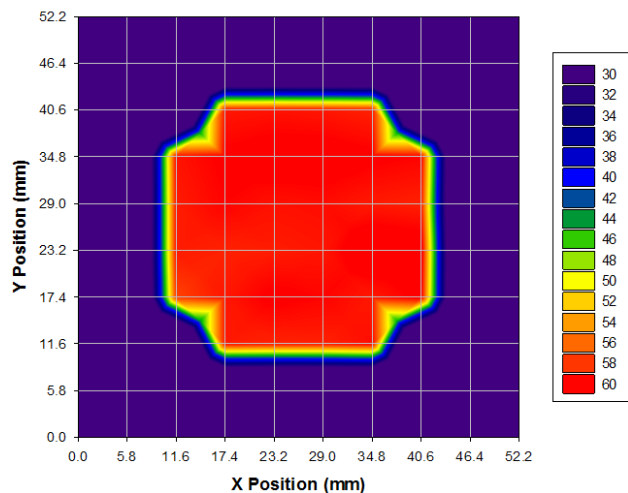


Figure 11. 32-Point Array (Source 2, Shot 1862).

V. LiF TLD TO PIN DIODE COMPARISON

LiF TLD's were compared to Pin Diodes in a standard location and through Tungsten to look at the harder spectrum of the sources. Review of the data has shown no direct correlation. The TLD's and Pin Diodes would not consistently match at either location. The measurement variability for a sample data set is shown for Source 1 in Table 4 and Source 2 in Table 5. Shots that are within ± 0.1 rads are highlighted in yellow.

Table 4. Source 1- LiF TLD to Pin Diode Comparison.

Shot #	Center TLD (Rad)	Center Pin (Rad)	Bulkhead TLD (Rad)	Spool Pin (Rad)
1741	4.46	4.3	4.48	4.3
1743	4.28	4.1	4.38	4.1
1745	4.77	4.5	4.63	4.6
1747	4.42	4.1	4.38	4.4
1749	4.41	4.2	4.33	4.2
1751	4.24	4.2	4.38	4.6
1956	4.28	4.1	4.38	4.3
1958	4.33	4.1	4.43	4.5
1960	4.76	4.7	4.58	4.8
1962	4.23	4.2	4.38	4.4
1964	4.54	4.5	4.43	4.4
1966	4.32	4.0	4.53	4.2
1968	4.19	3.9	4.18	4.2
1970	4.35	4.2	4.43	4.6
AVG	4.42	4.32	4.40	4.43

Table 5. Source 2- LiF TLD to Pin Diode Comparison.

Shot #	Center TLD (Rads)	Center Pin (Rads)	Bulkhead TLD (Rads)	Spool Pin (Rads)
1742	4.38	4.2	4.30	4.2
1744	4.27	4.3	4.30	4.2
1746	4.43	4.4	4.41	4.4
1748	4.12	4.5	4.24	4.3
1749	4.24	4.4	4.19	4.3
1752	4.01	3.9	4.19	3.9
1956	4.22	4.1	3.92	3.8
1958	4.27	4.5	4.19	4.2
1960	4.06	4.0	3.97	4.0
1962	3.90	3.8	3.92	3.7
1964	4.27	4.1	4.19	4.2
1966	4.20	4.3	4.13	4.0
1968	4.06	3.9	3.92	4.0
1970	4.34	4.4	4.08	4.2
AVG	4.16	4.21	4.06	4.08

VI. SUMMARY

Shot-to-shot reproducibility of x-ray parameters is an important demonstration that source quality is consistent and that good radiography performance will likely be delivered on a crucial shot [2].

The consistency and reliability of dose measurements provides a high quality metric for measuring Source performance with a tighter tolerance than the previous facility TLD's. The Lithium Fluoride TLD's were an effective means to measure dose symmetry around the Flash X-ray sources. There is no evidence of asymmetric rod pinch dose distribution from shot to shot after improvement of measurement system.

There is also no direct correlation with standard or shielded (Hard Spectrum) LiF TLD's compared to standard or shielded Pin Diodes.

VII. REFERENCES

- [1] J. Smith et al., "Performance of the Cygnus x-ray source" in Proceedings of the 15th IEEE Pulsed Power Conf., 13-17 June 2005, pp. 334-337.
- [2] J. Smith et al., "Cygnus Performance in Subcritical Experiments" in Proceedings of the 16th IEEE Pulsed Power Conf., 17-22 June 2007, pp. 1089-1094.