An Inventory Review of the Naval Dosimetry Center's DT-648 Thermoluminescent Dosimeter

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Abstract

This article summarizes a study and inventory review of the Navy's DT-648 Thermoluminescent Dosimetry (TLD) System managed by the Naval Dosimetry Center (NDC), located in Bethesda, Maryland. Data from this study encompasses March 1987 to March 1998. This study determined the quantity and reasons why DT-648 TLDs were removed from the system. The NDC has been accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) since the inception of the system to process DT-648 TLDs in all nine NVLAP categories.[1]

Key Words

Dosimeter
Lithium fluoride
NVLAP
Thermoluminescent

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Description and Assembly of the DT-648 TLD

The DT-648® Thermoluminescent Dosimeter (TLD) is a passive, whole-body dosimetry system designed by BICRON Radiation Measurement Products (BICRON RMP), formerly Harshaw TLD, located in Solon, Ohio. Technical assistance was provided by the NDC staff to ensure this dosimeter met the Navy's many radiological monitoring requirements.[2] These TLDs have been used to monitor personnel and environmental radiation exposure aboard ships and submarines; at naval weapons stations; in research laboratories; medical clinics, and hospitals.

Figure 1 shows two major components of the DT-648 TLD in various stages of assembly; the ruler is scaled in centimeters. One component holds the thermolumin-escent (TL) chips and is sometimes referred to as a "Card." There are four square TL chips mounted on the card and are composed of lithium fluoride material doped with magnesium and titanium. Chip numbers 1, 2, and 3 are beta- and gamma-sensitive; chip 4 is beta-, gamma-, and neutron-sensitive.

The other component of the DT-648 TLD is a black plastic case, sometimes referred to as a "holder." It contains metal and plastic filters to allow energy and particle dis-crimination, and an open window covered with a thin Mylar film to allow beta particles to reach the TL material. Water, dirt and other debris are kept from soiling the card by a small, cylindrical rubber gasket that meshes between the two halves of the case when snapped together. Two rigid plastic loops allow the TLD to be worn on a belt. Alter-natively, the TLD can be suspended from a shirt collar or pocket with a plastic clip passed through the slot. The card and holder are commer-cially manufactured and available from BICRON RMP under part numbers 8801 and 8802®, respectively.

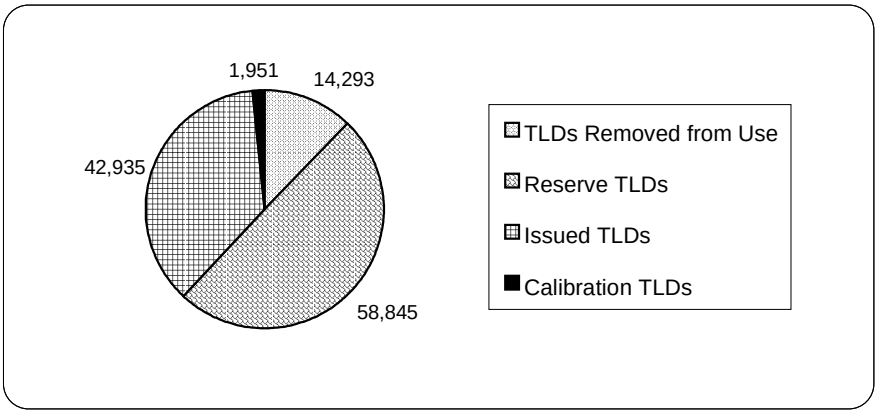
The significant design features relevant to this study included the following: (1) the two clear 0.0063 cm (0.0025 in) thick Teflon sheets sealing each TL chip; (2) the thickness of each TL chip with num-bers 1, 2, and 4 being 0.0381 cm (0.015 in) thick and chip 3 only 0.0091 cm (0.0036 in) thick; and (3) the durable plastic-laminated paper bar-code label for easy identification.

Inventory of DT-648 TLDs

A total inventory of 118,024 DT-648 TLDs were available for evalu-ation during this inventory review. Figure 2 shows the distribution of the inventory after the dosimeters were inspected for future use. The inventory review included a visual inspection of each TLD to determine its physical condition, and a query of

Figure 1. *DT-648 TLD with black plastic case*

Figure 2. *DT-648 TLD inventory*



electronic databases for calibration and dose-processing histories.

As of March 1998, 42,935 TLDs (36.4% of the inventory) were issued on a six-week rotational basis to meet current Navy dosimetry re-quirements. To minimize mailing costs and simplify processing at the NDC, only cards are mailed to each radiation health program administrator. The administrator maintains a supply of holders and is respon-sible for putting the cards into the holders and issuing them to per-sonnel. A system where TLDs are mailed to customers requires an inventory of between two and three times the number of TLDs for each person monitored. While one set of TLDs are being worn, previously issued TLDs are being processed. Additional quantities of TLDs are also needed to account for those TLDs needing recalibration.

A total of 58,845 TLDs (49.8% of the inventory) were designated as reserve TLDs. This large volume reflects both the desire to have a supply for contingency operations, and due to a reduction in fleet size and force structure over the past 10 years. Dosimeters were added back to the NDC's reserve stock as ships and shore-based commands were closed. The NDC ensures at least 20,000 of these TLDs are in a calibrated, "ready to issue" status to meet the demands of worldwide contingencies.

A total of 1,951 TLDs designated for calibration and quality control purposes within the system were also evaluated for continued service. This group consisted of three distinct populations based on the card's function. For logistical reasons and easy identification, these cards were color coded at the genesis of the system with gold, red, or green edges. Among the 1,951 special-purpose cards at the

time of this review, there were 80 master standard calibration Gold Cards, 1,036 Red Calibration Cards, and 835 Green Quality Control (QC) Cards.

Gold-edged cards were used as master standard calibration cards for maintaining the sensitivity record of the system. After the initial system was built, the Gold Cards were only read once a year to verify the sensitivity of the Red and Green Cards had not changed.

Red-edged cards were used as reader calibration cards. Ten calibration cards were used to calibrate each BICRON RMP Model 8800PC TLD Reader® each working day. These cards were annealed by reading, irradiated to 1.50 mSv with a National Institute of Standards and Technology (NIST) traceable Cs-137 calibration source, and readout on the same day. The 100-mCi source was housed in a fully automated BICRON RMP Model 6610C Gamma Irradiator®. These cards were rotated so each received approxi-mately the same usage. Over the 11-year period of the study, it was estimated each Red Card was heated about 200 times and irradiated about 100 times.

Green-edged cards were used to verify system integrity and were referred to as QC Cards. A minimum of one QC Card was placed as the first, last, and every 50th position in each group of issued TLDs returned for process-sing. These cards were annealed by reading, irradiated to 1.50 mSv with the Cs-137 source, and readout on the same day. Green Cards were also rotated so they received approximately the same usage. It was estimated these cards received about the same usage as the Red Cards.

Categories of DT-648 TLD Removal

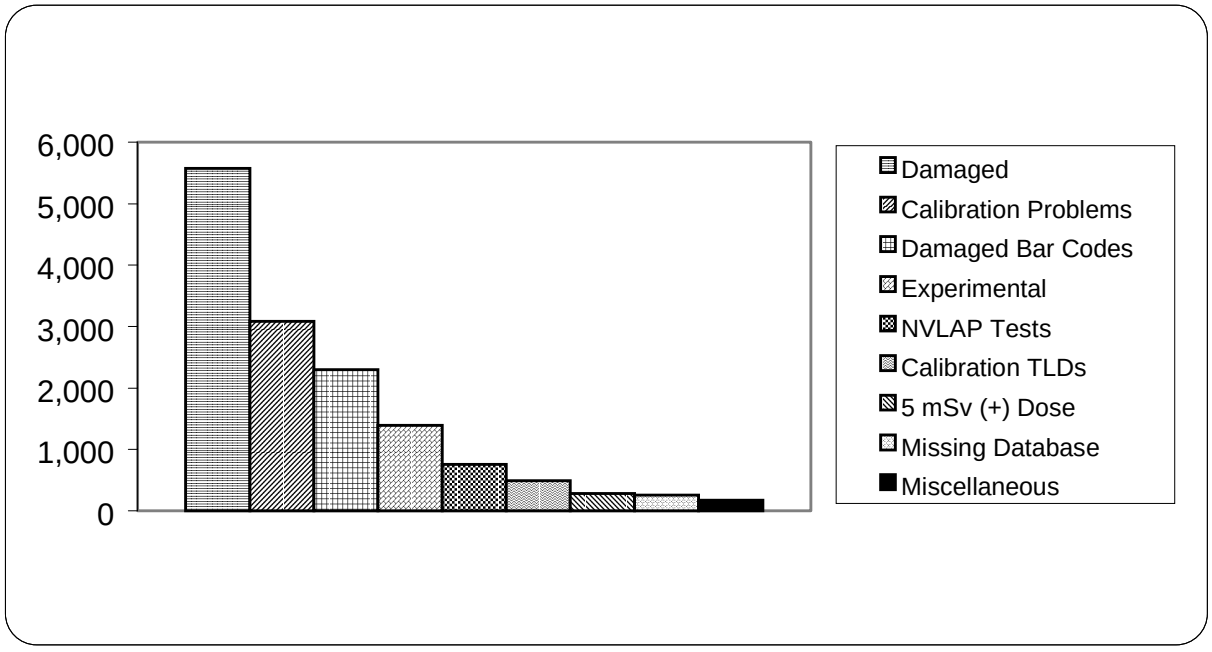
Figure 2 shows 14,293 TLDs (12.1% of the inventory) were permanently removed from future use. The legend in Figure 3 notes nine categories for removing TLDs. A hierarchy was defined to assign removed TLDs to a particular group because they could be removed for multiple reasons. For example, a TLD could have a chip with a dose history greater than 5 mSv, have a damaged bar code label, and have torn Teflon. Dosimeters were grouped in the following order:

1. Any of the four chips having a 5-mSv or greater one-time dose;
2. A damaged bar code on the card;
3. The card or its chips were damaged; and
4. The card had calibration problems.

Dosimeters previously used for special purposes or with incomplete database information were organ-ized into the remaining five cate-gories noted in Figure 3.

There were two ways each TLD was identified for retirement. The first method was by visual inspec-tion. The second method was by performing a quality assurance

Figure 3. *DT-648 TLDs removed from service (March 1987 – March 1998)*



check of TLD data using an automated shipping machine. By visual inspection, 5,575 TLDs (39% of the total removed) were retired for the following reasons: Broken chips (4,980); significantly soiled Teflon or bar codes with soap powder, rust or other residue (370); missing chips (160); damaged Teflon (40); and discolored chips (25).

Dosimeters with broken chips were removed from service as a conservative measure. These dosimeters could have provided reliable dosimetry results if reissued as long as the Teflon was intact. A study at the NDC showed a crushed TL chip inside the Teflon does not affect its light output as long as no mass is lost and there is no separa-tion of the Teflon around the broken chip.[3] When the Teflon separates, a thermal barrier can be formed which inhibits the heating of the chip. This causes a decrease in light output of up to 30%. Essentially all of the broken chips were the thin 0.0036-inch chip.

The chip in position 3—the thin chip—was especially manufactured for the NDC. The reasoning behind the design was so it could be cali-brated with a penetrating photon field, Cs-137, yet still measure beta and mixed beta/gamma fields without resulting in a large correc-tion factor. The under-response a thicker chip would experience is due to the beta particle's inability to fully penetrate a thick chip. The under- response is directly proportional to the increase in chip thickness and inversely proportional to the energy of the beta. Contento et al., 1984, correlated the magnitude of the correction factor with chip thickness and beta energy.[4] The data from their study show a thermolumin-escent chip could be as thick as 0.025 cm (0.01 in) for low energy beta emissions, such as Tl-204 (with a maximum energy of 0.76 MeV), without exceeding a correction factor of 1.2.

A quality assurance check of historical TLD data is performed before each card is mailed to a customer. This process is fully automated via two BICRON RMP Model 8800S Shipping Machines®. These Machines scan each TLD's bar code number, performs quality checks, counts, and separates the TLDs into groups for mailing.
Each TLD's bar code number is referenced to databases holding calibration and historical dose information. The Machines reject dosimeters failing the following quality assurance parameters:

1. Element Correction Coefficients (ECCs) must have been generated less than two years before the current date;
2. New or regenerated ECCs must be less than 15% different from previous values and be within a range of 0.77 to 1.43;
3. The card must have been annealed within the past fourteen days from the current date;
4. No single historical dose on the card can be over 5 mSv;
5. It must not be on any recall list, and
6. The bar code must be electronically readable.

Dosimeters are removed from the system if:

1. The database shows it has at least three failed calibration attempts;
2. The bar code is unreadable;
3. Any chip has a dose over 5 mSv; or
4. It is on the recall list.

The inventory review showed 3,088 TLDs (21.6% of the total removed) had calibration problems. A total of 1,845 TLDs failed due to exceeding the acceptable 0.77 to 1.43 ECC range. Dosimeters failing due to

an ECC exceeding 15% of its previous value totaled 1,243.

Sixteen percent (2,296 TLDs) of the retired dosimeters were due to damaged bar codes. The DT-648's bar code is printed on durable grade paper; however, repetitive handling, processing and shipping can result in damage. The reader automatically pauses for bar codes that can't be read electronically and allows the technician to enter the bar code manually. If the technician doesn't enter the bar code within thirty seconds, the card is not read. The reader puts the unprocessed card into a separate tray for reading at a later time. Replacement of the bar codes by BICRON RMP was available, but given the reserve inventory of 58,845 TLDs, they were simply retired.

A total of 277 TLDs (1.9% of the total removed) had at least one chip with a dose processing history of
5 mSv or more. These TLDs could have been reissued because they were successfully annealed. It was decided to place them in storage for future reference in case a customer wished to examine the TLD to complete a dose investigation or dose estimate.

In addition to visually inspecting the TLDs, a recall list of suspect bar code numbers were added as a database file to the Shipping Machines. The Shipping Machines would reject those TLDs whose bar code number matched a number in this file. Using this strategy, the following additional categories of TLDs were removed:

- TLDs assigned to experimental research projects;
- TLDs used during annual NVLAP performance testing;
- TLDs originally used for Reader calibration;
- TLDs with missing or incomplete database histories; and
- TLDs needing to be removed for miscellaneous reasons.

There were 1,393 dosimeters used in experimental research projects (9.7% of the total removed). Research projects are always in progress at the NDC to better deter-mine how to improve dosimetry services for the Navy. Various research projects at the United States Naval Academy, several universities in the Washington, DC region, and the Armed Forces Radiobiology Research Institute are also supported with NDC services. Dosimeters devoted to these research projects are retired to prevent future issue to other customers. Storing these TLDs also allows research investigators to reexamine them at a later time.

Dosimeters assigned to annual NVLAP performance testing totaled 751 TLDs (5.2% of the total re-moved). These TLDs could have been reissued because they were successfully annealed; however, they were stored by NVLAP test year for easy recall. Experience has shown that some on-site NVLAP assessors have asked to inspect the actual TLDs used during accreditation performance testing.

A total of 491 Red and Green Cards were retired from their respective populations because they were identified with paint rather than by colored indelible markers
(219 Red Cards or 1.5% of the total removed and 272 Green Cards or 1.9% of the total removed). It was concluded these TLDs were most likely the first calibration and QC dosimeters used to design the system. Experience has shown this paint sometimes caused the TLDs to get stuck in the tracking mechan-ism of the readers, hence the shift to using markers to color the edges for easy identification. The remaining population of 1,951 calibration TLDs noted in Figure 2 above was considered sufficient to meet reader calibration and quality control demands. Not explicitly shown in Figure 3 are 171 Red Cards (1.2% of the total

removed) and 76 Green Cards (0.5% of the total removed) were retired due to a failure in performance (primarily bad bar code labels, but also mechanical failure). These 247 cards were included as part of the 2,296 cards with damaged bar code labels shown in Figure 3.

Other TLDs removed from future service account for very small percentages. A total of 253 TLDs (1.8% of the total removed) had incomplete or missing database entries of ECC or dose histories. Lastly, 169 TLDs (1.2% of the total removed) were retired for miscel-laneous reasons. These TLDs had various combinations of red, black or green markings suggesting they were used for research projects or they were former calibration TLDs.

Conclusions

When averaged over the 11-year period, March 1987 to March 1998, the annual removal rate of *all* dosimeters, both those mailed to customers and the gold, red and green TLDs, is only 1.1% (12.1% TLDs removed/11 years), or 1,299 dosimeters annually (12,493 TLDs removed/11 years). The annual percentage of TLDs removed from use is actually less than one percent if the 2,296 TLDs with damaged bar codes were repaired by BICRON RMP and returned to service. In this case, the annual removal rate of failed dosimeters is 0.9% (11,997 TLDs removed/11 years), or 1,090 dosimeters annually (11,997 TLDs removed/11 years).

The Gold, Red, and Green Cards represented a unique group to study. Unlike the cards mailed throughout the Navy, they are kept in a clean and controlled laboratory environment, receive 1.50 mSv doses from the Cs-137 calibration source (which are typically larger than doses received on customer cards), and are read more fre-quently. There were no records kept as to the total number of original Gold, Red, and Green Cards. How-ever, totals could be inferred from the numbers counted during the inventory. There were 1,951 cards still in use (80 Gold Cards, 1,036 Red Cards; and 835 Green Cards); 491 removed because of painted edges; and 247 removed for other reasons for a total population of 2,689. The 1,426 Green Card inventory included 1,036 in service, 219 removed due to painted edges, and 171 removed due to a failure in performance. The 1,183 Red Card inventory included 835 in service, 272 removed due to painted edges, and 76 removed due to a failure in performance.

The inferred fractions of the original numbers of Gold, Red, and Green Cards removed because of failure (excluding those removed because they were painted) were 0% of Gold, 12.0% of Red (171/1,426), and 6.4% of Green (76/1,183). The gold TLDs were found to be in the best overall condition of all inventoried TLDs. This was not surprising, as these TLDs were only used once per year to verify no sensitivity changes occurred in the Red and Green Cards. When av-eraged over the 11-year period, the annual removal rate of the red and green dosimeters is truly remark-able. Only 1.1%/year of the Red Cards (12.0% Red Cards remov-ed/11 years), and only 0.58%/year of the Green Cards (6.4% Green Cards removed/11 years) were retired.

The sensitivity for the still-in-use Gold, Red, and Green Cards changed by less than 5% during the 11-year period. To determine this, calibration checks on the Cs-137 calibration source using the Red Cards were done every six months and thermoluminescent light output comparisons between the Gold, Red, and Green Cards were done every year. This shows the Gold, Red and Green Cards have been dosimetrically very stable over a long period of time, even with relatively heavy usage for the Red and Green Cards.

These data are indeed impressive given the volume of dosimeters processed at the NDC. This dosi-metry system has proven to meet the various radiation monitoring needs of the entire Navy in a wide variety of applications and radio-logical environments.

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Trademarks

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