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Sampling Plan for Measuring Dark Current in Model 8825 Whole Body Dosimeters Used at Sandia National Laboratories

David R. Farrar

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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David R. Farrar
Radiation Protection Department
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-0651

Abstract

Dark current is the measured response of dosimeters when they have been exposed to no radiation. A sampling plan was developed for measuring the average dark current associated with processing the Thermo Model 8825 whole body dosimeters currently used at Sandia National Laboratories. The dosimeters each consist of an array of 4 thermoluminescent dosimeter (TLD) chips. The population of dosimeters was found to consist of 2 strata: older and newer dosimeters. Results from some recently processed dosimeters were used to estimate the variability in response of the TLD chips of the newer and older dosimeters in the active population. The older dosimeters have more variability than the newer dosimeters across all the 4 TLD chips. TLD chip 3, which measures shallow dose, has the most variability of all the TLD chips. The sampling plan developed is based on stratified random sampling.

ACKNOWLEDGMENTS

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NOMENCLATURE

Dark current	Amount of gU measured from a TLD chip that has not been exposed to any external radiation
Dosimeter	Model 8825 whole body dosimeter, consists of 4 TLD chips
gU	Generic unit: Unit of measurement of data from reading dosimeters
Reader	Model 8800 dosimeter reader
Reading	Data from processing TLD chips, unit is gU
RPDP	Radiation Protection Dosimetry Program at SNL
SNL	Sandia National Laboratories
TLD	Thermoluminescent dosimeter

INTRODUCTION

The Radiation Protection Dosimetry Program (RPDP) at the Sandia National Laboratories (SNL) uses the Model 8825 dosimeter from Thermo Scientific for measuring external radiation dose to personnel. The dosimeters are processed with a Model 8800 dosimeter reader (reader hereafter). A dosimeter consists of a card with 4 mounted thermoluminescent dosimeter (TLD) chips. Each chip has a unique filter covering its outward face. The design of each filter and TLD chip is such that each chip measures a different kind of external radiation dose (Thermo, 2007).

When a dosimeter is processed, each TLD chip is measured separately and concurrently. This yields a measurement for each TLD chip, in units of gU. The resulting data are used to determine the external radiation dose. During the determination of radiation dose, the background reading of each TLD chip in a dosimeter has to be quantified.

One method for estimating the background reading is based on the following equation (modified from Thermo, 2007):

$$B_i = R_i + \left(D_{i,j} * T\right)$$

Where B_i is the background reading for TLD chip i (in gU), R_i is the dark current for TLD chip i (1-4) (in gU), $D_{i,j}$ is the rate of increase in reading due to ambient radiation (in gU day^{-1}) for TLD chip i in location j, and T is the amount of time between the current processing and the previous processing of the dosimeter (in days).

The dark current is the reading of a TLD chip when it has not been exposed to any radiation. In order to quantify dark current, a dosimeter has to be processed multiple times in quick succession (processing of a dosimeter resets its TLD chips). This quick processing is to minimize the amount of low-level ambient radiation the dosimeter receives in between.

The amount of dosimeters in RPDP’s active population numbers over 10,000, so measuring the dark current for each dosimeter is not feasible. Therefore, a sample of the active population of dosimeters will be chosen and these dosimeters will be processed multiple times in a short period to quantify the dark current for each TLD chip. This report details the development of a plan for sampling the active population.

MATERIAL AND METHODS

In order to develop a sampling plan, the population of dosimeters was defined and some data from previous processing of some dosimeters was used as a pilot sample. The analysis and calculations were conducted with the statistics program R (version 3.1.3) and the code and output are shown in the Appendix.

RPDP has a database of all dosimeters used. The database lists the last time that each dosimeter was calibrated, how many times it has been processed, and if the dosimeter has been de-activated (no longer used). The active population of dosimeters was considered to be all dosimeters in the database that has not been de-activated and have been calibrated recently.

Prior to issuing to personnel, dosimeters undergo preparation that includes being processed a specific number of times. On March 18, 2015, preparation of a quantity of active dosimeters (919) occurred where they were processed twice in the same day. The data from the second processing of these dosimeters was used as a pilot sample to estimate the variability in each of TLD chips 1-4.

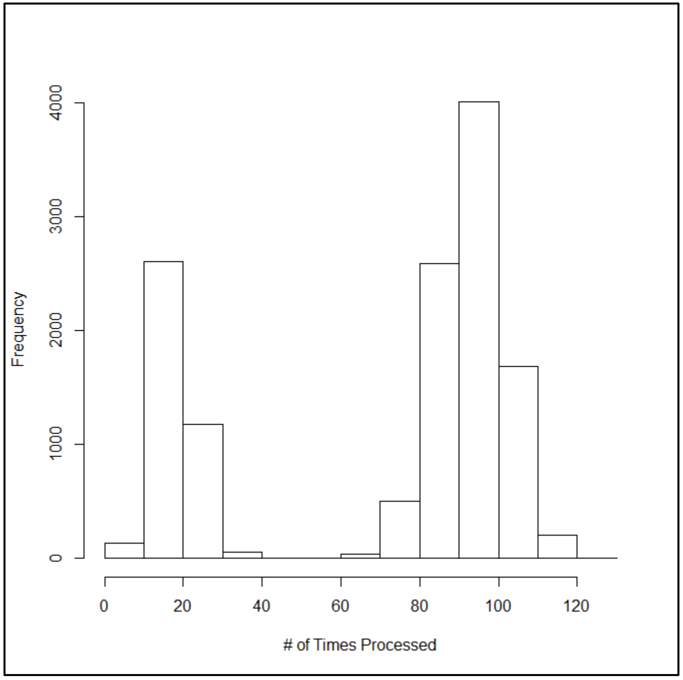
The data for the active population and the data from the pilot sample were used to define the stratification within the population, and develop a sampling plan based on stratified random sampling.

RESULTS

Active Population of Dosimeters

The amount of dosimeters currently used by RPDP was estimated to be 13,030. The amount of processing for each of these dosimeters was compiled. Figure 1 displays a histogram of the amounts of processing of the active dosimeters. The histogram shows 2 discrete groups in the active dosimeters: dosimeters processing less than 60 times (3989 dosimeters) and dosimeters processing greater than or equal to 60 times (9041 dosimeters).

Figure 1 – Histogram of the amount of times each active dosimeter has been processed (total number of active dosimeters = 13,030).



The complete processing history of some dosimeters (chosen at random) from each group was examined. The examined dosimeters that were processed less than 60 times were added to the dosimeter population within the past 10 years. The other examined dosimeters were added to the dosimeter population much earlier. This indicates that the amounts of processing of dosimeters correlate to age of the dosimeters, not unequal probability of being selected for processing and issuing. This also shows that the population of active dosimeters is stratified. The stratum of dosimeters processed less than 60 times is considered to be newer dosimeters and the other considered to be older dosimeters.

Pilot Sample

The data from the pilot sample was segregated by older and newer dosimeters. The mean and the variability of the TLD chips in the pilot sample were calculated and are listed in Table 1. The amounts of dosimeters in the active population are also listed in Table 1.

Table 1 – Average and variance of the readings of each TLD chip in the pilot sample, by dosimeter stratum.

Stratum	# in Active Population (13,030 Total)	TLD Chip 1		TLD Chip 2		TLD Chip 3		TLD Chip 4	
		Average	Variance	Average	Variance	Average	Variance	Average	Variance
Newer	3989	1.56	0.12	1.45	0.15	2.90	1.40	1.42	0.05
Older	9041	2.29	0.35	1.97	0.82	7.18	22.8	2.33	0.93

For the dosimeters in the pilot sample, TLD chip 3 had the largest average and most variable readings out of all the TLD chips. Also, the TLD chips in the older dosimeters had the largest average and most variable readings compare to TLD chips in newer dosimeters.

Stratified Random Sampling

The total sample size for stratified random sampling to achieve a desired margin of error is (Lohr, 2010):

$$n = \frac{z_{\alpha/2}^2 \nu}{e^2}$$

where $z_{\alpha/2}$ is 1.96 (for α = 0.05) and e is the margin of error. The quantity ν is (Lohr, 2010):

$$\nu = \sum_{h=1}^{H} \frac{(N_h/N)^2 S_h^2}{(n_h/n)}$$

where N_h is the size of stratum h in the population (H total strata), N is the total size of the population, S_h^2 is the variance of the population in the stratum, and (n_h/n) is the allocation to the stratum of total sample size n.

The results listed in Table 1 show that the variance is not equal across strata, so (n_h/n) is determined with optimal sampling (Lohr, 2010):

$$(n_h/n) = \frac{N_h S_h/\sqrt{c_h}}{\sum_{l=1}^{H} N_l S_l/\sqrt{c_l}}$$

where c_x is the cost associated with sampling from stratum x.

The cost associated with sampling dosimeters in the active population is the same regardless if the dosimeter is older or newer. Optimal allocation where costs are equal is Neyman allocation (Lohr, 2010), and (n_h/n) simplifies to:

$$(n_h/n) = \frac{N_h S_h}{\sum_{l=1}^{H} N_l S_l}$$

Sampling Plan for Dosimeters

The sampling plan for the active population of dosimeters (based on stratified random sampling) was developed from the results from Table 1. The variability in the readings of the TLD chips in the pilot sample was used to represent the variability in the dark current in the active population of dosimeters. Since the largest variation in the readings in the pilot sample was in TLD chip 3, the sampling plan was based on the results from that TLD chip.

For the newer dosimeters, the allocation of the total sample size is 0.099. For the older dosimeters, the allocation is 0.901. The quantity ν is 13.5. The margin of error used for the sampling plan is 1.0 gU, so the total sample size is 51.9 ≈ 52.

Therefore, the sample size for the newer dosimeters is 52 * 0.099 = 5.1 ≈ 5 and the sample size for the older dosimeters is 52 * 0.901 = 47.

CONCLUSIONS

The sampling plan for measuring the dark current is to randomly sample 5 newer dosimeters and 47 older dosimeters from the active dosimeter population. This sampling is based on a margin of error in the resulting average dark current of 1.0 gU at the 95 percent confidence level.

The observed variability in the readings of TLD chip 3 is larger than in the other TLD chips. This increase may be due to the differing thicknesses of the filters on the TLD chips and/or the differing thicknesses of the TLD chips themselves. The thickness of the filter on TLD chip 3 is 2-5 percent of the thickness of the other TLD chips. The thickness of the filter on TLD chip 3 is ~40 percent of the thickness of the other TLD chips. TLD chip 3 is used to measure shallow dose (Thermo, 2007).

Also, the observed variability in the readings of the TLD chips in the older dosimeters is larger than in the newer dosimeters. This indicates that, for at least very low amounts of radiation dose, variability in readings of TLD chips increases as the amount of processing of the dosimeter increases. This difference in variability is reflected in that the allocation of the sample size is much greater for the older dosimeters (47) than the newer dosimeters (5).

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Lohr, S.A. (2010). *Sampling: Design and Analysis: Second Edition*. Boston, MA: Brooks/Cole.

Thermo, (2007). WinAlgorithms: Dose Calculation Algorithm for Type 8825 Dosimeter – User's Manual. Publication No. ALGM-W25-U-0107-003, Oakwood Village, OH: Bicron.

APPENDIX: R CODE AND OUTPUT

```
> Pop <- read.csv("popstrat.csv", header = TRUE)
> Pilot <- read.csv("8825 Pilot.csv", header = TRUE)
>
> ### Histogram of Active Population
>
> hist(Pop$Reads, main = "", xlab = "# of Times Processed")
>
> ### Define population
>
> nrow(Pop)
[1] 13030
> N <- 13030
>
> Popdist <- table(Pop$Strata)
>
> Popdist

   1    2
3989 9041
>
> N_newer <- 3989
> N_older <- 9041
>
> ### Analyze pilot sample
>
> statsStrata <- cbind(c(1:2), rep(0,2), rep(0,2), rep(0,2), rep(0,2), rep(0,2), rep(0,2), rep(0,2), rep(0,2))
> colnames(statsStrata) <- c("Stratum", "MeanChip1", "VarChip1", "MeanChip2", "VarChip2", "MeanChip3", "VarChip3", "MeanChip4", "VarChip4")
> # $Stratum = 1 is newer dosimeter, $Stratum = 2 is older dosimeter
>
> for (i in 1:4)
+ {
+ for (j in 1:2)
+ # j = 1 is newer dosimeter, j = 2 is older dosimeter
+ {
+ statsStrata[j,(2*i)] <- mean(Pilot[which(Pilot$Stratum == j),(i+1)])
+ statsStrata[j,(2*i+1)] <- var(Pilot[which(Pilot$Stratum == j),(i+1)])
+ }
+ }
>
> statsStrata
     Stratum MeanChip1  VarChip1 MeanChip2  VarChip2 MeanChip3  VarChip3 MeanChip4  VarChip4
[1,]       1  1.562073 0.1152630  1.449765 0.1515721  2.901327  1.400832  1.420684 0.0460125
[2,]       2  2.287667 0.3473915  1.967794 0.8208774  7.175253 22.811930  2.334299 0.9252616
>
> Var_newer <- statsStrata[1,7]
> Var_older <- statsStrata[2,7]
>
> n_newer_n <- N_newer * sqrt(Var_newer) / (N_newer * sqrt(Var_newer) + N_older * sqrt(Var_older))
> n_newer_n
0.09855912
>
> n_older_n <- N_older * sqrt(Var_older) / (N_newer * sqrt(Var_newer) + N_older * sqrt(Var_older))
> n_older_n
0.9014409
>
> v <- (N_newer / N)^2 * Var_newer / n_newer_n + (N_older / N)^2 * Var_older / n_older_n
> v
13.51549
>
> z <- 1.96
> MOE <- 1.0
>
> n <- z^2 * v / MOE^2
> n
51.92109
> # round n up
```

```
> n <- 52
>
> n_newer <- n * n_newer_n
> n_newer
5.125074
>
> n_older <- n * n_older_n
> n_older
46.87493
```

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