OBTAINING THE ENVIRONMENTAL DOSE FROM THE MODEL 8823 DOSIMETER

Purpose

This Meteorology and Air Quality Group (MAQ) procedure describes the calculation of doses from the Model 8823 dosimeter for the MAQ DPRNET program.

Scope

This procedure applies to the individual assigned to calculate doses from the Model 8823 dosimeter for the DPRNET program.

In this procedure

This procedure addresses the following major topics:

Hazard Control Plan

The hazard evaluation associated with this work is documented in HCP-MAQ-Office Work.

Signatures

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General information about this procedure

Attachments   This procedure has the following attachments:

Number	Attachment Title	No. of pages
1	Details of (optional) Dose Calculation Method 2	2

History of revision   This table lists the revision history and effective dates of this procedure.

Revision	Date	Description Of Changes
0	6/4/02	New document.

Who requires training to this procedure?   The following personnel require training before implementing this procedure:
- Individual assigned to calculate doses from the Model 8823 dosimeter

Training method   The training method for this procedure is "**self-study**" (reading) and is documented in accordance with the procedure for training (MAQ-024).

General information, continued

Definitions specific to this procedure

None.

References

The following documents are referenced in this procedure:
- MAQ-024, "Personnel Training"
- Memo ESH-4-MTS-98-077, "Revision to LANL 8823 Background Characterization," Michael Mallett to Jeff Hoffman, December 3, 1998
- ESH4-PDO-TBD-02, "The LANL Model 8823 Whole-Body TLD and Associated Dose Algorithm", Jeff Hoffman and Mike Mallett
- ESH4-PDO-00:004, "Revision to LANL 8823 Background Subtraction", from Jeff Hoffman to external dosimetry historical records, January 13, 2000
- "The LANL Model 8823 Whole-Body TLD and Associated Dose Algorithm," Jeff Hoffman and Michael Mallett, published in Operational Radiation Safety (Supplement to Health Physics, The Radiation Safety Journal), Vol 77 No. 5 suppl, pages S96-S102, November 1999
- 8823-01a.bas computer program, maintained by HSR-4
- NCRP Report No. 94, "Exposure of the population of the US and Canada from Natural Background Radiation," 1987
- UNSCEAR-2000, "Sources and Effects of Ionizing Radiation," United Nations publication E.00.IX.3, ISBN 92-1-142238-8

Note

Actions specified within this procedure, unless preceded with "should" or "may," are to be considered mandatory guidance (i.e., "shall").

Description of dosimeter system

Background

The DPRNET project uses the HSR-4 Model 8823 TLD dosimeter to measure environmental direct penetrating radiation. The dosimeters are obtained from and processed by HSR-4. They are described in the article "The LANL Model 8823 Whole-Body TLD and Associated Dose Algorithm" by Jeff Hoffman and Michael Mallett. They are also described in the HSR-4 Personnel Dosimetry Operations Team procedure ESH4-PDO-TBD-02.

Dosimeter design

The dosimeter contains 8 TLD elements or chips. Each has a primary purpose, as follows:
- Element 1: deep dose (gamma)
- Element 2: shallow dose (beta)
- Element 3: shallow dose (penetrating beta)
- Element 4: gamma energy
- Element 5: anti albedo (thermal neutron plus gamma)
- Element 6: anti-albedo (gamma only)
- Element 7: albedo (gamma only)
- Element 8: albedo (fission neutron plus gamma)

Description of dosimeter processing

HSR-4 personnel anneal, assemble and issue the dosimeters. RRES-MAQ personnel collect them from HSR-4, deploy them in the environment, track their locations, retrieve them from the environment, and return them to HSR-4. HSR-4 personnel load them into a TLD reader, and send the reader output to the DPRNET team in RRES-MAQ.

Reading dosimeters

HSR-4 personnel will read the TLDs and provide the reader output, sorted by dosimeter ID. The DPRNET technician will provide a list of dosimeter IDs and the corresponding location numbers. The essential data are:
- The dosimeter identification number, ID, e.g. E17001.
- The station location number, e.g., L001.
- The issue and pickup dates.
- The "net corrected reading" (NCR) for each of the 8 elements, called NCR1 through NCR8.

Note on terminology

In this procedure and in the HSR-4 documents, "dose" is an abbreviation of "dose-equivalent" and is specified in mrem.

Retrieving data

Retrieving data from DPRNET database

From the HSR-4 TLD database, HSR-4 personnel will use the following SQL query to generate a text file of dosimeter data.

```
SPOOL E:\&FILENAME;
SET HEADING OFF;
SET LINESIZE 800;
SELECT '"'||CHKNAME||'"','|| BDG_NUM||','||
CD_NUM_B||','|| CD_NUM_N||','|| RD_DT_B||','||
RD_DT_N||','|| LST_RD_DT_B||','|| LST_RD_DT_N||','||
NET_COR_1||','|| NET_COR_2||','|| NET_COR_3||','||
NET_COR_4||','|| NET_COR_5||','|| NET_COR_6||','||
NET_COR_7||','|| NET_COR_8||','|| SHALL_DOSE ||','||
DEEP_DOSE||','|| NEU_DOSE||','|| LENS_DOSE
FROM TLD_ASSIGN_HIST
WHERE CHKNAME LIKE 'ENVIRONMENTAL'
AND ISS_PD = '&ISS_PD'
AND ISS_YR = '&ISS_YR';
SPOOL OFF;
```

Data resulting from query

The resulting text file consists of the following data:
- The badge number and card numbers, e.g., E17001.
- The read dates when each TLD card was zero-ed (about a month before it was issued from HSR-4) and the date when it was read (about a month after it was returned to HSR-4).
- The net-corrected Cs-137-equivalent dose (mrem) for each of the 8 elements.
- The shallow dose, deep dose, neutron dose, and eye dose (mrem) calculated using the standard HSR-4 algorithms described in ESH4-PDO-TBD-02.

Merge data with TLD locations and dates

The **DPRNET technician** generates a text file of badge numbers, DPR location numbers, and issue and pickup dates.

After receiving the data files from the technician:
1. Import the text files into Excel.
2. Sort by badge number.
3. Insert blank lines as needed to make the two lists match.
4. Paste them into the same worksheet so each badge has a location number.

Retrieving data, continued

Dose evaluation methods advantages and disadvantages

There are several possible methods to calculate a dose. Method 1 is simplest, method 3 is preferred and is the standard method we are using.

	Advantages	Disadvantages
Method 1	- Simple. - DOELAP QA. - Directly comparable with personnel doses.	The dose is not directly comparable with archived environmental data, because - An estimate of the background dose has already been subtracted. - Doses less than 10 mrem are set to zero.
Method 2	Do not need control dosimeters.	- Complicated. - In general, method 3 is preferable to method 2.
Method 3	- Conceptually simple. - Directly comparable to historical DPRNET data. - Does not prejudge the background.	Requires 50-100 control dosimeters.

Discussion of background

Background considerations

In New Mexico, the natural environmental background varies from about 100 to 200 mrem per year. Therefore, the background that is subtracted by HSR-4 is, at best, an average number. The numbers used for each of the 8 elements are listed in ESH4-PDO-00-004 as follows.

- Element 1: 0.256 mrem/day
- Element 2: 0.251 mrem/day
- Element 3: 0.243 mrem/day
- Element 4: 0.286 mrem/day
- Element 5: 0.284 mrem/day
- Element 6: 0.240 mrem/day
- Element 7: 0.236 mrem/day
- Element 8: 0.286 mrem/day

Notice that these are about 0.25 mrem/day, which is 90 mrem/year. This is less than the environmental background at any outdoor location. There are two basic reasons for this discrepancy. First, the background was measured inside the HSR-4 building at TA-3. Second, the HSR-4 background correction includes an implicit correction for fade and loss of sensitivity.

Background dose rates are generally smaller inside LANL buildings than in the environment, and are generally smaller on the mesa tops than in the canyons. Considering that most LANL workplaces are on mesa tops, and almost all residences are on mesa tops or in the Rio Grande valley where the background is small, the standard HSR-4 background subtraction is satisfactory for most workers.

Furthermore, within the HSR-4 building, the background varies significantly. The lowest background is on the shelf in the TLD-reader room, where TLD cards are stored. Preliminary investigations indicate that the dose here is lower than 0.25 mrem/day, so after the standard HSR-4 background subtraction, a card stored here will be reported with a negative net-corrected dose.

On the other hand, an environmental dosimeter deployed for 3 months in a high background area such as a canyon will be reported with a dose above the threshold of 10 mrem. In summary, there are some disadvantages to relying on the standard HSR-4 background subtraction.

Dose Calculation: Method 1

**Dose
calculation:
Method 1**

Use the deep dose and neutron dose (mrem) calculated by HSR-4.

Caveats

This method is simple, but can be misleading. The estimated background has
been subtracted from the doses calculated by HSR-4, i.e., the calculated dose is
purported to be the LANL contribution to the environmental dose. With
caution, these numbers can be directly compared with the limits in DOE orders
and regulations. However, locations where the environmental dose is greater
than about 130 mrem per year will be reported with >10 mrem per quarter even
when there is no LANL contribution.

Dose Calculation: Method 2

Method 2   To avoid the disadvantages of method 1, add the background (that was subtracted by HSR-4) and do not set doses less than 10 mrem to zero. The background subtraction is reported in the memo ESH-4-MTS-98-077 from Michael Mallett to Jeff Hoffman dated December 3, 1998 and the revised memo ESH4-PDO-00:04 from Jeff Hoffman dated January 13, 2000. If the background subtraction procedure is simply reversed, the result is lower than the archived environmental data, because the TLD fade is included in the background estimate. The detailed procedure to correct for both the background and the fade is described in Attachment 1. It is documented because it includes a detailed examination of the potential systematic errors associated with environmental dosimetry. However, it is not simple.

Dose Calculation: Method 3

Method 3

Method 3 is the preferred method. In principle, it uses control dosimeters to establish two calibration points, one near zero and one near 300 mrem.

HSR-4 supplies data called "net corrected readings", NCR. We derive "environmental corrected readings", ECR from NCR.

If x_{300} is the additional dose produced by 300 mrem, the slope of the calibration line is:

$$m = 300/x_{300}.$$

For example, if at a particular control location, NCR = 5 mrem for the unexposed dosimeters and NCR = 285 mrem for the dosimeters that were exposed to 300 mrem, x_{300} = 285–5 mrem and m = 1.07. This indicates a 7% correction for fade and loss of sensitivity during the 3 months in the field and the 2 months in the HSR-4 lab.

Then, if a dosimeter stored in the vault reads NCR = x_0 and receives a true dose of y_0, the calibration formula is $y = m(x-x_0) + y_0$.
For example, if NCR = –18 mrem for a vault dosimeter and the true dose (from cosmic-ray muons for 3 months) is y_0 = 6 mrem, the equation is

$$y = m(x - -18) + 6 = 1.07\ x + 25$$

Thus, if an environmental dosimeter reading was NCR = x = 14 mrem, the ECR = y = 40 mrem.

Note: NCR is negative for dosimeters stored in the vault because background of about 0.25 mrem/day has been subtracted by HSR-4.

Use of control dosimeters

As much as possible, the control dosimeters should be kept with the field dosimeters except when the field dosimeters are actually in the field. In this way, they all accumulate the same background dose. In practice, it is impossible to do this perfectly. Fortunately, a few days out of >100 days does not make a significant difference, but to minimize the error, use a standard procedure, as follows.

Dose Calculation: Method 3, continued

Steps to handle control dosimeters

To deploy TLD dosimeters with controls, perform the following steps:

Step	Action
1	Request "new" TLDs that were last read on (or near) the same day. **Note**: there are 55-100 control TLDs, some of which will be deployed at 5 control locations, so if the number of locations is N then at least N+50 TLDs are needed.
2	Expose 15-25 control TLDs to 300 mrem of Cs-137 gammas in the model-6610 TLD-card irradiator *before* they are deployed to the field and keep them in a marked bag.
3	Designate another 15-25 control TLDs to be exposed *after* they are retrieved from the field.
4	Designate another 15-25 TLDs to accompany the 30-50 controls designated in steps 2 and 3.
5	Designate another 10-25 TLDs to be stored in the vault, but do not put them in the vault yet.
6	Keep all the new TLDs together in a cool container marked *new*.
7	Each quarter, visit the sites in the same order, if possible.
8	Deploy TLDs from the cool container marked *new*, and place retrieved TLDs in a cool container marked *old*.
9	At each of the 5 control sites, deploy 3-5 TLDs from each of the control sets designated in steps 2, 3, and 4, i.e., deploy 9-15 TLDs at each of the 5 control sites.
10	When old TLDs are retrieved from control sites, keep them separate, in marked bags, ready for step 12.
11	Transfer the remaining 10-25 TLDs from the container marked *new* into the vault; and transfer the 10-25 old TLDs from the vault into the container marked *old*.
12	Find the 15-25 old TLDs that were designated last quarter to be exposed *after*, and expose them to 300 mrem.
13	Deliver all old TLDs to HSR-4 to be read.

Steps to calculate the environmental gamma dose

To calculate the environmental gamma dose, perform the following steps:

Step	Action
1	Import the data into Excel and match the IDs with the location numbers.

Steps continued on next page.

Dose Calculation: Method 3, continued

Step	Action
2	For each control location and for each of the 8 elements, calculate the average NCR for the dosimeters exposed to 300 mrem and subtract the corresponding averages for the dosimeters that were not exposed to 300 mrem to obtain x_{300}. For each of the 8 elements, calculate the slope: $m = 300/x_{300}$. There will be 8 slopes, m_{1-8}.
3	Calculate the average NCR for the dosimeters that were stored in the vault; this is x_0 and it is normally negative.
4	Calculate the dose, y_0, in the vault by multiplying the number of days the dosimeter was in the vault by the dose rate from penetrating cosmic ray muons, 0.07 mrem/day. For example, if the dosimeters were in the vault for 90 days, $y_0 = 6.3$ mrem.
5	Calculate the environmental corrected readings: $ECR = m*(NCR-x_0) + y_0$. Repeat this calculation for each element of each dosimeter; (Note: you can copy the formula from a previous Excel spreadsheet).
6	Calculate the standard deviation of ECR1, ECR6, and ECR7. Note any anomalies, e.g., standard deviations >10 mrem.
7	For stations that have zero neutron dose, calculate the standard deviation of ECR1, ECR5, ECR6, ECR7, and ECR8. Note any anomalies, e.g., standard deviations >10 mrem.
8	Use the method described in ESH4-PDO-TBD-02 and 8823-01a.bas to calculate R41, S0, and HDG from ECR1 and ECR4 (see samples below). Note any anomalies. **Note**: the Excel formulae are: S0=-528.111+87.051*R41-4.324*R41^2+1468.474/R41 HDGE1E7=0.937645+0.000032278*S0+27.716/S0-115.491/S0^1.5-9947371*EXP(-S0)
9	Use the method described in ESH4-PDO-TBD-02 and 8823-01a.bas to calculate the environmental dose from HDG, ECR1, and ECR7.
10	Calculate the quarterly dose, ENV, by dividing by the number of days between issue and pickup, and multiplying by 365/4 days.
11	Compare ENV with the results of previous quarters and note any anomalies.
12	Use the guidance in the next chapter to resolve the anomalies. Document the reasons for any departure from the standard calculation.

Dose Calculation: Method 3, continued

Document and peer review

Print out a copy of the spreadsheet(s) used to perform the calculations. Document any non-standard calculations used to resolve anomalies and the reasoning behind them. Obtain a peer review of the spreadsheet (to check for proper formula implementation as given in the steps above) and any non-standard calculations. Document the peer review and submit the documentation to the records coordinator.

File electronic records

Keep a copy of the electronic Excel files on the database drive.

Import the quarterly deep dose for each quarter and for each station into the table "Archive_TLDStationDose" in the DPRNET database.

Guidance to resolve data anomalies

Resolving data discrepancies

For most environmental dosimeters, all 8 elements should be similar. This section discusses the reasons for differences and anomalies.

Use professional judgement to decide if one or more of the 8 elements is malfunctioning and if so replace the standard calculation with a special calculation based on the following guidelines.

Damaged TLDs

Any TLD element could be damaged. Usually, damaged TLDs read low. If damage is suspected, inform HSR-4. HSR-4 personnel can find the TLD card, inspect and test it, and recalibrate it or take it out of service.

Element 1 TLD

Element 1 is designed to measure deep gamma dose. However, it is better to average more than one element, rather than rely on element 1 alone.

Element 2 TLD

Element 2 is thin, covered with a single thin layer of mylar, and light sensitive, therefore it often reads high. Direct sunlight combined with a damaged mylar cover is very likely to result in a high reading. In future, we plan to package the dosimeters in a robust light-tight package to try to reduce this problem.

Element 3 TLD

Element 3 suffers the same problems as element 2, but not so badly. However, low values of both NCR1 and NCR2 is evidence in favor of a low gamma dose. If other elements are suspect, and if both NCR1 and NCR2 appear normal, use the average of NCR1 and NCR2 and assign the same statistical weight to the average as to one of the other elements.

Element 4 TLD

Element 4 over-responds to low energy gammas and is thus used to measure the gamma energy (by comparing its response to element 1). The expected value of NCR4 as a function of gamma energy can be obtained from the HSR-4 program: 8823-01a.bas. A high value of NCR4 indicates low-energy gammas such as from americium-241. NCR4 tends to read low (its signal fades rapidly) when exposed to sunlight (e.g., if there is a pinhole in the nearby mylar covering element 2 or 3). However, if NCR2, NCR3, and NCR4 all appear normal, and if there is no americium-241 near the location, NCR4 can be averaged into the calculation of environmental gamma dose.

Guidance to resolve data anomalies, continued

Element 5 TLD

Element 5 measures thermal neutron plus gamma dose. If NCR5<NCR6 and both NCR5 and NCR6 appear normal, they could be averaged into the calculation of environmental gamma dose. See item 6 for a discussion of its gamma response.

Element 6 TLD

In principle, NCR6 could be averaged into the measurement of gamma dose, subject to the following cautions: the shielding in front is low, so elements 5 and 6 are sensitive to high-energy betas from Sr-90 or from the uranium decay product Pa-234m; also, low energy gammas reflect from the layer of cadmium behind elements 5 and 6 causing them to over-respond to low energy gammas.

Element 7 TLD

Element 7 is normally averaged into the calculation of deep dose, and also used to subtract the gamma contribution from element 8.

Element 8 TLD

NCR8 minus NCR7 measures the albedo neutron dose. If NCR8<NCR7, NCR8 could be averaged into the measurement of gamma dose.

Calculating neutron dose

Neutron dose   The environmental neutron background is small and does not vary significantly; therefore, the HSR4 background subtraction is accurate and the standard HSR-4 calculation almost always agrees with the following calculation.

Note: The neutron background is from cosmic rays, which depends on altitude; see NCRP-94 (page 18) and UNSCEAR-2000 (page 85) for details. However, the variation is small so this is not a significant problem.)

Hydrogenous material   The true neutron dose can only be calculated if the dosimeter was mounted on hydrogenous material, e.g., a 4-inch-thick slab of Lucite (poly methyl meth-acrylate, PMMA) or polyethylene. Otherwise, the dosimeter will indicate the presence of neutrons but the calculated dose will typically be about a factor of 2 low.

Steps to calculate the environmental neutron dose equivalent   To calculate the neutron dose equivalent, perform the following steps:

Step	Action
1	Use NCR4-8 to calculate ECR4-8 as described in step 5 of the procedure to calculate the environmental gamma dose
2	Calculate R5N8N = (ECR5-ECR6)/(ECR8-ECR7) and HDN following the HSR4 procedure: ESH4-PDO-TBD-02. **Note**: the Excel formula is HDN =0.545-0.288*R+0.07*R^3+0.014/R^2
3	In special cases, substitute a known value for HDN. For example, when the neutrons are moderated by air, HDNE8N=0.145.
4	The neutron dose equivalent = HDNE8N*(ECR8-ECR7).
5	Calculate the quarterly dose equivalent by dividing by the number of days between issue and pickup, and multiplying by 365/4 days.
6	Resolve anomalies as described in the chapter *Guidance to resolve data anomalies*.

Calculating neutron dose, continued

Document and peer review

Print out a copy of the spreadsheet(s) used to perform the calculations. Document any non-standard calculations used to resolve anomalies and the reasoning behind them. Obtain a peer review of the spreadsheet (to check for proper formula implementation as given in the steps above) and any non-standard calculations. Document the peer review and submit the documentation to the records coordinator.

Records resulting from this procedure

Records   The following records generated as a result of this procedure are to be submitted within 12 weeks as records to the records coordinator:

- printout of the Excel files
- electronic copy of Excel files on network drives
- description of any anomalies and non-standard calculations
- peer review documentation

[Click here to record "self-study" training to this procedure.](#)

DETAILS OF (OPTIONAL) DOSE CALCULATION METHOD 2

Start with the eight NCR values, one for each chip, reported in mrem. These are nominally the LANL contribution after subtracting the background, m, as a function of time, t, and an additive offset, b, from the raw signal, "RAW":

$NCR = RAW - mt - b$

The raw signal is the result of dose rates r for time t received while they are:
1. In the HSR-4 buildings;
2. in the DPRNET vault; and
3. in the field.

There is also a signal thought to come from the kapton seal, k; in theory, k=b. Also, the raw signal is subject to a fade factor, F. Thus:

$RAW = F(r_1t_1+r_2t_2+r_3t_3) + k$

Example:

F=0.9, $r_1 = 0.3$ mrem/day, $t_1 = 60$ days, $r_2 = 0.1$ mrem/day, $t_2 = 10$ days, $r_3 = 0.4$ mrem/day, $t_3 = 90$ days, b=k = 10 mrem.

RAW = 0.9(18+1+36) +10 = 59.5 mrem.

NCR is calculated from RAW assuming $t = t_1+t_2+t_3 = 60+10+90 = 160$ days.

For example, if: m = 0.27 mrem/day.

NCR = RAW - mt - b = 59.5 - 0.27 x 160 - 10 = 6.3 mrem.

The value of m was determined by exposing dosimeters to background in Mike Mallett's office and fitting a line to the graph of RAW versus t:

$RAW = mt + b$

In theory, for this situation, $RAW = F r_1 t + k$; so $m = F r_1$; and $b = k$.

This is checked by Rich McKeever's histograms, which indicate a residual correction, a=b-k= 5 mrem for chip 1 (closer to zero for the other chips).

Combining the equations:

$NCR = F(r_1t_1+r_2t_2+r_3t_3) - mt - a = F((r_2-r_1)t_2+(r_3-r_1)t_3) - a$.

Using the numbers in the examples:

NCR = 0.9((0.1-0.3)10+(0.4-0.3)90) - 5 = 1.3 mrem.

In fact, we need to derive r_3t_3:

$r_3t_3 = (NCR+a)/F - r_2t_2 + r_1t_2 + r_1t_3 = (1.3+5)/0.9 - 1 + 3 + 27 = 36$ mrem.

The fade factor, F, is obtained by exposing field-fade dosimeters and deploying them with regular field dosimeters. It is about 2 to 3% per month.

Implementation

The equation is implemented as

$91.25\ r_3 = (91.25/t_3)\ [\ (NCR+a)/F + (t_2+t_3)m/F - r_2t_2\ ]$