DEFENSE THREAT REDUCTION AGENCY

NUCLEAR TEST PERSONNEL REVIEW PROGRAM

RADIATION DOSE ASSESSMENT

STANDARD METHOD

ED01 – Film Badge Dose Assessment

Revision 1.3

Key to SOP ID Codes

RA (Radiation Assessment - SOP)
ED (External Dose - Standard Methods)
ID (Internal Dose - Standard Methods)
UA (Uncertainty Analysis - Standard Methods)

Revision Control			
Revision	Revision Description	Revision Date	Authorization Official
1.0	Original	10/31/2007	Paul K. Blake
1.1	- Section 5.1.2.2: Text added in first paragraph to refer to ID01 for the different treatment of mission and non-mission film badges. - Minor editorial changes	03/31/2008	Paul K. Blake
1.3	- Revision 1.2 not prepared - Minor editorial changes - Expanded discussion of film badge use in external dose reporting - Removed details of discussion about film badge use for internal dose reporting and added to SM ID01 - Deleted sections 5.2.1 and 5.2.2 on film badge uncertainty and errors to be incorporated into SM UA01 - Deleted Section 6 on Data and Input as unnecessary	01/31/2010	Paul K. Blake

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Standard Method

ED01 – Film Badge Dose Assessment

1 Purpose/Summary

Standard Method (SM) ED01, *Film Badge Dose Assessment*, provides general technical methods for the treatment of film badge dosimetry data in determining external gamma, skin and internal doses for participants in the Nuclear Test Personnel Review (NTPR) Program according to the procedures specified in SOP RA01.

2 Scope

This standard method provides technical guidance for the proper use of film badge dosimetry data in NTPR dose assessments. This standard method is used in conjunction with other standard methods for assessing whole body external gamma radiation doses, skin dose from sources other than dermal contamination, and internal doses accrued during the period(s) of film badge coverage in accordance with the requirements of Title 32, Code of Federal Regulations, Part 218, 2006, and relevant Department of Defense guidance (DoD, 2006).

3 Responsibilities

Qualified radiation dose analysis staff members use these methods and associated tools for assessing the radiation doses for exposed individuals.

4 Definitions

a. NuTRIS – Nuclear Test Research Information System is a veteran cohort search tool and database.

b. Individual – any person, (member of the armed forces or a DoD civilian employee) who participated in the atmospheric nuclear weapons testing program.

c. Film badge – an integrating dosimeter for measuring gamma radiation exposure that uses ordinary photographic or x-ray film as the sensitive element. The film packet contained the radiation sensitive film inside a flexible casing of light-tight plastic, which was placed inside a rigid plastic holder. The holder served to provide some physical protection, to hold a filter or filters for evaluating response to radiation of different energies, and to act as a means for attaching the badge to a monitored individual or object. In later operations, the film packet was dipped in ceresin wax to help protect it from exposure to light, water, or other factors that could compromise the integrity of the film. (NRC, 1989)

d. Period of coverage – the elapsed time from when a film badge was issued to an individual until it was turned in for processing.

e. Permanent film badge – a film badge dosimeter worn by an individual to monitor that person's radiation exposure over an extended period of coverage (typically 4 weeks or more).

f. Mission badge – a film badge worn by an individual to monitor that person's radiation exposure for a specific short-term activity with a period of coverage of about 1 day or less.

g. Cohort film badge – a badge worn by one individual among a group of individuals believed to have similar potential for exposure to radiation. The dose reported for a cohort film badge is considered to be representative of the dose accrued by the unbadged cohort members during the period of coverage.

h. Film badge reading – the reported reading from the individual's film badge in units of roentgens (R).

i. Film badge dose – the individual's equivalent dose in rem from external gamma radiation based on a film-badge reading. The whole-body dose in rem from exposure to external gamma rays determined from a film badge reading is considered to be equal to the film badge reading in R for a properly worn film badge, which is assumed to have been worn on the external clothing of an individual at chest level above the source plane (NRC, 1989).

j. Dose – Film badge dose, unless otherwise indicated.

5 Method Description

During the period of atmospheric nuclear weapon testing by the U. S. Military, the exposure of military and civilian personnel to radiation was monitored primarily with film badge dosimeters. The NTPR Program considers the film badge its principal device for measurement of radiation exposure, which is the basis for a participant's radiation dose assessment (DoD, 2006). Film badges were used to monitor the whole-body external gamma doses accrued during their recorded periods of coverage for some testing activities depending on the individual, group, shot, or operation. The film badges did not measure dose from neutrons or alpha and beta radiation. If a specific individual did not wear a film badge, it is often possible to estimate that individual's dose based upon the readings from cohort film badges if the individual belongs to an identifiable cohort available in the Nuclear Test Research Information System (NuTRIS) database. (Note that for non-badged periods, dose reconstruction using SM ED02 is required.) Film badge readings can also be used to indirectly estimate the dose to an individual's skin from beta radiation from surface-deposited sources (e.g., fallout) and dose to internal organs that resulted from intakes of radioactive materials during the period of coverage.

Specific details regarding film badge dosimetry practices employed for the atmospheric nuclear testing operations are found in the operation-specific Appendices A through C, and NRC (1989). That detailed information can be summarized as follows: prior to Operation CASTLE in 1954, film badges were typically only issued to individuals

involved in activities with anticipated potential for radiation exposure (e.g., cloud samplers and associated ground crews, sample recovery teams, decontamination crews, radiation safety personnel). At CASTLE, cohort badging was introduced as a means of monitoring the radiation exposures of all individuals, regardless of their anticipated potential for exposure. At Operation REDWING in 1956, film badge dosimetry practices were further expanded. Permanent film badges, which were to be worn at all times, were to be issued to all individuals who entered the test area. In addition, individuals involved in activities with known potential for radiation exposure were issued mission badges for those activities. Mission badges were to be worn with the individual's permanent film badges. Thus, the permanent badge reading will also include any doses reported for mission badges worn during the permanent badge period of coverage. For test series subsequent to Operation REDWING, most individuals were issued one or more film badges for the duration of their participation.

5.1 Applicability and Utility of Film Badge Dosimetry Data

The criteria for assessing the reliability of film badge dosimetry are based on answers to the following questions:

a) Is the dosimeter film damaged?

b) Is the reading truly representative of veteran's exposure scenario (activities and period of coverage)?

Most film badge doses for atmospheric nuclear test participants are consistent with corresponding reconstructed doses, considering the uncertainty inherent in the respective values. However, some dosimeter films, which were either damaged or not used in conjunction with appropriate background controls, have yielded readings that are inconsistent with exposure in the radiation environments in which they were worn. The treatment of readings from damaged or improperly controlled badges is discussed in detail below.

Many dosimeter films used in the atmospheric nuclear testing program are archived by the dosimetry custodian at the Nuclear Testing Archive (NTA), U.S. Department of Energy, National Nuclear Security Agency, Nevada Site Office, Las Vegas, Nevada) and may be available for visual inspection by that agency. Arrangements for such an inspection may require that a formal agreement be established to compensate the agency for this service. The Film Evaluation Request Form shown in Attachment 1 has been used in making such requests typically via e-mail under former support agreements. The NTA also maintains a database of film badge dosimetry records for atmospheric nuclear weapon testing participants and is a principal provider of such information for the NTPR.

See SOP RA01, Radiation Assessment of Cases Requiring Detailed Analysis for the hierarchy of dosimetry. See SM ED02, Whole Body External Dose – Reconstruction for methods of dose reconstruction not involving film badges.

5.1.1 Treatment of Readings from Potentially Damaged Film Badges

5.1.1.1 Background Information

To correct for the over response of dosimeter film to low-energy gamma radiation, film badges utilized a filter consisting of a thin lead strip that overlaid a portion of the film packet. Dosimeter films that have been exposed to the full energy spectrum of gamma radiation emitted by mixed fission products within their range of sensitivity are characterized by a clearly defined "filter image," which appears as a lighter rectangular area contrasted against a darker background. The degree of darkening of a film or particular region of a film, which is proportional to accrued radiation exposure, is quantified by its "optical density." The presence of a filter image is a good indication that a film was exposed to radiation at levels above the minimum detectable level (MDL), nominally 0.040 R for most low-dose range film used in film badge dosimeters during the period of atmospheric testing. (NRC, 1989; Mees and James, 1966)

5.1.1.2 Method for Evaluation and Dose Determination for Potentially Damaged Film Badges

If an individual's exposure scenario is well characterized, it is usually possible to identify film badge readings that are inconsistent with the individual's potential for exposure and that, therefore, warrant further investigation.

Suspect film badge readings usually fall into one of the following three categories, which are discussed below:

a. Zero film badge reading for a period of coverage when an individual had potential for exposure.

b. Positive badge readings for a period of coverage with no known potential for exposure or that greatly exceed the reconstructed dose from known exposure pathways (typically, by a factor of about 2[*] or more).

c. Film badge reading that is significantly less than the reconstructed dose from known exposure pathways (by about a factor of 2 or more).

Category a: If an individual has a zero film badge reading during a period of coverage when the individual had potential for exposure to radiation, the most likely explanation is that the accrued exposure was less than the MDL of the type of film utilized in the individual's film badge. In such cases, the actual dose reported for the individual can range from zero to the MDL. NTPR considers film badge readings of this type as "soft

[*] A factor of two is generally considered a level at which a badge reading warrants further investigation. If an individual's radiation exposure scenario is very well characterized, however, an analyst may decide to have a film inspected if it exceeds a reconstructed dose by a lesser amount.

zeros," and assigns values of one-half the MDL (typically 0.020 rem) in place of zero. (DTRA, 2007; NRC, 1989)

Category b: Film badge readings that fall into Category b are most often the result of environmental damage from the effects of heat and humidity on badges issued for several weeks or more, and are generally confined to Operations REDWING (1956) and DOMINIC I (1962) (NRC, 1989; DNA, 1982; SAIC and NST-LLC, 1989-2006). However, this situation can also arise if the individual turned in a film badge that was not processed until a later date and was exposed to fallout that occurred during the period of storage.

Most of the damage seen in film badges worn by REDWING participants resulted from the combined effects of heat and humidity that caused breaches in the casing that sealed the film package from the exterior environment. The most common effect was that moisture penetrated the film badge casing and damaged the film packet within. Water-damaged films can usually be identified visually by an irregularly shaped, often mottled, unevenly darkened image.

Many of the dosimeter films from badges worn by DOMINIC I personnel have water damage similar to that seen in Operation REDWING. DOMINIC I films, in addition to water damage, have a higher incidence of damage due to light leaks from breaches in the plastic covering of the badge. Such light damage occurred in film badges that had long periods of coverage, which appears to correlate with a higher frequency of emulsion and/or process damage. Films with long periods of coverage are also more likely to exhibit spurious "filter images" due to background radiation exposure (without appropriate controls) and/or pressure from the lead filter strip. (NRC, 1989; SAIC and NST - LLC, 1989–2006; Perkins and Hammond, 1980)

A key point for DOMINIC I films returned after November 1, 1962 is that they were processed at the Nevada Test Site (NTS), often without the correct set of control films. Compounding the issue is that film reading was automated. Automated film reading without critical review allowed gradients in darkening or damaged areas to be assessed as legitimate density readings. The lack of appropriate background subtraction and the inadequate screening of results are the principal reasons why doses were assigned to these individuals when no exposures had occurred. Despite the potential for exposure at tests at the NTS during the period of testing, doses of one to several rem were not systematically reviewed. (NRC, 1989)

NTPR submits film evaluation requests to the dosimetry custodian for all dosimeter films pertaining to individuals from Operations REDWING and DOMINIC I during production of the Scenario of Participation and Radiation Exposure (SPARE). NTPR treats film badge readings that fall into Category b as follows:

- If film evaluation results are available and the film is determined to have been damaged, the reading is superseded by a reconstructed dose for the period of coverage. Note that in most such cases, the film badge readings of similarly exposed

personnel ("cohorts") are also damaged. Thus, cohort dosimetry does not typically provide reliable dose estimates and the doses must be reconstructed.

- If film evaluation results are available and the film is determined to be undamaged, the reading is retained as the individual's dose of record for the period of coverage. At this point, the analyst should carefully review the information provided in the individual's case file and SPARE and/or arrange to contact the individual to further clarify their activities to account for additional exposure potential. While such information does not impact the individual's external dose assessment, it may have profound implications for skin and/or internal dose based on the film badge reading.
- If the individual's dosimeter film is not available for evaluation or cannot be reviewed, the film badge reading is retained as the dose of record for the period of coverage. As in the previous bulleted statement, the analyst should carefully review the information provided in the individual's case file and SPARE and/or contact the individual to further clarify their activities to account for any additional exposure potential.
    - If there was no source of exposure potential to the individual during the period of coverage, the reading is retained but no additional uncertainty increment is applied for an upper bound calculation (i.e., the reading is treated as an upper bound dose for the period of coverage) and no hypothetical source term should be invoked for beta dose to the skin or intakes for internal dose accrual, based on the reading.
    - If exposure potential existed during the period of coverage, the reading is retained, but no additional uncertainty increment is applied for an upper bound calculation. In this case it is permissible to calculate a skin dose or internal dose based on the reading.

Category c: Film badge readings that fall into Category c have doses that are significantly lower than the reconstructed dose from known exposure pathways. These readings usually result from a turn-in date that was actually earlier than recorded for the individual. The analyst should carefully review the veteran's case file, SPARE and/or the dosimetry records of other individuals in his unit to ascertain the correct turn in date.

Another source of Category c readings is the exposure of control dosimeter films that result in lower than expected film badge readings. If control badges were stored in areas that received greater fallout than the areas where veterans were operating, the individual film badge result could be lower than the dose actually received by the veteran. Detailed reviews of control badge issues for each operation and shot are in Appendices A–C.

In addition, a lower than expected dose can result from a period of absence from the test area during the period of coverage. If significant fallout took place during the veteran's absence and the individual did not turn in his badge before departing, a lower film-badge dose would result. If the recorded period of coverage for the badge appears to be correct, the film should be evaluated; sometimes long-term exposure to heat will result in latent image fading. (NRC, 1989)

5.1.2 Film Badge for Reporting External Gamma Dose

NTPR uses the FBDOSE program (SAIC, 2006) to calculate the mean (central estimate) of the external dose from film badge readings. The FBDOSE manual has a detailed discussion of how the program operates, how to enter data, and how to use the output from the program (see Table 1 for an example of FBDOSE output).

As shown in Table 1, the analyst uses the total in the MRADJ column of the FBDOSE output as the best estimate of the external gamma dose since the MRADJ total may include a non-zero value if place of a reported zero reading to account for sub-MDL exposures.

When using FBDOSE, the analyst will need to decide whether film badge readings of zero are considered "definite" zeros or "soft" zeros. A "definite" zero is typically specified for a period of coverage where the veteran did not have any potential for exposure while wearing the badge. A definite zero can also be specified for a situation where cohort or other relevant film badge readings are zero, or for a period of coverage for which the reconstructed dose is zero. A "soft" zero is specified for a period of coverage when the veteran potentially received a sub-MDL exposure.

Table 1. Sample Output from FBDOSE Program

FILM BADGE INTERVAL	MR	MRADJ	FILM BADGE DOSE EQUIV LOWER	MEAN	UPPER	UPP90	EXPL CODE
10 28 51 TO 10 28 51	380	380	221	332	498	466	
10 28 51 TO 10 28 51	0	0	0	0	0	0	3
10 30 51 TO 10 31 51	240	240	139	209	314	294	
11 5 51 TO 11 5 51	0	20	0	17	57	47	5
11 19 51 TO 11 19 51	100	100	52	87	145	134	
11 29 51 TO 11 29 51	140	140	77	122	192	178	
11 30 51 TO 12 2 51	320	320	186	279	419	393	
12 3 51 TO 12 3 51	190	190	109	166	252	235	
TOTALS FOR FB, FBDE:	1370	1390	903	1215	1633	(1557 @ 90 PCT)	

EXPLANATION CODES: 1 = UNIT DOSIMETRY READS ZERO
2 = RECONSTRUCTED ZERO DOSE
3 = NO EXPOSURE POTENTIAL
4 = HELD AS ZERO PENDING RESEARCH TO DEFINE EXPOSURE
5 = CONVERTED TO HALF OF MDL
6 = TOTAL OF MULTIPLE FILM BADGE READINGS

The FBDOSE variable names in the output above are defined as follows:

FILM BADGE INTERVAL – Period of coverage for each badge as input by the user in MM DD YY format

MR – Film badge reading (mrem) for each badge and their total sum

MRADJ – Adjusted film badge reading that accounts for sub-MDL doses and their total sum. In the example provided in Table 1, the first zero badge was treated as a "definite" zero and the second as a "soft" zero

LOWER – Lower limit of the 95-percent confidence interval associated with each individual mean dose equivalent and total dose equivalent

MEAN – Central estimate of dose equivalent for each exposure and for the total dose equivalent (Bias removed, see Section 5.2)

UPPER – Upper limit of the 95-percent confidence interval associated with each individual mean dose equivalent and total dose equivalent. UPPER includes 97.5 percent of the dose distribution

UPP90 – Upper limit of the 90-percent confidence interval, which brackets the 5^{th} to 95^{th} percentile values associated with each individual mean dose equivalent and total dose equivalent. This value is used for reporting the 95^{th} percentile upper bound dose

5.1.3 Film Badge Dose as Basis for Beta Dose to Skin and Internal Dose

5.1.3.1 Skin Dose

Skin dose from external gamma radiation accrued by an individual while wearing a film badge is simply the whole body external gamma dose as reflected by the film badge reading. Given the nature of gamma interaction with human tissue, skin dose due to gamma radiation is directly correlated to the estimated external dose as recorded by the film badge. For the purposes of dose reconstruction, skin dose due to gamma radiation is assumed to be the same as the whole body external dose estimate (the MRADJ for each period of exposure from the FBDOSE output as discussed above), not taking into consideration attenuation characteristics, distance, or geometry. This assumption establishes conservative worse-case gamma radiation skin dose estimations. For detailed methods for the determination of beta dose to the skin from surface-deposited contamination based on a film badge reading, see SM ED03 – Skin Dose from External Sources and the appropriate operation- and shot-specific data in Appendices A–C.

5.1.3.2 Internal Dose

The NTPR program uses film badge dose to estimate (50-year) committed equivalent dose (CED) to organs and tissues from intakes of radioactive materials that occurred during the accrual of external gamma dose. By relating the time-dependent gamma spectrum from mixed fission products, actinides, and neutron activated soil constituents to the surface activity density, and applying conservative estimates of the resuspension factor, breathing rate, activity scenario, and source term depletion, it is possible to derive an intake and associated CED to the organ or tissue. NTPR has developed the computer code FIIDOS (Fallout Inhalation and Ingestion Dose to Organs, Version 4) as the

principal tool for ascertaining internal dose from film badge dose (Raine et al., 2007). Details of the NTPR internal dose methodology are found in SM ID01, Doses to Organs from Intake of Radioactive Materials. SM ID01 also specifies how mission and non-mission badges are processed differently to calculate an internal organ dose. Operation- and shot-specific data are contained in Appendices A–C.

5.2 Uncertainty in Film Badge Readings

The uncertainty associated with film badge readings is treated differently than that for reconstructed doses (DTRA, 2007). The NTPR Program uses the computer program FBDOSE to evaluate the bias and uncertainty associated with film badge readings, based on National Research Council recommendations (NRC, 1989). FBDOSE calculates bias and uncertainty for six defined sources of error associated with each film badge reading and calculates the mean and upper and lower bound dose equivalents. Total mean dose equivalent and associated upper and lower bounds may also be determined for a set of film badge readings. (SAIC, 2006)

See SM UA01 for detailed methods of determining the uncertainty and upper bound dose from film badge readings.

6 Referenced SOPs and Standard Methods from this Manual

(1) SOP RA01 - Radiation Dose Assessment for Cases Requiring Detailed Analysis

(2) SM ED02 - Whole Body External Dose - Reconstruction

(3) SM ED03 - Skin Dose from External Sources

(4) SM ID01 - Doses to Organs from Intake of Radioactive Materials

(5) SM UA01 - Dose Uncertainty and Upper Bound Determinations

7 Reference Materials

(1) DoD (U.S. Department of Defense), 2006. Guidance for the Determination and Reporting of Nuclear Radiation Dose for DoD Participants in the Atmospheric Nuclear Test Program, Title 32, Code of Federal Regulations, Part 218.

(2) DNA (Defense Nuclear Agency), 1982. Operation REDWING - 1956, DNA 6037F, (Science Applications International Corporation, McLean, VA and Defense Nuclear Agency, Washington, DC).

(3) DTRA (Defense Threat Reduction Agency), 2007. Policy and Guidance Manual - Nuclear Test Personnel Review Program, Draft Revision 7 (Fort Belvoir, VA) , (November 26).

(4) Mees, C. E. K., and James, T. H., editors, 1966. *The Theory of the Photographic Process*, Third Edition, the Macmillan Company, New York.

(5) NRC (National Research Council), 1989. *Film Badge Dosimetry in Atmospheric Nuclear Tests*. (National Academy Press, Washington, DC).

(6) Perkins, W. W., and Hammond, R. R., 1980. Navy Film Badge Review: DOMINIC, Navy Nuclear Test Personnel Review Program, NOSC TR 583, Naval Ocean Systems Center (May 28).

(7) Raine, D.A. III, Egbert, S.D., Stiver, J.H., and Case, D.R., 2007. FIIDOS - A Computer Code for the Computation of Fallout Inhalation and Ingestion Dose to Organs, Computer User's Guide (Revision 4). DTRA-TR-07-11, Science Applications International Corporation, McLean, VA and Defense Threat Reduction Agency, Fort Belvoir, VA.

(8) SAIC (Science Applications International Corporation), 2006. FBDOSE User's Guide (McLean, VA) (June 26).

(9) SAIC (Science Applications International Corporation) and NST - LLC (National Securities Technologies LLC), 1989–2006. Evaluations of dosimeter films conducted from about 1989 to 2006, Las Vegas, Nevada.

Attachment 1 Film Evaluation Request Form

Date [Month dd, yyyy]

TO: [Addressee organization and analyst name (currently NST - LLC,)
Attn. analyst name]
FROM: [organization, analyst's name]
SUBJECT: Film Evaluation

Please evaluate the dosimeter film (s) listed below for the validity of the reading as reflecting nuclear test exposure. Considerations include the presence and characteristics of a filter image, evidence of environmental or processing damage, length of issue period, and the applicability of control films. To expedite the evaluation, please utilize the table provided below (attach additional sheets if necessary):
Thanks again for your cooperation!

OPERATION [NAME]					
Name/Badge Type	Film #	Reading (R)	Filter image present? (Y/N/ Ambiguous)	Appearance of film (including damage)	Adverse impact(s) on reading (damage type, bad control, long issue)

This message may contain information protected from disclosure under various laws, such as Privacy Act (5 USC 552a) or the Health Insurance Portability and Accountability Act (PL 104-191). Do not disseminate without the approval of the DTRA Nuclear Test Personnel Review Program Manager.