ORAU TEAM
Dose Reconstruction
Project for NIOSH

Oak Ridge Associated Universities I Dade Moeller & Associates I MJW Corporation

Document Title:	
Energy Technology Engineering Center – Occupational External Dose	Document Number: ORAUT-TKBS-0038-6 Revision: 00 Effective Date: 02/22/2006 Type of Document: TBD Supersedes: None

Subject Expert: Leo G. Faust

Document Owner Approval:	Signature on File Melton H. Chew, TBD Team Leader	Approval Date:	02/08/2006
Approval:	Signature on File Judson L. Kenoyer, Task 3 Manager	Approval Date:	02/09/2006
Concurrence:	Signature on File Kate Kimpan, Project Director	Concurrence Date:	02/07/2006
Approval:	Signature on File James W. Neton, Associate Director for Science	Approval Date:	02/22/2006

☒ New ☐ Total Rewrite ☐ Revision ☐ Page Change

FOR DOCUMENTS MARKED AS A TOTAL REWRITE, REVISION, OR PAGE CHANGE, REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/22/2006	00	New technical basis document for the Energy Technology Engineering Center – Occupational External Dose. First approved issue. Training required: As determined by the Task Manager. Initiated by Melton H. Chew.

TABLE OF CONTENTS

SECTION **TITLE** **PAGE**

Acronyms and Abbreviations 4

6.1 Introduction 5
 6.1.1 Purpose 6
 6.1.2 Scope 6

6.2 Missed Dose 6

6.3 Radiation Energies and Percentages at Selected ETEC Facilities 7

6.4 Neutron Radiations and Percentages 9

6.5 Recorded Dose Practices 10

6.6 Interpretation of Reported Doses 10

6.7 Adjustments to Recorded Dose 11

6.8 Bias and Uncertainty 11

References 13

Glossary 15

LIST OF TABLES

TABLE **TITLE** **PAGE**

6-1 Missed dose 7
6-2 Beta and photon energies and percentages (reactors and C.F.) 7
6-3 Beta and photon energies and percentages (support facilities) 9
6-4 Facilities, neutron energies and percentages 10
6-5 Recorded dose practices 10
6-6 Interpretation of reported data 11
6-7 Adjustments to recorded dose 11
6-8 Bias and uncertainty 12

ACRONYMS AND ABBREVIATIONS

AETR	Advanced Epithermal Thorium Reactor
cm	centimeter
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ETEC	Energy Technology Engineering Center
LM	Liquid Metal
MDL	minimum detectable level
MeV	mega electron-volt
mR	milliroentgen
mrad	millirad
mrem	millirem
MWt	megawatts thermal
NIOSH	National Institute for Occupational Safety and Health
NMDF	Nuclear Materials Development Facility
NTA	nuclear track emulsion, type A
NVLAP	National Voluntary Laboratory Accreditation Program
OMR	Organic Moderated Reactor
OW	open window
QF	quality factor
R	roentgen
rem	roentgen equivalent man
RMHF	Radiation Materials Handling Facility
S10FS3	SNAP 10 Flight Simulation Reactor
S2DR	SNAP 2 Development Reactor
S8DR	SNAP 8 Development Reactor
S8ER	SNAP 8 Experimental Reactor
SER	SNAP Experimental Reactor
SGR	Sodium Graphite Reactor
SNAP	Systems for Nuclear Auxiliary Power
SRE	Sodium Reactor Experiment
STIR	Shield Test and Irradiation Reactor (Modified STR)
STR	Shield Test Reactor
TBD	technical basis document
WB	whole body
WBC	whole-body count
U.S.C.	United States Code

6.1 INTRODUCTION

Technical basis documents (TBDs) and site profile documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist the National Institute for Occupational Safety and Health (NIOSH) in the completion of the individual work required for each dose reconstruction.

In this document the word “facility” is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an “atomic weapons employer facility” or a “Department of Energy [DOE] facility” as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility as “any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)” [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled “Exposure in the Performance of Duty.” That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer “shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the [probability of causation] guidelines established under subsection (c) ….” [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation) define “performance of duty” for DOE employees with a covered cancer or restrict the “duty” to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes “buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program” [42 U.S.C. § 7384l(12)]. While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled “Exposure in the Performance of Duty”] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all radiation exposures in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

The ETEC site had it’s own dosimeter in the beginning that is expected to be very similar to the two element film dosimeters used at ORNL (ORAU 2005) and Hanford (OARU 2004) based on the design developed by Pardue et al (1944) as well as pencil dosimeters (PIC). It started using commercial vendors in the early 1960’s and has continued that practice throughout the rest of it’s operating life.

6.1.1 Purpose

The purpose of this TBD is to describe external dosimetry systems and practices at the Energy Technology Engineering Center (ETEC). This document discusses historical and current practices in relation to the evaluation of external exposure data for monitored and unmonitored workers.

6.1.2 Scope

This TBD contains supporting documentation to assist in the evaluation of occupational external doses from processes that occurred at ETEC. An objective of this document is to provide supporting technical data to evaluate, with claimant-favorable assumptions, occupational external doses that can reasonably be associated with worker radiation exposures. This document addresses the evaluation of unmonitored and monitored worker exposure, missed dose, and the bias and uncertainty associated with the monitoring of external dose.

6.2 MISSED DOSE

Missed doses at ETEC and associated facilities were basically those resulting from dosimeter minimum detectable levels (MDLs) and exchange periods. In reviewing an individual dose record from 12-31-1956 to 12-30-1957, entries were both weekly and bi-weekly with the former starting May, 1957,(Unkown-1956). This would suggest that exchange periods varied with time, job, and individual. Further review (AI-Memo-5468-1960) states that “Normally film badges are to be worn for monthly periods except where the possibility of exceeding 100 mrem/week exposure is expected. Then the badges are to be analyzed more frequently”. Therefore missed doses prior to 1963, if not derived by review of individual records, would be based on weekly exchanges and would be applicable to both Hp (0.07) and Hp (10). Starting in 1963, most dosimeters were processed by their vendor (Landauer or its predecessor) (Garcia and Carpenter 1963). On occasion, workers wore special dosimeters to monitor nonroutine work such as “hot jobs or cell entries” and always without their regular dosimeter. These special dosimeters were always worn in pairs with the results averaged and that result sent to the vendor for inclusion to the total dose for that periods regular dosimeter result. It has not been determined if the special dosimeter procedure was in effect pre -1963. Extremity finger ring film dosimeters were worn on both hands with individual results recorded for each hand. It was not determined when this practice started but it was in place in the 12-31-1956 dose record (Unknown-1956) including what appears to be the same exchange periods.

In cases of lost or destroyed dosimeters, results were derived from past results of similar work, coworker results, or the product of instrument measurements and time spent in the radiation zone. These practices are typical of sites with similar circumstances.

Neutron doses were measured with NTA film beginning with the start of reactor operations and the use of Van de Graff accelerators. Both fast and thermal neutrons were measured and recorded as whole-body (WB) dose (rem). The NTA film is not effective at energies <.500 MeV or at exposures of < 50 mrem (Kerr, 2005). It has not been determined what quality factors (QFs) were used. However, because a Po-Be neutron source was used for calibration, a reasonable assumption would be QF = 10 (Garcia 1970).

Missed doses for unmonitored employees could be as much as 500 mrem or 10% of whatever standard was in effect at the time of employment. Workers who did not enter radiation areas did not receive dosimeters if the probability of exceeding 10% of the allowable standard was small.

Table 6-1 lists the period of use, type of dosimeter, exchange period, MDL, and estimated annual missed dose.

Table 6-1. Estimated Annual Missed Photon, Beta, and Neutron dose (rem).

Period of use[a]	Dosimeter[b]	Exchange period	MDL[c] (rem)	Estimated annual missed dose[d] (rem)
1954 through 1962	Pocket Dosimeter (PIC) Site-specific two-element film	Daily Weekly Biweekly Monthly	0.005 0.04 0.04 0.04	0.525 1.04 0.52 0.24
1963 through1979	Landauer multi- element film	Monthly Quarterly	0.04 0.04	0.24 0.08
1980[e] to present	Landauer multi-element film	Quarterly	0.01[f]	0.02
1954 to present	NTA Film	Bi-weekly Monthly	<50 <50	0.650 0.300

a. Estimated use periods for first entry. Landauer or its predecessor was the vendor in 1963 and maybe earlier (Garcia and Carpenter 1963).
b. Actual number of dosimeter elements of the first entry dosimeter has not been determined nor has the period of use of PIC.
c. Estimated MDLs for each dosimeter in the workplace even though many doses were reported at less than the MDL.
d. Estimated annual missed dose calculated using MDL ÷ 2 from NIOSH (2002).
e. Neutron dosimeters continued monthly exchanges (Tuttle 1979).
f. Yoder (2005).

6.3 RADIATION ENERGIES AND PERCENTAGES AT SELECTED ETEC FACILITIES

As described in ORAU (2005), there were many different types of facilities and processes at ETEC and other facilities during their periods of operation; these include reactors, critical test facilities, fuel preparation and postirradiation examination facilities, accelerator and calibration facilities, and support facilities. Most reactors were low power (a few kilowatts), with the maximum being 20 MWt, and all had relatively short operating histories. The major accelerator was a Van de Graaff D-T (Deuterium-Tritium) machine producing neutrons with a maximum energy of 14 MeV. The fuel examination, manufacturing facilities, reactors and critical facilities handled fissionable fuels with various enrichments, mostly compounds of uranium including carbides. They also handled relatively small quantities of plutonium and thorium with the exception of buildings 4023, 4029, 4030, and 4363. They did not perform separations of irradiated fuel and, therefore, there were minimal gross fission product problems. They did declad some fuels in their hot cells, resulting in considerable quantities of those fission products with high fission yields (e.g., ^{90}Sr and ^{137}Cs). There was some ^{152}Eu and ^{154}Eu along with some ^{3}H. Tables 6-2 and 6-3 list the facilities and related data.

Table 6-2. Beta and photon energies and percentages (Reactors and Critical Facilities).

Process/ building	Description	Operations Begin	Operations End	Radiation type	Energy (keV)	Percentage
All	Reactors	1956	1980	Beta Photons	>15 30-250 >250	100 25 75
4143	SRE reactor	1957	1964	Beta Photons	>15 30-250 >250	100 25 75
4010	SER and S8ER	1959	1965	Beta Photons	>15 30-250 >250	100 25 75

4024	S2DR S10FS3 SNAP test facilities	1961 1965 1971	1962 1966 1971	Beta Photons	>15 30-250 >250	100 25 75
4028	STR, STIR	1961	1972	Beta Photons	>15 30-250 >250	100 25 75
4059	S8DR	1968	1969	Beta Photons	>15 30-250 >250	100 25 75
4009	OMR, SGR	1958	1967	Beta Photons	>15 30-250 >250	100 25 75
4100	AETR	1960	1974	Beta Photons (Thorium)	>15 30-250 >250	100 25 75

Table 6-3. Beta and photon energies and percentages (support facilities).

Building	Description	Operations		Radiation	Energy KeV	Percentages
*SRE-4003, 4163, 4041, 4654, 4689, 4653, 4606, 4773	Support facilities	1954	1964	Beta Photons	>15 30-250 >250	100 25 75
*4020	Hot Laboratory	1957	1988	Beta Photons	>15 30-250 >250	100 25 75
*4064	Fuel Storage	1958	1993	Beta Photons	>15 30-250 >250	100 25 75
*4011	Rad Inst. Calibration Laboratory	1984	1996	Beta Photons	>15 30-250 >250	100 25 75
*4021/4022	RMHF	1959	Present	Beta Photons	>15 30-250 >250	100 25 75
*4100	Calibration Laboratory	1985	Present	Beta Photons	>15 30-250 >250	100 25 75
4363	Mech. Component	1956	1963	Beta Photons	>15 30-250 >250	100 50 50
4029	Radioactive Measurement Laboratory	1959	1974	Beta Photons	>15 30-250 >250	100 25 75
4030	Van de Graaff	1960	1964	Beta Photons	<15 30-250 >250	100 25 75
4023	LM Component Testing	1962	1986	Beta Photons	>15 30-250 >250	100 50 50
*4005	Union Carbide Fuel Pilot Plant	1964	1967	Beta Photons	>15 30-250 >250	100 25 75
*4055	NMDF	1967	1979	Beta Photons	>15 30-250 >250	100 25 75

*For operations involving Th-232, 1964 and 1979.

6.4 NEUTRON RADIATIONS AND PERCENTAGES

Table 6-4 lists facilities with neutron radiations. They are reactors, accelerators and fuel storage facilities. The table includes the plutonium fuel storage facilities buildings 4005, used for Pu storage, from 1967-1987 and 4064 from 1958-1993. However they are assumed to be a negligible contributor to neutron doses due to the limited quantities of fuel present at any one time. As near as can be determined NTA film was incorporated in the film dosimeters if there was a potential of exposure>100mrem in those facilities where neutron exposures were possible. How that was determined has not been found. In the dose record there are entries in the “n” column. It is assumed that the dose recorded was the result of fast neutron exposure.

A neutron survey report of the “SRE Hot Cell” containing a 14 MeV neutron Generator (Clow, 1966), lists dose rates of 75 mrem/hr fast and 11.8 mrem/hr thermal with “the assumption that all fast neutrons are 14 MeV”. It also states that “As further surveys are taken and the spectrum completely analyzed, the dose rates may be reduced”. These surveys were done on the roof of the facility and were higher than those taken at “a window”,(62.2 mrem/hr fast and 7.1 mrem/hr thermal) or” at the console” (7.1 mrem/ hr fast and 2.2 mrem/hr thermal). The Van de Graaff with it’s D-T reaction generates 14 MeV neutrons that are quite monoenergetic in the 0 and 180 degree directions, (Etherington, 1958). This may support the assumption that all fast neutrons can be treated as 14 MeV. The distribution of energies and ICRP 60 conversion correction factors are also listed in Table 6-4. The correction factor for the 2 to 14 MeV energy grouping was calculated from data given in the Y-12 TBD, (Kerr, 2005).

Table 6-4. Facilities, neutron energies, percentages, and correction factors.

Facility	Source	Neutron energy (MeV)	Default dose % and correction factors
Reactors	Reactors	0.1 to 2.0, Wr=20	100% Correction factor = 1.91
Pu fuel storage Bldg. 4005 & 4064	Spontaneous fission and alpha, n reactions		
4030 Van de Graaff	D-T reaction	2 to 14 max, Wr=20	100%, correction factor =1.32

6.5 RECORDED DOSE PRACTICES

Recorded doses at ETEC are given in Table 6-5 and include those provided by the site, by Landauer (the site vendor) and special dosimeters (Hart 1975). The special dosimeters were processed by site personnel, using site calibrations, with only the results sent to the vendor for inclusion in the individual’s total dose for that period. This could have resulted in different quantities, on occasion, from those listed in Table 6-5.

Table 6-5. Recorded dose practices.

Year	Dosimeter measured quantities	Compliance dose quantities[a]
1954 through 1962 + NTA film	Beta = Open Window, mrem[b] Photon (P), mR Fast Neutron (FN), mrem	Skin = OW + P WB = P + FN
1963 through 1984 Landauer +NTA film	beta (B) or nonpenetrating, mR Photon (P), mR Fast Neutron (FN), mrem	Skin = (B) + P WB = B + P + FN WB = 0.15 (B-Xray) +P+ FN[c]
1985 to present	Nonpenetrating (Npen) Penetrating (Pen) Fast Neutron (FN)	Skin = Npen + WB[d] WB = Pen + neutrons[d]

a. Prior to 1985, Landauer assessed or calibration quantity was the roentgen at the surface of the body. In 1985, Landauer switched to International Commission on Radiation Units and Measurements tissue doses in compliance with then-current DOE and American National Standards Institute standards (Yoder 2005).
b. Garcia and Carpenter (1963) discusses the use of eye and gonadal shields that, if used, reduce beta values by a factor of 2.
c. Garcia and Carpenter (1963).
d. Garcia (1970).

Garcia and Carpenter (1963) provides a formula for correcting beta doses measured by the special dosimeters that is different from that in Garcia (1970). The differences are not great and are limited to beta dose corrections. The differences could be the result of a change from DuPont to Kodak film, which could have occurred in the period between the two procedures. Landauer changed to Kodak film in 1968 with the introduction of its Gardray film badge (Yoder 2005).

6.6 INTERPRETATION OF REPORTED DOSES

Personnel doses from Landauer prior to 1985 were reported in units of mR, either penetrating (photon) or nonpenetrating (beta) exposure if beta activity was present. The reported total values included any special dosimeter results sent by ETEC for that exchange period. If it is necessary to obtain organ doses, dose reconstructors should use *External Dose Reconstruction Implementation Guidelines* (NIOSH 2002).

In general, reported doses have been background-corrected using site-furnished controls. The controls were dosimeters kept in locations on the site used for storing personnel dosimeters. All personnel dosimeters were stored in storage racks when workers left the site at the end of their shifts. No workers took their dosimeters home at night; all were kept at the site and, as far as could be determined, this practice was in place since startup.

The exception to background correction could occur if individual dosimeters were not exchanged in time to be included with the regular exchange, because controls were sent only with each exchange batch. While this could lead to an incorrect result, that result would be claimant-favorable because it would include background and, therefore, err on the high side (Rowles 1988).

Table 6-6. Interpretation of reported data.

Period	Reported quantity	Description	Interpretation of zeroes	Interpretation of blanks (no data)	Rollup of individual and annual data[a]	Monitored/ unmonitored
1954 to 1960	Skin = rad WB = mR Neutrons = rem	mrad, mR, and mrem used interchangeably	MDL/2 times number of zeroes	If no dosimeter for that period, treat as unmonitored.	If special dosimeters were used, include results.	All personnel expected to be exposed to > 100 mrem in an exchange period were monitored.
1960 to present	Skin = mrem WB = mrem Neutrons = mrem	mrem used for all	MDL/2 times number of zeroes	If no dosimeter for that period, treat as unmonitored.	If special dosimeters were used, include results.	Only those > 10% of current standard were monitored. Those entering controlled areas were issued a visitors dosimeter.

a. If special dosimeters were used, the results were forwarded to the vendor for inclusion in the totals for that period. It has not been determined if this was always accomplished.

6.7 ADJUSTMENTS TO RECORDED DOSE

Because most but not all penetrating photons are above 30 keV, it is suggested that an adjustment is necessary to account for the contribution to Hp(10) from low-energy photons from uranium and thorium. It is estimated that a correction equal to 10% of the < 250-keV values be made. However corrections can be applied to the total WB dose by using the product of 10% of the < 250keV, which is 25% for a total of 2.5%. Therefore a correction factor of 1.025 should be applied to the total WB doses. This adjustment also increases the non-penetrating Hp(0.07) dose, regardless of which dosimeter was used because that dose was always the sum of the “open-window and the WB doses”. Table 6-7 lists these corrections.

Table 6-7. Adjustments to recorded dose.

Period	Dosimeter	Facility	Adjustments to reported dose
1954 to 1963	Site-specific	All facilities	Multiply reported WB dose by 1.025 to estimate Hp(10).
1963 to 1985	Landauer	All facilities	Multiply reported WB dose by 1.025 to estimate Hp(10).
1985 to present	Landauer	All facilities	Same as above even with Landauer becoming NVLAP-certified.

6.8 BIAS AND UNCERTAINTY

Bias and uncertainty values were not found in any site data. Values given in Table 6-8 list those from the Hanford TBD (ORAU-2004) which should be similar to those at ETEC for the Multi-element dosimeter. These values agree with those of Landauer. In addition, ETEC used NTA film for it’s neutron dosimeter, as did Y-12, so data from the latter’s TBD was used to estimate the ETEC dosimeters bias and uncertainties. The results are an estimated error of

+/- 50% at a 100 mrem for the 0.1 to 2MeV energy range and +/- 35% for the 2 to 14 MeV range. The latter estimate was obtained using the product of the ratio of the correction factors given in Table 6-4, for the two energy ranges and the +/- 50% error. This is a reasonable assumption since most if not all the neutrons energies are above 0.5 MeV.

Table 6-8. Bias and uncertainty

Site specific dosimetry system	**Bias magnitude and range**		**Uncertainty factors**	
	Overall bias[b]	**Range in bias**[c]	**Systematic**[d]	**Random**[e]
Two element (1954 to 1963)	1.27	1.13-1.60	1.2	1.8
Multielement (1964 to present)[f]	1.02	0.86 – 1.12	1.1	1.4
NTA film 0.1 to 2 MeV 2 to 14 MeV	 1.5 1.35	 0.5—1.5 0.65—1.35	 1.5 1.35	

a. Table 6-8 values are repeated here from the Hanford External Dosimetry TBD, ORAU (2004) because the dosimeters in use at ETEC are assumed to be similar.
b. Based on the most likely distribution of energy levels and geometry. Divide recorded dose by table's bias value to determine deep dose.
c. Range of overall bias values.
d. Systematic uncertainty due to lack of knowledge of actual distributions of energies and geometries.
e. Random uncertainty due to variation among workers in energy levels and geometry.
f. These values agree with Landauer since NVLAP certification (Yoder 2005).

REFERENCES

AI-MEMO 5468, Radiological Safety at Atomics International, A division of North American Aviation, Inc., Issued July 13,1960, (Data Capture Document Discovery, 030005858,November 10,2005).

Clow, H. E. to E.T.Bramlitt, Neutron Survey of "SRE Hot Cell" Containing a 14 MeV Neutron Generator, Internal Letter, Atomics International, Issued February 3,1966, (Data Capture Document Discovery,030005737,November 10,2005).

Etherington, Harold, Editor, Nuclear Engineering Handbook, McGraw-Hill Book Company, Inc.,1958.
Garcia, R. R., 1970*, Dose Interpretation*, *Reporting, and Controls in the AI Personnel Film Badge Program*, PM-15, Health and Safety ,North American Aviation Inc.,Issued October 30 1970 (DOE Site Images-ETEC: Data Capture Document Discovery,030005857 November 10, 2005).

Garcia, R.R. and G.D.Carpenter, Handling of Routine Film Badges, North American Aviation Inc., Issued April 5, 1963 ,(Data Capture Document Discovery, 030005886 November 10,2005).

Garcia, R. R., and G. D. Carpenter, 1963, *Dose Determination*, PM-14, Health and Safety, North American Aviation Inc., Issued July 15 1963.

Hart, R. S., 1979, *Annual Review of Radiological Controls-1975*, N001T1990002, Rockwell International, Atomics International Division, Issued July 2. 1979 :(Data Capture Document Discovery, 030005851 November 10, 2005).

Hinter, B. R., and Carpenter, G. D., 1963, *Verification of Vendor Film Badge Charges*, PM-7, North American Aviation Inc, Issued August 26 1963 ,(Data Capture Document Discovery, 030005886).

NIOSH (National Institute for Occupational Safety and Health), 2002, *External Dose Reconstruction Implementation Guidelines*, OCAS-IG-001, Rev. 1, Office of Compensation Analysis and Support, Cincinnati, Ohio.

ORAU (Oak Ridge Associated Universities), 2004, Technical Basis Document for the Hanford Site – External Dosimetry, ORAUT-TKBS-0006-6, Oak Ridge, Tennessee.

ORAU (Oak Ridge Associated Universities), 2005, *Technical Basis Document for the Energy Technology Center – Site Description*, ORAUT-TKBS-0038-2, Oak Ridge, Tennessee.

ORAU (Oak Ridge Associated Universities), 2005, Technical Basis Document for the Y-12 National Security Complex- Occupational External Dosimetry, ORAUT-TKBS-0014-6, Oak Ridge, Tennessee.

Pardue, L. A., N. Goldstein, and R. O. Woltan, 1944, Photographic Film as a Pocket Radiation Dosimeter, CH-1553.

Rowles, J. A., 1988, *External Radiation Dosimetry Program*, N0010P00005, Rockwell Aviation, Rocketdyne Division, Issued March 29 1988: (Data Capture Document Discovery 030005857, November 10,2005).

Unknown, 1956, Examples of Data from Old Dosimetry Files: (Data Capture Document Discovery 0300063724, December 10, 2005).

Tuttle R. J., 1979, “Modification of Film Badge Program”, letter to “Those Listed”, Rockwell International; August 2 1979. (Data Capture Document Discovery, 030006186, December 7, 2005).

Yoder, R. C., 2005, “Landauer film info,” e-mail to L Faust, Landauer Inc, Glenwood, IL, December 7 2005.

GLOSSARY

accreditation

Recognition that a dosimeter system has passed the performance criteria of the DOE Laboratory Accreditation Program (DOELAP), (DOE 1986), in specified irradiation categories or the National Voluntary Laboratory Accreditation Program (NVLAP).

accuracy

If a series of measurements has small systematic errors, they are said to have high accuracy. The accuracy is represented by the bias.

beta particle

A charged particle of very small mass emitted spontaneously from the nuclei of certain radioactive elements. Most (if not all) of the direct fission products emit (negative) beta particles. Physically, the beta particle is identical with an electron moving at high velocity.

claimant-favorable

The process of estimation based on technical considerations such that the estimated dose is not underestimated.

deep dose equivalent [Hp(10)]

The dose equivalent at the respective depth to 1.0 cm in tissue.

dose equivalent (H)

The product of the absorbed dose (D), the quality factor(Q), and any other modifying factors. The special unit is the rem. When D is expressed in gray, H is in sieverts (1 sievert = 100 rem.)

dosimeter

A device used to measure the quantity of radiation received. A holder with radiation-absorbing elements (filters) and an insert with radiation-sensitive elements packaged to provide a record of absorbed dose or dose equivalent received by an individual.

dosimetry system

A system used to assess dose equivalent from external radiation to the whole body, skin and or extremities. This includes the fabrication, assignment, and processing of the dosimeters as well as interpretation of the results.

exchange period (frequency)

Period (weekly, biweekly, monthly, quarterly, etc.) for routine exchange of dosimeters.

exposure

A measure expressed in roentgens of the ionization produced by gamma (or X) rays in air.

film

Generally means a “film packet” that contains one or more pieces of film in a light-tight wrapping. The film when developed has an image caused by radiation that can be measured using an optical densitometer.

film dosimeter

A small packet of film within a holder that attaches to a worker.

filter
Material used to adjust radiation response of a dosimeter to provide an improved tissue equivalent or dose response.

gamma rays
Electromagnetic radiation (photons) originating in atomic nuclei and accompanying many nuclear reactions (e.g. fission, radioactive decay, and neutron capture). Physically, gamma rays are identical to X-rays of high energy, the only essential difference being that X-rays do not originate in the nucleus.

ionizing radiation
Electromagnetic radiation (consisting of photons or particulate radiation consisting of electrons, neutrons, protons, etc.) capable of producing charged particles through interactions with matter.

neutron
A basic particle that is electrically neutral weighing nearly the same as the hydrogen atom.

nonpenetrating dose [Hp(0.07)]
Designation (i.e., NP or NPen) on film dosimeter reports that implies a radiation dose, typically to the skin of the whole body, from beta and lower energy photon radiation.

open window (OW)
Designation on a dosimeter that implies the use of little or no shielding. It commonly is used to label the film response corresponding to the open window area.

penetrating dose Hp(10)
Designation (i.e. P, Pen, or Neutrons and Gamma) on a dosimeter of the dose recorded at depth of 10 millimeters.

Personal Dose Equivalent, Hp(d)
Radiation quantity recommended for use as the operational quantity to be recorded for radiological protection purposes by the International Commission on Radiological Units and Measurements. The Personal Dose Equivalent is represented by Hp(d), where d identifies the depth in millimeters and represents the point of reference for dose in tissue. For weakly penetrating radiation of significance to skin dose, d = 0.07 mm and is noted as Hp(0.07). For penetrating radiation of significance to whole-body dose, d = 10 mm and is noted as Hp(10).

photon
A unit of electromagnetic radiation consisting of X- and/or gamma rays.

PM
A procedure detailing specific actions or directions and usually limited to one service or Activity.

rad
A unit of absorbed dose equal to the absorption of 100 ergs per gram of absorbing material such as body tissue.

radioactivity
The spontaneous emission of radiation, generally alpha or beta particles, gamma rays, and neutrons from unstable nuclei.

rem (roentgen equivalent in man)

A unit of dose equivalent in human tissue equal to the product of the number of rads and the quality factor and any other modifying factors.

rep (roentgen-equivalent-physical)

Historically, used extensively for the specification of permissible doses of ionizing radiations other that X-rays or gamma rays. Several definitions have appeared in the literature but the most widely adopted is a unit of absorbed dose with a magnitude equal to 93 ergs per gram.

roentgen

A unit of exposure to gamma or X-rays. It is defined precisely as the quantity of gamma (or X) rays that will produce a total charge of 2.58×10^{-4} coulomb in 1 kilogram of dry air. An exposure of 1 roentgen is approximately equivalent to an absorbed dose of 1 rad in soft tissue.

sievert

The SI unit for dose equivalent. (1 sievert = 100 rem).

skin dose

Absorbed dose at a tissue depth of 7 mg per square centimeter.

tissue equivalent

Term used to imply that the radiation response of the material being irradiated is equivalent to tissue.

whole-body dose

Commonly defined as the absorbed dose at a tissue depth of 1.0 cm (1,000 mg per square centimeter); also used to refer to the “dose of record”.

X-ray

Ionizing electromagnetic radiation of extra-nuclear origin.