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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
09/14/2018	00	New document initiated to convert ORAUT-PROC-0006, *External Dose Reconstruction*, to a technical information bulletin. Included information on assignment of onsite ambient dose to facilitate cancellation of ORAUT-PROC-0060. Updated to current dose reconstruction approaches. Incorporated responses to the Advisory Board on Radiation and Worker Health Subcommittee on Procedures Reviews comments about ICD-9 codes. Incorporates formal internal and NIOSH review comments. Training is required. Initiated by Mark R. Fishburn.
10/21/2019	01	Revision initiated to correct error in Attachment A, Method for Assigning Missed Dose when the Number of Null Results Is Unknown, and include a new attachment to provide dates when U.S. Department of Energy sites incorporated the recommendations of ICRP Publication 60 for neutron weighting factors. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training is required. Initiated by Mark R. Fishburn.
06/11/2021	02	Revision initiated to provide additional guidance regarding the potential need to use ICRP 60 weighting factors with neutron missed dose after the ICRP 60 implementation dates for sites in the DOE complex. Incorporates formal internal and NIOSH review comments Constitutes a total rewrite of the document. Training is required: As determined by the Objective Manager. Initiated by Mark R. Fishburn.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE **TITLE** **PAGE**

ACRONYMS AND ABBREVIATIONS

AWE	atomic weapons employer
C.F.R.	*Code of Federal Regulations*
DCF	dose conversion factor
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
EALER	elevated ambient levels of external radiation
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
GM	geometric mean
GSD	geometric standard deviation
H(10)*	ambient dose equivalent at 10 millimeters depth in tissue
Hp(d)	personal dose equivalent at depth *d* in millimeters in tissue
hr	hour
HTML	hypertext markup language
ICD	International Classification of Diseases
ICRP	International Commission on Radiological Protection
ID	identification
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt (1,000 electron-volts)
LOD	limit of detection
MeV	megaelectron-volt (1 million electron-volts)
mrem	millirem
mSv	millisievert
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
ORAUT	ORAU Team
ORNL	Oak Ridge National Laboratory
PIC	pocket ionization chamber
POC	probability of causation
SRDB Ref ID	Site Research Database Reference Identification (number)
TBD	technical basis document
TIB	technical information bulletin
TLD	thermoluminescent dosimeter
U.S.C.	*United States Code*
wk	week
w_R	radiation weighting factor

yr	year
§	section or sections

1.0 INTRODUCTION

Technical information bulletins (TIBs) are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in 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), such as changing scientific understanding of operations, processes, or procedures involving radioactive materials. TIBs may be used to assist NIOSH staff in the completion of individual dose reconstructions.

In this document the word “facility” is used to refer to an area, building, or group of buildings that served a specific purpose at a U.S. Department of Energy (DOE) or Atomic Weapons Employer (AWE) facility. It does not mean, nor should it be equated to, an “AWE facility” or a “DOE facility.” The terms AWE and DOE facility are defined in 42 *United States Code* (U.S.C.) § 7384l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000, respectively.

1.1 PURPOSE

The purpose of this document is to outline external dose reconstruction under Part B of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA). 42 U.S.C. § 7384–7385. This document incorporates direction from NIOSH on the performance of external dose reconstructions as contained in OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* [NIOSH 2007], TIBs, approved site profiles, and Oak Ridge Associated Universities (ORAU) Team (ORAUT) procedures.

1.2 SCOPE

Reconstruction of external dose could involve the calculation and assignment of dose from multiple sources (i.e., photons, neutrons, electrons, environmental dose, and occupational medical dose). This document provides information about the calculation of external dose and how it should be assigned under EEOICPA.

2.0 GENERAL APPROACH

External dose reconstruction – along with internal dose reconstruction - is just one part of the overall dose reconstruction process. Under the EEOICPA and Executive Order 13179, dose reconstructions are performed using information from the U.S. Department of Labor (DOL), DOE, AWEs, and claimants while applying the science-based knowledge and practices of dose reconstruction. 3 C.F.R. EO 13179, 2000.

During external dose reconstruction, a dose reconstructor assesses the circumstances of exposure, the completeness of the supporting data in relation to the employment period, and other information relevant to the dose reconstruction approach. The site profiles are reviewed, as necessary, to assist the dose reconstructor. Much of the relevant information from site profiles is captured in site-specific calculation tools (or generic calculation tools for cases in which site-specific information is unavailable or unnecessary), and the dose reconstructor uses this information to assist in the performance of external dose reconstruction.

To provide for efficiency in processing claims, overestimating assumptions can be used if a claim is initially deemed likely noncompensable. Underestimating assumptions can be used if a claim is initially deemed likely compensable. These processing options, which are typically available in the calculation tools, are described in ORAUT-PROC-0106, *Roadmap to Reconstructing Dose* [ORAUT 2020]. A best-estimate analysis uses all of the available information and analytical processing capabilities to assign the most accurate dose possible for a claim. This approach is typically taken when a claim is close to the compensability probability of causation (POC). Best-estimate analyses of external doses are made using detailed knowledge of specific work locations, job responsibilities, and other claim-specific information, as well as the Vose capability process in the site tools to run Monte Carlo calculations to propagate dose uncertainty. Often a claim determination can be achieved with less detailed knowledge by using assumptions that are favorable to the claimant (i.e., overestimate or underestimate). The dose reconstruction approach is presented in Figure 2-1. This figure illustrates the manner in which progressively more information is analyzed to complete the external dose reconstruction.

As detailed in OCAS-IG-001, dose reconstruction takes into account only the dose the worker received at a covered facility [NIOSH 2007]. The dose is sorted by radiation type and energy and is reconstructed for a specific target organ, which is determined from the worker's DOL-verified primary cancer (see ORAUT-OTIB-0005, *Internal Dosimetry Organ, External Dosimetry Organ, and IREP Model Selection by ICD-10 Code* [ORAUT 2019a]). Only doses that were received before the diagnosis of the primary cancer are included in the dose reconstruction. A worker may have received medical X-ray examinations for occupational health screening as a condition of employment at a covered site. If these X-ray examinations were performed at a covered facility, the exposures from these exams are considered covered exposures and are included in the dose reconstruction [NIOSH 2007; ORAUT 2017a, 2019b]. Target organ selection for X-ray exposures should be done in accordance with ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-ray Procedures* [ORAUT 2019b]. The following sections summarize key information from OCAS-IG-001 about the external dose reconstruction process.

The dose reconstructor ensures that the records supporting the dose reconstruction are included in the submittal to NIOSH. The following records are the minimum that should be included in the submittal:

- Worksheets necessary to recalculate final input parameters for the Interactive RadioEpidemiological Program (IREP),
- IREP Input Spreadsheet,
- IREP HTML Summary Report of estimated POC, and
- Dose reconstruction report.

In addition to external dose, internal dose is reconstructed using the guidance given in ORAUT-OTIB-0060, *Internal Dose Reconstruction* [ORAUT 2018a].

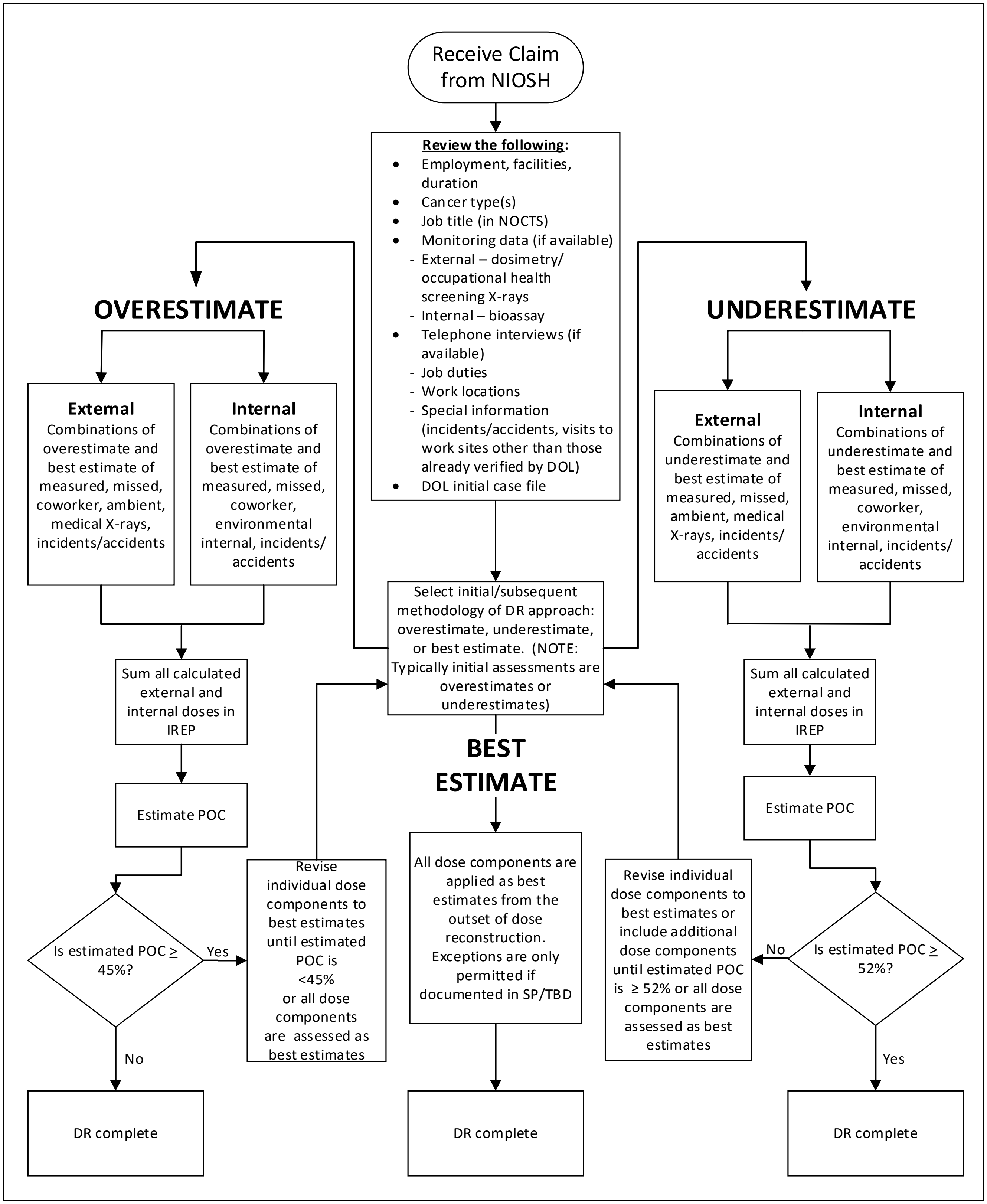

Figure 2-1. Overview of dose reconstruction approaches (DR = dose reconstruction, SP = site profile, TBD = technical basis document). Note: In relation to overestimating, underestimating, and best estimate approaches, please see ORAUT-PROC-0106 for additional guidance on the potential use of mixed approaches [ORAUT 2020].

2.1 RECORDS AND RECONSTRUCTION METHODS PERTAINING TO EXTERNAL RADIATION EXPOSURE

Potentially available radiation monitoring records typically consist of external dosimetry records, internal dosimetry records, diagnostic X-ray records, incident investigation reports, and other monitoring records. The records listed above – with the exception of internal dosimetry records – potentially affect the external dose reconstruction.

2.1.1 External Dosimetry Records

Table 2-1 (excerpted from OCAS-IG-001 [NIOSH 2007]) lists the general hierarchy of data sources dose reconstructors should employ for external dose reconstruction. Personal dosimeter results are typically the most accurate assessment of a worker's dose. In general, recorded dose data from a personal dosimeter [i.e., film badge or thermoluminescent dosimeter (TLD)] should be used whenever possible, and these data are given priority over personal monitors [i.e., pocket ionization chamber (PIC)], survey data, or source term data. The adequacy and completeness of the dosimeter data should be described in the site profile in terms of potential limitations in technology, calibration, workplace radiation fields, and administrative practices.

Table 2-1. Hierarchy for accuracy of data sources for external dose reconstruction.[a]

Hierarchy	Data source	Examples
1	Personal dosimeter	Film badge; nuclear track emulsion, type A; TLD.
2	Personal monitors	PIC.
3	Co-exposure data	Derived from distributions of film badge, TLD, and PIC data.
4	Area monitoring	Workplace radiation surveys, ambient air room monitors, duration of exposure.
5	Source term	Source nuclide, activity, exposure rate, distance from source, duration of exposure, and shielding information.
6	Radiation control limits	Generally, workplace posting has been required when the dose rate exceeded 0.025 mSv/hr.

a. Source: NIOSH [2007].

Personal dosimeter records typically include the worker's external dose history at each covered facility. These records can consist of annual doses or the individual dosimeter processing results for each dosimeter assigned to the worker, or both. If only annual doses are available, the required approach is described in Attachment A and is favorable to claimants.

In relation to the availability of personal monitoring data for each claim, three conditions can apply:

1. Worker was monitored adequately,
2. Worker was not monitored, and
3. Worker was monitored inadequately.

Each condition requires a different approach to reconstruction of external measured, missed, and unmonitored doses, as described below.

2.1.1.1 Worker Was Monitored Adequately

Workers are monitored adequately when the site has a robust dosimetry program. A robust dosimetry program involves a demonstrated quality control and quality assurance program for dosimetry procedures and policies in terms of who is assigned a dosimeter, the frequency of the monitoring, investigation of anomalous results, investigation of missing results, and retrievable records. The use of dosimetry should be reviewed for the site across the history of the site and is discussed in the site profile.

In general, external monitoring data that have been collected since the implementation of 10 C.F.R. Part 835, Occupational Radiation Protection (issued in 1993 and implemented in the following few years), are considered adequate. 10 C.F.R. 835, 2020. Monitoring in the “835” era is generally considered adequate because the regulations and implementing standards and guides for 10 C.F.R. Part 835 established a consistent DOE complex-wide program in line with what NIOSH considers a robust dosimetry program.

Accreditation of a site dosimetry program in accordance with the DOE Laboratory Accreditation Program or the National Voluntary Laboratory Accreditation Program indicates the site program has been reviewed for and has demonstrated quality control and quality assurance for the measurement of dose by the dosimeters. In these situations, the dosimetry data can usually be used as the basis for external radiation dose reconstruction (i.e., to compute the annual dose for each year of covered employment); that is, no adjustments are required other than incorporation of missed dose and conversion to organ dose.

For adequately monitored workers, the associated uncertainty should be assumed to be normally distributed unless indicated otherwise in the site profile. For overestimate or underestimate reconstructions, the dose distribution can be considered a constant (point estimate), which results in an IREP input of only one parameter. As an additional conservative measure for overestimates, a multiplicative factor may be applied to the assigned dose in lieu of uncertainty; this factor is not included for underestimates.

2.1.1.2 Worker Was Not Monitored

Dose reconstructors determine if the worker should have been monitored. Some unmonitored workers were not exposed to occupational external dose, but would have received ambient dose. Other unmonitored workers might have been exposed, and dose needs to be assigned by evaluating other sources of dose data (see the Table 2-1 data sources).

Most AWE workers and some DOE workers were not individually monitored for external radiation exposure using assigned personal dosimeters, including some who would have been classified as radiation workers by today’s radiation protection standards. Similarly, less-exposed workers who were not expected to exceed a significant percentage (e.g., 10% to 30%) of radiation protection standards lacked monitoring, a practice that continues at some sites today and is consistent with current regulations. If there was a significant potential for radiation exposure, recorded doses for monitored workers with similar exposure potentials may be used as surrogates (see ORAUT-OTIB-0020, *Use of Coworker Dosimetry Data for External Dose Assignment* [ORAUT 2011]). However, in the absence of such information, workplace radiation measurements (e.g., area monitoring data) could exist that can be used to estimate dose. For workers with no significant exposure potential, external radiation dose reconstruction is based on ambient dose (see Attachment B). In general, it is expected that reconstructed dose to unmonitored workers will be less than dose to monitored workers.

At some facilities, only a small sample of the workforce, or only workers who met certain criteria, were monitored to ensure compliance with radiation exposure limits. As an example, although construction workers were often unmonitored, it is possible in some instances to use data from representative workers who received similar exposures, such as radiological control technicians who monitored the work activities, to estimate a realistic maximum external dose. When assigning dose to construction trade workers, use the guidance in ORAUT-OTIB-0052, *Parameters to Consider When Processing Claims for Construction Trade Workers* [ORAUT 2014].

When no radiation monitoring data are available for a worker or representative workers, scientifically reasonable estimates of exposure should be developed based on survey data or the source term or quantity of radioactive material at the facility. Often a claim determination can be achieved with less detailed knowledge by using assumptions that are favorable to the claimant. It should be recognized that dose reconstructions based on survey data are probably biased high because monitoring data tended to be recorded at the highest level to ensure compliance; however, this is an acceptable bias in this compensation program. If no survey data are available, the dose should be estimated based on the activity of the source term, engineering and administrative controls, and work history at the same facility.

2.1.1.3 Worker Was Monitored Inadequately

Early workers at DOE and AWE facilities were typically monitored inadequately in comparison with current practices. This was due to less capable dosimetry technology, higher control limits, more frequent dosimeter exchanges, or monitoring records that were incomplete, missing, or unclear (or any combination thereof). Often, routine monitoring of worker neutron exposure was not performed in the 1940s and 1950s at most facilities.

Monitoring data from before 1960 must be evaluated cautiously due to technological shortcomings and because monitoring programs were designed to ensure compliance with historically higher radiation safety limits. In such cases, external radiation dose reconstruction is based on available dosimetry data in combination with available site profile information about site processes, radioactivity, radiation fields, and other pertinent information.

When workers were monitored inadequately, it would result in incomplete, missing, or unclear monitoring records. In these cases external dose reconstruction must consider options to estimate all or a portion of a worker’s dose and the associated uncertainty.

If there are sufficient monitoring records before and after the missing records, the dose to assign can be interpolated. The interpolation, or gap fill (which could be a simple average between the monitoring periods), is considered reasonable if the work practices, radiological protection measures, and administrative and engineering controls did not change. Gap fill can be conducted only if there is no indication from the claimant, worker, site radiological, or DOL records that a radiological incident resulting in a higher exposure occurred during the period of missing records or that the worker’s job duties or the exposure potential changed during the gap period. All documents associated with the claim should be reviewed to determine there were no significant changes in the worker’s job duties or exposure. Examples of information that could indicate significant changes in a worker’s job duties or exposure include:

- Information (e.g., from telephone interviews, DOL records) that the worker changed jobs during the period in question.
- Significant recorded dose changes during the covered periods surrounding the missing dosimeter records.
- Information about incidents occurring during the period in question.

The length of the gap fill period is dependent on the surrounding dosimetry exchange frequency, whether it was weekly, monthly, quarterly, or semiannually. The gap period must be bounded on both ends with reported dosimetry information. This information should only be used to address a gap equal to an exchange period that is bounded on both sides by provided dosimetry data. An example is a worker with first- and third-quarter dosimeter results but no dosimeter results for the second quarter. If the claim information (e.g., the worker site records, telephone interview) does not indicate a change in employment and there is no indication that a higher exposure occurred during the period of missing records (as discussed in the previous paragraph), then determine an appropriate dose that may be assigned to the second quarter. This second quarter dose should align with the assigned dose for the first and third quarters.

Site-specific guidance about dosimetry practices should be reviewed because some site guidance documents are more prescriptive in their methods for gap fill. In addition, the dose reconstructor should evaluate all dosimetry records to ensure that gap filling aligns with those records as appropriate (e.g., if an annual result is available, the amount of recorded and gap fill dose must not exceed the annual dose).

The assignment of dose using adjacent dosimetry information as described above should be the first method for assigning dose for a missing dosimetry exchange period. If monitoring data are not available, co-exposure data might provide a good option in cases involving missing or incomplete records. For records that are unclear, dose reconstruction management should be notified so an acceptable approach can be determined, which could involve requesting additional information from DOE.

2.1.2 Occupational Medical X-Ray Dose

Records from medical X-ray examinations that identify the date and clinical summary for each examination are often available. The site profile provides information about X-ray frequency and type and should be the initial document to review when evaluating site X-rays. Dose reconstructors should use the approach in ORAUT-OTIB-0079, *Guidance on Assigning Occupational X-Ray Dose Under EEOICPA for X-Rays Administered Off Site* [ORAUT 2017a] and ORAUT-OTIB-0006 [ORAUT 2019b] to determine if offsite examinations are covered and to then assign dose.

2.1.3 Incident Investigation Reports

Reports about incidents that might have involved the worker are often provided in the DOE records, either in separate files or embedded in the external or internal dosimetry records. The dose reconstructor should request records if they might exist but are not available in the file (e.g., on reading the claimant interview in which a reportable incident involving external dose is described). The dose reconstructor needs to determine if the dose from the incident was captured by the dosimetry records of the worker and is already included in the dose reconstruction. If not, the dose reconstructor needs to assign the dose from the incident (which might involve a calculation to determine the dose to assign) in addition to other dose the worker is assigned.

2.1.4 Other Monitoring Records

Other monitoring records (e.g., area dosimetry results, survey results) that potentially pertain to reconstruction of external dose might be available in the DOE files. The dose reconstructor needs to determine if the dose from other monitoring records needs to be included because dosimetry monitoring was not performed or was inadequate. It is not unusual to have monitoring for one type of radiation (e.g., photon) and not be adequately monitored for another radiation type (e.g., neutrons or low-energy photons). If monitoring was not performed or was inadequate, the dose reconstructor needs to assign dose in accordance with Sections 2.1.1.2 and 2.1.1.3 above. An example of this approach that used survey data to calculate and assign neutron dose is available in Section 6.4 of ORAUT-TKBS-0006-6, *Hanford Site – Occupational External Dose* [ORAUT 2010].

2.2 EXTERNAL RADIATION EXPOSURE TYPES

To arrive at an overall estimate of worker dose and uncertainty, dose reconstructions generally address the potential for recorded external dose, internal dose, missed dose, occupational medical exposures, and onsite ambient radiation exposures by applying assumptions that are favorable to the claimant, as necessary, to minimize the likelihood that dose is underestimated. External radiation includes three types of radiation, as described below.

2.2.1 Photon (Gamma and X-Ray) Radiation

There are four basic components of photon radiation dose. The sum of the dose components in each calendar year makes up a worker's annual occupational photon radiation dose D_γ. This is expressed as follows:

$$D_\gamma = D_D + D_M + D_{OM} + D_{EN} \tag{2-1}$$

where

D_γ = total annual photon radiation dose
D_D = recorded worker occupational dose typically based on personal dosimeter measurements
D_M = missed dose (unrecorded or unmeasured due to dosimeter limitations)
D_{OM} = occupational medical monitoring X-ray examination dose
D_{EN} = environmental (onsite ambient) dose, which might or might not have been included in the dosimeter dose the site reported

In addition to the calculation above, unmonitored photon dose can be assigned if a worker was not monitored for radiation exposure and the dose reconstructor determines that doses exceeding D_{EN} might have been received. Unmonitored photon doses can be estimated based on adjacent monitoring records, co-exposure doses, applicable dose limits, or area measurement data.

Recorded photon doses D_D are adjusted, if appropriate, based on site profile information. If a relevant site profile does not exist for a particular case, dose reconstructors should consult ORAUT-OTIB-0008, *A Standard Methodology for Overestimating External Doses Measured with Thermoluminescent Dosimeters* [ORAUT 2006a], or ORAUT-OTIB-0010, *A Standard Complex-Wide Methodology for Overestimating External Doses Measured with Film Badge Dosimeters* [ORAUT 2006b], depending on whether the measurements were from TLDs or film badges, respectively.

As discussed in OCAS-IG-001, the prescribed method for evaluating missed photon dose D_M is to assign a dose equal to the limit of detection (LOD) divided by 2 for each dosimetry measurement that is recorded as zero. However, for cases in which multiple badges were issued for a particular monitoring period, only one zero measurement should be assigned per monitoring period. These doses are then summed for a given year. The LOD/2 method results in a slightly positive bias (overestimate) of the true dose in most cases [NIOSH 2007].

Missed doses calculated in this manner have a lognormal distribution for the purpose of calculating POC. Specifically, the photon LOD/2 times the number of zero monitoring badges is the central estimate or geometric mean (GM) of a lognormal distribution, and the upper 95th-percentile estimate is the LOD times the number of zero monitoring badges, which equates to a geometric standard deviation (GSD) of 1.52 [NIOSH 2007]. As stated in OCAS-IG-001, this approach is for the calculation of missed doses and should not be applied to non-missed dose situations.

In addition, OCAS-IG-001 provides guidance on how to assign dose from nonzero dosimetry results that are less than the LOD. Dose should be assigned equal to the LOD divided by 2 for each dosimetry measurement (i.e., film badge, PIC, or TLD) that is recorded as zero or if it is below the LOD divided by 2. Readings greater than or equal to the LOD divided by 2 should be used as recorded.

When the number of zero measurements cannot be determined, determining the missed dose becomes more complicated. When the records provide only an annual dose, the number of zero doses should be estimated based on that dose; the monthly, quarterly, or annual limits for that year; and the maximum number of possible zero monitoring intervals (see Attachment A).

External ambient doses D_{EN} are determined using Attachment B of this document. Occupational medical X-ray doses D_{OM} are determined using ORAUT-PROC-0061, *Occupational Medical X-Ray Dose Reconstruction* [ORAUT 2017b] and ORAUT-OTIB-0006 [ORAUT 2019b].

As described in OCAS-IG-001, photon doses are categorized into three input categories for IREP as follows [NIOSH 2007]:

- <30 keV,
- 30 to 250 keV, and
- >250 keV.

Considering both the organ dose conversion factor (DCF) and the risk associated with photon dose as given in IREP, the 30- to 250-keV energy range is typically the photon energy most favorable to the claimant if a dose reconstructor is faced with (1) an unknown energy distribution or (2) a desire to process a likely noncompensable case using an overestimating approach. One notable exception is skin dose from work with or near isotopes of plutonium because the DCF for skin is considered to be 1 for all energies (ORAUT-OTIB-0017, *Interpretation of Dosimetry Data For Assignment of Shallow Dose* [ORAUT 2005]) and because <30-keV photons have a higher risk factor in IREP than do 30- to 250-keV photons based on information provided in *NIOSH-Interactive RadioEpidemiological Program (NIOSH-IREP) Technical Documentation* [NIOSH 2002]. A photon energy division of 25% 30 to 250 keV and 75% >250 keV can be assumed to be a reasonable minimum approach to process a likely compensable case because radiation scattering reasonably precludes the existence of exclusively high-energy photons in a workplace environment. Unless there is information to the contrary, external ambient doses D_{EN} and medical X-ray doses D_{OM} are always classified as 30 to 250 keV photons as favorable to claimants (see Attachment B and ORAUT-PROC-0061 [ORAUT 2017b]).

In accordance with OCAS-IG-001, all external photon doses may be assigned as acute or chronic using parameters of *NIOSH-Interactive RadioEpidemiological Program (NIOSH-IREP) Technical Documentation* [NIOSH 2002]. However, they are typically assigned as acute with the exception for external onsite ambient doses, which are always considered chronic [NIOSH 2007].

2.2.2 Neutron Radiation

There are two basic components of neutron radiation dose. The sum of the dose components in each calendar year comprises a worker's annual occupational neutron radiation dose D_N. This is expressed as follows:

$$D_N = D_D + D_M \qquad (2\text{-}2)$$

where

D_N = total annual neutron radiation dose
D_D = recorded worker occupational neutron dose, typically based on personal neutron dosimeter measurements
D_M = missed neutron dose (unrecorded or unmeasured neutron dose due to dosimeter limitations)

Because neutron exposures from manmade sources do not generally exist in the environment and because neutrons are not used in most occupational medical procedures, medical dose categories are not included and ambient doses are not typically included in the external neutron dose reconstruction.

Neutron monitoring may be present, but because of neutron energy distribution, dosimeters (e.g., film dosimeters) may not capture a portion of the energy spectrum and therefore the individual is not fully monitored. In these situations, an adjustment to the recorded dose (e.g., neutron-to-photon ratio or applying a correction factor) would need to be used.

As is the case with photons, unmonitored neutron dose can be assigned if a worker was not monitored or was monitored inadequately for neutron exposure. Unmonitored neutron doses are typically determined based on neutron-to-photon ratios from the site profiles or using a quantile regression approach. However, many workers would not have received a significant neutron dose, and evaluation of the neutron dose component might be unnecessary in such cases (see ORAUT-OTIB-0023, *Assignment of Missed Neutron Doses Based on Dosimeter Records* [ORAUT 2008]). Therefore, photon dose can often be the only type of external radiation dose that requires evaluation.

Recorded neutron doses D_D are adjusted, if appropriate, based on site profile information. When using film dosimetry, track fading and angular dependence might be an issue. If needed, the site profile should provide guidance. The neutron dose for each energy category is adjusted to the International Commission on Radiological Protection (ICRP) Publication 60 weighting factors [ICRP 1991] as generally described in OCAS-IG-001 [NIOSH 2007]. For example, since the 1950s a quality factor of 10 has generally been applied to fast neutron exposures; however, it has varied from 5 to 20 across facilities and times. Attachment C lists numerous sites and the date when they implemented ICRP Publication 60 neutron weighting factors. Contact the Principal External Dosimetry Scientist if information about the implementation of the ICRP Publication 60 values is needed for an unlisted site. It is possible the site did not incorporate the ICRP Publication 60 neutron weighting factors into the determination of the neutron LOD used for missed dose calculations after the implementation date (this issue should be addressed in the site TBD). If this is the case, or if this issue is not addressed in the current version of the site TBD, apply ICRP Publication 60 neutron weighting factors to neutron dosimeter missed dose after the dates listed in Attachment C. Table 2-2 lists the ICRP Publication 60 neutron radiation weighting factors for specific energy ranges.

Neutron monitoring was not fully implemented – or was generally inadequate – until the late 1950s. As a result, missed or unmonitored neutron doses D_M have the potential to contribute significantly to the annual occupational dose, especially in the early years of the DOE weapons complex.

If the monitoring data and methods were considered adequate according to site profile information, a neutron missed dose should be evaluated using the same method discussed for photons. Specifically, the neutron LOD/2 times the number of zero monitoring badges is the central estimate of a lognormal distribution, and the upper 95th-percentile estimate is the LOD times the number of zero monitoring badges. However, a zero in the records for neutron dose does not necessarily mean that there was a potential for neutron exposure, so exceptions apply (see ORAUT-OTIB-0023 [ORAUT 2008]).

Table 2-2. Neutron energy intervals and associated ICRP Publication 60 weighting factors with examples of relevant exposures or facilities.

Neutron energy (MeV)	Publication 60 radiation weighting factor (w_R)[a]	Typical exposure scenario
<0.01	5	Low-energy neutron exposures include thermal neutrons commonly found around nuclear reactors or moderated neutron sources. More prevalent around heavy-water reactors.
0.01–0.10	10	Intermediate-energy neutron exposures can also result from operation around nuclear reactors as high-energy neutrons are moderated to thermal energies.
0.10–2.00	20	Commonly called fission spectrum neutrons, this is the most typical energy range from operation of light-water or graphite-moderated reactors.
2.0–20.0	10	Reactions between alpha particles from materials such as plutonium or polonium and light materials such as beryllium can result in the production of neutrons. These reactions are commonly called alpha-neutron (α,n) reactions. This neutron energy interval also includes 14 MeV neutrons from fusion reactions.
>20.0	5	Exposures to neutrons greater than 20 MeV can result from work around accelerators.

a. Source: ICRP [1991].

Site profile information should be used to reconstruct unmonitored neutron dose. This dose is generally reconstructed using neutron-to-photon ratios based on the reconstructed measured and missed photon doses. An additional method involving quantile regression, described in ORAUT-RPRT-0087, *Applications of Regression in External Dose Reconstruction* [ORAUT 2018b], can also be used, which uses monitoring results from dosimeters that are sensitive to both photons and neutrons and models that relationship to determine possible neutron dose when only a photon result is available.

As described in OCAS-IG-001, neutron doses are categorized into five IREP input categories as follows [NIOSH 2007]:

- <10 keV,
- 10 to 100 keV,
- 0.1 to 2 MeV,
- 2 to 20 MeV, and
- >20 MeV.

Considering the neutron weighting factor adjustment, organ DCF, and the risk associated with neutron dose as given in IREP, the 0.1- to 2-MeV energy range is typically the most favorable to the claimant, but the dose reconstructor should use the guidance in the site profile for neutron dose distribution.

In accordance with OCAS-IG-001, all neutron doses should be entered as chronic in IREP [NIOSH 2007].

2.2.3 Electron (Beta) Radiation

In general, external electron radiation dose is significant for exposures to the surface skin tissue of the body. Other organs for which external electron exposure is relevant include the breast, testes, and lip; see ORAUT-OTIB-0017 [ORAUT 2005] for detailed information. The exposure to skin can originate from an unshielded electron source, such as $^{90}Sr/^{90}Y$ or uranium decay products, or from skin contamination with beta/gamma emitters.

There are three basic components of skin radiation dose. The sum of these components in each calendar year is a worker's annual occupational electron radiation dose D_E. This is expressed as follows:

$$D_E = D_D + D_M + D_S \tag{2-3}$$

where

- D_E = total annual electron radiation dose
- D_D = recorded worker occupational electron skin dose typically based on personal dosimeter measurements
- D_M = unrecorded or unmeasured electron dose commonly referred to as the missed electron or skin dose
- D_S = dose from skin contamination by beta/gamma-emitting nuclides; this dose poses a unique exposure scenario that should be evaluated in skin cancer cases

As is the case with photons, unmonitored electron dose can be assigned if a worker was not monitored or was monitored inadequately for electron exposure.

All components of electron dose (D_D, D_M, and D_S) must be calculated based on the guidance in ORAUT-OTIB-0017 [ORAUT 2005]. This involves an understanding of the open window result values (e.g., electron or low-energy photon), site dosimetry reporting schemes, limit of detection issues, dosimetry shielding by security credentials, and personal protective equipment. Recognizing these complicating factors and using the approach provided in ORAUT [2005] is necessary to determine the dose to assign. When calculating the electron dose, separate the nonpenetrating doses and determine if they result from >15 keV electrons (corrected for attenuation, if applicable) and include any applicable missed dose. As discussed in ORAUT [2005], a DCF of 1 is assumed for determining skin dose.

As described in OCAS-IG-001, electron doses are categorized into two IREP input categories as follows [NIOSH 2007]:

- ≤15 keV, and
- >15 keV.

However, only the >15 keV category is considered to be a source of external radiation. As described in OCAS-IG-001, Section 1.2, electrons ≤15 keV do not have sufficient energy to penetrate the epidermal layer of the skin and are therefore not considered an external radiation hazard [NIOSH 2007].

In accordance with OCAS-IG-001, external electron doses should be entered as acute in IREP [NIOSH 2007].

2.3 CONVERSION OF RECONSTRUCTED EXTERNAL DOSE TO ORGAN DOSE

For external dose reconstruction under EEOICPA, the organ or tissue that developed the cancer is the primary organ of interest. International Classification of Diseases (ICD) codes are used to determine general information regarding corresponding organ for which external dose should be calculated. Detailed information on ICD codes and the appropriate external organ is provided in

ORAUT-OTIB-0005 [ORAUT 2019a]. In addition, target organ selection for X-ray exposures should be done in accordance with ORAUT-OTIB-0006 [ORAUT 2019b].

Film badges and TLDs were typically worn on the upper front torso of the worker's body. Depending on the monitoring era, workplace radiation fields, and site, these devices were calibrated to a selected radiation quantity as follows:

- Exposure,[1]
- Absorbed dose in air,
- Ambient dose equivalent, or
- Penetrating dose at a selected depth in tissue (i.e., similar to current personal dose equivalent, *Hp(d)*, where d = 0.07 millimeter for shallow dose and d = 10 millimeters for deep dose).

The precise radiation quantity a site historically used to measure and record dose to workers is difficult to evaluate retrospectively. Under most circumstances, it is known that calibration of early film dosimeters using comparatively high-energy radium or ^{137}Cs gamma sources generally resulted in an overestimation of the dose to a worker in the comparatively lower-energy photon radiation fields typical of the workplace because of the film overresponse to lower-energy photons from shielding and scattering of the radiation. In view of these considerations, the corresponding uncertainties, and the desire to conduct consistent evaluations, organ DCFs are selected from OCAS-IG-001 based on the most favorable geometry [NIOSH 2007]. For most organs this is an anterior-posterior exposure, but for some organs (e.g., lung, esophagus, red bone marrow, bone surfaces) both anterior-posterior and rotational geometries must be evaluated and the geometry that results in the higher POC should be selected. When evaluating claims with multiple cancers, to be consistent, whichever geometry is determined to have the highest overall POC should be applied to all cancers.

Certain exceptions exist to the use of the DCFs in OCAS-IG-001 [NIOSH 2007]. For likely noncompensable cases, the calculation of measured doses involves rounding organ DCFs up to 1 unless the DCF exceeds 1, in which case the actual DCF is applied. This practice was established (1) to help ensure favorability to claimants and (2) to avoid, if possible, reporting a reconstructed organ dose less than the dose of record.

Other exceptions include:

- Reconstruction of dose to the skin, where a DCF of 1 is assumed in accordance with ORAUT-OTIB-0017 [ORAUT 2005],

- Reconstruction of external ambient dose (ambient dose equivalent [*H*(10)*] DCF in OCAS-IG-001 [NIOSH 2007] for an isotropic exposure geometry as indicated in Attachment B), and

- Reconstruction of organ doses from occupational medical X-rays. Organ-specific doses are presented in the respective site profiles as described in ORAUT-PROC-0061 [ORAUT 2017b]. In the absence of organ-specific dose in the site profile, ORAUT-OTIB-0006 provides default organ doses.

2.4 UNCERTAINTY

The uncertainties in the measured dosimeter dose and the occupational medical dose are assumed to have a normal distribution, while the uncertainties in the missed dose are assumed to have a

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1 *Exposure* is used to measure gamma and X-ray radiation interaction only with air and was historically measured in roentgens: 1 R = 2.58×10^{-4} coulomb per kilogram. It is a measure of the ionizations of the molecules in a mass of air. The quantity is easy to measure directly and was used historically to calibrate radiation protection instruments and dosimeters.

lognormal distribution. Ambient onsite dose is assumed to have a normal or lognormal distribution. The uncertainty in the organ DCF is assumed to have a triangular distribution as provided in NIOSH [2007].

Assessment of the overall external dose uncertainty is dependent on the dose reconstruction approach. For likely compensable claims (underestimates), uncertainty might not need to be applied. For likely noncompensable claims (overestimates), the uncertainty can be incorporated by increasing the assigned dose components and assigning them as constants. For best estimates claims, each dose component is treated as a distribution and Monte Carlo sampling of the distributions is employed to calculate the overall uncertainty of the dose estimate.

Attachment B and ORAUT [2019b] provide details on the assessment of uncertainties for external ambient and occupational medical X-ray doses, respectively.

3.0 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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ATTACHMENT A
METHOD FOR ASSIGNING MISSED DOSE
WHEN THE NUMBER OF NULL RESULTS IS UNKNOWN

The basis for these instructions is Section 2.1.2.3 of OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* [NIOSH 2007].

Overestimating Approach (Appropriate for Likely Noncompensable Cases)

Instruction: Calculate the maximum number of potential zeros (N_{max}), taking into consideration the published exchange frequency and applicable dose limits. This number multiplied by the LOD (i.e., $N_{max} \times LOD$) is considered the 95th percentile of a lognormal distribution. Multiply by LOD/2 (i.e., $N_{max} \times LOD/2$) to determine the GM. These values are assumed to have a lognormal distribution with a GSD of 1.52.

Example: Assume the case and site profile information has provided a 1-rem reported annual dose, weekly exchanges, LOD of 40 mrem, 300-mrem/wk dose limit for the era, and a 52-wk work year:

- The N_{max} is 48 (e.g., 300 mrem/wk for 3 wk, 100 mrem in 4th wk, zero the rest).

- The missed dose assigned is 48 × 0.040 rem/2 = 0.960 rem (lognormal, 1.52 in IREP Parameter 2).

Underestimating Approach (Appropriate for Likely Compensable Cases)

Instruction: Calculate the median between the maximum and minimum number of potential zeros (N_{med}), taking into consideration the published exchange frequency, applicable dose limits, and LOD. When multiplied by LOD/2, $N_{med} \times LOD/2$ is the GM. This is considered an underestimating approach in comparison with the guidance in OCAS-IG-001 [NIOSH 2007]. If the arithmetic median is a partial number, round up (cannot have a fraction of a dosimeter and rounding up is slightly claimant favorable). For example, the N_{med} between 27 and 48 dosimeters is 37.5 dosimeters. Use 38 dosimeters in the calculation.

Example: Using the same assumptions as above:

- The N_{max} is 48.
- The minimum number of zeros is 27 (e.g., 40 mrem in 25 wk, zero the rest).
- The N_{med} is 38.
- The missed dose assigned is 38 × 0.040 rem/2 = 0.760 rem (lognormal, 1.52 in IREP Parameter 2).

Best-Estimate Approach (Appropriate for Cases in Which Overestimating Approach Results in POC >45% and Underestimating Approach Results in POC <52%)

Instruction: Calculate the N_{med} between the N_{max} and minimum number of potential zeros, taking into consideration the published exchange frequency, applicable dose limits, and LOD. When multiplied by LOD/2 (i.e., $N_{med} \times LOD/2$), the resultant value is considered the GM of a lognormal distribution. When multiplied by the LOD (i.e., $N_{max} \times LOD$), the resultant value is considered the 95th percentile of a

ATTACHMENT A
METHOD FOR ASSIGNING MISSED DOSE
WHEN THE NUMBER OF NULL RESULTS IS UNKNOWN (continued)

lognormal distribution, and the GSD must be calculated accordingly using the 95th- and 50th-percentile dose. The GSD is calculated as:

$$GSD = \left(\frac{95th\ percentile}{50th\ percentile} \right)^{\left(\frac{1}{1.64485} \right)} \quad \text{(A-1)}$$

Example: Assumptions are the same as above.

- The N_{max} is 48.
- The minimum number of zeros is 27.
- The N_{med} is 38.
- The missed dose is 38 × 0.040/2 = 0.760 rem (lognormal).
- 95th percentile dose is 48 × 0.040 = 1.920 rem; $\mathrm{GSD} = \left(\frac{1.920}{0.760} \right)^{\left(\frac{1}{1.64485} \right)} = 1.757$.
- The missed dose assigned = 0.760 rem (calculated in previous bullet), lognormal, 1.757 in IREP parameter 2.

ATTACHMENT B
ONSITE AMBIENT DOSE ASSIGNMENT

TABLE OF CONTENTS

ATTACHMENT B
ONSITE AMBIENT DOSE ASSIGNMENT (continued)

This attachment provides guidance for the assignment of external onsite ambient dose. This attachment is intended to provide general information about assignment of this dose; site-specific guidance might be provided in the site profile.

B.1 GENERAL

As described in OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* [NIOSH 2007], doses from elevated background radiation as a result of DOE or AWE activities must be included in dose reconstructions. This requirement is complicated by site reporting practices, fallout from atmospheric weapons testing, and worker location in relation to site monitoring data. Because these exposures are a concern for workers who were not monitored or who worked at a site where elevated background radiation from DOE or AWE activities might have been subtracted from dosimeter results, reconstruction of doses must rely on information in site-specific site profiles and other published health physics resources.

External film dosimeters or TLDs have been used for occupational radiation monitoring since the 1940s. To account for background radiation levels that are not traditionally included in occupational radiation dose records, control dosimeters have been used from the outset. Good radiation protection practice dictates that during shipment a control dosimeter accompanies each batch of dosimeters issued to workers. Between manufacture or annealing and issuance, and between retrieval and processing, each shipment of dosimeters is irradiated by natural cosmic and terrestrial radiation sources and potentially inadvertently irradiated by other sources. The function of the control dosimeter is to measure all nonoccupational radiation exposure to the batch of dosimeters. When processed, the reading from the control dosimeter is subtracted from the reading of each of the other dosimeters in the batch, which yields a result for each dosimeter that is solely due to occupational radiation exposure. Note that the subtraction could occur with raw data, such as optical density readings for film or glow curves, or with transformed data, such as exposures in roentgens, absorbed doses in rad or gray, or dose equivalents in rem or sievert.

Determination as to whether control dosimeters were exposed to elevated ambient levels of external radiation (EALER) is generally associated with where the control dosimeters were stored. From the intended use of control dosimeters, it is clear that controls should be subjected to exactly the same nonoccupational radiation exposure as the issued dosimeters and differ only in the occupational component. The implementation of this intention (that is, procedures for issuance and retrieval of dosimeters) likely differed over time at a given facility and certainly differed among DOE and AWE sites. For example, at large facilities, controls might have been kept at a central dosimeter location or distributed with batches of dosimeters to remote identification (ID) badge or dosimeter exchange buildings such as guard stations near reactors, reprocessing facilities, or manufacturing facilities. During some periods, dosimeters were incorporated into ID badges to ensure that no one entered without a dosimeter, and these ID badges were picked up at the entrance station at the beginning of each shift and returned there at the end of each shift. If control dosimeters were kept at remote exchange facilities, they would have recorded EALER at those facilities. Such doses from EALER recorded by the controls would subsequently have been subtracted from each worker’s dosimeter reading. However, if control dosimeters were kept at a distant central badging facility where ambient radiation levels were lower than in the work areas, each worker’s dosimeter would have recorded not only his or her occupational exposure, but also his or her exposure to EALER. In the latter case, no adjustment for occupational environmental radiation levels is needed because it would have been included in the worker’s occupational measurements.

ATTACHMENT B
ONSITE AMBIENT DOSE ASSIGNMENT (continued)

For the early days of reactor operation, one important component of external environmental dose arises from submersion in, or irradiation at a distance from, a plume of ^{41}Ar (with a radiological half-life of 1.83 hours), which formed when naturally occurring ^{40}Ar nuclei absorbed neutrons near operating reactors. The emissions from ^{41}Ar are primarily a 1.2-MeV (maximum) beta particle and a 1.3-MeV photon. A wooden badge exchange building would likely provide very little shielding or attenuation of the photons and, if air exchange rates at the control dosimeter storage point were high, even the beta component could have approached outdoor levels. In addition to radiation from airborne releases of radioactive materials, other components of EALER could arise from:

- Scattered radiation from waste trenches, storage facilities, etc.;
- Terrestrial contamination; and
- Skyshine (radiation scattered to the ground from air over nuclear or high-energy accelerator facilities).

However, these components are unlikely to have been the same at dosimeter exchange facilities as they were on the rest of the site, so control dosimeters that were stored at remote exchange facilities would not have recorded this component.

Processes with potential for significant EALER include:

- Operating production reactors,
- Fuel reprocessing,
- Other radiochemical processing facilities,
- Atmospheric nuclear weapons testing,
- Underground nuclear weapons testing with significant venting of fission gasses,
- Accidental airborne releases of radioactive materials, and
- Certain high-energy accelerators (in the early years).

Large sites might have had inhomogeneous EALER, and control dosimeters that were distributed with batches intended for particular areas might have been able to measure significant EALER that the workers' dosimeters might have missed.

In general, there is a point in time at a particular site after which there is no need to assess specific EALER to add to the worker's dose because (1) levels were so low they would not significantly affect the POC, and (2) control dosimeters were kept under controlled conditions and EALER would not have been subtracted. As environmental monitoring programs matured, environmental TLD measurements ruled out significant EALER values. This point in time can only be established for a particular site by reviewing site and worker monitoring practices.

External dosimetry results account for both occupational and environmental penetrating radiation exposures if control dosimeters were not exposed to EALER due to operations. Not all DOE and AWE sites experienced the problem of missed EALER.

All external ambient doses are assigned in IREP as follows:

- <u>Exposure rate</u>: Chronic, and
- <u>Radiation type</u>: Photons E = 30 to 250 keV.

ATTACHMENT B
ONSITE AMBIENT DOSE ASSIGNMENT (continued)

Due to the variations in site geography, monitoring practices, reporting practices, facilities, and operations, a best estimate cannot be generated for a site that does not have a complete site profile. To assess doses in recent years that might not be covered in the site profiles, the most recent onsite ambient doses can be assumed to apply.

B.2 BEST-ESTIMATE METHOD

Most dose reconstructions, for which data are provided in the site profile, use a Monte Carlo method in which the external environmental dose with its uncertainty distribution is multiplied by the appropriate organ DCF distribution to calculate the best-estimate ambient dose. A best estimate must take into account all available records pertinent to determination of work location. For workers who worked in multiple areas of the site, if the worker's records and claimant interview do not provide enough information to determine specific work locations, the site GM dose, with GSD, is appropriate for best estimates. Battelle-TIB-5000, *Default Assumptions and Methods for Atomic Weapons Employer Dose Reconstructions* [BT 2007], provides guidance on the relationship between the arithmetic average and GM (and GSD).

Dose reconstructors should use site-specific guidance on the calculation of environmental dose when provided (i.e., number of hours, area dose rates, etc. for calculation of the ambient dose assignment). If site-specific guidance is not available, the assumption should be made that the worker worked 50 hr/wk and 50 wk/yr (to reasonably account for holiday and/or vacation time) or a total of 2,500 work hours per year when assigning ambient dose as a best estimate. Partial years of employment should be scaled accordingly. In addition, if the claimant interview indicates that fewer or more hours were worked, then this information should be used. For example, if the worker was off the site half of the time where only natural background radiation levels existed, only 25 hours of exposure per week should be assumed.

The calculated annual dose using site information is multiplied by the appropriate *exposure*-(*R*)-to-organ DCF in OCAS-IG-001 [NIOSH 2007] for an isotropic exposure geometry for most sites to determine the dose to be assigned for each year. Some sites provide environmental data based on survey measurements or calculations rather than film or TLD dosimeter results. For sites that provide the data, the calculated annual dose should be multiplied by the appropriate ambient dose equivalent [*H*(10)*] DCF in OCAS-IG-001 for an isotropic exposure geometry. A DCF of 1 for onsite ambient dose is applied for cancers where the skin is used to calculate external dose.

If supporting documentation for all of the elements necessary for a best-estimate dose reconstruction does not exist, conservative assumptions should be applied in relation to work location and area conditions, erring in favor of the claimant.

ATTACHMENT C
DOE ADOPTION OF
INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP) PUBLICATION 60

DOE sites provided information about their incorporation of the ICRP Publication 60 recommendations on neutron radiation weighting factors, which were published in 1990 [O'Connell 2011]. This information is presented below:

Table C-1. Site ICRP Publication 60 incorporation dates.

Site	Date ICRP Publication 60 incorporated
Argonne National Laboratory (East)	06/18/2010
Brookhaven National Laboratory	01/01/2010
Fermi National Accelerator Laboratory	07/01/2010
Hanford Site	01/01/2011
Idaho Cleanup Project	04/10/2010
Idaho National Laboratory – Battelle Energy Alliance	CWI dosimeters – 04/01/2010 Landauer – 06/13/2010
Kansas City Plant	No neutron dose to assign since 1997
Lawrence Berkeley National Laboratory	07/01/2010
Lawrence Livermore National Laboratory	01/01/2009
Los Alamos National Laboratory	01/01/2009
Mound Site	After 2006, under DOE Legacy Management
Nevada Test Site	01/01/2010
Oak Ridge Gaseous Diffusion Plant (K-25)	01/01/2010
Oak Ridge National Laboratories (ORNL) University of Tennessee – Battelle ORNL DOE ORNL Bechtel Jacobs Company (UCOR) TRU Project Los Alamos Technical Associates – Kentucky Oak Ridge Institute for Science and Education ORNL – Wackenhut	01/01/2010
Paducah Gaseous Diffusion Plant Uranium Disposition Services Paducah Remediation Service	01/01/2010
Paducah Gaseous Diffusion Plant – Swift & Staley	2011 (calendar year only)
Pantex Plant	01/01/2010
Portsmouth Gaseous Diffusion Plant Uranium Disposition Services Los Alamos Technical Associates/Parallax Fluor-Babcock & Wilcox	01/01/2010
Sandia National Laboratories (Albuquerque and California)	01/01/2010
Savannah River Site	01/01/2010
Stanford Linear Accelerator Center	07/01/2010
Thomas Jefferson National Accelerator Laboratory	07/01/2010
Waste Isolation Pilot Project	06/01/2010
West Valley Demonstration Project	Not implemented
Y-12 Plant	01/01/2010