Paper

EXTERNAL DOSE RECONSTRUCTION UNDER PART B OF THE ENERGY EMPLOYEES COMPENSATION ACT

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Abstract—**External doses reconstructed under Part B of the Energy Employees Occupational Illness Compensation Program Act include not only those that were recorded by personal dosimeters, but also those that were not recorded. Recorded doses may require corrections to account for measurement bias or limitations in the dosimeters' capabilities. Unrecorded doses that have been reconstructed include (1) those missed due to limits of detection associated with personal dosimeters, (2) external ambient doses that may have been inadvertently omitted from the monitoring results (or were not monitored altogether in the case of nonradiation workers), and (3) doses incurred as a result of medical x-ray examinations required by employers. Additionally, some workers were not monitored (or their dosimetry data are not available) even though there was a potential for exposure; doses to such workers are typically assigned based on the records of coworkers who performed the same, or similar, tasks. Additional issues that complicate the dose reconstruction process include the requirements that (1) all external doses must be partitioned according to radiation type and energy, and (2) the accompanying doses to specific body organs must be estimated. Since the external dose reconstruction process typically incorporates many claimant-favorable methodologies, parameters, and assumptions, the doses assigned do not necessarily reflect either realistic or actual estimates of the doses received, and external doses assigned to workers under the Act often are substantially higher than those contained in the dosimetry records.**
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INTRODUCTION

THROUGH THE Energy Employees Occupational Illness Compensation Program Act (EEOICPA), the U.S. Congress (2000) established a program to provide compensation to qualified current and former nuclear weapons workers who developed cancer after having worked at facilities operated under the U.S. Department of Energy (DOE) or its predecessors, or at facilities identified as Atomic Weapons Employer (AWE) sites. The National Institute for Occupational Safety and Health (NIOSH) was assigned the responsibility for implementing this program and subsequently published an External Dose Reconstruction Implementation Guideline (IG) (NIOSH 2006). In addition to establishing guidance and expanding on the requirements of Title 42 CFR Part 82 (U.S. DHHS 2002), the IG provides organ dose conversion factors (DCFs) and describes a detailed method for evaluating the associated uncertainties. The tenets of the IG were incorporated into an External Dose Reconstruction procedure.[§] Additional documents that establish the approach and basis for external dose reconstruction under EEOICPA include site profiles, which contain site-specific information related to external radiation fields and external dosimetry, and technical information bulletins (TIBs), which contain supplemental technical information and guidance. These are covered in more detail elsewhere in this issue (Kenoyer et al. 2008).

EEOICPA establishes, first and foremost, a compensation program. Consequently, doses reconstructed under this program represent as accurate or precise an estimate of the dose received by the worker as is needed to decide the claim.** For example, for a case that appears likely to be compensable,[††] it is common for the dose reconstructors to evaluate doses from only a sufficient number of sources to document this fact. In contrast, for claims

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§ Oak Ridge Associated Universities Team. External dose reconstruction [internal procedure]. Cincinnati, OH: ORAUT; ORAUT-PROC-0006, Rev 01; 2006.

** Throughout this paper, the generic term "dose" is used for simplicity and to ensure consistency with documents prepared in accordance with EEOICPA, notably dose reconstruction reports provided to claimants.

†† The U.S. Department of Labor (DOL) officially establishes the probability of causation (PC) and renders a compensation decision based on the dose reconstruction results.

that appear likely to be noncompensable, the dose reconstructors typically apply highly claimant-favorable assumptions to ensure that the dose has been overestimated and to expedite the claim [this approach is covered in detail elsewhere in this issue by Merwin et al. (2008)]. If, even under these conditions, the probability of causation (PC) is considerably less than 50%, the dose reconstruction is terminated and the estimates are submitted to the U.S. Department of Labor (DOL), which has the responsibility for rendering a final compensation decision. In either case, the claim has been processed in an efficient manner. As would be anticipated, the minority of claims that fall between these two extremes require the most time to reconstruct.

EXTERNAL DOSE MONITORING

In general, workers employed within the DOE weapons complex who had a potential for exposure to radiation were issued personal dosimeters for assessing external exposures. There were, however, significant exceptions; namely, there were workers at certain sites who were not monitored. These included:

- Most workers at AWE facilities;
- Many workers at certain DOE sites in the early days of site operations, especially those at plutonium, uranium, and enriched uranium facilities where the risks were thought to be generally low;
- Certain trade workers whose work was considered transient in nature or who were employed by subcontractors not subject to site monitoring requirements; and
- Workers in jobs considered "nonradiological" in nature, but who may have received doses above background levels.

Reconstructing the external doses received by such workers is challenging, and the doses have been reconstructed using a variety of approaches. These are described in subsequent sections of this paper. Even so, reconstructing doses based on measured values is equally challenging, not only because the dosimeter measurements were not always accurate, but also because the evaluation of the PC under the Act entails the application of different risk modifying factors, depending on the energy of the electrons, photons, and neutrons within the exposure source (Kocher et al. 2005). Further compounding the challenge is the fact that (1) the characteristics of the radiation fields often are not known with certainty, and (2) the external dosimeters being used were designed to measure external dose (typically deep and shallow), usually with little if any ability to partition the measured doses among the several energy ranges. Other challenges include the differences in the designs of the dosimeters being used over time and across the complex, and the accompanying inherent measurement inaccuracies of the various designs relative to certain radiation types and energies.

Photon dose

Since the beginning of the nuclear weapons research and production era, individual workers at many facilities have been monitored using personal dosimeters. Although pocket ionization chambers (PICs) were initially used at some facilities (and often remain in use for administrative control), film badges typically were used to provide the dose of record until the 1970's when thermoluminescent dosimeters (TLDs) became available. TLDs continue to be relied upon at DOE facilities today. With ongoing technological developments throughout the past six decades of the U.S. weapons program, both the accuracy and sensitivity of the dosimeters have continued to improve. This improvement has been driven, in part, by implementation of the DOE External Dosimetry Laboratory Accreditation Program, which helped define acceptable energy and angular response characteristics, testing proficiencies, field calibration factors, and overall program performance requirements to include procedures and documentation.

The measurement of the dose from exposures to photons is generally straightforward, particularly for high energy photons. For this reason, the recorded deep doses were relatively accurate, even in the early years of DOE and AWE operations. To estimate PC in accordance with EEOICPA, however, photon doses must be partitioned into three energy ranges: $<$30 keV, 30–250 keV, and $>$250 keV. In general, the responses of film dosimeters (especially those containing filters) and TLDs are relatively flat at energies above about 100 keV in comparison to the response of film without filtration [i.e., commonly termed "open window" (OW)]. For the higher photon energies, the specific dosimeter design and thicknesses of filters and the presence of security badges (which were positioned in front of the dosimeters at some facilities) did not significantly impact the measured dose. Thus, the overall quality and accuracy of external dosimeter measurements at these photon energy ranges (i.e., 30–250 keV and $>$250 keV) commonly require small, if any, adjustments to the recorded deep dose (also referred to as the "penetrating" or "shielded" dose) to derive the deep dose equivalent [$H_p(10)$]. The dose reconstructor must then partition the dose among these energy ranges based on the best available resources, including knowledge of the work locations and information on radiation fields as documented in the site profiles.

Accurate assignment of dose at the low (<30 keV) photon energy range is problematic, particularly for the film badge era, because (1) film over-responded significantly to these energies, and (2) the presence of high-atomic-numbered filters attenuated photons in this energy range. Therefore, reconstruction of photon doses in plutonium facilities, for example, uses site-specific information pertaining to dosimeter designs and calibration and reporting practices, and typically takes into account both the OW and shielded dosimeter measurements.

If information is not available to make precise estimates of photon dose, basic data, information, and assumptions (documented in site profiles, TIBs, etc.) are incorporated into the analysis such that the outcome is to the benefit of the claimant. For example, exposures to 30–250 keV photons have a higher risk factor per unit dose than exposures to >250 keV photons (NIOSH 2002); thus, to ensure claimant favorability, dose reconstructors may assign all photon doses to the 30–250 keV energy range if an employee's specific work locations are unknown. As another example, given the difficulties associated with external dose measurements in plutonium facilities during the film badge era, claimant-favorable assumptions (such as assigning dose based on the OW measurement) also may be applied.

Electron dose

Electron doses are partitioned into two energy ranges: ≥15 keV, which is pertinent to external dose, and <15 keV, which is a special category relevant only to exposures to beta (electron) emissions from tritium, doses from which are reconstructed as internal dose. Consequently, the estimation of the dose measured by the dosimeter is typically straightforward and involves the determination of shallow dose equivalent through comparison of the shielded and OW measurements and assignment of the differences entirely as >15 keV (unless all or a portion may be attributable to <30 keV photons).

Complications arise, however, when translating the estimated shallow dose equivalent into the dose that must be assigned to the cancerous organ. Shallow doses impact only the skin, breast, testes, and several other organs or body parts. For the skin, the calculated shallow dose equivalent based on the dosimeter measurement must be reduced to account for attenuation by clothing or protective equipment, depending on the cancer location. Doses assigned to the breast and testes must not only take into account clothing, but also the fact that the sensitive tissues are deeper than that for the skin. These issues are addressed in a TIB that provides dose reconstructors specific instructions on assigning shallow doses based on dosimeter measurements (ORAUT 2005c).

Neutron dose

Personal neutron monitoring initially was conducted, at most facilities, using boron-lined PICs or neutron glass track plates. As the science progressed, operators of many facilities began, in the mid 1950's, using neutron track emulsion type A (NTA) film. The latter units were further improved over time to distinguish between fast and slow neutrons. By the mid 1970's, however, TLDs were used for neutron measurements at most facilities.

To calculate PC in accordance with EEOICPA, neutron doses must be partitioned into five energy ranges: <10 keV, 10–100 keV, 100 keV–2 MeV, 2–20 MeV, and >20 MeV. In practice, the middle three ranges were the principal contributors to the dose at DOE facilities (neutrons were not a significant issue at most AWE facilities). For measurements with TLDs, an approach similar to that for photons is used; namely, the dose reconstructor typically multiplies the measured neutron dose by a correction factor associated with the dosimeter design and calibration method, and partitions the dose among these energy ranges based on knowledge of the work location and information on neutron radiation fields contained in the site profiles. An additional adjustment, however, must be made to account for changes in the value of the quality factor (now known as the radiation weighting factor) for neutrons. In 1959, Committee II of the International Commission on Radiological Protection (ICRP) recommended a nominal factor of 10 (ICRP 1960). Today the recommended values (ICRP 1991) range from 5–20 (depending on the neutron energy), and these are the values stipulated under EEOICPA for dose reconstruction. Guidance on an adjustment factor for each of the five energy ranges listed above is established in the site profiles based on the quality factors assumed by the sites during the history of their dosimetry programs.

Due to issues with accuracy and detection limits, PIC neutron measurements are not used to reconstruct neutron doses, and in some cases NTA measurements are not used because uncertainties associated with the correction factors are too large to provide a reliable dose estimate. In these cases, the doses typically are reconstructed based on the more reliable photon dose measurements and neutron-photon ratios established in the site profiles for specific facilities or types of work. Even in these cases, however, the uncertainties are large, and claimant-favorable assumptions are used.

Missed dose

External missed dose represents above-background dose that was received by a monitored worker but was not recorded due to detection limits of the dosimeter

and/or site recording or reporting practices. Because all dosimeters have detection thresholds, also known as limits of detection (LODs), small doses may have gone undetected. Additionally, some facilities elected not to record zero or <LOD doses in the worker's dose of record. LOD values for medium and high energy photons typically were 0.30–0.40 mSv (30–40 mrem) per dosimeter reading in the 1940's and 1950's, eventually improving to 0.10 mSv (10 mrem) or less by the 1980's (NIOSH 2006).

As described in the IG, missed dose is reconstructed by estimating the maximum potential missed dose and treating this value as the 95th percentile of a lognormal distribution. In practice, this means multiplying the LOD by the number of null dosimeter readings (i.e., those recorded as a zero result) in a year (nLOD), dividing by 2, and assigning the resultant value as the geometric mean (GM) of a lognormal distribution with a geometric standard deviation (GSD) of 1.52. While this approach provides a reasonable estimate when the missed doses approach the detection limits (NIOSH 2006), it is highly claimant favorable in most cases because missed doses are assigned based on the number of null badge readings regardless of the potential for exposure. In the most extreme examples, missed annual photon doses of 10 mSv (1 rem) or more are assigned in cases in which there was clearly little or no potential for exposure. In fact, external missed dose alone can result in a PC >50% (at the 99th percent confidence level) for some cancer types if the worker was employed for many years during the early phases of the weapons program. This also is true even for short periods of employment when multiple cancers are involved, notably multiple basal cell carcinomas, which occur relatively frequently and have relatively high PCs at the 99th percent confidence level due to highly uncertain risk factors (NCI 2003). As a result, the site badging and reporting practices for nonradiological workers play a key role in the compensation determination; such workers who were not badged typically are assigned ambient doses (see below), which may be very small, while those who happened to have been badged are assigned the full complement of potential missed dose regardless of exposure potential.

Missed electron doses are rarely assigned because it is more claimant favorable to assign missed doses to the skin, breast, testes or other relevant organs as photons, and because only a single missed dose is assigned for each dosimeter cycle in which a null reading existed (even if both the OW and shielded results were zero). Specific instructions on the assignment of missed shallow dose are provided in a TIB (ORAUT 2005c).

Neutron missed doses are addressed in much the same manner as those for photons, with two major exceptions. First, the presence of a reported null neutron dose in the records does not necessarily imply a potential for neutron exposure, and it sometimes does not even establish that the worker was monitored for neutrons (ORAUT 2005a). Second, neutron missed doses during the PIC and NTA eras are typically determined based on the calculated missed photon dose and the associated neutron-photon ratios. Since both of these parameters can be highly claimant favorable (i.e., the use of nLOD to calculate missed dose, and the use of neutron-photon ratios with large uncertainties), the reconstructed neutron doses under EEOICPA can be quite large in some cases (tens of rem, even for workers who likely received little or no actual neutron exposure).

Unmonitored external dose

Unmonitored dose differs from missed dose in that there is no evidence that the worker was monitored or that the dose was reported. There are two main categories of workers for whom monitoring was not provided or monitoring results were not documented. One category applies to those with a potential for radiation exposure (i.e., radiological workers); the other applies to those with no such potential (i.e., nonradiological workers). Unmonitored workers with no known or documented potential for exposure are typically assigned external ambient dose (see below). Unmonitored workers with a potential for exposure, on the other hand, are typically assigned external doses based on studies of doses received by monitored coworkers. The methodology for developing and assigning external coworker dose is established in a TIB (ORAUT 2005f), and site-specific information and data are provided in separate TIBs prepared for individual DOE sites.

A compilation of external coworker doses from site-specific TIBs, which include claimant-favorable adjustments for potential missed dose, is provided in Table 1. This table provides coworker doses for six major DOE sites. Datasets for the six sites were compiled using databases from the Comprehensive Epidemiological Data Resource and from individual site dosimetry record systems.

Other choices exist for assigning doses to unmonitored radiological workers. For example, if a worker was monitored for certain years but not others, and the job and likely exposures were similar across the entire employment period, then external doses for the unmonitored periods may be assigned using extrapolation and interpolation techniques. Also, in rare cases, more reliable data than coworker data may be available (e.g., survey data, or dose rate calculations based on source term information). Additionally, doses based on regulatory or administrative limits may be applied for clearly

Table 1. External coworker doses (cSv; 50th percentile/95th percentile) compiled for selected DOE sites.[a]

Year	X-10[b]	K-25[c]	Hanford[d]	Paducah[e]	SRS[f]	Portsmouth[g]
1944	0.915/2.810	—	1.300/2.176	—	—	—
1945	0.780/1.465	1.240/1.290	1.336/2.430	—	—	—
1946	0.780/1.373	0.805/1.455	1.448/2.125	—	—	—
1947	0.780/1.329	0.780/1.015	1.369/1.708	—	—	—
1948	0.780/1.290	0.780/1.264	1.334/1.541	—	—	—
1949	0.780/2.542	0.780/1.035	1.357/1.572	—	—	—
1950	0.780/1.604	0.780/0.841	1.357/1.721	—	—	—
1951	0.780/2.585	0.780/1.052	0.685/1.278	—	—	—
1952	0.780/3.750	0.780/0.951	0.721/1.541	—	1.117/1.599	—
1953	0.800/2.539	0.780/1.096	0.779/1.815	1.128/1.656	1.082/1.354	—
1954	0.780/2.206	0.780/0.913	0.720/1.863	1.183/2.218	1.062/1.192	0.780/1.736
1955	0.820/2.541	0.780/0.835	0.717/2.059	1.067/2.344	1.087/1.885	0.874/1.104
1956	0.470/2.161	0.780/0.855	0.682/2.306	1.073/2.712	1.138/2.188	0.799/0.945
1957	0.180/2.035	0.780/1.088	0.650/2.318	1.072/2.224	1.085/2.548	0.615/0.714
1958	0.320/1.610	0.780/1.049	0.321/2.599	1.040/2.019	0.658/1.704	0.574/0.857
1959	0.270/1.788	0.810/1.245	0.300/2.237	1.083/1.900	0.689/1.836	0.591/1.164
1960	0.110/1.304	0.791/1.154	0.311/2.756	0.672/1.544	0.781/2.724	0.195/0.283
1961	0.100/0.980	0.778/0.942	0.364/2.877	0.134/1.048	0.654/2.101	0.180/0.240
1962	0.110/1.020	0.780/0.824	0.452/3.018	0.080/1.024	0.654/1.943	0.180/0.332
1963	0.120/1.006	0.780/0.840	0.406/2.981	0.080/0.868	0.637/2.168	0.180/0.360
1964	0.090/0.904	0.780/0.841	0.505/3.018	0.080/0.519	0.711/2.769	0.120/0.262
1965	0.080/1.220	0.780/0.936	0.881/3.880	0.080/0.243	0.413/2.277	0.060/0.140
1966	0.080/1.230	0.780/0.952	0.524/2.690	0.080/0.225	0.412/2.168	0.060/0.136
1967	0.110/1.360	0.780/0.928	0.385/3.179	0.091/0.236	0.429/2.443	0.060/0.122
1968	0.100/1.302	0.780/0.906	0.436/2.801	0.080/0.411	0.409/2.337	0.060/0.338
1969	0.110/1.192	0.780/0.946	0.354/2.905	0.080/0.541	0.463/2.350	0.085/0.281
1970	0.100/1.029	0.780/1.041	0.323/3.159	0.080/0.349	0.427/2.306	0.158/0.459
1971	0.090/1.100	0.780/1.092	0.394/2.726	0.080/0.558	0.411/1.925	0.060/0.281
1972	0.100/1.386	0.779/1.034	0.293/2.339	0.080/0.451	0.213/1.615	0.078/0.367
1973	0.080/1.210	0.780/0.871	0.246/2.142	0.080/0.407	0.182/1.504	0.077/0.407
1974	0.060/0.750	0.835/1.065	0.283/2.099	0.080/0.217	0.151/1.378	0.060/0.337
1975	0.090/1.188	0.062/0.111	0.283/1.933	0.090/0.247	0.137/1.093	0.078/0.474
1976	0.060/1.121	0.060/0.149	0.226/1.667	0.062/0.233	0.136/0.955	0.060/0.415
1977	0.060/0.980	0.060/0.089	0.206/2.188	0.062/0.189	0.137/0.940	0.078/0.365
1978	0.100/1.021	0.052/0.136	0.214/1.252	0.089/0.193	0.132/0.913	0.077/0.414
1979	0.100/1.194	0.060/0.088	0.202/1.257	0.080/0.109	0.122/0.905	0.060/0.181
1980	0.080/1.269	0.060/0.145	0.203/0.968	0.080/0.200	0.127/0.838	0.060/0.307
1981	0.160/1.176	0.060/0.085	0.191/1.103	0.040/0.090	0.127/0.800	0.090/0.120
1982	0.180/1.030	0.060/0.060	0.191/1.432	0.040/0.053	0.132/0.791	0.090/0.112
1983	0.250/1.237	0.060/0.060	0.180/1.933	0.040/0.070	0.128/0.739	0.020/0.053
1984	0.175/0.949	0.060/0.060	0.191/1.643	0.040/0.156	0.068/0.623	0.020/0.053
1985	0.170/0.940	0.060/0.060	0.180/1.849	0.040/0.070	0.062/0.559	0.020/0.045
1986	—	—	0.180/1.985	0.040/0.130	0.051/0.440	0.020/0.058
1987	—	—	0.195/1.048	0.040/0.070	0.047/0.425	0.020/0.063
1988	—	—	0.180/0.236	0.040/0.055	0.041/0.431	0.020/0.057
1989	—	—	0.180/0.236	0.040/0.053	0.050/0.354	0.020/0.063
1990	—	—	—	0.040/0.040	0.053/0.304	0.022/0.075
1991	—	—	—	0.040/0.040	0.030/0.193	0.020/0.057
1992	—	—	—	0.040/0.040	0.030/0.191	0.020/0.054
1993	—	—	—	0.040/0.043	0.030/0.193	—
1994	—	—	—	0.040/0.040	0.030/0.187	—
1995	—	—	—	0.040/0.040	0.030/0.260	—
1996	—	—	—	0.040/0.060	0.030/0.196	—
1997	—	—	—	0.040/0.040	0.030/0.206	—
1998	—	—	—	—	0.030/0.227	—
1999	—	—	—	—	0.030/0.161	—

[a] Data include both measured and missed doses. Blanks in the table correspond to periods prior to site operations, or to periods when essentially all radiological workers were monitored and coworker data were not generally needed for dose reconstructions.
[b] ORAUT (2006b).
[c] ORAUT (2006c).
[d] ORAUT (2006d).
[e] ORAUT (2006e).
[f] ORAUT (2006f).
[g] ORAUT (2006g).

Table 2. Hierarchy of data sources for reconstruction of doses due to external radiation exposures (NIOSH 2006).

Hierarchy	Data source	Examples
1	Personal dosimeter	Film badge, TLD
2	Personal monitors	PIC
3	Coworker data	Film badge, TLD, PIC, etc.
4	Area monitoring	Workplace radiation surveys, ambient air room monitors, duration of exposure
5	Source term	Source strength, distance from source, duration of exposure, shielding information
6	Radiation control limits	Generally, workplace posting has been required when the dose rate exceeded 0.025 mSv h^{-1}

noncompensable cases to ensure that the dose has been overestimated, if it can be established by the dose reconstructor (based on job description, interview information, etc.) that the limits were not likely to have been exceeded. In all cases, the overall goal for assigning external dose to unmonitored workers is to provide reasonable and, when external exposures can not be unambiguously estimated, claimant-favorable estimates of reconstructed dose according to an established hierarchy (NIOSH 2006). This hierarchy is summarized in Table 2.

External ambient dose

External ambient dose, also cited in the IG as "environmental dose," is associated with radiation sources that are or were present at a site or facility but may or may not be directly related to the employees' work activities. Examples include exposures due to radionuclide emissions from stacks, from stored or buried waste, or from contaminated ground, facilities, or equipment. Such sources contribute to a general increase in dose rates when compared to natural background and affect both radiological and nonradiological workers. For nonradiological workers who were not monitored for radiation exposure, these doses, which are derived from site-specific environmental technical basis documents (TBDs), are included in the dose reconstruction. In cases that appear to be clearly noncompensable, site maxima (Table 3) often can be assigned without consideration of specific work locations; they may also be assigned for cases likely to be compensable when the work locations are uncertain or unknown.

In the case of monitored radiological workers, external ambient doses may be included if the site monitoring or recording practices resulted in elevated ambient doses being inadvertently excluded from the reported dose. At some sites, for example, control dosimeters were stored in areas of elevated background radiation (e.g., near entrances to radiological areas) and the control badges were used to represent the baseline or zero dose level.[‡‡]

Occupational x-ray dose

In accordance with regulations (U.S. DHHS 2002), doses from x-ray procedures performed for screening must be reconstructed. This typically includes annual (or other frequency) x-ray examinations that were required as part of a site's routine occupational medical program, and pre-employment and/or termination x-ray examinations. As stipulated, doses from x-ray procedures not performed for screening, such as those associated with job-related injuries, are not included.

Site profiles and a general TIB (ORAUT 2005b) provide default assumptions for use by dose reconstructors in the absence of detailed x-ray records. Included in these documents are organ-specific doses for various types of x-ray procedures. Experience shows that, in general, the doses from these sources decreased as time progressed and technology improved. Doses range from negligible in the case of organs not in the beam (e.g., the brain, testes, ovaries) to 10 mSv (1 rem) or more per procedure in the case of photofluorographic chest exams (employed at some sites prior to the 1970's) for organs and body locations in the torso region. The previously mentioned documents also provide information to dose reconstructors on how to proceed in cases in which there are (1) a lack of availability of the necessary records at some sites, (2) an inability to determine whether the procedures were performed for screening or other reasons, (3) uncertainties in calculating organ doses due to poorly documented procedures and equipment specifications, and (4) a need to calculate doses to organs or body locations (such as on the skin of the face or arm) where the proximity to the beam is variable based on the x-ray equipment and techniques employed. Additional details

[‡‡] Oak Ridge Associated Universities Team. Occupational on-site ambient dose reconstruction for DOE sites [internal procedure]. Cincinnati, OH: ORAUT; ORAUT-PROC-0060, Rev 01; 2006.

Table 3. Maximum external ambient doses (in cSv) for selected DOE sites.[a,b]

	Fernald	Hanford	INEL	K-25	LLNL	LANL	Mound	NTS	PADGDP	Pantex	PORGDP	RFP	ORNL (X-10)	Y-12
1944		0.252		0.130			2.500						0.473	0.315
1945		0.252		0.130			15.000						0.473	0.315
1946		0.159		0.130			15.000						0.473	0.315
1947		0.157		0.130			15.000						0.473	0.315
1948		0.150		0.130			15.000						0.980	0.315
1949		0.205		0.130			0.723						1.555	0.315
1950		0.072		0.130			0.640						0.270	0.315
1951	0.032	0.072		0.130			0.640			0.030			0.372	0.315
1952	0.032	0.125	0.159	0.130	0.130		0.640		0.260	0.030	0.946	0.315		
1953	0.032	0.082	0.159	0.130	0.130		0.640		0.260	0.030		0.073	0.710	0.315
1954	0.389	0.282	0.159	0.130	0.130		0.640		0.260	0.030	0.452	0.073	0.473	0.315
1955	0.389	0.345	0.159	0.130	0.130		0.356		0.260	0.030	0.452	0.073	0.406	0.315
1956	0.646	0.451	0.159	0.130	0.130		0.356		0.260	0.030	0.452	0.073	0.473	0.315
1957	0.646	0.350	0.159	0.130	0.130		0.356		0.260	0.030	0.452	0.073	0.372	0.315
1958	0.646	0.415	0.159	0.130	0.130		0.356		0.260	0.030	0.452	0.073	0.439	0.315
1959	0.646	0.225	0.159	0.130	0.130		0.356		0.260	0.030	0.452	0.073	0.642	0.315
1960	0.646	0.186	0.159	0.130	0.130		0.207		0.260	0.030	0.452	0.073	0.439	0.315
1961	0.646	0.186	0.159	0.130	0.130		0.207		0.260	0.030	0.452	0.073	0.338	0.315
1962	0.646	0.186	0.159	0.130	0.130		0.207		0.260	0.030	0.452	0.073	0.359	0.315
1963	0.646	0.153	0.159	0.130	0.130		0.207	0.123	0.260	0.030	0.452	0.073	0.351	0.315
1964	0.646	0.153	0.159	0.130	0.130		0.207	0.123	0.260	0.030	0.452	0.073	0.274	0.315
1965	0.646	0.153	0.159	0.130	0.130	0.126	0.127	0.123	0.260	0.030	0.452	0.073	0.243	0.315
1966	0.646	0.140	0.159	0.130	0.130	0.105	0.127	0.123	0.260	0.030	0.452	0.073	0.254	0.315
1967	0.646	0.163	0.159	0.130	0.130	0.090	0.127	0.123	0.260	0.030	0.452	0.073	0.241	0.315
1968	0.646	0.204	0.159	0.130	0.130	0.090	0.127	0.110	0.260	0.030	0.452	0.073	0.257	0.315
1969	0.646	0.163	0.159	0.130	0.130	0.090	0.127	0.123	0.260	0.030	0.452	0.073	0.283	0.315
1970	0.646	0.096	0.159	0.130	0.130	0.039	0.085	0.123	0.260	0.030	0.452	0.073	0.243	0.315
1971	0.291	0.040	0.159	0.130	0.117	0.082	0.085	0.123	0.260	0.030	0.452	0.073	0.237	0.315
1972	0.291	0.044	0.159	0.130	0.130	0.067	0.085	0.123	0.260	0.030	0.452	0.073	0.237	0.315
1973	0.291	0.048	0.144	0.130	0.130	0.102	0.085	0.123	0.260	0.030	0.452	0.073	0.237	0.315
1974	0.291	0.043	0.223	0.130	0.130	0.102	0.085	0.123	0.260	0.030	0.452	0.073	0.237	0.315
1975	0.291	0.040	0.127	0.130	0.130	0.113	0.061	0.123	0.260	0.015	0.452	0.073	0.237	0.315
1976	0.291	0.035	0.111	0.130	0.121	0.077	0.061	0.123	0.260	0.015	0.452	0.073	0.190	0.315
1977	0.227	0.035	0.113	0.130	0.130	0.081	0.061	0.123	0.260	0.015	0.452	0.073	0.142	0.315
1978	0.287	0.029	0.089	0.130	0.130	0.069	0.061	0.123	0.260	0.015	0.452	0.073	0.125	0.315
1979	0.000	0.029	0.084	0.130	0.125	0.075	0.061	0.074	0.260	0.015	0.452	0.073	0.112	0.315
1980	0.323	0.029	0.089	0.130	0.130	0.090	0.048	0.080	0.260	0.015	0.452	0.073	0.108	0.315
1981	0.500	0.038	0.091	0.130	0.130	0.052	0.048	0.084	0.260	0.015	0.452	0.073	0.098	0.315
1982	0.510	0.157	0.058	0.130	0.130	0.048	0.048	0.081	0.260	0.015	0.452	0.073	0.101	0.315
1983	0.521	0.127	0.062	0.130	0.130	0.056	0.048	0.079	0.260	0.015	0.452	0.073	0.098	0.315
1984	0.385	0.027	0.073	0.130	0.130	0.054	0.048	0.126	0.260	0.015	0.452	0.073	0.105	0.315
1985	0.406	0.025	0.073	0.130	0.104	0.056	0.041	0.134	0.260	0.015	0.452	0.073	0.101	0.315
1986	0.385	0.027	0.073	0.130	0.090	0.054	0.041	0.123	0.260	0.015	0.404	0.073	0.101	0.315
1987	0.100	0.027	0.073	0.130	0.092	0.049	0.041	0.095	0.260	0.015	0.452	0.073	0.101	0.315
1988	0.175	0.027	0.073	0.130	0.090	0.056	0.041	0.086	0.260	0.015	0.440	0.073	0.101	0.315
1989	0.202	0.030	0.073	0.130	0.130	0.044	0.041	0.084	0.260	0.015	0.435	0.073	0.101	0.315
1990	0.116	0.027	0.028	0.130	0.130	0.053	0.037	0.074	0.260	0.015	0.424	0.073	0.101	0.315
1991	0.128	0.035	0.028	0.130	0.101	0.053	0.037	0.075	0.260	0.015	0.441	0.073	0.101	0.315
1992	0.136	0.031	0.028	0.130	0.099	0.070	0.037	0.073	0.260	0.015	0.417	0.073	0.101	0.315
1993	0.149	0.030	0.027	0.130	0.096	0.044	0.037	0.082	0.260	0.015	0.254	0.073	0.101	0.315
1994	0.149	0.036	0.025	0.130	0.103	0.047	0.037	0.055	0.260	0.015	0.061	0.073	0.101	0.315
1995	0.137	0.026	0.032	0.130	0.087	0.112	0.037	0.082	0.260	0.015	0.152	0.073	0.101	0.315
1996	0.050	0.026	0.019		0.078	0.072	0.037	0.087	0.260	0.015	0.189	0.073	0.101	0.315
1997	0.051	0.026	0.016		0.083	0.137	0.037	0.066	0.260	0.015	0.222	0.073	0.101	0.315
1998	0.045	0.027	0.022		0.086	0.126	0.037	0.078	0.260	0.015	0.228	0.073	0.101	0.315
1999	0.045	0.029	0.017		0.082	0.072	0.037	0.074	0.260	0.015	0.222	0.073	0.101	0.315
2000	0.049	0.029	0.022		0.085	0.080	0.037	0.084	0.260	0.015	0.252	0.073	0.101	0.315
2001	0.049	0.029	0.011		0.130	0.169	0.037	0.115	0.260		0.254	0.073	0.101	0.315
2002	0.048	0.029	0.019			0.070	0.037				0.241	0.073	0.101	0.315
		0.029					0.037				0.241	0.073	0.101	

[a] Oak Ridge Associated Universities Team. Occupational on-site ambient dose reconstruction for DOE sites [internal procedure]. Cincinnati, OH: ORAUT; ORAUT-PROC-0060, Rev 01; 2006.

[b] For some sites (e.g., K-25 and Y-12), limited data were available to determine the maximum on-site ambient doses, so maximum values were calculated and applied to all years of site operation. For other sites, data were available for some, but not all years of operation; for the Mound site, for example, data were not available prior to 1950, so the maximum ambient doses prescribed were based on permissible levels.

are provided elsewhere in this issue (Shockley et al. 2008).

Conversion to organ dose

Because the NIOSH Interactive RadioEpidemiological Program (IREP) is designed to calculate cancer-specific PC values, doses must be estimated for specific organs depending on the cancer type and location (NIOSH 2006; ORAUT 2006a). Organ doses based on dosimeter measurements (including both measured and missed dose) are calculated using organ DCFs published in the IG. These factors were derived from ICRP Publication 74 (1996) for the photon and neutron energy ranges of interest. They are applied to the dosimeter reading or calculated missed dose in addition to any correction factors, quality factor adjustments (for neutrons), or other factors that may apply. DCFs essentially convert the personal dose equivalent as represented by the dosimeter reading to organ dose.

The appropriate organ DCF depends on the exposure geometry. Organ DCFs for four such geometries are provided in the IG. These are (1) anterior-posterior (AP), (2) posterior-anterior (PA), (3) rotational (ROT), and (4) isotropic (ISO). Since personal dosimeter badges were worn on the chest or torso in most cases, DCFs established in the IG are technically correct only for the AP geometry since the values derived from ICRP Publication 74 are based on the assumption that the dosimeter orientation was perpendicular to the radiation beam. In practice, however, a mixture of exposure geometries is more likely than a 100% AP geometry, and thus the dosimeters were not always incident to the radiation beam. An evaluation of the errors introduced by the assumption of 100% AP geometry indicated that this approach is, overall, claimant favorable when considering a reasonable distribution of exposure geometries (NIOSH 2006). Dose reconstructors are able to use a different approach if they find that the standard approach may underestimate the organ dose. In the most extreme case—a skin cancer on the back, a PA geometry, and the dosimeter worn on the front—the dosimeter result will significantly underestimate the skin dose at the location of interest, especially if significant electron doses were received. However, it is rare that an unusual exposure geometry, such as 100% PA, is known with certainty, and in such a situation it would be expected that the dosimeter would not have been worn on the chest.

Table 4. Cancer models and external dose organs for common cancer types (adapted from ORAUT 2006a).

Cancer type	ICD-9 code range	IREP cancer model	External dose organ
Lip	140	Oral cavity and pharynx	Skin
Tongue, mouth	141–145	Oral cavity and pharynx	Thyroid/remainder
Pharynx	146–148	Oral cavity and pharynx	Esophagus
Esophagus	150	Esophagus	Esophagus[a]
Stomach	151	Stomach	Stomach
Colon	153	Colon	Colon
Rectum	154	Rectum	Colon
Liver	155	Liver[b]	Liver[b]
Gallbladder	156	Gallbladder	Bladder
Pancreas	157	Pancreas	Stomach
Larynx	161	Other respiratory	Esophagus
Lung	162	Lung	Lung
Bone	170	Bone	Bone surface
Melanoma	172	Malignant melanoma	Skin
Non-melanoma skin	173	BCC or SCC[c]	Skin
Breast	174–175	Breast	Breast
Uterus, vagina	180–182, 184	Female genitalia less ovary	Uterus
Ovaries	183	Ovary	Ovaries
Prostate	185	All male genitalia	Bladder
Testes, penis	186–187	All male genitalia	Testes
Bladder	188	Bladder	Bladder
Kidney	189	Urinary organs less bladder	Liver
Eye	190	Eye	Eye lens
Brain, nervous system	191	Nervous system	Thyroid/remainder
Thyroid	193	Thyroid	Thyroid
Lymphoma	200–202	Lymphoma and multiple myeloma	Remainder[d]
Multiple myeloma	203	Lymphoma and multiple myeloma	Red bone marrow
Leukemia	204–208	Leukemia[e]	Red bone marrow

[a] Stomach in some cases.
[b] Gallbladder as IREP cancer model and bladder as external dose organ in some cases.
[c] Non-melanoma skin basal cell carcinoma (BCC) or non-melanoma skin squamous cell carcinoma (SCC) depending on diagnosis.
[d] Skin in some cases.
[e] Various cancer models depending on type of leukemia.

Table 5. Baseline assumptions used in the example organ dose calculation.

Parameter	Assumption
Employee gender	Male
Work location	SRS, 100 Area reactors
Year of exposure	1958
Cancer	Prostate (ICD-9 = 185)
External dose target organ[a]	Bladder
$H_p(10)$ correction factor[b]	1.119
Laboratory error[b]	25%
Limit of detection[b]	0.40 mSv (40 mrem)
Neutron to photon ratio[b]	Lognormal: GM = 0.18, GSD = 2.52, 95th percentile = 0.82
Best-estimate x-ray dose to bladder[c]	Normal: Mean = 0.018 mSv, SD = 0.005 mSv
Claimant-favorable external ambient dose to bladder[d]	0.150 mSv

[a] ORAUT 2006a.
[b] ORAUT 2005e.
[c] One annual x-ray procedure assumed. Oak Ridge Associated Universities Team. Occupational x-ray dose reconstruction for DOE sites [internal procedure]. Cincinnati, OH: ORAUT; ORAUT-PROC-0061, Rev 01; 2006.
[d] Maximum external ambient dose is included even though employee was monitored. Oak Ridge Associated Universities Team. Occupational on-site ambient dose reconstruction for DOE sites [internal procedure]. Cincinnati, OH: ORAUT; ORAUT-PROC-0060, Rev 01; 2006.

DCFs provided in ICRP Publication 74, and hence in the IG, represent a limited set of organs. Thus, in some cases, surrogate organs are used based on proximity. Table 4 provides general information on the appropriate external organ based on the cancer type and International Classification of Diseases (ICD) code range. More detailed information on this subject is provided in a TIB (ORAUT 2006a).

There are certain instances for which software programs are used to evaluate organ dose in lieu of the standard DCFs. For example, the Varskin code (Durham 2006) may be used to calculate skin doses from localized contamination, or the Attila Radiation Transport Software (Transpire 2005), Monte Carlo N-Particle (LANL 2003), or Microshield (Grove Software 2005) codes may be used to calculate organ doses or correction factors for unique exposure geometries.

Uncertainty

As described elsewhere in this issue (Merwin et al. 2008), for purposes of the described assessments, the median PC is calculated at the 99th percent confidence level. In other words, if the PC is 50% or more at the 99th percent confidence level (as determined by DOL), the claimant is awarded compensation. The PC calculation takes into account not only the uncertainty in the radiation risk factors, but also the uncertainty in dose. For example, if a dose of 10 mSv (1 rem) is assigned as a "best estimate," the dose may be assigned as the mean of a normal distribution (with a defined standard deviation), the geometric mean of a lognormal distribution (with a defined GSD), the mode of a triangular distribution (with defined minimum and maximum values), or some other distribution. Constant distributions also are used, but these typically involve a claimant-favorable uncertainty factor designed to ensure that the dose has been overestimated and are used only for likely noncompensable cases.

As described in various procedures,[§,‡‡,§§] external ambient and occupational x-ray doses are usually assigned as normal distributions, and the application of the dose distributions is usually straightforward. Accounting for the uncertainty associated with measured and missed dose, however, is complex, because dosimeter measurements have an associated uncertainty as do the organ DCFs (which are presented with minima, modes, and maxima in the IG). To account for both sources of uncertainty, Monte Carlo methods are employed (ORAUT 2005d) in accordance with the IG to derive the organ dose and overall uncertainty distribution using Crystal Ball software (Decisioneering 2001).

Example of external dose reconstruction process

The following example illustrates the calculation of organ dose due to exposure to external radiation using the methods and assumptions discussed above. It demonstrates the calculation of a claimant-favorable estimate of organ dose. This approach is used to overestimate dose efficiently in cases in which the PC is likely to be significantly less than 50% (due to factors including short work history, low lifetime dose, nonradiogenic cancer, and short time between exposure and cancer diagnosis).

The baseline assumptions for this example are shown in Tables 5–7. The scenario involves a hypothetical worker who was employed at the Savannah River Site (SRS) 100 Area reactors during the 1950's. The dose

[§§] Oak Ridge Associated Universities Team. Occupational x-ray dose reconstruction for DOE sites [internal procedure]. Cincinnati, OH: ORAUT; ORAUT-PROC-0061, Rev 01; 2006.

Table 6. Radiation type fractions for SRS 100 Area reactors (ORAUT 2005e).

Radiation type and energy	Fraction of dose
Photons, 30–250 keV	0.5
Photons, >250 keV	0.5
Neutrons, 10–100 keV	0.28[a]
Neutrons, 0.1–2 MeV	1.62[a]

[a] Fraction includes applicable ICRP 60 (1991) weighting factor.

Table 7. $H_p(10)$, AP geometry dose conversion factors for bladder (NIOSH 2006).

Radiation type and energy	Min	Mode	Max
Photons, 30–250 keV	0.426	0.873	0.929
Photons, >250 keV	0.876	0.913	0.929
Neutrons, 10–100 keV	0.798	1.268	2.243
Neutrons, 0.1–2 MeV	0.626	0.796	1.012

reconstructed for the year 1958 is presented based on a reported photon dose of 2.4 mSv (240 mrem), with a positive (above LOD) dose reported in 3 of 26 biweekly measurements.

In this scenario, the calculation of claimant-favorable organ dose due to external radiation sources is comprised of the following quantities:

- Measured photon dose;
- Missed photon dose;
- Unmonitored neutron dose;
- Occupational ambient dose; and
- Occupational x-ray dose.

Organ dose is determined from the measured photon dose by calculating the product of the first five factors listed in Table 8; this quantity is entered into IREP as a constant value. When using this approach, the DCF (Table 7) is rounded up to 1 as a claimant-favorable measure.[§] The resulting dose in this case is the same for 30–250 keV photons and >250 keV photons because (1) the dose fraction is divided evenly between these two ranges, and (2) the organ DCF is rounded up to 1 in both cases.

Table 8. Claimant-favorable measured photon dose calculation.

Parameter descriptions	Parameter value
Measured dose reported	2.40 mSv
$H_p(10)$ correction factor	1.119
Laboratory error	1.25
Organ DCF	1
Fraction of photons, 30–250 keV	0.5
Reconstructed measured photon dose, 30–250 keV	1.68 mSv
Fraction of photons, >250 keV	0.5
Reconstructed measured photon dose, >250 keV	1.68 mSv
Total reconstructed bladder dose	3.36 mSv

Table 9. Claimant-favorable missed photon dose calculation.

Parameter description	Parameter value
Number of zero readings (n)	23
LOD/2	0.20 mSv
Organ DCF	1
Fraction of photons, 30–250 keV	0.5
Reconstructed missed photon dose, 30–250 keV	2.30 mSv
Fraction of photons, >250 keV	0.5
Reconstructed missed photon dose, >250 keV	2.30 mSv
Total missed photon dose to bladder	4.60 mSv

Table 10. Claimant-favorable unmonitored neutron dose calculation based on measured photon dose.

Factor description	Factor value
Measured photon dose reported by SRS	2.40 mSv
$H_p(10)$ correction factor	1.119
Laboratory error	1.25
Neutron to photon ratio (95th percentile value)	0.82
Organ DCF for 10–100 keV neutrons	1.268
Fraction of neutron dose 10–100 keV (w/ICRP 60 factor[a])	0.28
Unmonitored neutron dose (10–100 keV)	0.98 mSv
Organ DCF for 0.1–2 MeV neutrons	1
Fraction of neutron dose 0.1–2 MeV (w/ICRP 60 factor[a])	1.62
Unmonitored neutron dose (0.1–2 MeV)	4.46 mSv
Total unmonitored neutron dose based on measured photon dose	5.44 mSv

[a] ICRP (1991).

Missed photon dose is determined for the 23 null biweekly dosimeter readings by calculating the product of the first four factors shown in Table 9. As described previously, the calculated missed dose based on LOD/2 is considered the GM of a lognormal distribution, with the missed dose based on LOD considered the 95th percentile.

Because NTA film technology used to measure neutron dose was inadequate, unmonitored neutron dose for that era is calculated using a neutron-to-photon ratio based on paired gamma and neutron dosimeter results (ORAUT 2005e). This ratio is applied to both measured and missed photon dose as shown in Tables 10 and 11,

Table 11. Claimant-favorable unmonitored neutron dose calculation based on missed photon dose.

Factor description	Factor value
Maximum number of zero readings (n)	23
LOD/2	0.20 mSv
Neutron to photon ratio (95th percentile value)	0.82
Organ DCF for 10–100 keV neutrons	1.268
Fraction of neutron dose 10–100 keV (w/ICRP 60 factor[a])	0.28
Unmonitored neutron dose (10–100 keV)	1.34 mSv
Organ DCF for 0.1–2 MeV neutrons	1
Fraction of neutron dose 0.1–2 MeV (w/ICRP 60 factor[a])	1.62
Unmonitored neutron dose (0.1–2 MeV)	6.11 mSv
Total unmonitored neutron dose based on missed photon dose	7.45 mSv

[a] ICRP (1991).

Table 12. IREP input table of external dose estimate components.

Exposure #	Exposure year	Exposure rate[a]	Radiation type	Dose distribution type	IREP param. 1	IREP param. 2	Comment
1	1958	Acute	Photons E = 30–250 keV	constant	0.168	0.000	Dosimeter dose
2	1958	Acute	Photons E > 250 keV	constant	0.168	0.000	Dosimeter dose
3	1958	Chronic	Neutrons E = 10–100 keV	constant	0.098	0.000	Unmonitored neutron dose
4	1958	Chronic	Neutrons E = 100 keV–2 MeV	constant	0.446	0.000	Unmonitored neutron dose
5	1958	Acute	Photons E = 30–250 keV	lognormal	0.230	1.520	Missed photon dose
6	1958	Acute	Photons E > 250 keV	lognormal	0.230	1.520	Missed photon dose
7	1958	Chronic	Neutrons E = 10–100 keV	lognormal	0.134	1.520	Missed neutron dose
8	1958	Chronic	Neutrons E = 100 keV–2 MeV	lognormal	0.611	1.520	Missed neutron dose
9	1958	Chronic	Photons E = 30–250 keV	constant	0.150	0.000	Ambient external dose
10	1958	Acute	Photons E = 30–250 keV	normal	0.018	0.005	Occupational x-ray dose

[a] Exposure rates are designated in the IG (NIOSH 2006) for each type of external exposure (e.g., measured and missed photon doses are acute, measured and missed neutron doses are chronic, occupational x-ray doses are acute, and ambient doses are chronic).

respectively, and the calculation is made even in cases in which no neutron dose is reported, provided that there was a potential for neutron exposure as determined from the worker's job location and activities.

External ambient and occupational x-ray doses are determined according to procedural instructions[‡‡,§§] and supporting information in the relevant site profile and worker records. In this particular example, it has been assumed that the dose reconstructor has applied a best estimate of the occupational x-ray dose, but a maximum potential external ambient dose. Such an approach may be adopted, for example, for a case that is likely to be noncompensable and the worker records are insufficient to support a best estimate of the ambient dose without a detailed investigation. If the calculated PC were to be 50% or greater in this example, the dose reconstructor would need to (1) perform the additional analysis required to determine a less claimant-favorable estimate and demonstrate that the PC is less than 50%, or (2) indicate why it is not possible to refine the estimates based on the available data, in which case the claim can be submitted as compensable even with dose estimates that are likely to be greater than the doses actually received.

The external dose components discussed above are shown in Table 12; this represents the "final entry" of organ dose estimates due to external radiation into IREP used to calculate PC. In this example, the external dose assigned was 23 mSv (2.3 rem) compared to 2.4 mSv (240 mrem) in the worker's dose of record.

CONCLUSION

A variety of external doses are reconstructed under Part B of EEOICPA, each involving different assumptions in terms of exposure geometry, radiation energy, uncertainty, and other parameters. External doses are reconstructed based on dosimetry and other information that represent imperfect knowledge of the external radiation doses actually received by workers. Additional uncertainties include the distribution of dose in terms of radiation type and energy—information that is necessary to calculate PC. Despite numerous challenges, the claimant-favorable procedures developed for this program ensure that, for each claimant, the overall external dose will have been overestimated; the only exceptions are clearly compensable claims for which some sources of exposure may be intentionally excluded when the 99th percentile PC is already >50%, thereby expediting the completion of the claims. In some cases, doses of 0.5 Sv (50 rem) or more (including missed dose, unmonitored dose, and x-ray dose) may be assigned even though there is little or no dose in the record. Overestimations exist even for so-called "best estimate" dose reconstructions because of the numerous claimant-favorable assumptions inherent in the data development, dose reconstruction, and peer review processes. A subsequent paper (Merwin et al. 2008) discusses the implications of the claimant favorability inherent in the program in terms of the compensation rate and other factors.

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