Paper

IMPLICATIONS OF CLAIMANT-FAVORABLE APPROACHES USED IN DOSE AND PROBABILITY OF CAUSATION CALCULATIONS UNDER EEOICPA

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Abstract—**There are many claimant-favorable factors inherent in both the reconstruction of radiation dose and the calculation of probability of causation under Part B of the Energy Employees Occupational Illness Compensation Program Act of 2000. These factors result in an approximate 30% compensation rate for claims filed under EEOICPA, which is roughly an order of magnitude greater than the likely incidence of increased cancers as predicted by epidemiology studies and risk models. Additionally, there is essentially no chance that a claim that is denied compensation actually involves a radiation-induced cancer. The claimant-favorable nature of the Part B program is often misunderstood or ignored when the merits of the program are reported and debated. This paper provides details on how the technical aspects of the EEOICPA program that favor the claimants are being implemented.**

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INTRODUCTION

The Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) established a program to provide "adequate compensation of covered employees and . . . survivors . . . suffering from illnesses incurred . . . in the performance of duty . . ." (U.S. Congress 2000). In establishing EEOICPA, it was clear to the U.S. Congress that there is difficulty determining whether a worker's illness could be attributed to radiation doses received in the performance of duty. Accordingly, certain claimant-favorable assumptions and methodologies have been implemented to ensure that workers who incurred cancer from ionizing radiation exposure are identified. One consequence of this goal is the compensation, in many cases, of workers (or their survivors) whose illnesses would not have been considered to be caused by workplace radiation if standard assumptions and methodologies had been utilized.

Perhaps the most significant claimant-favorable aspect of the program is the manner by which the probability of causation (PC) is required by EEOICPA to be evaluated in determining compensation. Recognizing the uncertainties involved in the dose reconstruction and PC calculation process, Congress established the 99th percentile (as opposed to the median or some other determination of a best-estimate value) of the PC as the criterion to help ensure that a claimant is not wrongly denied compensation (U.S. Congress 2000). In short, if the 99th percentile of the distribution of possible PCs is $\geq$50%, the case qualifies for compensation. This approach renders it extremely unlikely that an individual could have developed a covered cancer from occupational exposure to radiation and not be compensated under the program. It also, by definition, results in compensation for people whose cancers would be considered unrelated to radiation exposure when using a best-estimate PC value.‡ By contrast, in many radiation litigation cases, the "more likely than not" standard is applied, and is taken to mean that if the best estimate of the PC (also known as the assigned share) exceeds 50%, a causal relationship is established (Jose et al. 2001). A 99th-percentile PC criterion, on the other hand, assigns causation even if the best estimate of the PC is $<$50%. The adoption of this approach to account for uncertainty in the dose and PC calculations seems to reflect Congress's discomfort with the government's previous practice of routinely opposing

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‡ While this may be understood by health physicists and other scientists, it may not be clear to members of the media, public, or legislators, as indicated by statements such as "Radiation victims have been denied compensation. . . ," which occur frequently in media reports.

Table 1. PC calculated by IREP for common cancer models.

IREP cancer model	Dose required to achieve a PC of 50% at the 99th percentile [rem (mSv)][a]	Associated PC at the 50th percentile[b]	Lognormally distributed dose required to achieve a PC of 50% at the 99th percentile [rem (mSv)][c]	Associated PC at the 50th percentile[b]
All male genitalia[d]	44.8 (448)	8.1%	23.2 (232)	6.5%
Bladder	32.7 (327)	15.5%	15.5% (155)	12.6%
Breast[e]	28.1 (281)	15.5%	12.6 (126)	11.7%
Colon	26.1 (261)	15.5%	12.1 (121)	12.7%
Leukemia (excluding CLL)	11.4 (114)	21.9%	3.8 (38)	13.2%
Liver	8.3 (83)	10.7%	3.7 (37)	8.7%
Lung[f]	16.0 (160)	11.8%	7.5 (75)	10.7%
Lymphoma and multiple myeloma	48.1 (481)	7.9%	24.0 (240)	6.0%
Skin (basal cell carcinoma)[g]	27.9 (279)	7.7%	12.0 (120)	5.6%
Stomach	20.9 (209)	6.0%	10.4 (104)	5.7%
Thyroid	13.3 (133)	7.2%	5.4 (54)	5.1%

[a] This is the dose that would qualify for compensation for a male (except for breast cancer), born in 1936, with a cancer diagnosed in 2000. The dose was assumed to be constant (i.e., no uncertainty) and arising from acute exposures to 30–250 keV photons distributed equally over ten years from 1970–1979. The dose shown is the total over the 10-y period.
[b] This is the median or "best estimate" PC calculated under the same assumptions and for the same compensable dose as in the previous column.
[c] For this comparison, the applied dose is not considered a constant as in the previous two columns, but rather as a lognormal distribution defined by a geometric mean (GM), with a geometric standard deviation (GSD) of 3.
[d] This model is applied for cancer of the prostate, among others.
[e] Female.
[f] For smoking category of "never smoked."
[g] For ethnicity category of "white non-Hispanic."

occupational illness claims based on radiological or toxic exposures.[§]

As described in detail elsewhere in this issue (Kocher et al. 2008), PC calculations are performed under Part B using the National Institute for Occupational Safety and Health (NIOSH) Interactive RadioEpidemiological Program (IREP) computer code.** As shown by Toohey (2008), the differences between the 50th and 99th percentile PCs calculated by IREP can be significant, and are attributable to uncertainties in both the dose estimates and the risk of cancer induction associated with the assigned radiation types, energies, and exposure rates.

Table 1 indicates the significance of the uncertainties in risk and radiation effectiveness by showing the doses required to achieve 99th percentile PCs of 50% (i.e., the Part B compensation criterion) for various cancers, and the 50th percentile PCs for the same doses. The table also demonstrates the additional impact of the uncertainty associated with dose estimates. Cases with 50th percentile PC values of less than ten percent can exceed the compensation criterion when evaluated at the 99th percentile. This occurs for cancers with generally low median PC values but having considerable uncertainties in the risk estimates; examples include prostate and stomach cancer, and basal cell carcinoma of the skin. Additionally, assigning a dose in IREP with an uncertainty distribution, rather than as a constant value, results in an even lower dose required to achieve compensability because the upper end of the dose distribution has a significant influence on the calculations at the 99th percentile PC.

As is described subsequently in this paper, implementation of the Part B program involves numerous claimant-favorable assumptions, methodologies, and parameters. These are present in certain risk estimates inherent in the IREP program: the PC calculation process, notably the treatment of multiple cancers; and the dose reconstruction process. Collectively, they make the final PC calculation, even at the 50th percentile, an overestimate in most cases, including essentially all of the cases deemed noncompensable. Their overall effect is apparent when noting the compensation rates under the Part B program by cancer type (Table 2). In the case of U.S. Department of Energy (DOE) workers, these rates are substantially higher than the actual percentage of cancers that are radiation induced [predicted to be a percent or two at most (Jose et al. 2001)]. For example, approximately 30% of cases at the Hanford Site have exceeded the compensation criterion, and yet a comprehensive epidemiology study of tens of thousands of exposed workers at that site showed little or no increase

[§] As stated in section 7384, paragraph 4, of the EEOICPA statute (U.S. Congress 2000), "The policy of the Department of Energy has been to litigate occupational illness claims, which has deterred workers from filing workers' compensation claims and has imposed major financial burdens for such employees who have sought compensation. Contractors of the Department have been held harmless and the employees have been denied workers' compensation coverage for occupational disease."

** Hereafter referred to as IREP for brevity. Version 5.5.1 of the code was used for the calculations presented in this paper; subsequent versions could yield different results.

Table 2. Compensation results by NIOSH-IREP cancer model.[a]

NIOSH-IREP cancer model	ICD-9 code(s)	Number of cases processed[b]	Compensation rate (%)[c]
Lung	162	2,200	70.1
Chronic myeloid leukemia	205.1	45	64.4
Acute lymphocytic leukemia	204.0	47	61.7
Non-melanoma skin-basal cell	173	593	57.8
Acute myeloid leukemia	205.0	80	51.3
Liver	155.0	72	48.6
Leukemia (excl. CLL)	204–208 (excl. 204.1)	58	46.6
Malignant melanoma	172	243	38.3
Other respiratory	160, 161, 163–165	267	34.1
Lymphoma & multiple myeloma	200–203	576	23.8
Bone	170	85	23.5
Thyroid	193	103	23.3
Gallbladder	155.1, 156	40	22.5
Oral cavity and pharynx	140–149	186	22.0
Eye	190	24	16.7
Other endocrine glands	194	7	14.3
Stomach	151	219	14.2
Urinary organs (excl. bladder)	189	226	8.9
Colon	153	573	8.4
Other and ill-defined sites	195	13	7.7
Bladder	188	307	7.2
All digestive	150–159	44	4.6
Esophagus	150	73	4.1
All male genitalia	185–187	1,871	2.7
Breast	174–175	396	2.3
Connective tissue	171	66	1.5
Rectum	154	248	1.2
Non-melanoma skin-squamous cell	173	182	1.1
Pancreas	157	282	1.1
Nervous system	191–192	200	0.5
Female genitalia (excl. ovary)	179–182, 184	110	0.0
Ovary	183	57	0.0
Total[d]		9,493	28.0

[a] Based on DOL compensation decision notices received by NIOSH through 19 September 2007 for 12,391 cases.
[b] Includes only those cases with a single primary cancer listed.
[c] Rates may not be predictive of future results, may be skewed by the dose reconstruction efficiency process, and in some cases are based on a small number of cases.
[d] Compensation decisions were rendered for an additional 2,898 cases having multiple primary cancers; the compensation rate for these cases was 43.7%, bringing the overall compensation rate to 31.7%.

(and potentially a decrease) in the number of observed, vs. expected, cancers (Gilbert et al. 1993). Even when considering the possibility that the Hanford claims are biased toward those with higher doses and a higher likelihood of compensation, this high percentage of favorable compensation decisions demonstrates that the intent of providing compensation more broadly than traditionally has been the case is being accomplished.

CLAIMANT FAVORABILITY INHERENT IN IREP RISK MODELS

As discussed elsewhere in this issue (Kocher et al. 2008), IREP calculates the PC using a Monte Carlo approach for evaluating the uncertainty distributions associated with both cancer risk and dose estimates. In addition to the modeled uncertainty distributions, IREP contains inherently claimant-favorable assumptions and default parameters in certain instances. One such example, which is described in detail by Kocher et al. (2008), is the use of two lung cancer models and the selection of the model yielding the highest 99th-percentile PC; this approach is consistent with the policy to give the benefit of the doubt to the claimants when two or more plausible alternatives exist. As another example, for skin melanomas, which are relatively uncommon compared to basal and squamous cell carcinomas, the PC is likely to be overestimated because the IREP code developers defaulted to the most claimant-favorable (basal cell carcinoma) model for the skin, citing insufficient data otherwise (NIOSH 2002).

An additional factor associated with IREP is the assignment of probability distributions for certain parameters and the importance of the low probability values when calculating the upper 99% credibility limit of the PC. For example, a dose and dose rate effectiveness factor (DDREF) of less than 1 is assigned a finite probability based largely on subjective judgment (Kocher et al. 2008). As another example, in the case of

Table 3. PC calculated by IREP for lung cancer and various radiation types.[a]

Radiation type	PC at 50th percentile	PC at 99th percentile
Photons (>250 keV)	3.69%	17.72%
Photons (30–250 keV)	6.96%	37.59%
Alpha	3.28%	33.96%

[a] Standard assumption is a nonsmoking male, born in 1936, cancer diagnosed in 2000, who received a dose of 1 rem per year (10 mSv y^{-1}) from 1970–1979.

solid tumors, IREP includes a radiation effectiveness factor (REF) for alpha particles that is represented by a lognormal distribution having a value of 80 at the 97.5 percentile. Similarly, electrons and >250 keV photons are assigned a REF of 1, while 30–250 keV photons and tritium (electrons >15 keV) are assigned a REF of 5 at the upper end of the distribution. Examples of calculated PCs for lung cancer for various radiation types are presented in Table 3. These factors contribute significantly to the calculated PC used for compensation decisions, even though they are highly improbable.

The overall effect of such factors can be substantial when considering the fact that, in many cases, the doses used in the IREP calculations have already been substantially overestimated. For example, lung cancer claims under Part B have very high compensation rates (Table 2), and this is largely attributable to a combined effect of the assigned missed internal doses and the inherent claimant favorability of the relevant IREP risk models and parameters, particularly when they are used to establish a PC at the 99th percentile. The overall impact of these factors is that other causal factors, like cigarette smoking, are ultimately less important than they might have been under traditional compensation decisions, even though an adjustment for cigarette smoking history is incorporated into the IREP model (Fig. 1). The claimant favorability of the dose reconstruction process is covered later in this paper.

CLAIMANT FAVORABILITY INHERENT IN THE PC CALCULATION PROCESS

Whereas the calculation of PC for a single cancer with a single risk model is relatively straightforward, the calculation becomes more complex when multiple cancers and/or risk models are involved. In general, these situations are addressed in a claimant-favorable manner.

Multiple cancers

Under EEOICPA and associated rules [Title 42 CFR Parts 81 (U.S. DHHS 2002a) and 82 (U.S. DHHS 2002b)], multiple cancers determined by the U.S. Department of Labor (DOL) to be "primary" cancers are evaluated independently, and the compensation criterion is the probability (at the 99th percent credibility limit) that at least one of the cancers was caused by radiation. For example, if two primary cancers were identified, one with a PC of 30% and one with a PC of 40%, the combined PC would be 58% and the claim would qualify for compensation.[††] This is true even when it is possible that the multiple "primary" cancers may not truly be independent. As an extreme example, cases with dozens of skin lesions have been treated as multiple, independent primary cancers; cases with more than 100 such cancers for a single claimant have been submitted. Although all such cancers may not actually be independent, a criterion for identifying dependencies among malignancies has not been established. Consequently, the diagnosed cancers are treated as independent under Part B, and such cases often qualify for compensation even at low dose levels. This is especially true for cases involving multiple basal cell carcinomas; in some cases dozens of such carcinomas have been diagnosed.

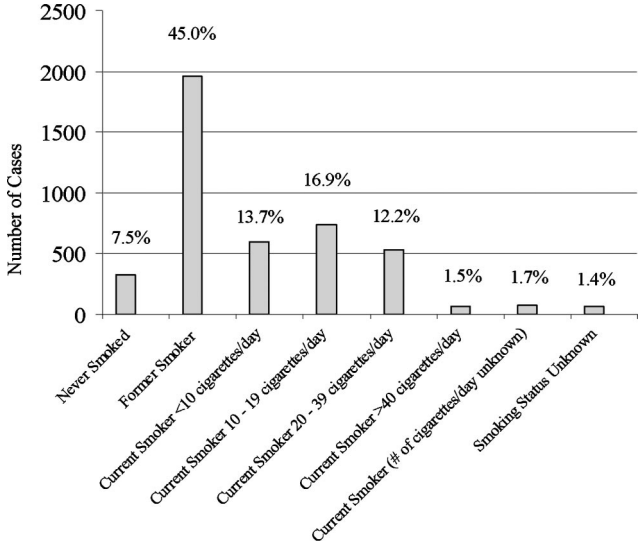

Fig. 1. Smoking history for cancer cases under the NIOSH dose reconstruction program (through 29 August 2007).

Secondary cancer diagnosis and identification of primary cancers

Dose reconstructions are performed for primary cancers. However, the diagnoses in some EEOICPA cases identify only secondary cancers with no known primary cancer. In these instances, doses are reconstructed for all the likely primary cancers associated with the identified secondary cancer [as listed in Title 42 CFR Part 81 (U.S. DHHS 2002a)], and the primary cancer

[††] Calculated as unity minus the probability that neither cancer was caused by radiation exposure, i.e., $[1 - (1 - 0.4) \times (1 - 0.3)]$.

providing the highest PC is used. When multiple secondary cancers are listed, each secondary cancer is treated as originating from a different primary cancer, and the approach for calculating the PC from multiple primary cancers is followed. For example, a case with two cancers diagnosed as "secondary—bladder" and "secondary—liver" could be treated as a case with two primary lung cancers (because lung cancer often results in the highest calculated PC), even if there is no evidence of lung cancer in the worker's medical records.

Multiple risk models

Inherent in the process of calculating PC is the assessment of certain cancers (e.g., various types of leukemia, certain skin cancers, and several others) for which more than one IREP model may apply. In these instances, IREP is used to evaluate each cancer model and the one resulting in the highest PC is adopted.

CLAIMANT FAVORABILITY INHERENT IN THE DOSE RECONSTRUCTION PROCESS

In addition to the claimant favorability associated with the PC calculation process, claimant-favorable assumptions and approaches are used throughout the dose reconstruction process. Much of this favorability is attributable to the requirements of Title 42 CFR Part 82 (U.S. DHHS 2002b) and, more importantly, the manner in which this rule has been implemented. For example, although the rule states that "reasonable, fair and scientifically based assumptions may be used as substitutes for additional research and analysis to provide an efficient dose reconstruction process," it goes on to state that this means applying certain assumptions that "err on the side of overestimating exposures." The rule further interprets the term "reasonable" as "the application of science-based, logical assumptions to supplement or interpret the factual basis," while it states further that "NIOSH will give the benefit of the doubt to claimants when there is uncertainty or unknowns concerning radiation exposures." Additional claimant-favorable language is provided in paragraph 82.2(a) of the rule which states: *"If radiation exposures in the workplace environment cannot be fully characterized based on available data, default values based on reasonable and scientific assumptions may be used as substitutes . . . this practice may include use of assumptions that represent the worst case conditions* [*emphasis added*]. *For example, if the solubility classification of an inhaled material can not be determined, the dose reconstruction would use the classification that results in the largest dose . . . possible given existing knowledge of the material and process."*

The requirements of Title 42 CFR Part 82 (U.S. DHHS 2002b) have generally been implemented by NIOSH in a way that treats individual methods, assumptions, and parameters in a claimant-favorable manner. Consequently, guidance documents relied upon for dose reconstructions [e.g., site profiles and technical information bulletins (Kenoyer et al. 2008)] and the individual dose reconstruction calculations sometimes default to claimant-favorable or maximizing assumptions unless there is substantial evidence to the contrary. The implications of this approach are significant because of the numerous claimant-favorable assumptions that may be incorporated into a single dose reconstruction. These are exemplified by the following discussions of the two general types of doses (external and internal) that are reconstructed.

External dose

The extent of claimant favorability in the reconstructed external dose depends, to a great extent, on the approach taken by the health physicist. External doses reconstructed for cases with PCs well below 50% are likely to significantly overstate the actual doses received, because the cases were processed in an efficient manner with a less refined estimate. Cases with PCs >50%, on the other hand, may understate the external doses received because Title 42 CFR Part 82 (U.S. DHHS 2002b) permits partial dose reconstructions for compensable cases to expedite the case processing. Cases with PCs near 50% require the most time to process because emphasis is placed on accuracy and precision of the external dose estimate and PC calculation, even at the expense of processing efficiency. This is done to ensure that the compensation decision is correct based on the totality of information available; however, the external dose estimates and associated PCs are likely to be inherently claimant favorable, even for these cases. In the following subsections, the major claimant favorabilities associated with the five main components of reconstructed external doses (Merwin et al. 2008) are described.

Measured external dose. In general, measured external doses greater than the limit of detection (LOD) of the monitoring device represent a reasonable assessment of the doses received by workers, especially in the more recent years of site operations. Furthermore, the translation of these doses to organ dose, while somewhat uncertain due to variable exposure geometries, also is reasonable in most circumstances and does not require the incorporation of claimant-favorable approaches (Merwin et al. 2008). There are, however, several notable exceptions.

One such exception is neutron doses received during the early years (generally in the 1940's and 1950's) at

DOE and predecessor sites, when neutron monitoring was not performed consistently across the sites for all situations in which significant neutron doses were possible, and when the monitoring devices used did not always measure doses accurately across the neutron energy spectrum. To account for these issues, neutron doses have been reconstructed for these years using neutron-photon ratios in a claimant-favorable manner, since maximizing ratios often are used in the absence of known information regarding areas in which an employee worked and the processes in which the employee was involved. Even in cases in which neutron doses were not monitored but there was at least some potential that the employee encountered neutrons in the workplace, unmonitored neutron doses may be assigned for the entire work period. This can be highly claimant favorable.

Another exception involves the assignment of measured doses to specific photon energy ranges. As described elsewhere in this issue (Merwin et al. 2008), external photon doses must be divided into energy ranges in order to be accommodated by the IREP code. The assigned energy range has a significant impact on the calculated risk (e.g., the risk associated with a unit dose in the 30–250 keV range is considered to be several times greater than the risk associated with the same dose in the >250 keV range). Considering that an employee's work locations are often not known with certainty, in these situations the dose reconstructor defaults to the most reasonably plausible claimant-favorable assumption (e.g., that the measured external dose is associated entirely with 30–250 keV photons). In some circumstances, consistent with Title 42 CFR Part 82 (U.S. DHHS 2002b) guidelines, the analysts who prepared the site profile documents followed the same approach for the site as a whole.

Missed external dose. As described elsewhere in this issue (Merwin et al. 2008), external missed doses are calculated based on an approach termed "LOD/2." In applying this approach, each null dosimeter result (or reported result less than half of the LOD) is treated as if the actual measurement were one-half of the LOD, and the LOD/2 value is treated as the geometric mean of a lognormal distribution with the LOD representing the 95th percentile. This approach provides a generally accurate assessment of missed dose for workers exposed routinely at levels near the dosimeter LOD, but it is extremely claimant favorable in many cases when this is not the situation. Since the information available does not provide for a confident decision about whether or not workers were exposed near the LOD, the claimant-favorable assumption that they were exposed at this level is adopted. This approach is adopted even though it is highly unlikely that an individual could have been exposed to a series of doses near or at the detection limit without at least one of the badges indicating a positive value.

Unmonitored external dose. Many workers at DOE and Atomic Weapons Employer sites were not monitored for radiation exposure. This included some who would be considered radiological workers by today's standards. Unmonitored workers with a potential for exposure are typically assigned doses based on coworker studies (Merwin et al. 2008).

Several aspects of the development and use of coworker studies involve claimant-favorable approaches. External coworker doses are based on a compilation of dosimetry records from a particular site, which are converted to annual doses. Under current procedures for assessing coworker doses, the 50th percentile of the distribution of monitored annual doses is assigned if the unmonitored worker was determined by the dose reconstructor to be only intermittently exposed, while the 95th percentile values are assigned if the worker was deemed to be routinely exposed (ORAUT 2005). This general approach is claimant favorable for two major reasons: first, the typical intermittently exposed worker probably received less than the median doses received by all workers at the site, and the typical routinely exposed worker probably received less than the 95th percentile doses; second, the coworker data are based on analysis of data for *monitored* workers, and at most sites unmonitored workers would have been expected to have received, on average, less dose than monitored workers. Additionally, missed doses using the LOD/2 approach described above (assuming the maximum potential number of null badge readings) are added to the measured doses prior to the identification of the 50th and 95th percentile annual doses, even though missed dose is an artifact of an issued dosimeter and is not directly applicable to a worker who was not issued a dosimeter.

External ambient dose. Elsewhere in this issue (Merwin et al. 2008; Rollins 2008), the manner by which external ambient doses were developed both under EEOICPA Part B in general, and for the Savannah River Site specifically, is described in detail. As discussed in these papers, there are three primary reasons why external ambient doses assigned to workers are likely to be claimant favorable. First, these doses may be assigned even for workers who wore personal dosimeters, unless it could be established definitively that the control dosimeter locations and background subtraction processes utilized by the site would not have inadvertently subtracted background radiation doses that were elevated

above the natural background levels. Second, external ambient doses provided in the site profiles often are overestimated, usually due to a lack of complete data for the site throughout its operating history and/or the lack of information allowing for the subtraction of natural background doses from the published data. Third, the specific work locations of employees often are not known with certainty, so claimant-favorable or maximizing assumptions are adopted regarding the potential exposure rates.

Occupational x-ray dose. Because the approaches to assigning occupationally related medical x-ray doses have been described in detail elsewhere in this issue (Shockley et al. 2008), this subject is not discussed extensively here. Significant claimant-favorable assumptions and approaches associated with these dose assignments include (1) the use of default x-ray frequencies established in the site profile if a worker's x-ray records could not be found; (2) assigning doses from photofluorographic procedures, even for cases in which the evidence that these procedures were provided is minimal or nonexistent; and (3) in the case of skin dose assignments, applying entrance skin doses for locations on the body for which it cannot be established definitively that the skin was not directly in the x-ray beam.

Internal dose

As described elsewhere in this issue (Brackett et al. 2008), in order to expedite case processing, internal doses to atomic weapons complex workers are typically overestimated for noncompensable cases and underestimated for compensable cases (or ignored entirely if they are not required to demonstrate that a PC of 50% or greater has been achieved), rather than providing a more refined dose reconstruction. Cases that are near the compensability criterion require a more refined estimate of internal dose, but even these typically include numerous claimant-favorable approaches, assumptions, and parameters and are likely to overstate the internal organ doses received.

Like the external dose estimate, claimant favorability is applied throughout the internal dose reconstruction process. The first area of claimant favorability applied to dose reconstructions is that *all* workers are presumed to have received internal exposures unless the case file and any applicable site information demonstrate that an internal exposure was clearly improbable. The examples provided below address claimant favorability inherent in internal dose reconstructions based on (1) evaluation of bioassay records, (2) hypothetical intake assumptions, and (3) application of coworker data.

Claimant favorability in detailed dose reconstructions based on bioassay records. Reconstruction of internal doses is often complex, and exposure histories must typically be inferred from the few data points supplied by internal dose monitoring records, if they exist. To accurately estimate internal dose from a given exposure (or potential exposure), a number of factors must be known. Specifically, to calculate an internal dose using the Integrated Modules for Bioassay Analysis code, the following information is required:

1. **Duration of intake.** For a dose history with extensive monitoring and positive results, it is possible to identify acute intakes from the data. In a few cases, information in the dosimetry files may include documentation of incidents that can be determined to correspond with specific bioassay results. Claimant interviews may also contain information on potential intakes, though this information rarely has sufficient detail on which to base an intake characterization. For this reason, unless positive data suggest there were discrete acute intakes, dose reconstructions typically assume chronic intakes. This may have a significant impact on the calculated dose. Missed internal doses are also assumed to result from chronic exposures over the period of potential exposure. The potential exposure period must also be inferred in most cases, because facility assignments and exact work descriptions are rare. This results in considerable uncertainty, which is addressed using claimant-favorable assumptions;
2. **Date of acute intake.** When the positive and negative bioassay data suggest potential acute inhalation intakes, the dose reconstructor may apply acute exposure scenarios including one or more intakes. Incident data or a notation that a given bioassay sample was specially collected may be used to identify the dates of intake in some cases, but this is often not possible. In other cases, the excretion pattern in the bioassay record may provide evidence of a credible intake date. In the absence of data to justify the selection of a specific date, the dose reconstruction uses a date at the approximate midpoint between the positive sample under consideration, and the latest prior negative (or the assumed beginning of the potential exposure period if there is no previous negative value), based on the reasoning that this corresponds with the LOD/2 approach used in external missed dose as described above. The dose reconstruction may also overestimate the intake in noncompensable cases, or underestimate it for a compensable case. This may be done by assuming an intake date closer to or further away from the positive sample;
3. **Dates of chronic intakes.** Bioassay records typically do not contain information on the date(s) of potential

exposures. Those few results noted as "baseline" bioassays may be used to infer a beginning date for a potential exposure; however, these are not common in the internal dose monitoring records considered in this project. For this reason, the dose reconstructor assigns a claimant-favorable date, often the first day of employment, when another date cannot be justified by case data, such as a comment in the interview record, or a documented transfer to a given facility;

4. **Radionuclide.** Given that the analyte typically is listed in bioassay results, or may be easily inferred from site-specific information in the site profile, identification of the radionuclides to which an individual was exposed would seem to be straightforward. However, a positive plutonium result, for example, could indicate an exposure to a mixture composed of several radionuclides (e.g., a typical weapons-grade mix would include ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and, perhaps, ^{241}Am). The proportions of the individual radionuclides in a given exposure typically must be determined based on site-specific information in the site profile rather than from the bioassay records themselves. Because it usually is not possible to identify an exact workplace or process on which an employee may have worked, very often this results in the assignment of the most claimant-favorable of several possible mixtures. The example provided above for plutonium indicates the nature of the problem, but this issue is also associated with other radionuclides, notably uranium. Other bioassay results may be for generic samples, such as "beta-gamma" or "total alpha." In these cases, the dose reconstructor typically selects the most claimant-favorable of a number of potential radionuclides as listed in the site profile. As an example, "fission product" bioassay results for certain years at the Savannah River Site are assigned to one of several lists of radionuclides, depending upon the organ dose being reconstructed; this ensures a claimant-favorable dose is assigned for the unknown result;
5. **Minimum detectable amount.** Recent bioassay records typically contain a stated minimum detectable amount (MDA) for each result. This allows the estimation of missed dose with a minimum of overestimation. Earlier bioassay results, however, typically do not have the MDAs listed with the results. When this is the case, they are based on the default values listed in the site profile. Development of these default values often is a process that contains considerable uncertainty itself, and the site profiles typically use the highest known MDA for a given period;
6. **Absorption type.** Organ doses are highly sensitive to the absorption type associated with a given intake. For example, relatively insoluble material (which takes a long time to enter the bloodstream from the lung) will result in high doses to the lung and the extra-thoracic regions. More soluble material may pass through the lung in a shorter time, resulting in a lower dose to that organ. Other organs may receive the highest dose from one or the other of the available absorption types.

   An accurate dose estimate typically will be based on a known absorption type. This information may be presented in the site profile. For instance, if it is known that potential exposures to airborne plutonium in a given facility are consistent with absorption type M, and that the worker was assigned to this facility, an assumption of type M may be justified by the dose reconstructor. However, sufficient detail to identify the absorption type is usually not available.

   It is more often possible to identify an absorption type based on the excretion curve fitted to the positive and negative data. Though this can be a painstaking process, it has the advantage of being based on actual case data. However, this option is not available to reconstruct the dose for workers with sparse internal dose monitoring data.

   Absent the opportunity to identify a specific absorption type by fitting the excretion curve, the dose reconstructor defaults to assigning the most claimant-favorable of the possible absorption types. As discussed previously in this paper, this example is cited specifically in Title 42 CFR Part 82 (U.S. DHHS 2002b). For respiratory organs in particular, this makes a significant difference in the organ dose (up to several orders of magnitude), and in the resulting PC.

   The effect of absorption type selection is illustrated in Tables 4 and 5. Table 4 illustrates the case of a hypothetical worker at a uranium-handling facility diagnosed with lymphoma. The worker was monitored for intake of uranium for a limited time with no positive bioassay results. The calculated intake, dose to the thoracic lymph nodes (based on ^{234}U), and the associated PC for lymphoma are provided in the table for three potential absorption types; type S would be selected for this case if there was no definitive information to the contrary. Table 5 illustrates the effect of absorption type on lung dose given similar assumed intakes; and
7. **Missed dose assessments.** Missed internal dose is presumed in the case when an individual has a bioassay monitoring result below the MDA (unless the analysis was clearly associated with routine outprocessing). These doses are assigned based on intakes calculated from one-half the MDA for the bioassay method upon which they are based. The dose

Table 4. Impact of assumed absorption type on calculated intake, dose to the thoracic lymph nodes [Ln(TH)], and PC for lymphoma for a negative uranium bioassay.[a]

Absorption type	Claimant favorability	Intake [pCi d^{-1} (Bq d^{-1})]	Ln(TH) dose [rem (mSv)]	PC (%) at various confidence intervals		
				99th	95th	50th
F	Least	54.43 (2.014)	0.019 (0.19)	0.04	0.02	0.00
M	Middle	148.7 (5.502)	0.511 (5.11)	1.61	0.53	0.03
S	Most	3624 (134.1)	1570 (15700)	97.07	93.40	51.38

[a] Assumptions: Intake calculated based on one-half the MDA of 13.39 pCi d^{-1} (0.4954 Bq d^{-1}) assuming a chronic intake throughout 1962; male employee born in 1929; cancer diagnosed in 1993.

calculated from this intake is assumed to be the mode value of a triangular dose distribution. The minimum dose is assumed to be zero, and the maximum dose is assumed to be twice the mode value to address the potential that radioactive material was present in the sample (or present in the body in the case of an in-vivo procedure), but not detected.

Overestimates of internal dose based on hypothetical intakes. For expediency, several standard overestimates of internal dose have been formulated (Brackett et al. 2008). Whether these overestimates are used in a given case depends upon a number of factors, including, most importantly, whether the dose can be shown to be larger than any dose that the worker is likely to have received. These are clearly overestimating assumptions that add greatly to the margin of claimant favorability in any case for which they are used. Since they are currently only applied to cases that do not exceed the compensation criterion, the internal overestimates add to the assurance that no uncompensated case is based on an underestimate of dose, but they do not result in compensation of cases based on claimant-favorable assumptions. Because this approach has been used widely in the dose reconstruction program to process certain cases in a timely manner, the internal doses reported for the organ(s) of interest for a large number of claims exceed several rem (tens of mSv) even though the doses actually received by the workers were certainly much smaller.

Coworker internal dose. For workers for whom an exposure to potential intakes of radioactive material cannot be ruled out based on case-specific data or information in the site profile, coworker doses may be applied. To accomplish this, coworker internal doses have been formulated for a number of sites. While the dose received by a worker who is performing similar activities in the same immediate work area as the individual for whom the dose is reconstructed may be very accurate, the current values of coworker internal dose presented for most sites are necessarily broad, and are based on a compilation of data from monitored individuals at a given site. This results in two "built-in" claimant-favorable attributes, namely that:

1. Internal dose monitoring results for monitored workers are likely to indicate a higher dose than was typically received by unmonitored workers, on average; and
2. In most cases, a potentially exposed worker's dose is accurately estimated by the doses calculated to the 50th percentile values.

OVERALL EFFECT OF CLAIMANT-FAVORABLE FACTORS

As the preceding discussions have shown, there are many claimant-favorable features of the EEOICPA Part B program. First and foremost, the compensation criterion is based on the 99th percentile PC, which ensures a claimant-favorable evaluation. In most cases, however, a large number of other factors come into play. As summarized in Table 6, there are dozens of such factors, any number of which may be involved in a particular claim. The overall impact of all these factors combined can be

Table 5. Impact of absorption type on dose to the lung and PC for lung cancer from an assumed chronic intake of 1,844 dpm d^{-1} (30.73 Bq d^{-1}) of ^{234}U.[a]

Absorption type	Claimant favorability	Lung dose [rem (mSv)]	PC (%) at various confidence intervals		
			99th	95th	50th
F	Least	0.303 (3.03)	2.19	1.02	0.14
M	Middle	18.23 (182.3)	68.44	43.98	6.68
S	Most	45.05 (450.5)	81.06	65.32	18.53

[a] Assumptions: Chronic intake throughout 1954; non-smoking male employee born in 1921; cancer diagnosed in 1985.

Table 6. Examples of claimant-favorable aspects of the NIOSH Radiation Dose Reconstruction Program.

Area of claimant favorability	Number or types of cases affected
Application of the 99% PC compensation criterion	All cases
Certain parameters and assumptions in the IREP code used for estimating PC	Most cases
Multiplicative nature of models and missed dose	Most cases
Treatment of multiple primary cancers as being independent	The fraction of cases involving multiple primary cancers (approximately 23% of total cases)
Evaluation of secondary cancers as most favorable primary cancers	Most of the cases involving secondary cancers (approximately 2% of total cases)
Treatment of multiple secondary cancers as potentially multiple primary cancers	Some of the cases involving multiple secondary cancers (less than 1% of total cases)
Use of worst-case cancer model with nonspecific primary cancer	Some skin and most leukemia cases
Assignment of measured photon dose as acute and measured neutron dose as chronic	All cases involving measured photon and neutron doses
Maximization of neutron/gamma ratios to account for poor neutron monitoring	Many cases from the 1940's and 1950's with neutron exposure potential
Use of maximizing correction factor for nonuniform exposure geometries as a default assumption	Claims for certain cancers involving employees with a potential for having worked close to sources, for example, in gloveboxes or laboratory hoods
Assignment of the worst case photon energy ranges	Most cases in which the specific work locations are unknown
Application of missed external dose when actual exposures were likely to not have been near the dosimeter LOD	Most cases in which missed external dose is assigned
Overestimation of dosimeter LODs in site profiles	Cases from certain sites
Application of missed external dose even if it is not clear that there was appreciable potential for exposure	Cases in which an employee wore a dosimeter but there was little evidence of exposure potential
Use of 50^{th} and 95^{th} percentiles for external coworker dose assignment	Most cases in which external coworker doses are assigned (i.e., unmonitored workers with a presumed exposure potential)
Inclusion of LOD/2 missed dose in assigned external coworker doses	All cases in which external coworker doses are assigned
Application of conservative assumptions regarding exposure potential when assigning coworker vs. ambient dose	Some cases involving unmonitored workers
Assignment of neutron doses to workers with little evidence of neutron exposure potential	Cases from certain sites, and cases involving neutron monitoring with little evidence of neutron exposure
Addition of external ambient dose to measured dose	Cases from certain sites (i.e., those in which it could not be determined whether the background subtraction process inadvertently excluded elevated background radiation from the measurements)
Use of maximum potential ambient doses due to unknown work locations	Most cases involving the inclusion of external ambient dose
Use of ambient doses without natural background subtraction	Cases involving the inclusion of external ambient dose from certain sites
Assumption of default frequency for x-ray examinations, even if claimant interview indicates that no x-ray exposures were received	Many cases
Assignment of photofluorography doses with minimal evidence	Cases for certain time periods at certain sites
Application of default energy ranges for shallow dose assignments	Most cases involving skin cancer and certain other cancers
Presumption of an exposure when any negative bioassay results are present in the record	All cases with negative bioassay results other than single samples at termination
Assumption of maximum dose absorption type for intake of radionuclides	Most cases with internal dose monitoring records
Assumptions involving radionuclide mixtures in lieu of specific data in the site profile or case file	Certain cases with internal dose monitoring records, including most with plutonium monitoring results
Basing default bioassay MDAs on claimant-favorable assumptions in the site profiles	Many cases with internal dose monitoring records
Assumption of the more claimant-favorable acute and chronic intake types when definitive information is unavailable	Most cases with internal dose monitoring records
Assumption of the most claimant-favorable dates of acute intakes when specific information is unavailable	Many cases with internal dose monitoring records
Assumption of the most claimant-favorable durations of chronic intakes when specific information is unavailable	Many cases with internal dose monitoring records
Applying hypothetical intakes that exceed upper bounds of actual or potential intakes	Many cases with PCs $<50\%$ and certain cancer organs
Use of internal coworker bioassay data to estimate the doses to unmonitored workers who may have been less likely to have been exposed	Most cases in which internal coworker dose is assigned

many orders of magnitude, so for any case that is deemed to be noncompensable, there is essentially no chance that the employee's cancer was actually caused by radiation exposures in the workplace. Similarly, for most cases deemed compensable, it is more likely than not that the cancers were not actually caused by radiation exposures in the workplace. Whereas the 99th percentile PC is calculated by IREP based on modeled uncertainty distributions of dose and risk, many uncertainty factors that are not modeled are assigned claimant-favorable default values and, hence, the actual PC for a particular case is not only likely to be far below the calculated 99th percentile value, but also substantially less than the calculated 50th percentile value.

While each of the factors listed in Table 6 could be debated in terms of its individual impact on the calculated doses and PCs, when considered as a whole, the claimant-favorable factors inherent in this program result in a high compensation rate in comparison to the cancer rates that could have been experienced by current and former DOE workers due to radiation exposures in the workplace, as indicated by epidemiology studies. These compensation rates are attributable primarily to (1) claimant-favorable approaches to evaluating PC, and (2) reconstructed doses that are overestimated for many claims, in some cases by more than an order of magnitude. While the overall claimant-favorable aspect of the program is consistent with the intent of Congress, and certain specific aspects are addressed explicitly in Title 42 CFR Part 82 (U.S. DHHS 2002b), many of the claimant-favorable approaches and parameters are attributable to a lack of precise and accurate information on the employees' work histories, locations, and exposure environments.

SUMMARY AND CONCLUSION

The EEOICPA Part B program and associated regulations require that dose reconstructions favor the claimant when parameters are uncertain. This may include the application of maximizing assumptions which can individually impact the assigned dose by more than an order of magnitude, and many such assumptions may be applied within an individual dose reconstruction. Combined with the 99th percentile PC compensation criterion, the claimant favorability embedded in some of the risk calculation models and parameters in the IREP code, and the manner by which primary cancers are identified and assessed, the analyses often result in a determination by DOL that a case qualifies for compensation even though the PC would not be found to approach 50% by more traditional methods of determination (such as the "more likely than not" approach often applied in radiation litigation).

While the combined effect of the numerous claimant-favorable approaches, assumptions, and parameters ensures that essentially all claims with merit are compensated, it also has resulted in a substantial number of claims being compensated even though the associated cancers were highly likely not to have been attributable to radiation exposure in the workplace. As discussed in this paper, the compensation rate in this program is approximately 30% even though the rate of radiation-induced cancers in DOE workers is, at most, only a few percent according to epidemiology studies. This point is typically not understood, nor accepted, by claimants and various other stakeholders, and is rarely appreciated and reported by the media. Additionally, to date, various oversight groups have tended to focus on areas that may not be claimant favorable, even if such examples are relatively trivial in comparison to the numerous claimant-favorable factors embedded in the program.

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