Dose Reconstruction under the U.S. Energy Employees Occupational Illness Compensation Program Act

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Abstract. The United States nuclear weapons production workforce has been provided a compensation program which covers claims from workers for radiation-related cancer. The compensation decision is made through individual dose reconstruction followed by an estimate of the likelihood that a cancer was as least as likely as not due to the worker's occupational exposure. This program, which was established under the U.S. Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), compensates workers for cancer incurred as a result of exposure to ionizing radiation at over 300 U.S. Department of Energy and contractor facilities. Under the EEOICPA, the U.S. National Institute for Occupational Safety and Health (NIOSH) has been designated as the agency responsible for reconstructing the radiation doses received by these workers. To date, NIOSH has received more that 25,000 cases that require individual dose reconstructions to specific organs or tissues that developed a cancer. Because the risk models used to compute causation are time dependent, all doses are reconstructed on an annual basis. The reconstructed doses include exposures from all possible pathways, including internal, external, environmental and medical exposures. To ensure that these cases are expeditiously processed in a fair and scientifically defensible manner, NIOSH has adopted a triage process that expedites processing and a reconstruction method that, to the extent possible, relies on standard consensus models. This paper provides a discussion of: 1) our experience with the application of standard ICRP models to these dose reconstructions; 2) a description of the techniques employed to efficiently process the large volume of cases we have received; 3) the progress made to date in the completion of dose reconstructions; and, 4) the current distribution of compensation rates by cancer type.

KEYWORDS: dose reconstruction, exposure assessment, compensation

1. Introduction

The U.S. Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), established a program for compensating workers for cancers incurred as a result of occupational exposure to ionizing radiation at over 300 U.S. Department of Energy (DOE) and contractor facilities [1]. Under the EEOICPA, the U.S. National Institute for Occupational Safety and Health (NIOSH) has been designated as the agency responsible for reconstructing the radiation doses received by these workers [2]. An overview of the components of the NIOSH compensation program has recently been published [3].

The decision to award compensation is based on a determination of the likelihood that the cancer that developed was caused by the employee's radiation exposure in the workplace. For each case, the U.S. Department of Labor must make a determination that the cancer was at least as likely as not the cause of the cancer. In the implementing regulations by the U.S. Department of Health and Human Services, this has been defined to be a probability of causation (PC) of greater than or equal to fifty percent as calculated by the NIOSH Interactive RadioEpidemiological (NIOSH-IREP) program. A detailed description of the technical aspects of the NIOSH-IREP program has been published by Kocher et. al [4]. A real-time interactive version of the program, along with associated technical documentation, can be viewed on the NIOSH website at: http://www.cdc.gov/niosh/ocas/ocasirep.html.

Because hundreds of thousands of people have been employed in nuclear weapons-related activities for the U.S. Department of Energy and its predecessor agencies, a large volume of claims requiring dose reconstruction was anticipated at the onset of the program. This turned out to be the case with NIOSH receiving more than 27,000 cases that require dose reconstruction as of June 2008. To

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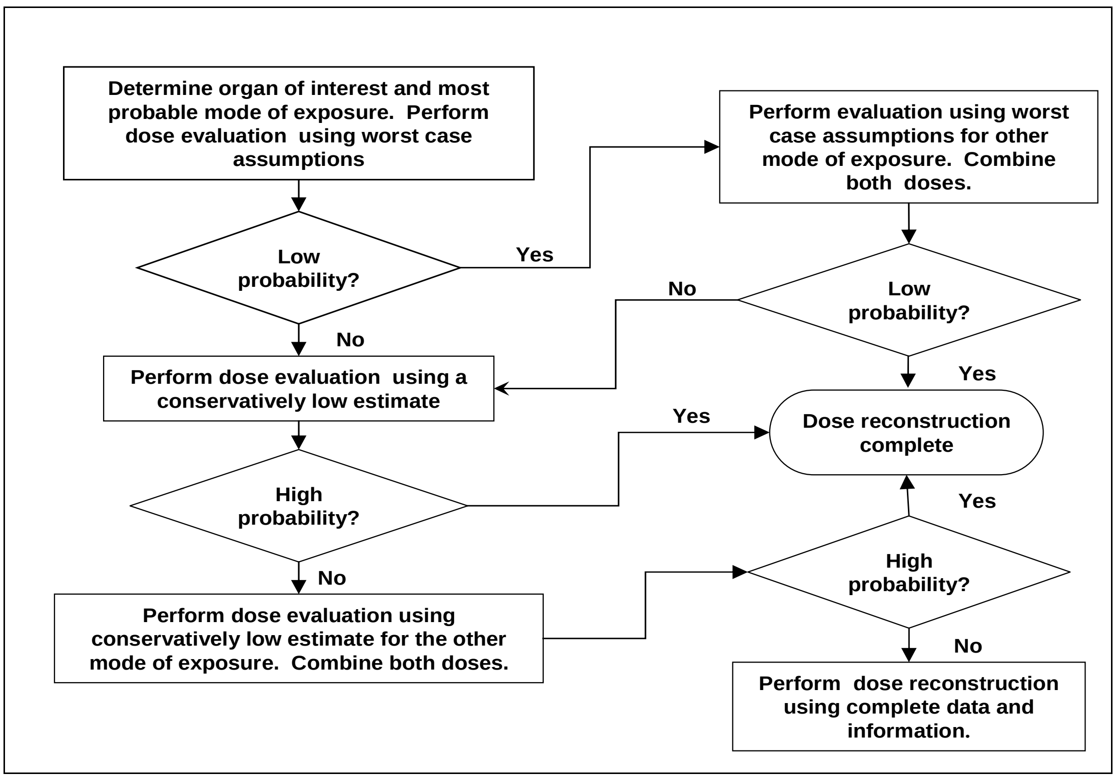
accommodate such a work load, a process that maximized throughput, while still utilizing the best available science, was established during the early phase of program development. This was accomplished by: 1) basing the dose reconstructions on consensus scientific documents (such as those generated by the International Commission on Radiological Protection) whenever possible; 2) prescribing a hierarchical scheme in the utilization of available data; and, 3) developing a triage process that only processes a reconstruction as far as necessary to allow for an unambiguous compensation decision.

2. Efficiency Process

As discussed above, it was necessary to process claims in an efficient manner as possible without sacrificing the scientific integrity of the reconstruction. The triage process that was developed to accomplish this took advantage of the dichotomous nature of the compensation decision. That is, it was decided that a dose reconstruction only needed to be processed until it could be definitively established that the probability of causation was greater than or less than fifty percent. For example, if the summation of all the external film badge readings measured during an employee's work history results in a PC of greater than fifty percent, there is no need to reconstruct the internal dose component, which is oftentimes quite time consuming. Conversely, if upper bound estimates of the worker's total dose result in values of PC less than fifty percent, there is no need to further refine the dose estimate. Figure 1 provides a flow diagram of the efficiency process that is employed in the NIOSH dose reconstruction program.

Figure 1: Flow diagram of the efficiency process for performing dose reconstructions



In practice, the efficiency process has worked well in minimizing the amount of time spent on an individual dose reconstruction. It is estimated that more than 90 percent of the cases processed thus far have been expedited, at least to some extent, using this approach. The extent to which the process saves time is dependent on a number of factors that include: 1) the organ that developed a cancer; 2) the number of primary cancers; 3) the duration of employment; and, 4) the relative magnitude of the internal and external exposures. Although the adoption of this technique has proven to be effective, it can create confusion among the claimant population if a case requires rework. This is because, by design, the process does not provide a best estimate of the dose. For those cases that are expedited using overestimates of the dose, the associated PC value that is provided to the claimant by the U.S. Department of Labor is also an overestimate. When cases require reprocessing because of a change in demographics such as employment history or cancer status, the original overestimates sometimes must be reduced to a more realistic value. When this happens, the PC value reported to the claimant will be reduced. Although this is merely a technical artifact of the process, this is oftentimes not easily understood or accepted by the claimant.

3. Reconstruction of Dose

3.1 General Concepts

Under the EEOICPA, NIOSH is required to reconstruct radiation dose that was received at a U.S. DOE or its predecessor facility that was involved in the development or production of nuclear weapons. This includes internal and external dose that was received directly from working with radioactive materials, as well as from environmental dose that was received from exposure to ambient contamination of the facility. Medical x-ray exposure is also included when it was required as a condition of employment.

The quantities and types of monitoring data available for a dose reconstruction can vary widely. Because of this, a hierarchy has been defined of the preference in which specific data types are used. In general, personal monitoring information, such as film badges and bioassay samples, are considered to be the most representative of the claimant's individual exposure situation. This, of course, assumes that the monitoring data is unbiased and accurately reflects the various radiological components of the individual's exposure. If personal monitoring data are unavailable, then coworker monitoring data is considered to be the next best source of information. Care must be exercised, however, to establish that the coworker population used as a surrogate for the individual is representative of his/her exposure conditions. Area monitoring data is the next source of information that can be used in a reconstruction. As with coworker data, care must be used to ensure that the area monitors are representative of the actual exposure scenario being reconstructed. Lacking sufficient area monitoring data, it may be possible to reconstruct an exposure using source term information that might be available for the particular operation or process. For example, if a worker was known to have been involved in the filling of drums with natural uranium, it may be possible to reconstruct his/her external exposure based on the known external dose rates associated with quantities of uranium under various geometrical configurations. Finally, using available source and process information, it is sometimes possible to rely on surrogate data that are available from a similar facility. Tables 1 and 2 provide a summary of the hierarchy of data that has been adopted in the reconstruction of internal and external doses under the Energy Employees Occupational Illness Compensation Program Act.

Table 1: Hierarchy of data sources used in the reconstruction of internal doses

Hierarchy	Data source	Examples
1	Personal monitoring	In-vivo analyses, in-vitro analyses, breathing zone air samples
2	Indicator radionuclides	Known mixtures of materials, such as recycled uranium, where the individual was monitored for some of the nuclides
3	Individual monitoring of coworkers	Information based on in vivo or in vitro bioassays of coworkers
4	Workplace monitoring	General work area air samples.
5	Work area (source term) data	Identification of radionuclides and quantities available for dispersal
6	Surrogate site data	Data from a site where similar processes were being performed

Table 2: Hierarchy of data sources used in the reconstruction of external doses

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}
7	Surrogate site data	Data from a site where similar processes were being performed

A detailed description of the reconstruction of internal and external doses under the EEOICPA has been published Brackett et. al [5] and Merwin et. al [6].

The internal and external doses reconstructed under the EEOICPA differ in many respects from those normally evaluated in traditional radiation protection programs. This is primarily due to the fact that the probability of causation calculation is both organ-specific and time-dependent. Thus, for external dose the exposure recorded on personnel badges must be adjusted to account for the difference between the deep dose measured at 1 cm below the skin surface and the actual dose received by the organ that developed cancer. This adjustment, which uses the values computed by the ICRP [7], can make a large difference in the reconstructed dose, especially for exposures involving lower energy photons. In addition to this, care must be taken to account for any differences in the exposure geometry between the position of the monitoring device and the source. For example, it has been established that badges worn on the upper torso by glove box operators do not necessarily accurately record the dose to the organs in the lower torso.

For internal doses, the time-dependence of the risk coefficients requires that annual, not 50 year effective, doses be calculated. The annual dose received by the organ of interest for each radiation type must also be calculated individually. This is necessary because each radiation type has an associated radiation effectiveness factor that is treated as a distribution in the final PC calculation [8]. A list of the differences, including those described above, between typical radiation protection dose calculations and those employed under the EEOICPA are provided in Table 3.

Table 3: Differences between dose estimates under the EEOICPA and those of typical radiation protection programs

Differences in Dose Reconstruction under EEOICPA
External badge results require adjustment for organ location
External exposure geometry must be considered
Annual organ doses required for internal exposures
Dose from individual radiation types treated as distributions
Missed and undetected doses must be evaluated
Doses from some medical exposures included
Doses to organs other than the lung must be evaluated for radon exposures
Only the dose received up to the date of cancer diagnosis evaluated

3.1 Missed Dose

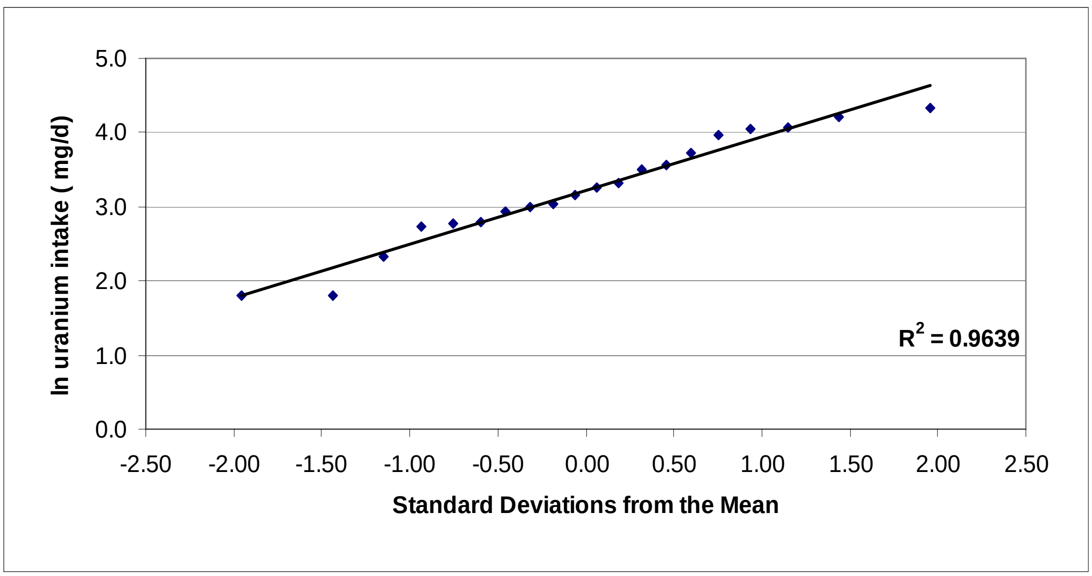
Because measurements associated with radiation protection monitoring programs have an inherent limit below which they can not detect exposure, there is a minimum detectable dose which could have been received by a worker that went undetected. To account for this, all dose reconstructions completed by NIOSH evaluate the magnitude of this potential source of bias. For bioassay data that is below the limit of detection, a model is used that employs a triangular uncertainty distribution with a minimum of zero, a maximum equal to the detection limit and the central value equal to the limit of detection divided by two.

For external monitoring data, it has been reported that worker's exposures at low does are best represented by a log normal distribution [9]. Because of this, external doses reported as zero or below the detection limit are modeled using a log normal uncertainty distribution where the central estimate is the detection limit divided by two and the upper 95th percentile is equal to the limit of detection.

3.2 Unmonitored Dose

An approach that is commonly used to account for dose received by unmonitored workers is the evaluation of coworker data. Although it would be best to closely match data from workers who were monitored with those being reconstructed based on based on similar job descriptions or titles, this is often not possible. Given that many of the exposures occurred decades ago, and that more than 50% of the claims come from survivors, a detailed accounting of the exact job and work locations for a specific claim is typically not possible. To overcome this deficiency, doses for unmonitored workers are reconstructed based on the distribution of observed results for the overall monitored population. To accomplish this, a cumulative probability distribution of the log transformed monitoring data is constructed. For the reconstruction of internal dose, the bioassay data are converted to a daily intake. A value for the daily intake is then selected from the distribution. Figure 2 provides an example of the cumulative probability plot of the distribution of uranium intakes for a uranium production operation.

Figure 2: Cumulative probability plot of the distribution of daily uranium intake (mg/d) in a phosphate plant that produced uranium as a byproduct material



In this example, the upper 95th percentile of distribution of daily intakes was used to bound the exposures of unmonitored workers. This technique has been successfully applied for reconstructing both internal and external dose at a number of facilities. Prior to using this technique, it is important to verify that the monitoring data validly represent the range of work activities that occurred in the facility during the time period under evaluation.

3.3 Reliance on Standard Models

To ensure that the NIOSH dose reconstruction program is based on the best science available, standard consensus models have been adopted to the extent possible. In the area of internal dosimetry, the reconstructions are based on the concepts outlined in ICRP 66, along with the other ICRP models that describe the metabolic properties of specific radionuclides [10,11]. In general, this approach has allowed for the reconstruction of internal doses for a variety of exposure situations. The flexibility contained in the ICRP models for adjusting parameters such as particle size, solubility type, breathing rate, etc., has provided an excellent framework to handle most exposure situations.

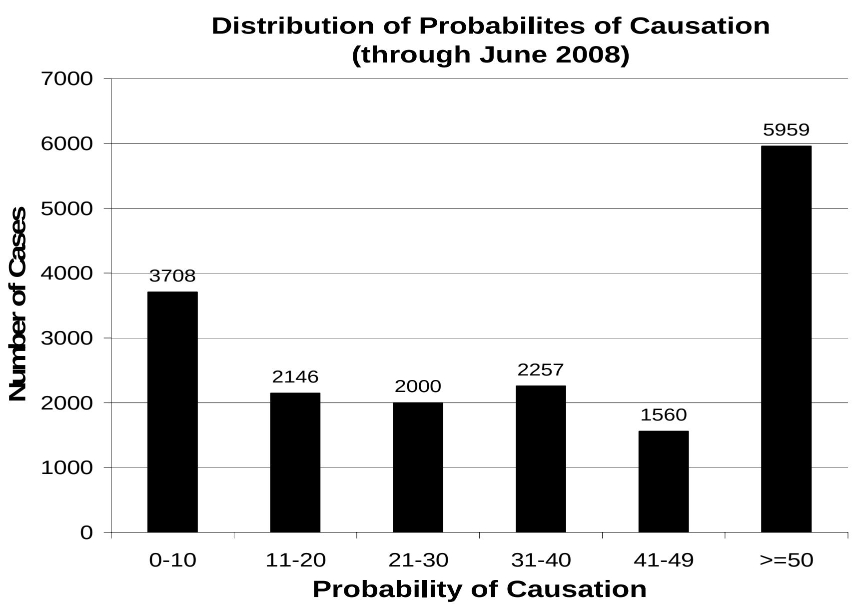
In several instances, however, the standard models were found to be insufficient. In the case of extremely insoluble compounds of plutonium, it was found that the type S designation did not match the long-term clearance observed in some individuals. Because of this, an in depth analysis of the existing data on very insoluble compounds of plutonium (i.e., the so-called "super class S solubility type) was conducted. Based on this analysis, the dose to individuals who could have been conceivably exposed to super S plutonium was reconstructed using a bounding analysis approach.

Another situation where the ICRP models lacked sufficient detail is in the calculation of dose to the lymph nodes. While the standard lung model will calculate the dose to the tracheo-bronchial or thoracic lymph nodes, a cancer in the lymph system (e.g., a lymphoma) could have originated in any of the lymph nodes that are distributed throughout the body. This necessitated a review of the literature to establish the exact organ of origin for the various types of lymphomas. Based on this, a detailed accounting of the organ to be reconstructed for each type of lymphoma was developed. At the current time, proportionally weighted dose models for the various organs of interest are being examined.

4. Program Status

As of June, 2008, 27,367 cases have been referred to NIOSH for dose reconstruction. NIOSH has completed dose reconstructions for 17,620 of these cases and returned them to the U.S. DOL for adjudication. Based on the NIOSH reconstructions, it is estimated that 34% of these cases will have a probability of causation greater that or equal to 50% (i.e., they are likely to be compensated once they undergo final adjudication by the U.S. DOL). The distribution of the probability of causation for the cases reconstructed to date is provided in Figure 3.

Figure 3: Distribution of probability of causation for completed dose reconstructions.



A review of the compensation rate by type of cancer was completed within the last year. Table 4 provides a list of the cancers with the highest compensation rates under EEOICPA.

Table 4: Listing of compensation rates by cancer model type as of September, 2007.

Cancer Model	% of Claims Compensated
Lung	70.1
Chronic myeloid leukemia	64.4
Acute lymphocytic leukemia	61.7
Basal cell carcinoma	57.8
Acute myeloid leukemia	51.3
Liver	46.6
Leukemia, excluding CLL[a]	46.6
Malignant melanoma	38.3
Other respiratory	34.1
Lymphoma and multiple myeloma	23.8
Bone	23.5
Thyroid	23.3
Gall Bladder	22.5
Oral cavity and pharynx	22.0
Eye	16.7
Other endocrine glands	14.3

[a] Chronic Lymphocytic Leukemia

Many of the workers have been exposed through inhalation of insoluble alpha-emitting radioactive material. Because the missed dose associated with this type of exposure in radiation monitoring programs is large, lung cancer has the highest compensation rate to date. As might be expected because of its relatively high excess relative risk per Sievert, various types of leukemia have four of the top seven compensation rates.

It should be mentioned that this analysis was performed only on cases that had been finally adjudicated by the Department of Labor. Because of this, the analysis consisted of an evaluation of approximately 12,000 claims. Given that a large number of claims have been processed since this time, it is quite possible that these compensation rates may change considerably.

5. Summary and Conclusions

The U.S. Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), established a program for compensating workers for cancers incurred as a result of occupational exposure to ionizing radiation at over 300 U.S. Department of Energy (DOE) and contractor facilities. Under the EEOICPA, the U.S. National Institute for Occupational Safety and Health (NIOSH) has been designated as the agency responsible for reconstructing the radiation doses received by these workers. The volume of doses to be reconstructed under this program required the development of innovative approaches that maximized throughput while maintaining the scientific integrity of the process.

To ensure that the program was grounded in the best available science, the dose reconstruction process was based, to the extent possible, on consensus standards, such as those published by the International Commission on Radiological Protection. In several instances, where there was no available consensus standard, NIOSH adapted current science to meet the program's needs. The dose evaluations completed under EEOICPA have substantial differences from those conducted for regulatory purposes. NIOSH has accounted for these differences in their reconstructions by accounting for, among other things, missed and unmonitored dose. Finally, an efficiency process has been put in place that minimizes the time required to process a case. Under this system, cases are reconstructed only as far as necessary to allow for an unambiguous compensation decision to be made.

As of June, 2008, 27,367 cases have been referred to NIOSH for dose reconstruction. NIOSH has completed dose reconstructions for 17,620 of these cases and returned them to the U.S. DOL for adjudication. At this point, 34% of the cases have been judged to have probabilities of causation of greater than or equal to 50%.

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