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ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

REVIEW OF THE NIOSH SITE PROFILE FOR THE KANSAS CITY PLANT

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ABBREVIATIONS AND ACRONYMS

Advisory Board or Board	Advisory Board on Radiation and Worker Health
AMAD	activity median aerodynamic diameter
AP	anterior-posterior
AWE	Atomic Weapons Employer
BNL	Brookhaven National Laboratory
cm^2	square centimeter
DCF	dose conversion factor
DOE	U.S. Department of Energy
DOELAP	DOE Laboratory Accreditation Program
dpm	disintegrations per minute
DU	depleted uranium
FRC	Federal Records Center
g/cm^3	gram per cubic centimeter
GSD	geometric standard deviation
Hp	personal dose equivalent at tissue depth d (d = 10 mm or 0.07 mm)
ICRP	International Commission on Radiological Protection
KCP	Kansas City Plant
$\mu Ci/m^3$	microcurie per cubic meter
µg/L	microgram per liter
µm	micron
MDL	minimum detectable level
MeV	million electron volt
mg/cm^2	milligram per square centimeter
mrem	millirem
NARA	National Archives and Records Administration
NIOSH	National Institute for Occupational Safety and Health
NNSA	National Nuclear Security Administration
n/p	neutron-to-photon ratio
NOCTS	NIOSH OCAS Claims Tracking System
NTA	Nuclear Track A (film)

pCi	picocuries
ORAUT	Oak Ridge Associated Universities Team
rem	Roentgen equivalent man
RGD	radiation generating device
SC&A	S. Cohen and Associates (SC&A, Inc.)
SRDB	Site Research Database
TBD	Technical Basis Document
TLD	thermoluminescent dosimeter
TMA	Thermo Analytical, Inc.
UO_2	uranium oxide

EXECUTIVE SUMMARY

This report presents a review of ORAUT-TKBS-0031, *Site Profile for the Kansas City Plant* (ORAUT 2006), which provides data and guidance for dose reconstruction of workers at the Kansas City Plant (KCP) located in Kansas City, Missouri. This review was conducted in accordance with SC&A's Board-approved *Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). Under these guidelines, SC&A is charged with evaluating the approach set forth in the site profiles that is used in the individual dose reconstruction process. These documents are reviewed for their completeness, technical accuracy, adequacy of data, consistency with other site profiles, and compliance with the stated objectives, as defined in SC&A (2004).

The following presents our findings.

Finding 1: Without specific information regarding the chemical form and particle size distribution of uranium exposure experienced by a worker, dose reconstructors should use default assumptions regarding particle size and chemical form that result in the highest dose to the organ of concern.

Finding 2: The bioassay data summarized in Table 12 of the site profile appear to be incomplete, which raises concerns regarding its use in developing a coworker model.

Finding 3: SC&A believes that the default chronic pattern of intake used in the uranium coworker model, which apparently is being applied to all workers, may not apply to many workers. Our review of actual cases reveals that many workers have legible bioassay records and show patterns of excretion rates that indicate that the coworker model may not be claimant-favorable for all workers.

Finding 4: The system used to categorize workers by administrative code for the purpose of implementing the coworker model might result in misassignments that result in underestimates of reconstructed doses.

Finding 5: There appears to be limited information available to the dose reconstructor with respect to the nature of the work performed by the workers. This issue warrants further investigation, along with the investigation of the legibility/accuracy/completeness of the database(s) used for dose reconstruction, in order to assess the ability to reconstruct worker doses, as supplemented with the coworker model.

Finding 6: It appears that there are large time periods where beta exposure records are lacking, making it difficult to reconstruct beta doses for workers during those time periods, and for developing a coworker model that can cover those time periods. In addition, the details of beta exposures are lacking.

Finding 7: The scarcity of positive neutron doses might be explained, in part, by the limited ability of Neutron Track A (NTA) film to detect neutron energies below 1 MeV. Additionally, neutron exposures may have been missed during neutron area surveys, because the only neutron

survey instrument listed in Table 5 (ORAUT 2006, p. 13) is a Nuclear Chicago Model #2715, and this instrument may not have correctly responded to the pulsed neutron fields with the generator(s) being operated in the microsecond pulse mode, which was typical at KCP, as indicated in Table 4 (ORAUT 2006, p. 12).

Finding 8: The fading of the NTA film as a function of time, temperature, and humidity was not addressed in the site profile, nor were there any correction factors provided. Lower-energy moderated neutrons would show even more fading, as compared to the higher-energy. Additionally, the angular response of NTA film and polycarbonate neutron dosimeters was not addressed, which generally requires a 30% correction factor.

Finding 9: Neutron-to-Photon (n/p) ratios require additional investigation in order to develop a recommended approach for dose reconstructors.

Finding 10: It may not be always correct to assume that unmonitored workers experienced exposures that were generally lower than those experienced by monitored workers, because monitoring in the early years may not have been as thorough as would be desired. In addition, as discussed in previous findings, coworker categories are ambiguous and might result in inappropriate coworker dose assignments. Furthermore, Table 15 may reflect decreased average recorded doses, as the number of zero dose records included may not be a complete accounting of the actual dose to workers.

Finding 11: A correction factor for exposures to photon radiation might be needed, due to the differences between the actual photon energy distributions created largely by x-ray machines, and the relatively high-energy photons associated with Co-60, which was used for calibration of dosimeters. This issue is especially of concern regarding exposures to skin and shallow organs.

An SC&A site visit was performed during the preparation of this report in order to supplement the information provided in the Site Research Database (SRDB). However, there is a need for additional data capture activities, including worker interviews, in order to complete our investigations. At the time of the preparation of this report, arrangements were being made for additional outreach activities. Upon completion of those activities, this report will be amended.

1.0 INTRODUCTION

On January 1, 2006, the National Institute for Occupational Safety and Health (NIOSH) issued ORAUT-TKBS-0031, *Site Profile for the Kansas City Plant*, which provides data and guidance for dose reconstruction of workers at the Kansas City Plant (KCP) located in Kansas City, Missouri. This report presents a review of the site profile, as requested by the Advisory Board on Radiation and Worker Health (the Board) during the full board meeting held in Manhattan Beach, California, in February 2010.

1.1 SCOPE OF THE REVIEW

This review was conducted in accordance with SC&A's Board-approved *Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). Under these guidelines, SC&A is charged with evaluating the approach set forth in the site profiles that is used in the individual dose reconstruction process. These documents are reviewed for their completeness, technical accuracy, adequacy of data, consistency with other site profiles, and compliance with the stated objectives, as defined in SC&A (2004).

1.1.1 Objective 1: Completeness of Data Sources

SC&A reviewed the site profile with respect to Objective 1, which requires SC&A to identify principal sources of data and information that are applicable to the development of the site profile. The three elements examined under this objective are (1) determining if the site profile made use of available data considered relevant and significant to the dose reconstruction, (2) investigating whether other relevant/significant sources are available, but were not used in the development of the site profile, and (3) determining if worker input was considered in the development of the site profile.

1.1.2 Objective 2: Technical Accuracy

Objective 2 requires SC&A to perform a critical assessment of the methods used in the site profile to develop technically defensible guidance or instructions, including evaluating field characterization data, source term data, technical reports, standards and guidance documents, and literature related to processes that occurred at KCP. The goal of this objective is to analyze the data according to sound scientific principles, and then evaluate this information in the context of dose reconstruction.

1.1.3 Objective 3: Adequacy of Data

Objective 3 requires SC&A to determine whether the data and guidance presented in the site profile are sufficiently detailed and complete to conduct dose reconstruction, and whether a defensible approach has been developed in the absence of data. In addition, this objective requires SC&A to assess the credibility of the data used for dose reconstruction. The adequacy of the data identifies gaps in the facility data that may influence the outcome of the dose reconstruction process. For example, if a site did not monitor all workers exposed to neutrons who should have been monitored, this would be considered a gap and thus an inadequacy in the data. An important consideration in this aspect of our review of the site profile is the scientific validity and claimant-favorability of the data, methods, and assumptions employed in the site profile to fill in data gaps.

1.1.4 Objective 4: Consistency among Site Profiles

Objective 4 requires SC&A to identify common elements within site profiles completed or reviewed to date, as appropriate. In order to accomplish this objective, the KCP Technical Basis Document (TBD) was compared to other TBDs, particularly those referenced in the site profile and those related to frequently visited facilities. This assessment was conducted to identify areas of inconsistencies and determine the potential significance of any inconsistencies with regard to the dose reconstruction process.

1.1.5 Objective 5: Regulatory Compliance and Quality Assurance

Objective 5 requires SC&A to evaluate the degree to which the site profile complies with stated policy and directives contained in 42 CFR Part 82. In addition, SC&A evaluated the TBD for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions.

SC&A's draft report and preliminary findings will subsequently undergo a multi-step resolution process. Resolution includes a transparent review and discussion of draft findings with members of the Advisory Board Work Group, petitioners, claimants, and interested members of the public. Prior to and during the resolution process, the draft report is reviewed by the U.S. Department of Energy (DOE), Office of Health, Safety, and Security, to confirm that no classified information has been incorporated into the report.

The NIOSH KCP site profile contained information and references that led to the discovery of additional information that was not addressed in the site profile. SC&A review efforts included a data capture plan and a keyword data search of DOE records. Analysis of the search results identified 50 boxes of unclassified site records of potential interest at the National Archives and Records Administration (NARA) Federal Records Center (FRC) in Lenexa, Kansas, and 200 additional boxes of indeterminate classification status at the KCP National Nuclear Security Administration (NNSA) site. A scanning level review of the 50 boxes of unclassified records revealed a significant number of dose reconstruction-related records that were subsequently added to the SRDB. SC&A is planning to review the 200 boxes at the site in the near future. A number of former workers from the Bannister Complex (including NNSA and non-NNSA workers) were identified for interview purposes as well. SC&A is in the process of verifying the unclassified interviews with non-NNSA workers and intends to schedule future interviews with former and current NNSA workers.

1.2 REPORT ORGANIZATION

In accordance with directions provided by the Advisory Board and with site profile review procedures prepared by SC&A and approved by the Advisory Board, this report is organized into the following sections:

- Executive Summary
- Introduction
- Background Information
- Occupational Medical Dose
- Occupational Environmental Dose
- Internal Dose
- External Dose during Operations

2.0 BACKGROUND INFORMATION

2.1 SUMMARY OF THE HISTORY OF KANSAS CITY PLANT (KCP) OPERATIONS

As described in Section 2 of the site profile, the KCP has its origins as a World War II facility to assemble engines for navy planes, and continues to operate today in the fabrication of non-nuclear components for the nuclear weapons programs. Many aspects of KCP's testing and manufacturing programs in support of the fabrication of weapons involved the use of uranium, radiation sources, and x-ray facilities, and the plant has maintained a formal radiation protection program since 1958. Tables 2, 3, and 4 of the site profile present categories of KCP activities and descriptions of radiation sources and electronic devices that could have resulted in internal and external exposures. These activities involve handling of uranium oxide powders, industrial x-ray units, x-ray devices for the measurement of the density and thickness of components, neutron generators and neutron sources, Cs-137 and Co-60 for radiography and testing of components, and beta-emitting sources for gauges. There were also other types of electronic equipment with the potential to cause external exposures to x-rays, such electron beam welders.

2.2 DESCRIPTION OF KCP'S RADIATION PROTECTION PROGRAM

Sections 2.5 and 2.6 of the site profile describe the radiation protection program at KCP, which was first described in 1964. Table 5 presents a listing of radiation detection equipment, and Section 2.6 summarizes the radiological records maintained for about 4,400 workers. The following summary of the records was extracted directly from page 13 of the site profile.

- *Positive deep, shallow, and extremity doses were first recorded in 1950.*
- *Positive neutron doses were first recorded in 1966.*
- *Before about 1959, the recorded deep and shallow doses were essentially equal.*
- *Recorded extremity dose was higher in 1951 and 1952 than in any other year.*
- *Relatively high shallow dose (in comparison with deep dose) was recorded from 1959 to 1964 and during 1973.*
- *Recorded neutron dose is typically equal to recorded deep dose and to recorded shallow dose. The shallow dose is typically equal to the deep dose.*
- *There are comparatively few records with positive neutron dose.*
- *The only years with recorded positive uranium bioassay results are 1959 to 1971.*

3.0 OCCUPATIONAL MEDICAL DOSE

Section 3.0 of the site profile describes the occupational medical exposures experienced by workers, which apparently has a long history beginning with routine chest x-rays in 1949. Detailed instructions are provided for reconstructing occupational medical exposures, drawing heavily from ORAUT-OTIB-0006 (ORAUT 2005) and making use of historical records that provide the type of frequency of medical x-ray examinations for different categories of worker. SC&A has previously reviewed OTIB-0006, and we have no comments on this section of the site profile.

4.0 OCCUPATIONAL ENVIRONMENTAL DOSE

Section 4 and Appendix A of the site profile address the reconstruction of occupational environmental dose. In order to place an upper bound on potential occupational environmental exposures experienced by unmonitored workers, the site profile uses the simplifying assumption that the average annual airborne concentration of uranium outdoors is equal to 1% of the median indoor concentration, as provided in Table 11 of the TBD (i.e., 5.49E-13 μg/cm^3). As described in Attachment A to the TBD, this rule of thumb is a screening methodology recommended in NCRP Report No. 123, *Screening Models for Releases of Radionuclides to Atmosphere, Surface water, and Ground* (NCRP 1996). SC&A agrees with this basic strategy for bounding the average annual outdoor airborne concentrations of uranium and their associated doses.

Attachment A of the site profile also addresses the airborne concentration of depleted uranium (DU) that might have been experienced by workers on the roof working near the airborne effluent release point. The site profile concludes that the 1% rule of thumb also works for these workers. When one considers building wake effects, along with the fact that such workers would not have been involved in maintenance work close to the effluent release point for extended periods of time, and the fact that the wind direction varies, it seems unlikely that even these workers would experience protracted exposures in excess of 0.01 of the indoor airborne concentrations of uranium.

Based on the above discussion, we concur with the approach used in the site profile to derive occupational environmental doses.

5.0 INTERNAL DOSE

This section presents a brief description of the material provided in the site profile with respect to the type of operations that took place at KCP and the type of data that are available for reconstructing internal exposures at the facility. This is followed by a description of the instructions provided in the site profile for reconstructing internal exposures, and a critical review of those instructions and the data upon which they are based.

5.1 INTRODUCTION AND OVERVIEW

Section 5.0 of the site profile describes the data available and the methods for performing internal dose reconstructions at KCP. As described in Section 5, from 1958 through about 1971, the primary source of internal exposure was machining items containing DU oxide. The site profile also explains that, after 1971, operations changed and the potential for internal exposure to uranium became minimal because the process did not result in airborne uranium. In addition, the site profile explains that the potential for internal exposure to other sources of radionuclides is also considered minimal because the other sources, such as Cs-137 and Co-60, were sealed.

5.2 URANIUM

Uranium oxide (UO_2) was ordered by KCP in 10,000-lb lots and had the mass and radiological characteristics described in Table 9 of the site profile. One of the more important parameters describing the uranium is that the powder used to make the uranium had an activity median aerodynamic diameter (AMAD) of 1.175 microns and a geometric standard deviation (GSD) of 2.48. However, the site profile explains that there is uncertainty regarding the particle size distribution of the aerosols of uranium produced during machining.

Table 10 of the site profile provides information on the gross alpha contamination levels on surfaces in various locations at the KCP, as measured from 1962 to 1969. Both average and maximum contamination levels are presented in units of dpm/100 cm^2; presumably the values refer to removable contamination. Table 11 of the site profile presents statistical data characterizing the airborne DU concentration in units of $\mu Ci/m^3$ from 1958 through 1970. These data are all useful for the purpose of deriving internal doses from uranium.

Most importantly, the site profile indicates that there are bioassay records for individual workers written on cards, but the site profile states that these are nearly illegible. The implications are that it might not be possible to reconstruct uranium intakes for individual workers based on their personal bioassay records. However, electronic data in the form of statistical summaries of the individual records are available in the Site Research Database (SRDB), which can be used to build a coworker model. The following describes the coworker model developed in the site profile to support dose reconstruction for workers that were not monitored or whose records are illegible.

Section 5.1.3 of the site profile presents statistical data in electronic bioassay records characterizing the concentrations of uranium in urine samples collected from workers from 1959 through 1971 expressed in units of µg/L, and the associated derived inhalation rates expressed in units of pCi/day. The site profile explains that NIOSH assumed that the minimum detectable level (MDL) was 10 µg/L, which is presumably used to derive missed dose. The site profile also explains that the frequency of bioassay sampling varied for different individuals and time periods. These data are provided in Table 12 of the site profile, which is reproduced here as Table 1 because of its importance to dose reconstruction.

Table 1: Statistical Parameters of Recorded DU in Urine[a]

Year	Recorded Annual Urine Concentration[b]			Lognormal Fit		Chronic Intakes (pCi/d)[c]		
	No. of Workers Reported	Concentration (µg/L)		Concentration (µg/L)				
		Mean	Maximum	Median	GSD	5th	Median	95th
1959	214	4.125	52.60	2.642	2.675	1.05E+02	6.42E+02	3.92E+03
1960	281	36.58	140.	19.53	3.813	7.79E+02	4.75E+03	2.89E+04
1961	123	51.40	192.1	37.44	2.402	1.49E+03	9.10E+03	5.55E+04
1962	148	4.327	15.75	3.162	2.508	1.26E+02	7.69E+02	4.69E+03
1963	211	10.96	72.00	7.564	2.532	3.02E+02	1.84E+03	1.12E+04
1964	219	5.627	78.38	3.888	2.431	1.55E+02	9.46E+02	5.76E+03
1965	175	9.572	38.00	5.583	3.422	2.23E+02	1.36E+03	8.27E+03
1966	223	6.432	45.05	4.214	2.640	1.68E+02	1.02E+03	6.24E+03
1967	159	5.438	21.50	3.574	2.713	1.43E+02	8.69E+02	5.30E+03
1968	11	6.055	6.600	6.052	1.029	2.42E+02	1.47E+03	8.97E+03
1969	1	0.15	0.150	0.150	1.000	5.99E+00	3.65E+01	2.22E+02
1970	59	11.64	45.00	7.576	2.686	3.02E+02	1.84E+03	1.12E+04
1971	47	0.03596	0.1000	0.02993	1.903	1.19E+00	7.28E+00	4.44E+01
ALL	1,871	14.1	192.1	5.5	4.7			

a. All bioassay measurements.
b. The recorded annual sum of urine concentration is the sum of all bioassay results for the year. There is one sum for each person-year record. The listed statistics are based on the analysis of the data, which are the sums of all bioassay data for every person for that year.
c. Chronic intakes that produce the urinary excretion per day on the 365th day of intakes corresponding to the median excretion from the lognormal fit, and 5th and 95th percentile intakes using a GSD of 3. Assumes 5-micron (µm) AMAD particle size; intakes for 1-µm AMAD particle size, 10.97 g/cm^3 density, and absorption Type S are smaller.

Source: ORAUT-TKBS-0031, Table 12 (ORAUT 2006)

The footnotes provide important information. Specifically, footnote b indicates that the tabulated concentrations are based on the sums of all bioassay results for a given year. Presumably this means that in 1959, there were 214 workers with reported bioassay samples and, if you added up the uranium concentrations observed in urine samples for each worker and divided by the number of samples collected in that year for that worker, you would get the average annual uranium concentrations in the urine of 214 workers for 1959. Then you would simply report the maximum, average, median, and GSD of this population of 214 values. Using these values, chronic intake rates are derived by estimating the chronic intake rate that would give you the indicated concentration of uranium in urine on the last day of that year.

Footnote b and the accompanying text state that the intake rates were based on an assumed 5-micron AMAD and Type S uranium, because these assumptions result in higher intake rates than if 1-micron AMAD or other than Type S is assumed when calculating intake rates based on measured uranium concentrations in urine. We agree with this strategy. However, as discussed below, we have some concerns regarding the assumption that the intakes were chronic.

Table 13 of the site profile provides the number of bioassay measurements and the total and average uranium concentrations in urine sorted by occupational description over the years 1959 to 1971. If a dose reconstruction is being performed for a worker with a known job category, this table could help in assigning intakes to unmonitored workers or for workers whose bioassay records are illegible.

Given this information, Section 5.1.4 of the site profile provides guidance on deriving internal doses to uranium using the above-described tables. The site profile instructs the dose reconstructor to try to assign each worker undergoing dose reconstruction to one of the following four categories (ORAUT 2006, p. 22):

> *(1) workers routinely exposed to airborne or loose material, (2) workers occasionally exposed, (3) workers rarely exposed or exposed only to very low workplace airborne or contamination levels, and (4) workers with little or no potential for radiological exposure. Unmonitored workers in category 1 should be assigned the 95th percentile intakes; category 2 to the median intakes; category 3 to the 5th percentile intakes; and category 4 workers should be assigned internal exposures per the environmental section of this document.*

Given the above description of the coworker model, which apparently is intended to be used for most, if not all, workers due to the illegibility of the individual worker records, the following presents SC&A's review of the coworker model and the data upon which it is based.

5.2.1 Powder Activity Median Aerodynamic Diameter

The KCP had substantial quantities (10,000-lb lots) of UO_2 onsite at various times. Machining and grinding of DU metal creates fine dust available for intake by workers, and NIOSH states that (ORAUT 2006, p. 18):

> *In fitting bioassay data, dose reconstructors may wish to start with a 1-μm AMAD, a GSD of 2.5, a density of 10.97 g/cm^3, a lung solubility Type S, and f1 of 0.002 (ICRP 1995). However, it is not known what impact processes at KCP had on the particle size of uranium. Use of the* ***default 5-μm AMAD*** *particle size is also acceptable unless it is known that the intake was of unaltered UO_2 powder.* (Emphasis added.)

SC&A evaluated internal doses associated with inhaling uranium and determined that, since the Atomic Weapons Employer (AWE) activities at KCP involved handling substantial quantities of UO_2 powder, it does not appear to be appropriate to use the default option of 5-µm AMAD. Without specific information regarding the chemical form and particle size distribution experienced by a worker, dose reconstructors should use combinations of 1- and 5-µm AMAD and Types M and S uranium, and use those assumptions that result in the highest dose to the organ of concern.

Finding 1: Without specific information regarding the chemical form and particle size distribution of uranium exposure experienced by a worker, dose reconstructors should use

default assumptions regarding particle size and chemical form of uranium that result in the highest dose to the organ of concern.

5.2.2 Annual Sum of Bioassay Measurements

The KCP has developed and maintained a radiological records database that contains records for all monitored worker exposures at KCP for all years of record. According to NIOSH (ORAUT 2006), the database contains exposure data for about 4,400 workers. Page 19 of the site profile states the following:

> *The available data are shown on an annual basis and might be the sum of one or more bioassay measurements. If the individual case information does not yield additional information, dose reconstructors should make the claimant favorable assumption that the recorded bioassay quantities represent a single bioassay measurement taken at the end of the calendar year.*

SC&A reviewed the files of 528 claimants (see Table 2), and 50 of these workers had uranium results. Table 2 presents the results of that review. We found that in each year, there were various unreadable results, but the majority of the results, with the exception of 1970, were legible. The point we would like to make is that the site profile leaves the reader with the impression that it is not plausible to perform dose reconstructions using the workers' bioassay data, but instead appears to recommend the use of the coworker model described above. In fact, our review found that it is possible to reconstruct the internal exposures of workers to uranium using the workers' bioassay results. We suggest that the site profile make it clear that the workers' bioassay records should be used when available.

Observation: The site profile should state that the coworker model should be used when it is not possible to use the workers' bioassay records, presumably because they are illegible, incomplete, or lacking.

Table 2: Claimant File Review of Uranium Bioassay

Year	No. of Workers	Excretion Rates (µg/L)	Max excretion rate (µg/L)	Total No. Samples
1959	8	0–3.9	3.9	32
1960	11	0–10	72	28
1961	4	0–20	70	8
1962	5	0–1.5	4.3	5
1963	7	Not reported	16.5	11
1964	9	Not reported	5.3	12
1965	11	Not reported	16.5	16
1966	14	Not reported	13	21
1967	11	Not reported	20	16
1968	4	0	6	5
1969	6	0	0.6	7
1970	10	0–14	25	10
1971	3	0	0	3

Notes: Frequency of monitoring not related to results.
Frequency did not increase after high result.

5.2.3 Bioassay Coworker Model

Table 12 of the site profile (p. 20), which summarizes the electronic bioassay records, shows only one worker with a bioassay result in 1969. However, SC&A's review of the records upon which Table 12 is based reveals that six workers among the claimant group had bioassay records in 1969. Consequently, Table 12 appears to be incomplete, which raises questions regarding the use of the data in Table 12 as the basis for a coworker model.

Finding 2: The bioassay data summarized in Table 12 of the site profile appear to be incomplete, which raises concerns regarding its use in developing a coworker model.

5.2.4 Chronic Uranium Intake

For the purpose of reconstructing internal exposures using the coworker model, the site profile presumes that intakes of uranium dust are chronic. The derivation of chronic intake rates based on the sums of individual results in a year may result in a less-than-favorable dose reconstruction for some workers. Our analysis of the claimant data has shown that some workers have high results in 1 month, followed by very low results at the following sampling period. For example, one worker had 3 low results in 1959, on the order of 2 µg/L. The worker's results were below the MDL in 1960, 30 µg/L in January, below the MDL in February, 72 µg/L in May, and 0 in July and December. This pattern of excretion rate results is not characteristic of chronic intakes, and averaging concentrations in urine to obtain an average annual chronic intake rate would result in an underestimate of internal exposures.

The pattern of high results was not uniform among workers. In 1960, another worker presented the following excretion rate results: 0 in January, 14 µg/L in February, 10 µg/L in April, and 42 µg/L in December. This same worker in 1961 presented 20 µg/L in June and 70 µg/L in December. A third worker in 1961 had a result equal to 0 in August and a result equal to 20 µg/L in December.

In addition, document SRDB 049002 (Nasca 2005) contains uranium bioassay results of a worker in 1960, which presented the following results: 0 in January, 29 µg/L in February, 0 in April, 39 µg/L in May, and 66 µg/L in December. In the same document, a worker presented the following results in 1960: 35 µg/L in January; 0 in February, April and May; followed by 20 µg/L in September; and 0 in December. Those results are not characteristic of chronic intakes.

Finding 3: SC&A believes that the default chronic pattern of intake used in the uranium coworker model, which apparently is being applied to all workers, may not apply to many workers. Our review of actual cases reveals that many workers have legible bioassay records and show patterns of excretion rates that indicate that the coworker model may not be claimant favorable for all workers.

In addition to issues related to Table 12 of the site profile, we also have concerns regarding the way in which the site profile categorizes unmonitored workers for the purpose of implementing the coworker model. On page 22, workers are grouped into the following four exposure categories: (1) workers routinely exposed to airborne or loose material, (2) workers occasionally exposed, (3) workers rarely exposed or exposed only to very low workplace airborne or contamination levels, and (4) workers with little or no potential for radiological exposure.

SC&A is concerned that the use of Table 13 of the site profile and this system to categorize workers might lead to less than claimant-favorable dose reconstructions. For example, our review of the SRDB revealed that administrative support/clerical/work planner Occupational Code Category 450 has a relatively high average bioassay measurement. Specifically, Document SRDB 15925 (Traub 2005) contains an e-mail from Richard Traub to Brent M. Nasca asking about the high excretion rates of code 450. Nasca's response was that this category includes not only secretaries with no expected exposures, but also work planners (Nasca 2005). The work planners are expected to show uranium uptakes. Thus, workers with a high potential of exposures are classified in the same code as workers not expected to have any exposures to uranium.

Finding 4: The system used to categorize workers by administrative code for the purpose of implementing the coworker model might result in misassignments that result in underestimates of reconstructed doses.

5.3 OTHER RADIONUCLIDES

Section 5.2 of the site profile addresses internal exposures other than uranium, explaining that there were no other significant worker intakes other than uranium. SC&A concurs with this position. However, a site visit would help to confirm that this conclusion is valid.

6.0 EXTERNAL DOSE DURING OPERATIONS

This section presents a brief description of the material provided in the site profile with respect to the type of operations that took place at KCP and the type of data that are available for reconstructing occupational external exposures at the facility. This is followed by a description of the instructions provided in the site profile for reconstructing external exposures, and a critical review of those instructions and the data upon which they are based.

6.1 BACKGROUND

Section 6.0 of the site profile, which addresses external radiation exposures at KCP, explains that the sources of external exposure at KCP were primarily associated with fabrication and quality control testing of non-nuclear weapons components, and that clear descriptions of those activities are not readily available due to their classified nature. However, Table 3 of the site profile lists the external radiation sources at KCP, and Table 4 lists the radiation generating devices (RGDs), which consisted of beta, gamma, x-ray, and neutron emitting/generating sources. Section 6.3 of the site profile describes the dosimeter technology that was used to record worker exposure to photon, beta, and neutron exposures associated with the variety of sources, and RGDs used at KCP over the years. This section reviews the data, models, and assumptions used in the site profile to reconstruct external exposures to KCP workers.

As explained in the site profile, because of its long history, a variety of personnel dosimetry devices were employed over the years, and an effort was made in the site profile to compare these different methods, so that dose reconstructions for different time periods can be performed in terms of a common metric, namely Hp(10) for penetrating dose and Hp(0.07) for non-penetrating dose.

Section 6.4 presents the methods recommended in the site profile to perform external dose reconstruction. Section 6.4.1 explains that external dosimetry exists for most workers, but some workers were not monitored. The site profile takes the position that workers who were not monitored experienced exposures that generally were lower than those experienced by monitored workers. This might be true in general, but it might not apply to all workers. Figure 2 of the site profile presents a statistical analysis of the annual penetrating dose experienced by all workers as compiled by NIOSH for 1950 through 2003. Also, Table 15 of the site profile presents a statistical analysis of the exposures for each year from 1950 through 1990. Because of its importance, Table 15 is reproduced here as Table 3:

Table 3: Statistical Parameters of Recorded Penetrating Annual Doses

Year	Arithmetic, All Recorded Dose			Lognormal, dose>0			
	No. of Workers	Dose, rem		No. of Workers	Dose, rem		GSD
		Mean	Maximum		Median	95%	
1950	46	7.09E-02	6.47E-01	29	5.01E-02	5.54E-01	4.31E+00
1951	227	2.78E-01	5.32E+00	158	4.97E-02	2.02E+00	9.52E+00
1952	233	1.91E-01	5.90E+00	220	2.45E-02	7.42E-01	7.96E+00
1953	103	1.37E-01	5.32E+00	72	2.13E-02	4.50E-01	6.38E+00
1954	65	1.61E-01	2.99E+00	21	1.19E-01	4.74E+00	9.39E+00
1955	41	9.18E-02	4.18E-01	25	1.10E-01	4.59E-01	2.39E+00

Table 3: Statistical Parameters of Recorded Penetrating Annual Doses

Year	Arithmetic, All Recorded Dose			Lognormal, dose>0			
	No. of Workers	Dose, rem		No. of Workers	Dose, rem		GSD
		Mean	Maximum		Median	95%	
1956	26	2.89E-01	1.75E+00	26	1.35E-01	1.07E+00	3.52E+00
1957	65	5.24E-01	7.89E+00	36	1.77E-01	6.33E+00	8.80E+00
1958	301	3.90E-02	8.43E-01	89	5.44E-02	4.84E-01	3.78E+00
1959	464	8.97E-03	2.30E-01	72	3.57E-02	1.78E-01	2.66E+00
1960	1,043	1.21E-02	1.35E+00	165	4.53E-02	2.31E-01	2.70E+00
1961	948	2.39E-02	5.90E-01	400	3.17E-02	1.64E-01	2.72E+00
1962	700	1.25E-02	1.65E+00	59	4.25E-02	4.53E-01	4.22E+00
1963	597	1.18E-02	1.63E+00	100	3.65E-02	2.02E-01	2.83E+00
1964	530	6.85E-03	6.90E-01	59	3.09E-02	1.97E-01	3.08E+00
1965	436	1.35E-03	8.00E-02	26	1.66E-02	5.59E-02	2.09E+00
1966	415	2.32E-03	2.00E-01	27	2.54E-02	8.95E-02	2.15E+00
1967	370	1.71E-03	2.50E-01	20	2.06E-02	7.14E-02	2.13E+00
1968	469	1.75E-03	3.50E-01	5	1.10E-01	6.84E-01	3.04E+00
1969	577	[a]	0.00E+00	0			
1970	580	1.60E-03	3.20E-01	29	1.61E-02	7.47E-02	2.54E+00
1971	575	9.39E-04	2.00E-01	16	2.02E-02	9.09E-02	2.50E+00
1972	195	1.19E-02	4.26E-01	68	2.04E-02	8.61E-02	2.40E+00
1973	199	9.86E-02	1.81E+01	69	1.87E-02	1.09E-01	2.91E+00
1974	169	1.30E-02	8.80E-02	67	2.86E-02	6.89E-02	1.71E+00
1975	150	5.72E-03	8.60E-02	44	1.25E-02	5.96E-02	2.58E+00
1976	126	9.65E-03	2.48E-01	53	1.37E-02	7.34E-02	2.77E+00
1977	123	5.45E-03	3.00E-01	12	2.76E-02	1.72E-01	3.04E+00
1978	152	7.53E-03	1.25E-01	18	4.55E-02	2.25E-01	2.64E+00
1979	162	2.69E-03	8.30E-02	17	2.12E-02	5.64E-02	1.81E+00
1980	185	4.19E-03	1.33E-01	22	2.74E-02	8.49E-02	1.99E+00
1981	210	4.12E-03	1.20E-01	24	2.72E-02	9.27E-02	2.11E+00
1982	209	2.00E-03	5.20E-02	22	1.67E-02	3.72E-02	1.63E+00
1983	226	2.98E-03	3.14E-01	12	2.76E-02	2.06E-01	3.39E+00
1984	216	1.89E-02	3.57E+00	18	2.44E-02	2.80E-01	4.41E+00
1985	201	4.67E-02	8.66E+00	49	1.41E-02	8.34E-02	2.95E+00
1986	194	3.22E-03	5.50E-02	27	2.05E-02	4.71E-02	1.66E+00
1987	196	1.65E-03	4.00E-02	20	1.18E-02	4.82E-02	2.35E+00
1988	188	3.52E-03	1.80E-01	11	4.62E-02	1.81E-01	2.29E+00
1989	233	8.03E-04	1.60E-02	17	1.09E-02	1.37E-02	1.15E+00
1990[b]	217	1.16E-03	4.10E-02	17	1.37E-02	2.50E-02	1.44E+00

a. Recommend using values for 1968. All 1969 recorded doses = zero.
b. Recommend using values for 1990 for all subsequent years.
Source: ORAUT-TKBS-0031, Table 15 (ORAUT 2006)

Given these data, the site profile makes the following recommendation:

> *Dose reconstructors should assign the ambient environmental dose to an unmonitored worker with minimal potential for radiation exposure from KCP operations, median coworker dose to an unmonitored worker with minimal likelihood of actual workplace exposure and the 95th percentile coworker dose to workers with a potential for workplace radiation exposure for each year of employment without a recorded dose. There should not, typically, be a significant*

neutron exposure of unmonitored workers because sources of neutron radiation were very limited.

The following presents SC&A's review of the data and the instructions provided in the site profile.

6.1.1 Accuracy/Completeness of Dose Records

Page 13 of the site profile (ORAUT 2006) states that:

> *KCP has developed and maintained a radiological records database that contains records for all monitored worker exposures at KCP for all years of record. The database contains exposure data for about 4,400 workers.*
>
> *Dose reconstructors should use recorded doses from the KCP database to supplement the hard-copy original dosimeter processing information submitted by DOE because the respective claims are often difficult to read.*

SC&A's review of several KCP claimant files on the NOCTS database indicates that some of the original dose records are indeed difficult to read, if not illegible. Apparently, there are hard copies and an electronic KCP database that contain the dose records for the workers; however, the accuracy and completeness of neither data source was addressed in the site profile. From the hardcopies examined of a limited number of claimant records, it would be difficult to decipher the correct recorded dose, and sometimes the dates, bringing into question the accuracy of the electronic database, if it was populated from the hardcopy records.

SC&A searched the 731 KCP claims on the NOCTS database using occupation descriptions that may indicate potential exposure, such as mechanics/repairers, machinists and engineers contained in Table 13 of the KCP site profile. SC&A scanned 61 of these cases for DOE external dose files and found that 14 cases contained external exposure records. It was found that for most of these 14 cases, the external dose records only had one sheet of data, generally listing dose for only 1, 2, or 3 years (maximum of 7 years). This information is summarized in Figure 1 below.

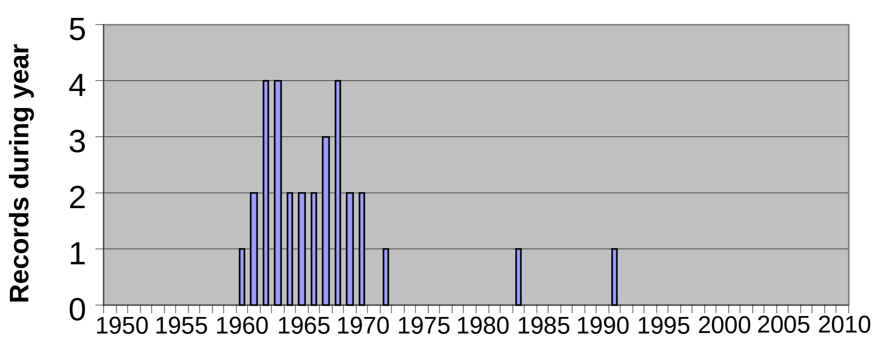

Figure 1: Number of External Exposure Records during a Given Year for 14 Cases with Records

Some workers had the same job title for many years, and the work period covered a wide range from 1951 to the present. It seems highly unlikely that workers (of those analyzed) would be monitored for only a year or two if they were performing the same task for many years. Additionally, as shown in Figure 1, the external dose records of these 14 cases seem to be centered around the mid-1960s with very few outside that time period.

Finding 5: There appears to be limited information available to the dose reconstructor with respect to the nature of the work performed by the workers. This issue warrants further investigation, along with the investigation of the legibility/accuracy/completeness of the database(s) used for dose reconstruction, in order to assess the ability to reconstruct worker doses, as supplemented with the coworker model.

6.1.2 Beta Dose

Page 25 of the site profile indicates that beta dose was measured from 1950–1964. However, prior to 1964, exposure record forms did not have a column to enter beta dose. Table 3 (ORAUT 2006, p. 11) covers 1964–1987 and not the entire period (1958–1972 and 1997) of DU operations, which could involve beta exposure.

The geometry of the worker's body parts with respect to the radiation source was not described. The use of gloveboxes/fume hoods was not mentioned; these fixtures would alter the dose received to the different organs in comparison to the badge worn on the chest. Sufficient details concerning the potential for beta exposure from the various electron-producing and beta-emitting sources, as a function of time and work location, are lacking in the TBD.

Finding 6: It appears that there are large time periods where beta exposure records are lacking, making it difficult to reconstruct beta doses for workers during those time periods and for developing a coworker model that can cover those time periods. In addition, the details of beta exposures are lacking.

6.1.3 Moderated Neutron Dose

The site profile states that neutron generators (D-T producing 14.7 MeV mono-energetic neutrons) and radioisotope neutron sources (PuBe producing an average energy of 4.5 MeV neutrons) were used at the KCP from 1960s to 2004; additionally, these neutron sources are listed in Table 4 of the site profile (ORAUT 2006, p. 12). NTA film and polycarbonate neutron dosimeters can be calibrated to these medium-energy neutron sources in the energy range of 1 MeV to 15 MeV; however, for any occupied working area, there will be neutron shielding consisting of moderating (hydrogenous) material between the neutron source and the workers, which degrades the neutron energy and creates gamma radiation from neutron-capture reactions. Some of these degraded neutrons will be below the ~1 MeV thresholds of the NTA film and polycarbonate.

SC&A considers this an unregistered dose that would not be recorded on the workers' records. If a significant fraction of the dose is less than 1 MeV, there will not be a detectible neutron dose recorded, when an actual neutron dose was received. This may partly account for the NIOSH statement (ORAUT 2006, p. 27):

> *Overall, the recorded neutron dose is a relatively insignificant component of the worker dose.*

NIOSH does not provide any information (as a function of time) concerning the physical setup, shielding, operating parameters (neutron output and usage fraction), and specific use of the generated neutron fields to allow for an evaluation of the potential neutron exposures to the workers. Documentation providing benchmark neutron exposure surveys would be helpful in assessing the potential neutron exposures. Additionally, job titles for the workers that may have potentially been exposed to neutrons are necessary to evaluate the recorded neutron dose records, and to also assist the dose reconstructor in looking for, and assigning, neutron doses during the dose reconstruction process.

Finding 7: The scarcity of positive neutron doses might be explained, in part, by the limited ability of NTA film to detect neutron energies below 1 MeV. Additionally, neutron exposures may have been missed during neutron area surveys, because the only neutron survey instrument listed in Table 5 (ORAUT 2006, p. 13) is a Nuclear Chicago Model #2715, and this instrument may not have correctly responded to the pulsed neutron fields with the generator(s) being operated in the microsecond pulse mode, which was typical at KCP, as indicated in Table 4 (ORAUT 2006, p. 12).

6.1.4 Neutron Dosimetry Correction Factors

Section 6.3.2 of the site profile describes the personal neutron dosimetry systems employed at the KCP, including techniques and exchange frequencies provided in Table 14 (ORAUT 2006, p. 25). One of our concerns is that quarterly exchange of NTA film can result in complete loss of countable track and yield 0 dose recordings for low-level and/or low-energy neutron exposures. This is illustrated in a 1974 article by L. Phillips (Phillips 1974, pdf p. 18), which describes tests run at Brookhaven National Laboratory (BNL) to determine NTA track fading. The results, using a relatively high-energy bare PuBe neutron source, are shown in Figure 2.

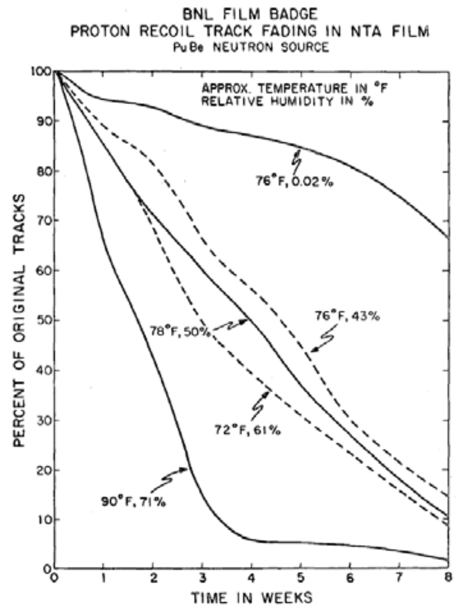

Figure 2: Percent of Original Tracks vs. Time

Finding 8: The fading of the NTA film as a function of time, temperature, and humidity, was not addressed in the site profile, nor were there any correction factors provided. Lower-energy moderated neutrons would show even more fading as compared to the higher-energy neutrons. Additionally, the angular response of NTA film and polycarbonate neutron dosimeters was not addressed, which generally requires a 30% correction factor.

6.1.5 Neutron-to-Photon Ratios

Page 27 of the site profile (ORAUT 2006) states the following:

> *KCP worker recorded positive neutron dose was recorded a total of 35 times over a period from 1966 through 1996, with most instances occurring in the 1980s with good dosimetry capabilities, from a total of 14,758 annual dose records. In all cases, except for 2, the recorded annual deep dose is equal to the recorded annual neutron implying all recorded deep dose resulted from the neutron dose. … As such, the recommended approach is to use a neutron to photon dose ratio of 1:1 as a conservative estimate of neutron dose to the few workers with any potential of neutron exposure.*

In light of concerns regarding the reliability of NTA film with respect to lower-energy neutrons, it is not apparent that there is a sound basis for assigning a n/p ratio of 1:1. In other site profile reviews, SC&A has stated that n/p ratios can be used to derive neutron doses if a reliable set of paired data of neutron and photon measurements are available and which employed instruments that can detect the full range of neutron energies. It does not appear that this approach was used to derive the n/p ratio of 1:1.

Finding 9: Neutron-to-Photon (n/p) ratios require additional investigation in order to develop a recommended approach for dose reconstructors.

6.2 COWORKER DATA ISSUES

Page 26 of the site profile (ORAUT 2006) states the following:

> *…it is reasonable to assume that any unmonitored dose would be less than the dose received by monitored workers.*

Figure 2 of the site profile, which presents a lognormal probability plot of KCP recorded annual penetrating dose (ORAUT 2006, p. 27), shows the probability of occurrence versus the annual dose (mrem) for 1950–2003. This plot indicates a median dose of around 20 mrem/year and a 95th percentile of around 70 mrem/year. Table 15 (ORAUT 2006, p. 28) provides a list of coworker doses as a function of year for the period of 1950–1990. There appears to be a reasonable amount of data available for this coworker model. However, it would be useful to obtain a spreadsheet of the data in Table 15 to allow creation of a plot consisting of dose versus year to better visualize trends and abnormalities in the data.

Table 15 also shows that there were 577 workers monitored during 1969, with all 0 recorded doses. This appears to be unusual, because the adjacent years had approximately the same number of workers monitored with the median and 95th percentile doses both positive. To use the information in Table 15 as coworker data, the reason for the 1969 abnormality needs to be investigated to determine if there were problems with the dosimetry system (which may have spilled over into other years), or if the lack of recorded positive dose was a result of other influences, such as changes in operations, lost records, etc.

Finding 10: It may not be always correct to assume that unmonitored workers experienced exposures that were generally lower than those experienced by monitored workers, because monitoring in the early years may not have been as thorough as would be desired. In addition, as discussed in previous findings, coworker categories are ambiguous and might result in inappropriate coworker dose assignments. Furthermore, Table 15 may reflect decreased average recorded doses as the number of zero dose records included may not be a complete accounting of the actual dose to workers.

6.2.1 Dosimeter Response to Low-Energy Photons

Page 24 of the site profile (ORAUT 2006) states the following:

> *The photon energy spectra in KCP workplaces have not been measured. The spectra are related to the configuration of the X-ray machines, the process, and the extent of shielding. However, regardless of the precise spectra, significant photon radiation would have been readily measured at KCP by the available dosimeter technology during all years of operation.*

And on p. 28, it is stated:

> *The energy of prevalent photons based on the radiation sources is readily measured, so no adjustment of recorded dose would be likely based on the response characteristics of the different dosimeters.*

However, on p. 25, it is stated:

> *Eberline standard (three-chip, TLD-100) TLD – used from 1983 through 1990. This dosimeter employs one chip under a 10-mg/cm^2 filter to measure the shallow or skin dose and one or two chips under a 285-mg/cm^2 filter to measure the deep or whole-body dose (TMA 1990). The use of this dosimeter was terminated due to its inability to pass DOELAP lower energy photon performance testing categories…*

The dosimeters were apparently calibrated using Co-60 (ORAUT 2006, p. 24), which is a relatively energetic photon source (1.17 and 1.33 MeV). However, numerous x-ray producing units were used at the KCP, as listed in Table 4 (ORAUT 2006, p. 12). These x-ray machines produced a wide spectrum of primary and scattered photons down to very low energies. The dosimeters calibrated using Co-60 may not have correctly responded to these lower-energy photons. Therefore, a correction factor may be needed, especially for determining the dose to skin and shallow organs.

Finding 11: A correction factor for exposures to photon radiation might be needed, due to the differences between the actual photon energy distributions created largely by x-ray machines, and the relatively high-energy photons associated with Co-60, which was used for calibration of dosimeters. This issue is especially of concern regarding exposures to skin and shallow organs.

6.2.2 KCP Site Profile Text Issues

The following areas need clarification/correction to provide more definitive information for the reader or dose reconstructor:

- **Radiation Sources –** Table 4 (p. 12.) provides a list of the typical radiation sources used at the KCP. The 230-curie Cesium Irradiator is listed as used for "Calibration of radiation detection instruments." However, this would be a very large source to use for calibration of instruments; most likely it was an irradiation source for parts or inspection, not for calibrating instruments.

- **Neutron Dosimeters –** The text in Section 6.3.2 (p. 25) discusses only the Lexan neutron detector, but lists other neutron detectors in Table 14. The text should provide information concerning all types of neutron detectors used at the KCP. Additionally, Table 14 is incomplete for the 1961–1967 and 1967–1973 time periods, because the type of neutron detector is not specified (1967–1973 only lists "film," not specifically NTA film).

- **Shallow Dose Uncertainty –** Section 6.5.4 (p. 31) discusses using Tables 19 and 20 for determining the uncertainty for shallow doses. However, Section 6.5.3 recommends an alternative approach for photon dose that is simpler; the KCP site profile should state whether this alternative approach also is applicable to shallow dose.

- **MDL Method not Applicable to Gaps in Records –** The last paragraph on page 26 reads:

  > *Dose reconstructors should use Method 1 if there is sufficient information and only occasional missed doses, and Method 2 if significant doses are zero or missing. Use Method 2 for workers who were monitored with missing or zero recorded dose or who worked in an area or an occupation where positive dose would be expected but was not recorded.*

  The term "missing" in this content refers to the lack of entry in the dose records, or the lack of dose records. Therefore, assigning dose based on Method 2 (MDL of the detector) is scientifically incorrect, because the worker did not wear a monitor, or the results were not recorded. Instead, coworker or adjacent recorded doses in the worker's records should be used to fill this gap.

- **Incorrect Table Reference –** The last paragraph on page 33 of Section 6.6 states "…is to use the organ DCFs for an AP exposure geometry as indicated in Tables 6 and 7." However, Tables 6 and 7 are from Section 3 for occupational medical exposures. It appears that this statement should refer to **Tables 21 and 22** in this section.

7.0 REFERENCES

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