Draft

REVIEW OF SPECIAL EXPOSURE COHORT ISSUES FOR THE HANFORD SITE FOR THE PERIOD JULY 1, 1972, TO DECEMBER 31, 1990

Volume I – Main Report
Revision 1

Contract No. 200-2009-28555

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September 2011

S. Cohen & Associates: ***Technical Support for the Advisory Board on Radiation and Worker Health Review of NIOSH Dose Reconstruction Program***	Document No. Hanford SEC Issues Review Effective Date: Draft – August 18, 2011 Revision No: 1 – Draft
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Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	07/28/2011	Initial issue
1	09/30/2011	Vol. I: Section 20 regarding Building 324 incidents has been expanded and modified, along with changes to Findings 27-1 and 27-2. Vol. II: "Appendix D: Summary of Interviews Related to Building 324 Incidents" has been added.

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LIST OF ACRONYMS AND ABBREVIATIONS

Advisory Board or Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
ARHCO	Atlantic Richfield Hanford Company
BNW	Battelle Northwest
CATI	Computer Assisted Telephone Interview
c/m or cpm	counts per minute
CSMO	Central Scrap Management Office
DNFSB	Defense Nuclear Facilities Safety Board
DOD	Department of Defense
DOE	Department of Energy
DPM	disintegrations per minute
FFTF	Fast Flux Test Facility
FP	Fission Products
FRG	Federal Republic of Germany
FY	Fiscal year
GSD	geometric standard deviation
HEPA	High-Efficiency Particulate Air
HEDL	Hanford Engineering Development Laboratory
HEU	highly enriched uranium
HT	tritiated hydrogen gas
HTO	tritiated water
IMBA	Integrated Modules for Bioassay Analysis
kgs	kilograms
L	liter
µCi/lb	microcurie per pound
MDA	minimum detectable activity
MeV	million electron volts
MFP	Mixed Fission Product
mL	milliliter
mrem	millirem

mR/hr	milliroentgen per hour
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH OCAS Claims Tracking System
OBT	organically bound tritium
ORAUT	Oak Ridge Associated Universities Team
pCi/d	picocurie per day
PFP	Plutonium Finishing Plant
PNNL	Pacific Northwest National Labs
ppb	parts per billion
ppm	parts per million
PUREX	Plutonium-Uranium Extraction
R&D	research and development
RCRA	Resource Conservation and Recovery Act
REX	Radiological EXposure (Hanford exposure database)
RM	Radiation Monitoring
RTD	Resistance Temperature Detector
RWP	Radiation Work Permit
SC&A	S. Cohen and Associates
SEC	Special Exposure Cohort
SR	Savannah River
SRDB	Site Research Database
SRS	Savannah River Site
TBD	Technical Basis Document
TLD	thermoluminescent dosimeter
TOFDL	Thorium Oxide Fuel Development Laboratory
UST	U.S. Testing

1.0 OVERVIEW

This is a review of the issues remaining in the Hanford Special Exposure Cohort (SEC) petition, SEC-00057-2. On October 20, 2009, the Advisory Board on Radiation and Worker Health (ABRWH) accepted NIOSH's recommendation to extend the Hanford SEC to all Hanford workers who met the eligibility criteria for an SEC. The period between July 1, 1972, and December 31, 1990, which was the balance of the period in SEC petition SEC-00057-2, was reserved for future examination. NIOSH was to publish a revised Technical Basis Document (TBD) for Hanford to describe how it was going to approach dose reconstruction for this remaining period.

SC&A prepared an update to the SEC issues matrix and sent it to the Hanford Work Group in November 2009. This matrix update specified the remaining outstanding SEC issues (Appendix B) and also noted the issues that were resolved. The following issues were resolved so far as the SEC review was concerned, because they involved dose reconstruction prior to June 30, 1972, the period for which Hanford employees with qualified employment have been added to the SEC class, or because they do not involve feasibility of dose reconstruction in the July 1, 1972, to December 31, 1990, period, but rather the details of how it might be approached with available data:

- Matrix Issue 1. Thorium-232 internal exposure from September 1, 1946, up to December 31, 1959.
- Matrix Issue 2. Americium-241 internal exposure, January 1, 1949 to December 31, 1968.
- Matrix Issue 5. Uranium intake estimation prior to 1948.
- Matrix Issue 15. Hot particle ingestion (only relevant to the 1940s and 1950s).
- Matrix Issue 17. Neutron doses to December 31, 1971 (after which TLDs were introduced).
- Matrix Issue 18. External exposure geometry. This was determined during the Work Group process to be a site profile and not an SEC issue.
- Matrix Issue 24. Po-210. (Not relevant after June 30, 1972)

NIOSH published a revision of the Hanford site profile in 2010 [six volumes covering Introduction, Site Description, Occupational Medical Dose, Occupational Environmental Dose, Occupational Internal Dose, and Occupational External Dose (ORAUT 2010a through ORAUT 2010f]. One reason this revision was published was to demonstrate its approach to dose reconstruction for the rest of the SEC period from July 1, 1972, to December 31, 1990. The revision also specifies dose reconstruction approaches for the SEC period that enable partial dose reconstruction in the period up to June 30, 1972, for which an SEC has been granted, as well as dose reconstruction for 1991 and beyond.

The Hanford Work Group asked SC&A to review the 2010 version of the Hanford Site Profile to examine issues only as they relate to the feasibility of dose reconstruction during the remaining

period of the SEC petition (July 1, 1972, to December 31, 1990). Issues relating to details of dose reconstruction methods once feasibility of dose reconstruction is established were to be left for later review as Site Profile issues at the direction of the Work Group. This enables as rapid a review of the remaining SEC issues as possible.

In addition, this report also addresses an additional issue brought to the attention of the Advisory Board during the course of its deliberations. This issue relates to whether the high radiation levels found under Building 324 after 1990 are relevant for the SEC period from July 1, 1972, to December 31, 1990.

It should be noted that while some issues relating to data quality have been addressed as relevant and necessary for this report, the issue of the quality of the data as it related to analyses done by U.S. Testing (UST) from January 1, 1987, to December 31, 1989, for workers in the 200 Area Plutonium Finishing Plant is not covered in this report. That issue is the subject of a separate SEC Petition (SEC-00155) and is being addressed in a parallel, but distinct, process of investigation by NIOSH and by SC&A (at the direction of the Board). SC&A was asked to begin review of this petition during the May 23–25, 2011, meeting in St. Louis, Missouri.

For ease of reference, the finding numbers are keyed to the matrix issue numbers.

1.1 Findings

Finding 3-1: There were Th-232 production and handling operations in the July 1, 1972, to December 31, 1979, period; these operations may have been intermittent. Specific examples of such operations in the 1970s have been documented above. There was also some intermittent exposure potential during surveys and some construction operations in the 1970s and 1980s, but the extent of such exposure potential is unclear.

Finding 3-2: NIOSH's interpretation of the Th-232 data as being based on Ac-228 counts is based on "an educated guess," and appears to be at variance with Hanford internal dosimetry protocols. NIOSH should investigate whether there is a documentary basis for interpreting the available in-vivo thorium data.

Finding 3-3: There are scattered thorium in-vivo counts available for the July 1, 1972, to December 31, 1990, period, but the data are sparse and insufficient for dose reconstruction and coworker models.

Finding 3-4: NIOSH's approach of using uranium bioassay data for thorium intake estimation for the WR Vault and Buildings 3722 and 3732 is technically unsupported and not appropriate for dose reconstruction.

Finding 4-1: Highly enriched uranium (HEU) was present in some parts of Hanford, notably, but not only, in the Hanford Engineering Development Laboratory (HEDL), throughout the July 1, 1972, to December 31, 1990, period. Some handling and packaging was periodically done, and there may also have been some processing; hence, some HEU exposure potential existed.

Finding 4-2: NIOSH's approach to interpretation of fluorometric bioassay data for enriched uranium depends on knowledge of workers' locations at the general times when the samples were taken. A limited SC&A examination indicates that such information is usually available.

However, a consultation with NIOSH Hanford dose reconstructors, as well as a more detailed verification from individual worker files, is needed before the method can be applied with confidence to HEU exposure in the SEC period under consideration (July 1, 1972, to December 31, 1990).

Finding 4-3: There are in-vivo data that may indicate HEU exposure for the period in question. NIOSH should examine these data to see if they are relevant for the HEDL laboratory. Prior to use of the U-235 in-vivo data, the discrepancies in minimum detectable activity (MDA) between the technical basis document (TBD) and the REX (Radiological EXposure) database need to be explained and resolved.

Finding 6-1: Overall, NIOSH's method for uranium coworker modeling for the July 1, 1974, to December 31, 1988, period is sound. However, there are some caveats noted in Findings 6-2 to 6-4. NIOSH needs to better justify extending 1988 coworker data to 1989 and 1990, instead of using data from those years for facilities other than the 100 Area.

Finding 6-2: The number of in-vitro measurements in the July 1, 1972, to December 31, 1973, period is small. NIOSH might consider using a 95th percentile or some other upper bound value for the coworker dose assignment for this period.

Finding 6-3: The fit for the early part of the 1975–1983 period needs to be revised to be claimant favorable; at present it is not.

Finding 6-4: The MDAs from 1982 onward to at least 1984 and possibly beyond were higher than assumed by NIOSH, since the contractual and target values were not being met. Since values below the MDA dominate the results, the coworker model in the TBD is not claimant favorable for at least part of the period considered here. SC&A has not been able to locate data quality audits for the 1972–1979 period. These need to be located, if they exist.

Finding 7-1: NIOSH should determine the last date for U-233 production, since thoria pellets were manufactured at least until the end of 1979 at Hanford. SC&A has not found any documentary evidence for thoria target irradiation or U-233 separation in 1979 or later.

Finding 7-2: If thoria targets were irradiated and U-233 was separated in the July 1, 1972, to December 31, 1990, period, NIOSH should determine a bounding intake estimation procedure that is specific to that period or establish that the plutonium intake value used for the pre-July 1, 1972, period is technically appropriate.

Finding 8-1: Trace contaminant data exist for the 1970–1972 period. They can be used for estimating a claimant-favorable value for plutonium and neptunium trace contamination ratios. These data appear to be a more appropriate basis than late 1980s and early 1990s data for estimating recycled uranium doses suggested by NIOSH. NIOSH should analyze the 1970–1972 data to determine a better bounding value to plutonium trace contamination in recycled uranium. For neptunium, it will be necessary to find the calibration factor to convert counts per minute into nanocuries of neptunium per gram of uranium. Other trace contaminant values should also be checked against the available raw data.

Finding 9-1: Neptunium-237 separation (or at least handling) lasted until December 1972 at Hanford, about 6 months after the beginning of the SEC period being reviewed here. Neptunium

data are too sparse (and, moreover, appear to be mainly incident-related) to allow for a reliable coworker model to be developed for the July 1, 1972, to December 31, 1972, period.

Finding 9-2: Neptunium recovery at Hanford was discussed in the context of processing high-level waste from the Barnwell Nuclear Fuels plant. While the Barnwell plant was never operated for reprocessing spent fuel, NIOSH should make a more complete effort to determine whether neptunium was separated in the 1983–1990 period when the PUREX plant was periodically operated.

Finding 9-3: NIOSH has not provided a technical basis for its choices for Np-237 intake assignment in relation to plutonium from 1973 onward.

Finding 10-1: Tritium was produced at Hanford until June 1973. NIOSH has not specified a coworker model for tritium for the period of July 1, 1972, to June 30, 1973, that takes this into account. The approach specified by NIOSH of calibrating tritium intake to total uranium burnup is not likely to be claimant favorable for this period.

Finding 10-2: NIOSH has not provided a quantitative justification for using a small set of data from 1982 and 1983 to derive a conclusion that the chosen coworker intake value for tritium is also valid for July 1, 1972, to the end of 1981.

Finding 10-3: NIOSH should provide a technical basis for using the same value for N Reactor workers from July 1, 1972, to the end of 1981 as for 1950s' unmonitored reactor workers.

Finding 10-4: NIOSH has pointed to the presence of organically bound tritium (OBT) in 108-B and potentially of metal tritides starting in 1988. However, NIOSH has not specified which workers had exposure potential or a basis upon which OBT or tritide dose would be assigned.

Finding 10-5: NIOSH has pointed to the possible presence of metal tritides starting in 1988. However, NIOSH has neither confirmed the presence of metal tritides, nor specified a dose reconstruction method for metal tritides. NIOSH needs to identify the periods of tritide exposure potential and the group of workers who might have been exposed to metal tritides.

Finding 11-1: Contrary to an inference in the NIOSH site profile, Pm-147 processing occurred in the 1972–1975 period and appears to have continued into the late 1970s.

Finding 11-2: NIOSH's assigning the same Pm-147 intakes throughout the 1970s is not claimant favorable, given that processing operations occurred during portions of this period. NIOSH has ample Pm-147 data for the 1960s that may be more appropriate as a basis for coworker models, since that was also a period of production. This is indicated by NIOSH's coworker analysis in the TBD. NIOSH should investigate whether this is appropriate for demonstrating dose reconstruction feasibility during the times in the 1970s when Pm-147 processing occurred. Specifically, NIOSH should investigate whether working conditions were comparable enough to allow the use of earlier data for the period of production in the 1970s.

Finding 11-3: NIOSH should investigate how it is going to address possible intakes, as a result of documented incidents in 1974 and 1975. NIOSH should also investigate other Pm-147 incidents in the SEC period, especially during 1972–1979.

Finding 12-1: Overall, there seem to be ample data for Sr-90 and Cs-137 to create coworker models except in certain years.

Finding 12-2: NIOSH's approach for assigning the same Sr-90 intake values for the period from 1971 onward is not claimant favorable. A more claimant-favorable approach needs to be developed. The Cs-137 and mixed fission product models should also be reviewed in light of the Sr-90 and Cs-137 recovery operations and the processing to condition Cs-137 and Sr-90 for encapsulation out to the completion of the encapsulation process in October 1983 for Cs-137 and January 1985 for Sr-90.

Finding 12-3: The mixed fission product data for tank farm workers for July 1, 1972, to the end of 1977 are very sparse. NIOSH needs to examine whether its present approach is adequate for tank farm workers or whether a special coworker model is needed for them for this period.

Finding 12-4: The implications of the failure to meet contractual MDA limits for several fission products (though not Sr-90) are unclear. NIOSH has not discussed this issue.

Finding 12-5: NIOSH has specified coworker models for several specific fission products. The method specified by NIOSH is applicable to reactor areas, but not to separations or waste handling and processing areas. An explicit approach for unmonitored workers in reprocessing and waste handling and processing areas needs to be developed for radionuclides that have not yet been covered for the 200 Area and for certain buildings in the 300 Area.

Finding 14-1: NIOSH has not considered Type Super S plutonium for intake estimation.

Finding 14-2: NIOSH should take the different, non-contractual MDA for 1981 into account in its coworker model.

Finding 14-3: NIOSH should ensure that extending 1988 values to 1989 and 1990 is claimant favorable for separations workers.

Finding 14-4: NIOSH's method of redacting samples relating to incidents may bias coworker intake estimates towards a lower intake level.

Finding 16-1: Curium-244 exposure potential existed due to experimental operations in 1973 and due to other operations later in the SEC period, probably related to refurbishment of facilities. SC&A has documented exposures due to incidents in 1978. It is unclear whether this potential continued into the 1980s. Routine sampling appears to have begun in November 1983.

Finding 16-2: Curium-244 data do not exist for 1973, and are sparse thereafter until October 1983.

Finding 16-3: A coworker model for Cm-244 may be feasible after 1984 (inclusive).

Finding 16-4: NIOSH has not provided a technical rationale for using plutonium data for Cm-244 dose reconstruction. This does not appear to correspond to documented situations with Cm-244 exposure potential.

Finding 16-5: NIOSH should develop a coworker model that is specific to Am-241, apart from its association as a trace contaminant in plutonium, especially for the period up to 1976. This

may be difficult, given that much of the Am-241 in-vitro monitoring was in the context of incidents.

Finding 21-1: A large number of records have been destroyed as a matter of government record-keeping practices. The vast majority of these records were administrative records of no relevance to dose reconstruction.

Finding 21-2: A small portion of these boxes appear to have contained data relevant to dose reconstruction, but most appear to have been prior to the period under consideration. Some boxes that may be relevant have no dates indicating the period of the documents in the box. Finally, a small portion of the boxes have labels that indicate they are relevant and a date that places some or all of the contents in the period under review here. SC&A has not been able to establish whether the destroyed boxes contained data that could fill in some of the gaps described above for internal dosimetry.

Finding 22-1: The individual records, consisting of a combination of the records supplied by DOE and Computer Assisted Telephone Interview (CATI) reports, appear to document the vast majority of incidents. There does not appear to be a detectable pattern of not recording incidents.

Finding 22-2: The REX databases do not appear to contain the detail of information or the quantity of information available in the claimant records.

Finding 25-1: The MDA for several of the radionuclides in question in this section were not met in 1981. There are no other audit reports for the 1972–1986 period that address these radionuclides. (SC&A is examining some quality of data issues for the 1987 to 1989 period separately, as noted in the Overview section.)

Finding 25-2: Some of the unusual radionuclides, such as Co-60, only have a significant quantity of in-vivo data from about 1983 or 1984.

Finding 25-3: NIOSH should discuss the pre-1987 quality issues in the TBD relating to several fission products, as well as sodium-24, and specify how it will handle MDA and other problems that may have existed in years other than 1981. (SC&A is in agreement with NIOSH that sodium-24 is only relevant to the 400 Area for the period under consideration here (ORAUT 2010e, p. 53) and only during the period of operation of the Fast Flux Test Facility (FFTF).

Finding 25-4: While NIOSH has specified coworker models for a number of radionuclides and areas, it has not specified a coworker model for mixed fission and activation products in the 200 Area and in the waste-handling and processing buildings in the 300 Area.

Finding 27-1: There were at least two incidents in which radioactive materials migrated from presumably contained hot cells and/or pipes to reach the soil. The material recently discovered under B-Cell is unlikely to have created internal exposure potential during the leak; however, the stabilization operations that began in the late 1980s may have created internal exposure potential. Furthermore, we note that the source of the leaks discovered under A and C cells is not well understood.

Finding 27-2: In general, there appear to be ample internal monitoring data for 300 Area workers for Cs-137 and mixed fission products (MFPs), and overall for Sr-90 during the 1980s,

which is the period in question for the B-Cell incidents. However, it is important for NIOSH to verify whether the specific employees who worked in Building 324 at the time of the leaks, including the A-Cell and C-Cell leaks and their management, and during the B-Cell stabilization operations have adequate internal monitoring data for dose reconstruction. A detailed review of the logbooks and incident records relating to B-Cell operations in the mid- to late-1980s and of the operations in A-Cell and C-Cell may also be warranted given the scale of the contamination. For quality of data comments prior to 1987, see Section 10.

Finding 27-3: NIOSH should investigate whether there were ad hoc mixtures of fission products for which there are scant data for the period used in B-Cell feasibility studies during the mid- to late-1980s. If such operations were done, NIOSH should specify a dose reconstruction approach for those operations.

2.0 MATRIX ISSUE 3: THORIUM-232 EXPOSURES FROM 1960 ONWARDS

This issue was resolved from 1960 up to June 30, 1972, by the extension of the Hanford SEC. The balance of the period from July 1, 1972, to 1990 remains to be addressed.

2.1 Thorium-232 Handling and Processing

ORAUT 2010e, the updated Site Profile, provides the following information regarding thorium handling and processing at Hanford:

Table 1. Buildings with Thorium Processing

(Gerber 1992; Isochem 1967; Walser 1978)

Building, Area	Date
313, 300	1945–1970
314, 300	1945–1970
305, 300	1945–1946
306, 300	1955–1970
3706, 300	1954–1963
3707 A&B, 300	1945–1970
3732, 300	1965–1970
3722, 300	1946–1970
325, 300	1963[a]
321, 300	1964–1970
202 A, PUREX, 200 East	1965–1970
241-WR vault, 200 West	1965–1978
224-U, 200 West	1966–1967
a – Hot cell work only. Worker exposure unlikely.	

Source: Reproduced from ORAUT 2010e, p. 48

The only item that is relevant to this report in the above table is the handling of thorium in the 241-WR vault in the 200 West Area, since it includes the period from July 1, 1972, to 1978, which is part of the SEC period under review in this report. Of the publications referenced in the above table, Isochem 1967 is not relevant to the period under consideration; neither is Walser 1978, which only concerns a 1970 thoria campaign, and does not address any thorium handling or processing beyond 1970. The TBD further notes that the main thorium projects ended in 1970, though there may have been some limited projects:

> *Except for small-scope, limited-time projects that might have occurred occasionally (such as shipping of stored thorium from the PUREX campaigns), exposure to thorium at Hanford stopped in 1970.* [ORAUT 2010e, p. 49]

According to a December 1976 National Lead of Ohio memorandum, National Lead (also known as the "Fernald Plant") expected to receive 100, 150, and 100 metric tons of thorium nitrate stored at the time of the writing of the memorandum in tank cars at Hanford in FY 1977, FY 1978, and FY 1979, respectively (Audia 1976). The shipments did take place, since a 1979 Fernald memorandum states that the thorium nitrate from Hanford was processed into thoria gel at Fernald between May 1977 and January 1979 (Gessiness 1979). However, it should be noted that the dates of the filling of the tank cars at Hanford were not researched by SC&A. It is unlikely that there was routine internal exposure potential after the tank cars were filled.[1] But there may have been internal exposure potential during the filling of the tank cars and due to any incidents, such as spills, that may have occurred. There was also thorium nitrate on site after the 1976 shipments, as noted during the interviews that SC&A did with Hanford employees:

> *In 1979, 222-S Laboratory analyzed some thorium nitrate for the purpose of disposal. There were some outside underground tanks of thorium nitrate at the east end of U Plant. Thorium in these tanks was left over from the thoria runs conducted in the late 1960s. Samples were collected from the tanks and brought to the 222-S Laboratory. Aliquots of the samples were taken, and destructive analysis was run on the aliquots. The 222-S Laboratory also did Pm-147 analysis in the 1960s and worked on several different types of fission products. There was a shed on the east side of 222-S that was contaminated by Pm-147. There may have been a spill.* [See Appendix B of this report, p. 19]

Furthermore, thorium processing did take place after June 30, 1972. Specifically, the monthly activities report for November 1979 describes thorium processing in Building 306 as follows:

> *A new RWP was issued to cover decontamination and removal of two ventilation hoods from existing duct work and transporting and installing them in the Thorium Oxide Fuel Development Laboratory (TOFDL).*
>
> ***Three batches of thorium oxide have been made into pellets in the TOFDL.*** *Thorium oxide with 20% UO_2 oxide is presently being processed in TOFDL.* [Monthly Activities Report – November 1979, in SRDB 67785, pdf p. 71] [Emphasis added.]

The December 1979 activities report describes more on the set of thorium pellets that were fabricated in that month:

> *JA Jones construction is still in the process of renovating room 120 in preparation for installing new equipment. The floor and walls in the room need to be painted; the floor is scheduled to be covered with tile after it is painted. The fixed uranium contamination on the floor has been painted over with yellow paint.*

[1] SC&A has not explicitly researched the topic, but did not come across any incident related to a thorium nitrate spill from tank cars once they were filled during the document review for this report.

> *Maintenance continues to machine depleted uranium rods for DOD in the hot shop.* ***The last batch of thorium pellets*** *is presently being fabricated in TOFDL (approximately 7 kgs). The pellets will have to be weighed, sintered, ground, reweighed, and ultrasonic cleaned before they can be loaded into 36" zirconium rods. A radiation level of 0.6 mR/hr has been detected at the side of a rod loaded with thorium pellets.* [Monthly Activities Report – December 1979, in SRDB 67785, pdf, p. 68] [Emphasis added.]

It is unclear from these two monthly reports whether the December batch was the last one in the series of four batches described therein, or whether they were the last ever fabricated at Hanford. Certainly, the date of processing is beyond that described in the TBD (reproduced in the table from the TBD above). In fact, the Thorium Oxide Fuel Development Laboratory was built or refurbished in 1978:

> *Work on the Thorium Oxide Fuel Development Laboratory (TOFDL) in 306 is continuing with the installation of new piping, new duct work, and new equipment.* [Jech 1978b, pdf p. 335]

Since a new or refurbished facility was built in 1978, there may have been an intent to do thorium oxide-related work for some time. As noted above, thorium pellets were fabricated in 1979. SC&A has not investigated if the thorium oxide work continued into the 1980s and, if so, for how long.

In addition, there was extensive thorium contamination in parts of the 300 Area in the 1970s. For example, volume 2 of the TBD notes that, after the 1960s, there was thorium (and uranium) contamination in Building 321 (ORAUT 2010b, pp. 23–24).

Gerber's history of the 300 Area provides evidence of contamination in other 300 Area buildings as well:

- In 1976, it was found that "much uranium and thorium contamination lies in and beneath the 306 Building floor, slab, pipe trenches, and sewer lines" (Gerber 1992, p. 16).
- In 1977, thorium contamination was found in the West process trench lime pit (Gerber 1992, pp. 16–17).
- The 3732 Building was a process development laboratory where work ended in 1970. However, contamination from the thorium process development existed "throughout and near the building" when Gerber wrote the 300 Area history in 1992 (Gerber 1992, p. 55)
- When a new 3719 Building was built in 1977 and 1978, "contamination readings of 50,000 c/m [counts per minute] of U-235 and thorium were found in the sewer line… Some contaminated soil was removed at that time" (Gerber 1992, p. 95). According to Gerber, the building served as a first aid building, a photography processing shop, and headquarters for fire protection. While it was sometimes referred to as the "old laundry building," Gerber states that no laundry was done there (Gerber 1992, p. 95). No explanation for the thorium and uranium contamination is provided.

- According to Gerber, "every process drain, pipe, pipe trench, and sewer manhole in the 300 Area also must be expected to contain some degree of process waste buildup, the amounts varying depending on the age and type of facility… For example, surveys in the late 1980's found thorium and uranium contamination in a manhole southeast of the 321 Building…" (Gerber 1992, pp. 114–115).

Evidently there was some exposure potential to the personnel conducting the surveys in the 1970s and 1980s. The extent of the exposure potential cannot be deduced from these descriptions, which were recorded as guides to decommissioning operations in the post-1992 period. However, two points can be noted. First, the exposure potential from such survey activities was likely very intermittent. Second, the internal exposure potential may have been limited, except when soil or residual matter was disturbed. This latter observation derives from the fact that the above list compiled from Gerber is connected with residual, rather than production-related, exposure potential.

2.2 Thorium Monitoring Data – Quantity

There are some in-vivo thorium monitoring data for the post-June 30, 1972, period. The data are reported as Th-232, but according to the TBD, the monitoring was based on Ac-228 counting (ORAUT 2010e, p. 49):

> *Although the in vivo records show the results as ^{232}Th, the measured activity was ^{228}Ac… The two radionuclides would not have been in equilibrium; both disequilibrium at intake and separate biological processes on the ^{232}Th parent and the ^{228}Ra progeny mean that the ^{232}Th activity in the body would not have been the same as the measured ^{228}Ac.* [ORAUT 2010e, p. 49]

Thorium-232 in-vivo data are sparse for the period of July 1, 1972, to December 31, 1990. There are only two in-vitro measurements in 1981. Nine in-vitro measurements in all are labeled "TH." Until 1979, a few in-vivo counts for Th-232 are listed with a detection limit of 0.5 nCi. There are 21 Th-232 counts recorded in the 1980s with count-specific detection limits that vary from 0.19 to 0.93 nCi, with a median of 0.43 nCi (ORAUT 2010e, pp. 48–50). Table 2 shows the number of available measurements by year.

The measurements are scattered over a number of job titles. In about half the cases, the job title is unknown. The data do indicate thorium intakes, for instance in 1985. SC&A has not investigated whether some special decommissioning or processing or other work led to the thorium counting in 1983, 1985, and 1986.

Overall, these Th-232 data would be insufficient to reconstruct doses during the period of processing and handling of Th-232, which appears to extend at least to the end of 1979. However, it should be noted that such handling or processing may have been intermittent, rather than continuous. SC&A has not investigated whether the in-vivo Th-232 samples were associated with actual processing or with exposure related to decommissioning activities.

Table 2. Thorium-232-Related Measurements at Hanford, July 1, 1972, to December 31, 1990

Year	Total # Workers	# of Workers Monitored by In Vivo		# of Workers Monitored by In Vitro	
		Th-228	Th-232	Th (see note)	Th-232
1972	8,494	–	1	–	–
1973	9,051	–	1	–	–
1974	10,740	–	–	–	–
1975	11,374	–	–	–	–
1976	12,164	–	–	–	–
1977	14,751	–	2	–	–
1978	16,063	–	–	–	–
1979	16,626	–	7	1	–
1980	16,281	–	–	7	–
1981	16,161	–	–	1	1
1982	15,220	–	–		–
1983	16,657	1	4	–	–
1984	16,949	–	–	–	–
1985	17,826	–	10	–	–
1986	18,200	–	4	–	–
1987	18,318	–	–	–	–
1988	16,542	–	–	–	–
1989	16,016	–	–	–	–
1990	16,920	–	–	–	–

Note: Measurements labeled "Th" appear to be total thorium (ORAUT 2010e, p. 39), i.e., combined Th-232 and Th-228.

2.3 Thorium-232 Monitoring Data – Quality

Thorium cannot be measured directly; it is the decay products of Th-232 that are measured. Therefore, it is necessary to know which decay products were measured and the age of the thorium to assess the extent of the disequilibrium. NIOSH assumed that in-vivo thorium measurements were made by measuring Ac-228, and that the thorium age from the time of last processing was 0.5 years (ORAUT 2010e, p. 49). NIOSH has provided no technical basis or data for this choice. For instance, NIOSH has not cited typical storage times before processing. Further, NIOSH provides a note attributed to Don Bihl, the Battelle Principal Health Physicist, that the conclusion that Ac-228 was monitored was not based on actual documentation:

> *This is based on discussion with T.P. Lynch [the In Vivo Monitoring Project Manager at Pacific Northwest Laboratory]; however this is an educated guess by Lynch based on present practices and his knowledge of the detection systems at the time. Documentation that the Th-232 body burdens were based on Ac-228 has not been found.* [ORAUT 2010e, p. 74]

In addition, the 1989 Hanford Internal Dosimetry Program Manual states that Th-232 was measured via Tl-208 gamma radiation; the manual gives 2 nanocuries as the whole-body limit of detection, and 1.5 nCi as the lung burden detection limit for the "Preview Counter" (Carbaugh et al. 1989, p. 6.10, pdf pg. 77). We note that the TBD lists the same 2 nCi detection limit, but attributes it to Ac-228. It is unclear why "an educated guess" has been chosen over documentation in the Hanford internal dosimetry manual. At the same time, the accuracy of Th-

232 detection using six germanium planar detectors and counting Pb-212 is listed as 0.36 nCi (Carbaugh et al. 1989, Table 6.8). The dates of use of the various counters and methods are not clear and have not been further investigated by SC&A. The Hanford Whole Body Counting Manual is in agreement with this last statement [Th-232 based on Pb-212 for lung counting using 6 germanium detectors with a 0.36 nCi detection limit (Table 7.1, Palmer 1990)]. It also lists Th-232 being measured through the 2.612 MeV (Tl-208) on the Preview Counter and when the shadow shield counter is used.

In summary, data for Th-232 are not only sparse, they are difficult to interpret because of conflicting statements and documentation about how they are to be interpreted. It is possible that document research going back into various editions of internal dosimetry procedures may be able to clarify the issues sufficient to enable reliable information as to which decay product was actually measured in the in-vivo count. Furthermore, we note that reliable in-vivo monitoring for Th-232 requires separate lung counting and a bone count, such as a cranial or knee count, that would distinguish the lung from the bone count. This enables a determination of the distribution of activity between lung and skeleton, which is very important to correctly estimate organ doses. Generally, whole-body counting is not enough to accomplish this. While the TBD notes that head counts and other specialized counts were done at Hanford (ORAUT 2010e, Section 5.3.5), SC&A has found no indication that these methods were applied to Th-232 detection. On the contrary, NIOSH notes that Hanford used whole-body counting contrary to the practice at the time:

> *Note: Use of whole-body counting for thorium monitoring was apparently different than at other AEC sites that used chest counting. Be sure to recognize that the following discussion and Tables 5-26 to 5-28 apply only to whole-body counts.* [ORAUT 2010e, p. 49]

NIOSH then states that, "[c]hest counting for thorium replaced whole body counting in 1979" (ORAUT 2010e, p. 59). However, the Th-232 intakes that NIOSH has specified for in-vivo counting in the TBD do not correspond to chest counting, but to whole-body counting (ORAUT 2011e, Table 5-27, p. 49); therefore, the NIOSH method would not apply to in-vivo measurements after 1979.

2.4 NIOSH's Approach for Thorium-232

NIOSH proposes to interpret the Th-232 data assuming that Ac-228 was the measured radionuclide. We have already detailed the problems with this approach above. Furthermore, for unmonitored workers who were in the WR Vault and Buildings 3722 and 3732 in decontamination activities, NIOSH proposes to use uranium bioassay data for thorium intake estimation:

> *Only five whole body counts specific for ^{232}Th were conducted from 1970 through 1978 and there were a few urinalyses for "total actinides" during this period, but it is possible that workers involved with shipping of the thorium from the WR Vault (primarily storage and transfer of liquid thorium nitrate solution) or involved with decontamination of the 3722 and 3732 Buildings did not receive bioassay monitoring. If there is evidence of exposure to thorium from shipping of the material in the WR Vault or decontamination of the 3722 or 2732 Buildings*

> *without bioassay, unmonitored workers should be assigned intakes of thorium (with progeny per Section 5.3.4) using the 95th percentile of the uranium coworker intakes (constant distribution).* [ORAUT 2010e, pp. 59–60]

Based on the analysis in the prior sections, these approaches are inadequate for several reasons:

- Thorium in-vivo data are very sparse, difficult to interpret reliably, and of uncertain quality.

- There was thorium processing at least up to the end of 1979. The NIOSH approaches do not address the workers who were involved in it.

- NIOSH has provided no evidence to show that uranium bioassay data would provide a satisfactory basis for thorium dose reconstruction in the areas where it has proposed this approach. NIOSH had proposed this approach in the 300-M Area for the Savannah River Site for the 1953–1965 period. In that case, NIOSH had provided a rationale for such use. Nonetheless, SC&A found this to be inappropriate and not well founded scientifically for a variety of reasons (SC&A 2011). In the present case, the approach has been suggested for a specific group of workers without any technical basis for the specific circumstances and for the period under consideration.[2] For instance, NIOSH has not analyzed exposure conditions, location, and timing of thorium and uranium processing to show a similarity between the two. While such technical information may not be sufficient, it is required as a necessary starting point for justifying the use of uranium bioassay for thorium intake estimation. At present, it is difficult to see how NIOSH's instruction that there should be "evidence" of exposure to thorium can be implemented with only five whole-body counts for thorium between 1970 and 1978 (four of which were between July 1, 1972, and 1978). It is even more difficult to see how a uranium bioassay can be shown to be a scientifically supportable bounding estimate, given that bone surface committed dose for the same mass intake is roughly two orders of magnitude greater than that for uranium. This would magnify small errors for certain cancers. It is not apparent how errors can be kept small enough to meet the goal of a scientifically reasonable bounding dose.

2.5 Findings on Matrix Issue 3 – Thorium-232

Finding 3-1: There were Th-232 production and handling operations in the July 1, 1972, to December 31, 1979, period; these operations may have been intermittent. Specific examples of such operations in the 1970s have been documented above. There was also some intermittent exposure potential during surveys and some construction operations in the 1970s and 1980s, but the extent of such exposure potential is unclear.

[2] The internal dose TBD states that "[t]horium exposure was associated with uranium exposure in 300 Area facilities from 1950 to 1970" (ORAUT 2010e, p. 131). However, this statement is not relevant to the period under consideration, which is July 1, 1972, to December 31, 1990. Moreover, it is also insufficient to establish scientific reasonableness of using uranium bioassay data, much less a bounding dose estimate.

Finding 3-2: NIOSH's interpretation of the Th-232 data as being based on Ac-228 counts is based on "an educated guess," and appears to be at variance with Hanford internal dosimetry protocols. NIOSH should investigate whether there is a documentary basis for interpreting the available in-vivo thorium data.

Finding 3-3: There are scattered thorium in-vivo counts available for the July 1, 1972, to December 31, 1990, period, but the data are sparse and insufficient for dose reconstruction and coworker models.

Finding 3-4: NIOSH's approach of using uranium bioassay data for thorium intake estimation for the WR Vault and Buildings 3722 and 3732 is technically unsupported and not appropriate for dose reconstruction.

3.0 MATRIX ISSUE 4: HIGHLY ENRICHED URANIUM EXPOSURES FROM JULY 1, 1972, TO DECEMBER 31, 1990

The use of HEU for production purposes (irradiation of target rods for the production of tritium and U-233) continued into the mid-1960s (Gerber 1992, p. 9), but appears to have ended prior to the SEC period under review in this report. However, as noted in matrix issue 4, some R&D uses of HEU continued into the 1980s in the HEDL, which was created in 1972 from a part of Building 306 (Gerber 1992, p. 15).

Specifically, work on plutonium and enriched uranium fuels, including HEU, seems to have continued in the HEDL. SC&A has not been able to find detailed descriptions of these activities, but has not conducted a complete search. However, that these activities took place can be inferred from documents in the late 1970s and early 1980s referring to continued accumulation of scrap, including HEU scrap. These documents are collected in a single file in the Site Research Database (HEU Documents SRDB 66599). There are references to packaging and shipping the scrap for evaluation and possible processing to the Savannah River Site (SRS). For instance, a 1981 document describes the problem as follows:

> *HEDL's scrap storage problem is obstructing program objectives. Request SR* [Savannah River] *to provide scrap disposition instructions by 3/19/1982, to establish whether any relief is imminent through retrievable storage or earlier recovery because of highly enriched uranium associated with some of the scrap.* [HEU Documents SRDB 66599, pdf p. 10].

The problem apparently was excessive radiation exposure due to crowding of stored items. A November 1981 document describes the problem as follows:

> *The accumulation of scrap in HEDL's vault has been a long-standing problem. SR has not been able to receive HEDL scrap since 1978. CSMO* [Central Scrap Management Office] *disposition instructions have been to hold much of the scrap designated for SR recovery until 1987. Funds have not become available for added HEDL vault capacity. Because of the crowding of stored items, HEDL has a serious problem with personnel radiation exposure caused by the necessity for double handling of items to gain access to material needed for work.*

> *We urge that SR reassess the possibility of receiving some of the scrap in the near future.* [SRDB 66599, pdf p. 15]

It is unclear when the backlog of HEU was packaged and shipped in its entirety. However, there is some evidence that scrap shipments may have occurred well into the decommissioning period. A search for HEU documents conducted by ORAUT has brief, one-phrase descriptions of documents in various boxes. These descriptions have several mentions of HEU (HEU Search Results 2008, pp. 2 and 3 for example).

The HEU vulnerability report published by the Department of Energy in 1996 describes the Hanford HEU holdings as follows:

> *The total Westinghouse Hanford inventory is 79 kilograms of HEU, 198 kilograms of commingled plutonium and HEU, and 37 grams of U-233. Three site facilities contain HEU materials within the scope of this assessment: the Fast Flux Test Facility (FFTF), the Plutonium Finishing Plant (PFP), and the 222-S Laboratory. Highly enriched uranium holdings at FFTF include approximately 42.7 kilograms in one stainless steel fuel test assembly in Building 405, and 24 grams within 12 fission chambers in Building 4713-C. Holdings at PFP include approximately 36.3 kilograms of U-235 and 37 grams of U-233. These are in the form of stable powder, pellets, or pins encased in triple-containment packages. This facility also contains 198 kilograms of commingled plutonium and HEU that is the object of a scheduled stabilization program in response to DNFSB 94-1 and the plutonium vulnerability assessment. Holdings of the 222-S Laboratory consist of 7 grams of HEU in three samples.* [DOE 1996, pp. 43–44]

It is clear from the above quote that HEU holdings continued to exist at Hanford past the end of the SEC period under examination here. Some exposure potential is likely in circumstances of processing or handling for packaging for the purpose of shipment, but it appears that it was likely confined to the HEDL and to a much smaller extent elsewhere, as for instance in the 222-S Laboratory mentioned in the above quote from DOE 1996.

3.1 Uranium Monitoring Data

There are extensive uranium bioassay data in the SEC period (see Section 4). However, until 1983, measurements were made by the fluorometric method, from which isotopic composition cannot be determined. Even after 1983 to the end of the SEC period under consideration here (December 31, 1990), alpha spectrometry was only selectively used:

> *Starting in 1983 an alpha spectrometry procedure has been used for some workers, but these data were less robust and were not representative of the overall Hanford workforce. The results were recorded as micrograms per liter from 1947 to July 1, 1982, and as micrograms per sample from July 2, 1982, to present. The latter were converted to micrograms per liter using the sample volume that was recorded as part of the information in the database… Elemental uranium samples were not usually 24-hour samples; a mix of sample collection periods was used from 1947 to 1988 with overnight sampling being one of the*

> *more frequent methods. Therefore, samples of less than 400 mL were not removed from the uranium data.* [ORAUT 2010e, pp. 119–120]

The TBD further states the following:

> *When alpha spectrometry was introduced in 1983, two uranium urinalyses procedures were offered: the elemental procedure above and the alpha spectrometric procedure to provide isotopic results. In general, the elemental procedure was used for workers who were exposed to natural or slightly enriched forms of uranium, and the isotopic procedure was used for depleted or more than slightly enriched forms of uranium. In general, personnel who worked in the production facilities were monitored by the elemental analysis, whereas PNL workers were monitored by the isotopic analysis because of the wide scope of research projects that occurred over the years.* [ORAUT 2010e, p. 30]

3.2 NIOSH Proposed Approach for HEU

Since the vast majority of workers in the period under review were exposed to uranium from depleted to slightly enriched (up to 1.25%[3]), the bioassay data interpreted as 1.25% would be appropriate for estimating uranium dose. For those who had exposure potential to HEU, NIOSH has proposed the following approach for estimating dose:

> *There was exposure to highly enriched uranium (HEU) at Hanford, starting in July 1948, occurring heavily in 1949 through 1956 and sporadically after that. Almost all the known work was done in the 300 Area although there is indication that some work might have occurred in 231-Z. See the Hanford Site Description (ORAUT 2010c) for details. The workers exposed to HEU were most likely also exposed to natural or slightly enriched uranium. There does not seem to be a way to determine from measurements in workers' files whether an intake of uranium included HEU. If exposure to HEU seems likely, the mass urinalysis results should be interpreted as HEU using the 93.5% mixture in IMBA…. If claim-specific evidence is found for HEU from July 1, 1972 through October, 1983, the elemental uranium urinalysis and chest counts will be used to reconstruct dose. From October 1983 on, isotopic urinalysis results that indicate HEU (^{235}U) will be used to reconstruct dose.* [ORAUT 2010e, p. 33]

This method requires knowledge of the location of the worker in the context of bioassay sampling; in other words, for the period from July 1, 1972, up to October 1983. SC&A has conducted audits of individual dose reconstructions for Hanford workers that include this period. These audits indicate that the location of the worker is often, but not always, available in individual claimant DOE files after about 1972 in both internal and external dose records. However, SC&A has not performed a statistically valid check of worker data in this regard. NIOSH should consult with its team of dose reconstructors who have the most experience on Hanford for the period in question to determine whether the method it has set forth in the TBD, quoted above, is a valid one. This is especially important for work in a very specific area like

[3] The highest enrichment of uranium used in the N reactor, the only one to operate in the period under review, was 1.25% (see ORAUT 2010b, p. 12).

HEDL that contained HEU that was not handled in any other area, so far as SC&A can determine, in the period under consideration.

SC&A points out that there are also in-vivo data for uranium. Specifically, there are more than 10,000 U-235 in-vivo measurements starting in 1974, up to and including 1990. Of these, 67 were above the MDAs specified in the REX database. The measurements greater than the MDA may indicate HEU exposure; they are associated with locations in the 300 Area where the HEDL was located. However, the MDAs indicated in the TBD are different than those in the REX database. The MDA, which varies (for instance according to chest wall thickness of the individual), is stated to be 0.17 to 0.37 nCi for the 1968 to 1983 period in the TBD (ORAUT 2010e, p. 46). However, the MDA values for the same period in the REX database are 0.07 to 0.22 nCi. NIOSH specifies a single calculated MDA value for the 1983–1986 period of 0.08 nCi (ORAUT 2010e, p. 46; the 1983 overlap between the two periods for which MDA is specified is not explained). There is a wide range of MDAs indicated in the REX database. SC&A has not investigated the reasons for the discrepancies in in-vivo uranium MDAs between the REX database and the TBD.

3.3 Findings Regarding HEU

Finding 4-1: Highly enriched uranium (HEU) was present in some parts of Hanford, notably, but not only, in the HEDL, throughout the July 1, 1972, to December 31, 1990, period. Some handling and packaging was periodically done, and there may also have been some processing; hence, some HEU exposure potential existed.

Finding 4-2: NIOSH's approach to interpretation of fluorometric bioassay data for enriched uranium depends on knowledge of workers' locations at the general times when the samples were taken. A limited SC&A examination indicates that such information is usually available. However, a consultation with NIOSH Hanford dose reconstructors and a more detailed verification from individual worker files are needed before the method can be applied with confidence to HEU exposure in the SEC period under consideration (July 1, 1972, to December 31, 1990).

Finding 4-3: There are in-vivo data that may indicate HEU exposure for the period in question. NIOSH should examine these data to see if they are relevant for the HEDL laboratory. Prior to use of the U-235 in-vivo data, the discrepancies in MDA between the TBD and the REX database need to be explained and resolved.

4.0 MATRIX ITEM 6: URANIUM COWORKER MODEL FOR UNMONITORED WORKERS

Potential for exposure to uranium in various enrichments from depleted to slightly enriched existed throughout the period from July 1, 1972, to December 31, 1990. SC&A has compiled the characteristics of monitoring data for uranium (and other radionuclides). The details are provided in Appendix A. Table 3 shows the percentage of workers monitored for uranium (in vitro only) by year and area, and Table 4 shows the absolute number of workers monitored for uranium by year. The values in bold indicate that the samples were taken in areas judged to have some exposure potential—generally the areas with operating facilities using or processing uranium. It should be noted that identification of workers with a particular area was done

because they worked there at some point in time during their employment. It does not mean that that particular worker has worked there throughout their term of employment at Hanford. This is a limitation of the analysis (explained in more detail in Appendix A, Attachment 1) and should be kept in mind when reviewing the data on percentages and absolute numbers of workers monitored in any particular area. It should also be noted that the count of the workers and the percentages is a raw count and not adjusted for records where the internal dose numbers could not be interpreted, for instance because the units of measurement were missing. See Appendix A for more details as to the way in which the data were compiled.

Table 3. Percentage of Workers Monitored for Uranium during the Period of July 1, 1972, to December 31, 1990

Uranium In-Vitro Overview

Year	Percentage of Workers Monitored In Vitro for Uranium						
	U-233	U-234	U-235	U-238	Elemental U	U Nat†	Combined In-Vitro Samples
1972	–	–	–	–	0.58%	0.15%	0.72%
1973	–	–	–	–	–	0.69%	0.69%
1974	–	–	–	–	–	1.43%	1.43%
1975	–	–	–	–	0.18%	1.20%	1.20%
1976	–	–	–	–	0.62%	–	0.62%
1977	–	–	–	–	0.96%	0.01%	0.96%
1978	–	–	–	–	1.67%	–	1.67%
1979	–	–	0.01%	–	1.29%	–	1.29%
1980	–	–	–	–	1.41%	–	1.41%
1981	–	–	–	–	1.48%	–	1.48%
1982	–	–	0.01%	–	1.33%	–	1.33%
1983	–	–	–	–	1.09%	–	1.09%
1984	–	–	–	–	2.04%	–	2.04%
1985	0.02%	–	0.02%	0.02%	2.06%	–	2.09%
1986	0.05%	0.01%	0.05%	0.05%	1.47%	–	1.51%
1987	0.01%	–	0.01%	0.01%	1.73%	–	1.74%
1988	0.02%	–	0.02%	0.02%	1.37%	–	1.38%
1989	0.02%	–	0.02%	0.02%	1.48%	–	1.50%
1990	–	0.44%	0.44%	0.44%	1.35%	–	1.77%

† This urinalysis type is likely also an elemental uranium analysis, as spectrometric uranium analyses were not introduced to the Hanford site until 1983.

Dashes (-) indicate that no data are available for that sampling type and year.

Table 4. Number of Workers Monitored for Uranium during the July 1, 1972, to December 31, 1990, Period by Area

Year	Number of Workers Monitored for Uranium (In Vitro + In Vivo)							
	All Workers	100 Area	100N Area	200 Area	200 Tank Farms	300 Area	400 Area	700 Area
1972 (July 1 onward)	56	*[redacted]*	*[redacted]*	***19***	*[redacted]*	***19***	*[redacted]*	*[redacted]*
1973	81	*[redacted]*	*[redacted]*	*[redacted]*	0	***49***	0	*[redacted]*
1974	658	***48***	***41***	***110***	*[redacted]*	***264***	13	*[redacted]*
1975	150	***10***	***10***	***17***	*[redacted]*	***64***	0	*[redacted]*
1976	747	***42***	***36***	***121***	*[redacted]*	***346***	22	9
1977	878	***61***	***56***	***158***	*[redacted]*	***353***	46	*[redacted]*
1978	1258	81	***71***	***293***	17	***492***	116	15
1979	1450	105	***87***	***386***	20	***489***	235	*[redacted]*
1980	1573	86	***71***	***430***	24	***627***	***262***	21
1981	1519	117	***96***	***496***	24	***697***	***303***	17
1982	1437	91	***70***	***440***	32	***783***	***405***	12
1983	1424	91	***60***	***543***	47	***711***	***314***	15
1984	1627	142	***110***	***658***	52	***768***	***308***	14
1985	1745	191	***148***	***764***	66	***788***	***267***	21
1986	1847	226	***183***	***892***	86	***755***	***223***	13
1987	1868	172	***135***	***906***	82	***716***	***232***	15
1988	1758	321	285	**1066**	78	***658***	***224***	25
1989	2020	382	342	**1294**	75	***681***	***206***	27
1990	2655	563	519	**1799**	103	***767***	***210***	34
All Yrs	8171	1161	1057	3233	188	2226	848	130

The results presented in bold italics indicate areas and years with exposure potential (see Appendix A).

Tables 3 and 4 show that there are potentially a large number of measurements from which to construct a coworker model, except for 1972 and 1973, when data are relatively sparse. Table 3 also shows that there were almost no isotopic analysis in-vitro results (at least in the REX database) until 1985, even though the capability may have been established in 1983. However, as noted above, U-235 in-vivo measurements are available for most of the period under review starting in 1974. In addition, there are Th-234 in-vivo measurements, which measure U-238. These could supplement other uranium data.

NIOSH proposes to use a coworker model based only on in-vitro results. Table 5 shows the number of positive in-vitro uranium bioassay results. Note that the number of positive results for 1972 and 1973 are sparse. The number of positive results for 1983 is also low.

Table 5. Number of Positive In-Vitro Uranium Results during the Period of July 1, 1972, to December 31, 1983

Year	U	U Nat	U-233/U-234	U-235	U-238
1972	20	0	0	0	0
1973	0	3	0	0	0
1974	0	160	0	0	0
1975	26	95	0	0	0
1976	50	0	0	0	0
1977	48	0	0	0	0
1978	27	0	0	0	0
1979	36	0	0	0	0
1980	22	0	0	0	0
1981	57	0	0	0	0
1982	148	0	0	5	0
1983	10	0	0	0	0
1984	619	0	0	0	0
1985	731	0	15 (See note)	7	7
1986	731	0	10	0	10
1987	740	0	1	0	1
1988	461	0	1	1	2
1989	204	0	2	0	0
1990	275	0	10	0	8

Note: Six positive samples came from the same person, probably involved in an accident. The first 3 samples were very high, but the MDA was also very high, giving some doubts about the results. The same is true for seven U-235 results. The U-238 results were much smaller, indicating exposure to enriched uranium (possibly HEU).

4.1 Uranium Data Quality

As noted in Section 3.0, the main measurements for uranium were mass measurements made by the fluorometric method. This is not directly usable for uranium exposures that may have involved low enriched uranium, but it could be adjusted to take enrichment into account without stretching scientific reasonableness. Hanford had low or slightly enriched uranium in its reactors. The N Reactor used 0.95% or a combination of 0.95% and 1.25% enriched uranium. Fluorometric data can reasonably be used if an adjustment is made for the enrichment. This was the only production reactor operating at Hanford during the period under review in this report. NIOSH's choice of 0.97% enrichment for defense operations (ORAUT 2010e, Table 5-11), while reasonable for a typical situation, is not claimant favorable. A choice of 1.25% would be reasonable as a claimant-favorable value except for commercial fuel.

A 1982 audit of the Hanford bioassay program found that the performance met the requirements, except that the MDA was 0.37 micrograms per sample, instead of the required 0.2 micrograms per sample of 500 mL (Fleishman 1982, p. 4 of the pdf file). But NIOSH is using an MDA value of 0.05 to 0.25 micrograms per liter, with 0.1 being the "most probable" value (ORAUT 2010e, p. 31) for 1982. The NIOSH choice of 0.1 micrograms per liter is not claimant favorable for 1982. A choice of 0.1 micrograms per liter is justified for 1983–1984, since the audit for 1983–1984 indicates that 0.1 micrograms per liter would be met as the MDA (Spitz 1984). However, NIOSH assumes that the target MDA of 0.03 microcuries per liter was met (ORAUT 2010e, p. 31). The MDA in the 1981 audit appears to have been met (Hickman 1982). SC&A has not

been able to locate earlier audits. As noted in the Overview section of this report, issues related to data quality for the 1987 to 1989 period (inclusive) will be covered separately.

4.2 NIOSH's Proposed Approach for Uranium

NIOSH proposes to estimate intakes for Types F, M, and S solubilities for its coworker model based on bioassay data. This provides intakes by year. NIOSH notes that only 65 samples were collected in 1973 (ORAUT 2010e, p. 121), but included the statistical parameters derived from that data, since the values were "comparable to neighboring years." However, this result is heavily dependent on the below MDA values. As is clear from Table 5, there were only 3 above MDA values in 1973. This would not provide an adequate basis for providing sufficient confidence that all workers were being treated in a claimant-favorable manner. Furthermore, of the workers that had any monitoring at all in 1973, only a small fraction (0.69%) were monitored (see Table 3); the same was true in the last half of 1972, when the PUREX plant was still operating.[4]

NIOSH's choice analysis for the early part of the 1975–1983 period, as shown in Figure C-23 (ORAUT 2010e, p. 151), does not appear to be claimant favorable. The fitted line is systematically below the 50th percentile of the measured values throughout the first part of this period.[5]

Tables C-11 through C-13 specify intakes for Types F, M, and S solubilities of uranium (ORAUT 2010e, pp. 131–132). However, the last date in these tables is 1988 (and also in Table C-2, p. 121), though the last date for the period under review is 1990. NIOSH has provided the following rationale for this:

> *For assignment of coworker intakes after 1988, the intake rates for 1988 for each radionuclide may be assigned. Given that the internal dosimetry and radiation safety programs generally improved with time, especially after 1988, the assignment of the 1988 intake rates for periods after 1988 is considered to be favorable to claimants. For radionuclides with no assigned intake rate in 1988, no intake post-1988 should be assigned.* [ORAUT 2010e, p. 136]

This appears to be a reasonable approach in general, and is likely to be claimant favorable in some cases, for instance for N Reactor workers, since that reactor was not operated after 1987. However, it may not be appropriate in other cases, for instance for PUREX plant workers, since that plant operated intermittently from November 1983 to its final closure at the end of 1992 (ORAUT 2010b, p. 15).

Finding 6-1: Overall, NIOSH's method for uranium coworker modeling for July 1, 1974, to December 31, 1988, is sound; however, there are some caveats, as noted in Findings 6-2 to 6-4. NIOSH needs to better justify extending 1988 coworker data to 1989 and 1990, instead of using data from those years for facilities other than the 100 Area.

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[4] The TBD states that the PUREX plant was closed in June 1972 and did not reopen until November 1983 (ORAUT 2010b, p. 15). However, as discussed in Section 7, there is clear evidence of PUREX plant operation in the latter half of 1972.

[5] It is difficult to read the number of years in the first part of the period to which this statement applies, due to the scale at which the graph is drawn.

Finding 6-2: The number of in-vitro measurements in the July 1, 1972, to December 31, 1973, period is small. NIOSH might consider using a 95th percentile or some other upper-bound value for the coworker dose assignment for this period.

Finding 6-3: The fit for the early part of the 1975–1983 period needs to be revised to be claimant favorable; at present, it is not.

Finding 6-4: The MDAs from 1982 onward to at least 1984, and possibly beyond, were higher than assumed by NIOSH, since the contractual and target values were not being met. Since values below the MDA dominate the results, the coworker model in the TBD is not claimant favorable for at least part of the period considered here. SC&A has not been able to locate data quality audits for the 1972–1979 period. These need to be located, if they exist.

5.0 ISSUE 7: URANIUM-233

According to the site description volume of the TBD, as well as the history of the 300 Area, the last date for thorium target manufacture for irradiation and later separation of U-233 was 1970 (ORAUT 2010b, p. 31; Gerber 1992, p. 51). The internal dose volume of the TBD states that U-233 was separated in the Hanford PUREX plant until 1971 (ORAUT 2010e, p. 28). However, as noted in Section 2.1, thoria pellets were manufactured at Hanford at least until the end of 1979. It is not clear from the documents cited for 1979 whether these pellets were irradiated. As a result, we do not know whether there was any exposure potential for U-233 after 1971, due to production-related activities.

5.1 NIOSH's Proposed Approach for U-233

NIOSH has discussed the dose reconstruction method for U-233 as follows:

> *For the period for which there was exposure potential, NIOSH proposes the following approach to estimating uranium-233 dose:*
>
> *Operators, radiation monitors, and equipment maintenance workers at PUREX who were involved in the ^{233}U campaigns might have had intakes without specific monitoring for ^{233}U. The same might be true for chemists, chemical technicians, and radiation monitors associated with the Plutonium Chemistry Laboratory in Z-Plant in 1965. The highest urinalysis result (4.39 pCi/d) from a batch of 1970 PUREX worker records was used to estimate potential chronic intakes for the period from 1965 through 1970.* [ORAUT 2010e, p. 59]

While the analogy to plutonium exposure conditions is appropriate for the period for which the SEC has been granted (prior to July 1, 1972), it is unclear whether this would be claimant favorable or bounding for the SEC period that is under review here (July 1, 1972, to December 31, 1990) if U-233 was produced or separated in this period. As noted in Section 2, thoria targets were manufactured up to 1979, but it is unclear if they were shipped offsite or if some were irradiated at Hanford. NIOSH should establish that U-233 separation exposure potential in the separations area was equivalent to plutonium separation exposure potential if there was U-233 separation in the period under review here.

Finding 7-1: NIOSH should determine the last date for U-233 production, since thoria pellets were manufactured at least until the end of 1979 at Hanford. SC&A has not found any documentary evidence for thoria target irradiation or U-233 separation in 1979 and later years.

Finding 7-2: If thoria targets were irradiated and U-233 was separated in the July 1, 1972, to December 31, 1990, period, NIOSH should determine a bounding intake estimation procedure that is specific to that period, or establish that the plutonium intake value used for the pre-July 1, 1972, period is technically appropriate.

6.0 ISSUE 8: RECYCLED URANIUM

NIOSH has specified trace contaminant ratios to be applied to uranium bioassay results to estimate dose due to recycled uranium handling and processing at Hanford. NIOSH's table for these impurities ratios is reproduced here as Table 6, along with the note that is referenced in the table. It is clear that the measurements on which these ratios are based were all made in the late 1980s and early 1990s. Plutonium and neptunium would be the most important trace radionuclides contributing to internal dose. Hence, SC&A performed a check as to whether these ratios were claimant favorable when back extrapolated to the earlier part of the 1980s and to the 1970s. SC&A deemed such a check necessary not only to attempt to check the validity of the back extrapolation, but also because the PUREX plant was shut down periodically during the period of the cited measurements (ORAUT 2010b, p. 15).

SC&A compiled data for the 1970–1972 period relating to plutonium and neptunium trace contamination of uranium. These are the closest years to the start of the SEC period under review in the present report. The raw datasheets reviewed by SC&A also contain data prior to the 1970–1972 period.

The data used here consist of over 340 PUREX uranium samples taken in the 1970–1972 period. The plutonium data are in terms of parts per billion (ppb) of uranium, while the neptunium data are in counts per minute (cpm) per gallon. Trace contaminant data for zirconium/niobium-95, ruthenium-103 and ruthenium-106 are also available on these datasheets.

The empirical lognormal average is 2.7 ppb and the empirical lognormal 95th percentile is about 41 ppb. The maximum measurement is 1,550 ppb. Hence, this is a distribution with a particularly long tail. The contaminant concentration of Pu suggested by NIOSH equals about 13 ppb of plutonium, which is above the empirical lognormal mean, but more than 100 times less than the maximum value. The trace contaminant value for plutonium chosen by NIOSH is (arguably) not claimant favorable. The available data should allow NIOSH to determine a more claimant-favorable value. There are also some fission product trace contaminant data.

SC&A has not found the calibration data for converting Np-237 counts into parts per billion of uranium or nanocuries per gram of uranium. But the data do exist to estimate a claimant-favorable value if the calibration data can be located.

Table 6. Impurities in RU at Hanford

Constituent	Maximum Allowed[a]	Observed Range[b]	Recommend Level[c]
Plutonium	10 ppb U	<1–2 ppb U	0.8 nCi Pu-alpha/g U
Neptunium	Not established	0.04–0.16 ppm U	0.4 nCi Np-237/g U
Thorium	750 ppm U	8–10 ppb U	5 pCi Th-232/g U
Tx-99	Not established	3–4 ppb U	0.2 µCi Tc-99/g U
Ru-103, 106	<20 µCi/lb U	<6 µCi/lb U	40 nCi Ru-106/g U
ZrNb-95	<10 µCi/lb U	<4 µCi/lb U	20 nCi ZrNb-95/g U[d]
Other Gamma Emitters	<2 µCi/lb U	0.09–0.75 µCi/lb U	Negligible

a – From UO_3 Plant operating specifications (Sula, Carbaugh, and Bihl 1991).
b – From analysis of uranium lots 88-1, 88-2, and 88-3 that were processed in 1988, and lots 93-01, 93-02, 93-03, 93-04, and 93-05, processed in 1991.
c – The recommended levels are expected to result in a slight overestimation of dose compared to levels actually observed as presented in the DOE investigation of RU at Hanford (DOE 2000). The plutonium reference level was based on the 10-ppb specification, which was reached or exceeded in a few drums throughout Hanford history (DOE 2000).
d – Interpret as 10 nCi each of the two radionuclides [39].
Reproduced from ORAUT 2010e, Table 5-12.

[39] Bihl, Donald E. Battelle Memorial Institute. Principal Health Physicist. November 2006. Because both the DOE Hanford RU document (DOE 2000) and the Hanford internal dosimetry manual (PNNL 2003a) express the entity as 95Zr/95Nb, it is hard to know for sure if the activity is for each radionuclide or a total of both; however, DOE (2000) also refers to ^{106}Ru/^{106}Rh. In the latter case, it is clear that the activity refers to the sum of the parent and progeny, so it was deemed reasonable to assume that the 20 nCi of ^{95}Zr/^{95}Nb also refers to the sum of the parent and progeny. Because the radionuclides are usually found close to equilibrium, the recommendation was made to use 10 nCi ^{95}Zr and 10 nCi ^{95}Nb.

6.1 Recycled Uranium Findings

Finding 8-1: Trace contaminant data exist for the 1970–1972 period. They can be used for estimating a claimant-favorable value for plutonium and neptunium trace contamination ratios. These data appear to be a more appropriate basis than late 1980s and early 1990s data for estimating recycled uranium doses suggested by NIOSH. NIOSH should analyze the 1970–1972 data to determine a better bounding value to plutonium trace contamination in recycled uranium. For neptunium, it will be necessary to find the calibration factor to convert counts per minute into nanocuries of neptunium per gram of uranium. Other trace contaminant values should also be checked against the available raw data.

7.0 MATRIX ISSUE 9: NEPTUNIUM-237

Neptunium-237 was separated at Hanford and targets fabricated for irradiation in Hanford reactors to produce Pu-238. Subsequently, the neptunium and Pu-238 were separated. The site description volume of the TBD states that the last date for neptunium nitrate in the 200 Area where separation was done was 1972, since the PUREX plant was shut in that year. The monthly report for December 1972 states that the last shipment of neptunium prior to shutdown occurred in December 1972:

> *Approximately 450 grams of neptunium were dispatched from the Purex Plant on December 12, for offsite shipment. This was the last shipment of Purex produced neptunium until the plant is restarted.* [Monthly report for December 1972, p. A-1]

There are only four neptunium bioassay samples in the REX database, and all are for the same date (September 6, 1972), possibly related to an incident. In any case, the data are not sufficient to create a coworker model for neptunium for the last half of 1972, when neptunium appears to have been separated in the Hanford PUREX plant (presuming the shipment referred to freshly separated material).

There were 10 other Np-237 bioassay samples and 5 in-vivo counts in total taken in the 1980s, scattered throughout that decade. The majority of these also appear to be incident related. Hence, there appear to be essentially no data that would capture routine exposure during the period of production in the last half of 1972. SC&A has not done an investigation to locate the possible Np-related incidents.

Neptunium recovery from high-level waste was also considered in the context of Cm-244 recovery as part of the effort involving the development of a production flowsheet for the Barnwell Nuclear Fuels Plant (Curium Recovery Flowsheet 1974, Section V). SC&A has not found any evidence that the 1974 flowsheet was implemented at Hanford.[6]

7.1 NIOSH's Approach to Np-237

NIOSH has specified the following approach for dose reconstruction in the period under review:

> *No evidence of significant exposure to neptunium after 1972 has been found, but small research projects with the material can not be ruled out. If an intake estimate is required from July 1, 1972 on, unmonitored workers should be assigned intakes at the 95th percentile of the plutonium coworker intakes (constant distribution) prior to 1984 and at the 50th percentile (with GSDs) from 1984 on.* [ORAUT 2010e, p. 60]

Given that neptunium was separated, or at least shipped (and hence handled), in the last half of 1972, the method specified by NIOSH is not appropriate for those 6 months. While one would expect plutonium and neptunium to be associated with each other in reprocessing operations after Np-237 separation stopped, NIOSH has not explained its choice of the 95th percentile value of plutonium for neptunium dose prior to 1984; nor has it explained the choice of the 50th percentile after that. This may be associated with the restart of the PUREX plant in November 1983, but NIOSH should make the technical case for its choices.

7.2 Neptunium Issue Findings

Finding 9-1: Neptunium-237 separation (or at least handling) lasted until December 1972 at Hanford, about 6 months after the beginning of the SEC period being reviewed here. Neptunium data are too sparse (and, moreover, appear to be mainly incident-related) to allow for a reliable coworker model to be developed for the July 1, 1972, to December 31, 1972, period.

Finding 9-2: Neptunium recovery at Hanford was discussed in the context of processing high-level waste from the Barnwell Nuclear Fuels plant. While the Barnwell plant was never operated for reprocessing spent fuel, NIOSH should make a more complete effort to determine whether

[6] The Barnwell Nuclear Fuels Plant was never operated to reprocess spent fuel.

neptunium was separated in the 1983–1990 period, during which the PUREX plant was periodically operated.

Finding 9-3: NIOSH has not provided a technical basis for its choices for Np-237 intake assignment in relation to plutonium from 1973 onward.

8.0 ISSUE 10: TRITIUM

According to the TBD, tritium data were included as part of external dose records until about 1987:

> *Tritium intakes were accounted for as part of external dose until about 1987, when they were entered in the dose database as an internal dose… Section 5.6 contains a more detailed discussion and guidelines for assigning intakes. Tritium exposure was assumed to be chronic during the exposure period, unless a very large acute intake was known to occur.* [ORAUT 2010e, p. 27]

However, NIOSH also states that an examination of the external dose records show that external dose data do not contain tritium data in many years, including the years between 1973 and 1984 (ORAUT 2010e, p. 56).

The REX database contains over 1,650 bioassay measurements for tritium from 1978 onwards to the end of 1990, with the vast majority being between 1983 and 1990.

The site description volume of the TBD states that target rods were irradiated for tritium production until 1967 (ORAUT 2010b, p. 12), but the DOE record shows that tritium was produced until 1973 (Westinghouse 1994). Therefore, specifying a dose reconstruction method for workers who were not monitored for tritium from July 1, 1972, to December 31, 1973, appears to be especially important.

Besides tritiated water [HTO], NIOSH points to the presence of OBT at Hanford:

> *Tritium was present in an organic form in the 108-B facility in the pump oil, which became contaminated over time. According to a retired radiation monitor at the facility, the contamination in pump oil was orders of magnitude below general HT and HTO levels in the facility…* [ORAUT 2010e, p. 27]

Finally, the TBD also points to the possible presence of metal tritides:

> *Metal tritides were potentially present as part of the Tritium Target Program work starting in 1988, the metal mostly likely being zirconium. The irradiated targets were examined and the tritium driven off in hot cells. Samples were taken for analysis, but where the analyses were performed has not been discovered yet.* [ORAUT 2010e, p. 27]

8.1 NIOSH's Approach to Tritium

NIOSH dose reconstruction approach for the 1984 to 1986 period is based on a coworker analysis of the tritium data. These values are used for later years for 100 Area and 200 Area workers on the hypothesis that the N Reactor was shut down in 1987, and since reprocessing was intermittent in the 1987–1992 period (ORAUT 2010e, p. 58). There are data available for the later years, including above MDA results, for instance for 1989 and 1990. The rationale provided for extending the 1984–1986 analysis to later years for 200 Area workers in particular seems rather weak, given that data are available for the years in question.

For the 1973–1983 period for which no tritium data exist in the external dose records (according to NIOSH either because measurements were not made or were below MDA and not recorded), NIOSH has calibrated tritium doses to uranium fuel dissolution in a rather complex way.

First it has assumed that reactor and fuel dissolution plant workers had 10% of the intakes of the workers in the Tritium Extraction Facility, which shut down in 1955 (ORAUT 2010e, pp. 56–58). This is simply an assumption based on the judgment of one site expert (ORAUT 2010e, p. 77). Secondly, this value is calibrated to the total burn-up of uranium fuel dissolved. Thirdly, the resulting value of an intake of 3.2×10^{-5} pCi/day, is extrapolated to the 1973–1983 period. This value was much higher than indicated by the 1982–1983 bioassay results of a "small set" of reactor workers; NIOSH notes that the set was "too small for a complete statistical analysis" (ORAUT 2010e, p. 58). Since the suggested value is almost 27 times higher than the actual measurements, NIOSH's approach seems reasonable for 1982 and 1983. However, the N Reactor was operating throughout the 1973–1981 period; in view of that, a technical basis that relates N Reactor exposures to earlier 1950s exposure estimates should be provided. This is especially true for the period until June 30, 1973, when tritium production still continued at Hanford.

Finally, NIOSH has not specified a dose reconstruction method for either OBT or for metal tritides (if their presence is confirmed). The main problem here is not so much determining the model to be applied for metal tritides, which NIOSH has specified in ORAUT-OTIB-0066 (ORAUT 2007a), but whether and where the tritides were used and which of the workers at Hanford had exposure potential. Some quantitative basis for determining exposure potential is needed; so far, it is lacking.

8.2 Tritium Issue Findings

Finding 10-1: Tritium was produced at Hanford until June 1973. NIOSH has not specified a coworker model for tritium for the period of July 1, 1972, to June 30, 1973, that takes this into account. The approach specified by NIOSH of calibrating tritium intake to total uranium burnup is not likely to be claimant favorable for this period.

Finding 10-2: NIOSH has not provided a quantitative justification for using a small set of data from 1982 and 1983 to derive a conclusion that the chosen coworker intake value for tritium is also valid for July 1, 1972, to the end of 1981.

Finding 10-3: NIOSH should provide a technical basis for using the same value for N Reactor workers from July 1, 1972, to the end of 1981 as for 1950s' unmonitored reactor workers.

Finding 10-4: NIOSH has pointed to the presence of OBT in 108-B and potentially of metal tritides starting in 1988. However, NIOSH has not specified which workers had exposure potential or a basis upon which OBT or tritide dose would be assigned.

Finding 10-5: NIOSH has pointed to the possible presence of metal tritides starting in 1988. However, NIOSH has neither confirmed the presence of metal tritides, nor specified a dose reconstruction method for metal tritides. NIOSH needs to identify the periods of tritide exposure potential and the group of workers who might have been exposed to metal tritides.

9.0 ISSUE 11: PROMETHIUM-147

Hanford separated Pm-147 from fission products for use as a heat source. Major production started in 1964 (ORAUT 2010b, p. 40). The site description volume of the TBD does not mention Pm-147 work past 1969 (ORAUT 2010b, p. 41); however, the internal dose volume indicates sporadic work well into the 1970s:

> *Specific bioassay for ^{147}Pm was initiated when PNNL began manufacturing ^{147}Pm heat sources in the 325 Building in 1966. The number of workers in the bioassay program and the number of samples were small in comparison to the numbers for the plutonium, uranium, or strontium bioassays, with a high of 65 workers in 1968. There was almost no sampling from 1972 to 1975, which probably indicates a cessation of the original heat source program, and only 20 workers were sampled from 1976 to 1979. The exact end date of the heat source program has not been determined. For purposes of this study, it was assumed that exposure occurred from 1966 to 1979, although it is likely that any exposure from 1972 to 1975 was only due to residual activity.* [ORAUT 2010e, p. 122]

The NIOSH inference from scarce bioassay data that promethium work may have stopped from about 1972 to 1975 appears to be incorrect. Specifically, an attachment to a February letter from Carl Unruh, Occupational and Environmental Safety Manager, describes an incident in which Pm-147 in solution was released in the 325-A Building and caused contamination "of the floor over a wide area." While the clothing of a technician was contaminated, the technician was not (Attachment to Unruh 1975). The incident took place on January 29, 1975.

Hence, there is clear documentation of Pm-147 processing in early 1975. Interestingly, none of the Pm-147 bioassay sample dates in 1975 are in the early part of the year. Five of the six Pm-147 bioassay samples in that year were taken on the same date, in mid-September 1975, and the remaining one was in November 1975. Perhaps this is because a spot check at the time of the incident seems to have led to the conclusion that the technician involved as well as another technician in the room were not contaminated. It is also interesting to note that 1975 seems to have been a year when bioassay sampling frequency dipped for other radionuclides as well.

The description of this 1975 incident also notes that, "[a] similar release from the hot cell was detected on 9-12-74…" (Unruh 1975, pdf, p. 10). There are no Pm-147 bioassay samples in 1974.

These two incidents make it clear that some Pm-147 work was ongoing in the 1972–1975 period. The number of bioassay samples available in the REX database is shown in Table 7.

Table 7. Promethium-147 Sampling Frequency

Year	Number of Bioassay Samples	Comments
1972 from July 1 onward	16	
1973	None	
1974	1 (labeled "PM")	Sample was in April; Pm-147 incident was in September.
1975	6	Pm-147 Incident in January; no samples until September
1976	23	
1977	39	
1978	54	
1979	25	
1980	6	
1981–1990	5	One in 1981, three in 1985 and one in 1989

Table 7 shows that the frequency of Pm-147 measurements increased in 1976, as recognized in the TBD. This may have been due to a larger number of workers involved in 1976 and continuing through to 1979. However, NIOSH's inference that there was no Pm-147 processing in the 1972–1975 period appears to be incorrect. SC&A has not found any documentation regarding processing of Pm-147 in the 1980s, so it may have stopped then. However, an April 1981 memorandum from the DOE refers to the preparation of a plan for the processing of Am-241 and Pm-147 (Heusser 1981). SC&A has not found any documentation as to whether or not this project was implemented.

NIOSH's assumption that there was no processing in the 1972–1975 period appears to have led to the proposed approach of assigning the same Pm-147 intakes throughout the 1970s as a claimant-favorable approach (ORAUT 2010e, Table C-28, p. 139). However, as noted above, there was processing in the 1972–1975 period, but little data. NIOSH has a significant amount of data from the 1960s that could possibly be used for the 1972–1975 period when data were sparse. NIOSH should examine whether the use of this data is appropriate. The coworker model analysis in the TBD (ORAUT 2010e, pp. 153–155) indicates that the use of data from the 1960s would be more appropriate, in view of the fact that there was production in the 1972–1975 period. Furthermore, NIOSH also needs to address the issue of doses incurred during the incidents in the July 1, 1972, to 1975 period.

Finding 11-1: Contrary to an inference in the NIOSH site profile, Pm-147 processing occurred in the 1972–1975 period, and appears to have continued into the late 1970s.

Finding 11-2: NIOSH's assigning the same Pm-147 intakes throughout the 1970s is not claimant favorable, given that processing operations occurred during portions of this period. NIOSH has ample Pm-147 data for the 1960s that may be more appropriate as a basis for coworker models, since that was also a period of production. This is indicated by NIOSH's coworker analysis in the TBD. NIOSH should investigate whether this is appropriate for demonstrating dose reconstruction feasibility during the times in the 1970s when Pm-147 processing occurred. Specifically, NIOSH should investigate whether working conditions were comparable enough to allow the use of earlier data for the period of production in the 1970s.

Finding 11-3: NIOSH should investigate how it is going to address possible intakes, as a result of documented incidents in 1974 and 1975. NIOSH should also investigate other Pm-147 incidents in the SEC period, especially during 1972–1979.

10.0 ISSUE 12: STRONTIUM-90, CESIUM-137, AND MIXED FISSION PRODUCT DOSE ESTIMATION

Hanford operated the PUREX reprocessing plant during the July 1, 1972, to December 31, 1990, period, which created exposure potential in the 200 Area, including the high-level waste tank farms. Furthermore, Sr-90 and Cs-137 were separated in the B Plant from 1968 to 1978, and then conditioned for encapsulation between 1978 and 1984. Hence, there was specific exposure potential to MFPs during the separation period, as well as to Sr-90 and Cs-137 during the conditioning from 1978 to 1984 (B Plant 1985).

10.1 Periods of Operation and Exposure Potential

According to the TBD, the PUREX plant was shut down from June 1972 to November 1983 (ORAUT 2010b, p. 15). However, as noted above, neptunium was separated at least until December 1972. According to a 1993 Westinghouse report, the PUREX plant was temporarily closed in early 1990, but was never reopened for production (Westinghouse 1993, p. 6). Hence, exposure to MFPs in PUREX plant associated facilities (200 Area) would have continued in the last half of 1972, which is the starting point of the SEC period under review in this report.

Furthermore, strontium and cesium separation from high-level waste continued throughout the first part of the SEC period until 1978. Figure 1, taken from a B-Plant history (B-Plant 1985, p. 12 of the pdf file), shows the history of Sr-90 and Cs-137 recovery.

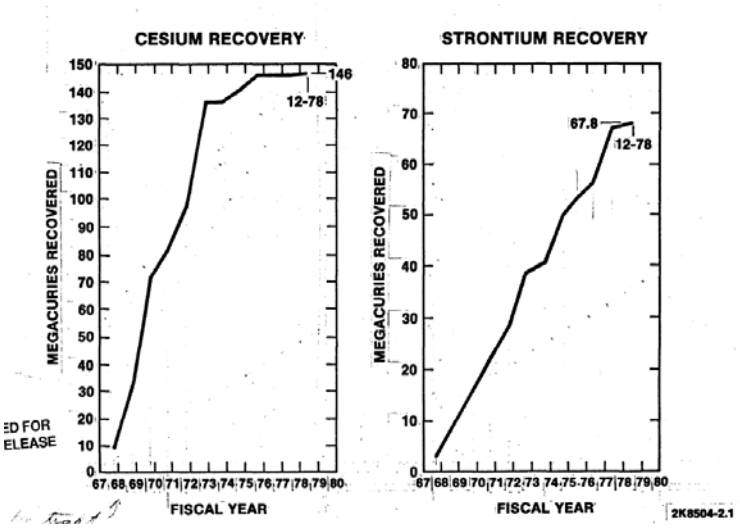

Figure 1. B-Plant Strontium and Cesium Recovery History

As is evident from the figure, which shows cumulative recovery, very little cesium recovery took place during the 1976–1978 period, and very little Sr-90 recovery took place during 1978. From 1974 to 1978, the recovered Cs-137 and Sr-90 were purified for encapsulation. From 1978 to November 1983, there was no separation of Sr-90 and Cs-137, but both were conditioned for

encapsulation. The cesium capsule production run ended in October 1983, and the Sr-90 capsule production run ended in January 1985 (B Plant 1985, pdf file p. 13; ORAUT 2010b, p. 16). Hence, except for the tank farms, the main exposure potential from reprocessing and Hanford high-level waste activities was to Sr-90 and Cs-137 during 1978 to 1983 period. The dates can be summarized as follows:

- July 1, 1972, to 1976 or 1977: MFPs, Cs-137, and Sr-90
- 1977 or 1978 to October 1983: mainly Sr-90 and Cs-137, except possibly in the high-level waste tank farms
- November 1983 (PUREX restart date) to January 1985 (Sr-90 encapsulation ends): Sr-90 and MFPs (due to restart of the PUREX plant)
- February 1985 to February 1990: MFPs

These dates should be kept in mind when evaluating adequacy of data for coworker models. It should also be remembered that other work on fission product mixes for waste treatment and vitrification development occurred in Building 324/325 in the 1980s. This is discussed separately in Section 19 ("Building 324 Incident").

10.2 In-Vivo and In-Vitro Data for Sr-90, Cs-137, and Mixed Fission Products

Table 8 shows the number of workers who were monitored for MFPs from July 1, 1972, to December 31, 1990, by year and area of work. Table 9 shows the in-vivo monitoring for Cs-137.

As can be seen from Tables 8 and 9, monitoring data for MFPs are rather sparse for the 1975–1977 period, and for Cs-137 for 1975 and 1985. It should be noted that the Cs-137 measurements in vitro that are designated as indicative of MFPs were also sparse in 1975 and 1985 (See Appendix A). NIOSH should examine the reasons for the sudden decline in monitoring, and whether the earlier data can be used to fill in the gaps for this period for MFPs and Cs-137. Furthermore, we note that tank farm workers had exposure potential for fission products throughout this period. The mixed fission product data for tank farm workers appear to be sparse in terms of the absolute number of workers during the period 1972 to 1977 (see Table 8). However, as noted in Appendix A, the percentage of workers designated at some time during their employment as tank farm workers who were monitored for fission products at some time during their employment was the highest of any category. But this does not alleviate the concern about tank farm worker monitoring during the 1972 to 1977 period, which was much lower than in the subsequent period for the same group (see Appendix A, Table 21).

There are ample Sr-90 in-vivo data for 1973 and 1974 (over 1,000 and 2,000 measurements, respectively). After that time, there are almost no in-vivo Sr-90 measurements in the REX database; measurements for Sr-90 from 1975 onwards were made by analyzing urine samples. There are just over 40 measurements for 1976, and the data adequacy for that year needs to be examined. There are more than 500 bioassay records for 1978 and each year after that until 1990 (inclusive).

Table 8. Number of Workers Monitored for Mixed Fission Products, July 1, 1972, to December 31, 1990

Year	Number of Workers Monitored for Fission Products (In Vitro + In Vivo)*							
	All Workers	100 Area	100N Area	200 Area	200 Tank Farms	300 Area	400 Area	700 Area
1972	110	20	***19***	***37***	***[redacted]***	***[redacted]***	***[redacted]***	0
1973	1403	149	***131***	***179***	***[redacted]***	***291***	22	22
1974	2008	238	***224***	***240***	***13***	***477***	40	29
1975	104	***[redacted]***	***[redacted]***	***46***	***[redacted]***	***25***	***[redacted]***	***[redacted]***
1976	32	***[redacted]***	***[redacted]***	***[redacted]***	***0***	***22***	0	***[redacted]***
1977	114	***[redacted]***	***[redacted]***	***58***	***[redacted]***	***25***	***[redacted]***	0
1978	421	27	***25***	***305***	***35***	***47***	***[redacted]***	***[redacted]***
1979	682	65	***55***	***518***	***86***	***51***	12	***[redacted]***
1980	668	88	***72***	***535***	***85***	***46***	***[redacted]***	***[redacted]***
1981	729	106	***92***	***611***	***93***	***52***	12	***[redacted]***
1982	492	68	***60***	***422***	***73***	***34***	12	***[redacted]***
1983	455	48	***34***	***417***	***82***	***36***	12	***[redacted]***
1984	744	70	***48***	***715***	***92***	***56***	22	***[redacted]***
1985	818	142	***107***	***755***	***112***	***53***	23	***[redacted]***
1986	908	251	***214***	***757***	***113***	***88***	28	***[redacted]***
1987	991	217	***181***	***872***	***122***	***73***	30	***[redacted]***
1988	1234	369	339	***1052***	***125***	***221***	63	29
1989	1304	352	325	***1124***	***137***	***206***	55	44
1990	1340	325	297	***1194***	***123***	***186***	70	36
All Years:	6588	1328	1218	3091	275	1149	225	152

* Includes a small number of Cs-137 in-vitro results, driving sampling for in-vitro FP was for Sr-90.
The results presented in bold italics indicate areas and years with exposure potential (see Appendix A).

Table 9. Number of Workers Monitored In Vivo for Cs-137

Year	Number of Workers Monitored In Vivo for Cesium-137							
	All Workers	100 Area	100N Area	200 Area	200 Tank Farms	300 Area	400 Area	700 Area
1972	993	91	84	***122***	***[redacted]***	***211***	16	14
1973	1879	208	185	***203***	***[redacted]***	***408***	31	33
1974	2080	253	236	***226***	***[redacted]***	***487***	43	33
1975	***[redacted]***	***[redacted]***	***[redacted]***	***0***	***0***	***[redacted]***	0	0
1976	1926	305	281	***253***	***[redacted]***	***556***	47	41
1977	2761	429	393	***694***	***74***	***661***	82	33
1978	3479	534	492	***854***	***75***	***841***	175	61
1979	4323	746	681	***1225***	***104***	***959***	318	58
1980	4575	819	748	***1447***	***125***	***1305***	419	90
1981	5332	984	914	***1874***	***152***	***1495***	551	105
1982	5402	1438	1349	***2359***	***187***	***1716***	631	165
1983	5507	1657	1528	***2532***	***196***	***1693***	606	205
1984	441	307	295	***148***	***14***	***106***	26	21
1985	52	25	24	***28***	***[redacted]***	***9***	0	***[redacted]***
1986	3562	1312	1236	***1649***	***115***	***998***	326	247
1987	7109	2512	2344	***3472***	***283***	***2058***	678	308
1988	6463	2232	2098	***3381***	***280***	***2086***	702	241
1989	7974	2002	1863	***4565***	***299***	***2392***	876	406
1990	8474	1922	1788	***4949***	***309***	***2451***	918	414
All Years:	23629	4530	4209	7600	335	4407	1414	1078

The results presented in bold italics indicate areas and years with exposure potential (see Appendix A).

10.3 Quality of Data

The 1982 data quality report indicates considerable problems with meeting contractual MDA's for a number radionuclides important to MFPs (though not Sr-90):

> *Based on analysis of audit samples submitted to UST* [U.S. Testing] *with zero activity of the following radionuclides, it is concluded that UST is unable to achieve the contractual detection level (Ld) for the following radionuclides:* ^{140}*Ba-La,* ^{22}*Na,* ^{24}*Na,* ^{137}*Cs,* ^{59}*Fe,* ^{106}*Ru,*^{134}*Cs,* ^{239}*Np,* ^{95}*Nb-Zr,* ^{131}*I. As with uranium, this is determined by analysis of audit samples which did not contain any of these radionuclides.* (Fleishman 1982)

None of the other audit reports reviewed (Bihl 1986; Hickman 1982) contained a substantive discussion of these radionuclides. Stronium-90 limits were apparently being met. SC&A has not located similar audit reports for the 1970s.

NIOSH has not discussed the implications of this problem for dose reconstruction where data for these radionuclides are available.

10.4 NIOSH's Approach to Coworker Models

NIOSH proposes to assign the same intake rate for Sr-90 in the 1971–1988 period as in the period extending from 1989 to the present, when there was essentially no exposure potential due to production operations (ORAUT 2010e, Table C-27, p. 139). This does not appear to be claimant favorable in view of the extensive operations involving Sr-90 until January 1985. The year-by-year data from the 200 Area should preferably be used for the coworker models not only for Sr-90, but also for mixed fission products and Cs-137. There appear to be ample data for most years. NIOSH will have to examine how to approach the selection of an intake level for the years in the mid-1970s, when there are far fewer data points than in other years in the time periods examined here.

NIOSH does not propose to use mixed fission product data for coworker dose assignment:

> *A large number of different radionuclides were present at Hanford at various times, but the available bioassay data for radionuclides in addition to those in this attachment were considered to be too few to be statistically reliable for intake estimation. Workers who were exposed to* ^{137}*Cs,* ^{90}*Sr,* ^{24}*Na, and* ^{65}*Zn could also have been exposed to other fission and activation products. From 1960 to 1988, intakes of most fission or activation products would have been detectable in whole-body counts, but the recording practice for fission and activation products other than* ^{137}*Cs,* ^{24}*Na, and* ^{65}*Zn was not amenable to statistical analysis. Guidance for assigning intakes of additional radionuclides is provided in ORAUT-OTIB-0054* [ORAUT 2007b] *and for specific buildings in Section 5.6.*
>
> *Assignment to unmonitored workers of radionuclides that were not analyzed in this study should be in accordance with guidance in Section 5.6.* [ORAUT 2010e, p. 141]

The coworker model approach in ORAUT-OTIB-0054 (ORAUT 2007b) states that it applies "to intakes of fission and activation products associated with most reactor operations, destructive fuel examination, fuel dissolution, and high-level waste management." However, it only specifies source terms for reactors. A procedure for estimating dose from air monitoring data is also provided, but the Hanford TBD does not provide such data for mixed fission product dose reconstruction.

Hence, ORAUT 2007b could be applied to N Reactor and other reactor workers who were not monitored for fission products. However, it would not apply to PUREX operations (until the end of 1972, and then from November 1983 onward), or to source terms related to the processing of waste, notably those related to the separation of Sr-90 and Cs-137 for high-level waste until 1978.

Since ORAUT 2007b cannot be used for unmonitored separations and waste-handling workers, there is a circular reference between Attachment C and Section 5.6 for these operations. As the quote above shows, Attachment C of ORAUT 2010e refers to Section 5.6, which is for unmonitored worker dose estimation procedures; yet Section 5.6 refers back to Attachment C for fission and activation product dose estimation for operations relating to the 200 Area:

> *Use fission and activation products (from September 1, 1946 on), plutonium (from September 1, 1946 on, types M, S, or Super S), and uranium (type F from January 1, 1949 on) from Attachment C (except* ^{147}*Pm) and* [ORAUT (2007b] *but may ignore* ^{24}*Na from Attachment C for best estimates.* [ORAUT 2010e, p. 64]

Similarly, NIOSH refers back to Attachment C of ORAUT 2010e for fission product dose estimation for unmonitored workers for several 300 Area buildings where fission products were handled and processed [including Buildings 324, 325, 327, and 3706 (ORAUT 2010e, p. 65)]. This is puzzling, since Attachment C of ORAUT 2010e does not specify a coworker model for mixed fission products in general, though it does have coworker intake assignments for several specific ones, such as Sr-90, Cs-137 and Pm-147.

10.5 Findings for Mixed Fission Products, Sr-90, and Cs-137

Finding 12-1: Overall, there seem to be ample data for Sr-90 and Cs-137 to create coworker models, except in certain years.

Finding 12-2: NIOSH's approach for assigning the same Sr-90 intake values for the period from 1971 onward is not claimant favorable. A more claimant-favorable approach needs to be developed. The Cs-137 and mixed fission product models should also be reviewed in light of the Sr-90 and Cs-137 recovery operations and the processing to condition Cs-137 and Sr-90 for encapsulation out to the completion of the encapsulation process in October 1983 for Cs-137 and January 1985 for Sr-90.

Finding 12-3: The mixed fission product data for tank farm workers for July 1, 1972, to the end of 1977 are very sparse. NIOSH needs to examine whether its present approach is adequate for tank farm workers, or whether a special coworker model is needed for them for this period.

Finding 12-4: The implications of the failure to meet contractual MDA limits for several fission products (though not Sr-90) are unclear. NIOSH has not discussed this issue.

Finding 12-5: NIOSH has specified coworker models for several specific fission products. The method specified by NIOSH is applicable to reactor areas, but not to separations or waste handling and processing areas. An explicit approach for unmonitored workers in reprocessing and waste handling and processing areas needs to be developed for radionuclides that have not yet been covered for the 200 Area and for certain buildings in the 300 Area.

11.0 MATRIX ISSUE 13: TANK FARM ALPHA MONITORING

SC&A has analyzed data completeness and adequacy by area, and broken out tank farm areas separately. Hence, this issue is subsumed under the other headings discussed in this report, as well as in Appendix A.

12.0 MATRIX ISSUE 14: PLUTONIUM DATA ADEQUACY

Hanford had extensive operations involving plutonium and has extensive monitoring data for plutonium in the period under consideration. SC&A compiled the data from the REX database to analyze for completeness as to quantity; SC&A also analyzed the quality of the available data and the REX data entries for plutonium. The REX database reports results in microcuries per sample of dpm/sample. Most of the plutonium results are below the MDA. NIOSH uses these results in its dose reconstruction to assign missed dose.

12.1 Plutonium Data – Quantity

Table 10 shows the number of workers monitored each year for plutonium. It is clear that a large number of workers had either bioassay or in-vivo records for plutonium for this period, especially in the 200 and 300 Areas where there was exposure potential.

It is clear from Table 10 that there are ample plutonium monitoring data available. However, since NIOSH is using only bioassay data for its coworker model, we also reviewed how many positive results are available by year. The majority of the plutonium monitoring consisted of in-vitro measurements.

Table 11 shows the positive plutonium bioassay results by year.

It is important for NIOSH to evaluate whether only positive results should be used for coworker modeling, especially for unmonitored workers in the PUREX (202-A) reprocessing plant and the plutonium finishing facilities (231-Z and 234-5Z) during the years of their operation in the period under review here (see Section 12.2).

It should be kept in mind that in compiling the information in Table 11, we have inserted an interpretation of what the units are in many of the measurements. A large number of these measurements are entered into the REX database without units. However, since we know the MDA, a reasonable inference about units can be made. Without making such an inference, there would be a few years (1975, 1977, and 1979) when there would be no interpretable in-vitro data.

Table 10. Number of Workers with Plutonium In-Vitro or In-Vivo Monitoring Data by Year

Year	Number of Workers Monitored for Plutonium (In Vitro + In Vivo)							
	All Workers	100 Area	100N Area	200 Area	200 Tank Farms	300 Area	400 Area	700 Area
1972	965	42	38	***316***	***14***	***204***	16	13
1973	1514	72	60	***483***	***21***	***332***	38	20
1974	1645	84	72	***539***	***21***	***363***	44	19
1975	1750	85	72	***567***	***28***	***425***	47	22
1976	1866	104	89	***636***	***45***	***431***	56	23
1977	1795	92	78	***694***	***44***	***432***	74	19
1978	1486	122	106	***475***	***19***	***485***	147	14
1979	1159	85	71	***559***	***39***	***337***	81	16
1980	1591	136	116	***555***	***37***	***579***	***269***	25
1981	1443	110	94	***620***	***49***	***576***	***291***	25
1982	1327	73	58	***531***	***43***	***602***	***325***	13
1983	1572	57	39	***721***	***68***	***640***	***297***	19
1984	1514	85	51	***904***	***76***	***505***	***228***	17
1985	1811	100	55	***1030***	***86***	***567***	***261***	22
1986	1767	103	59	***1002***	***90***	***542***	***220***	11
1987	1903	105	63	***1124***	***84***	***492***	***238***	16
1988	2079	419	381	***1359***	***86***	***586***	***235***	36
1989	2122	409	371	***1459***	***78***	***615***	***214***	54
1990	2047	438	403	***1496***	***62***	***535***	***193***	50
All Years	10996	1240	1124	3964	233	2057	839	224

The results presented in bold italics indicate areas and years with exposure potential (see Appendix A).

Table 11. Positive Plutonium Bioassay Results by Year

Year	Pu	Pu-239	Pu-238	Total
1972	105	41	1	147
1973	0	253	6	259
1974	0	181	5	186
1975	0	88	3	91
1976	0	89	0	89
1977	0	53	3	56
1978	0	106	0	106
1979	0	106	1	107
1980	7	183	68	258
1981	27	5	0	32
1982	239	0	0	239
1983	53	17	5	75
1984	0	196	81	277
1985	0	217	199	416
1986	0	195	65	260
1987	0	109	15	124
1988	0	265	9	274
1989	0	178	27	205
1990	0	44	4	48

12.2 Plutonium Data – Quality

The MDA value for plutonium in-vitro data from October 1955 to September 30, 1983, was 0.05 dpm/sample (ORAUT 2010e, Table 5-1, p. 18). The value reported in case of results below MDA is called the decision level or reporting level equal to half this value (reported as 1.1×10^{-8} µCi/sample until 1974, and 0.025 dpm/sample after that in the REX database). After October 1983, the results for Pu-238 and Pu-239+240 have been reported separately.

NIOSH also did fecal sampling for plutonium:

> *Fecal sampling was normally done in response to suspected intakes, but routine fecal sampling was used for some high-risk plutonium workers, mostly operators of Plutonium–Uranium Extraction (PUREX) facility and the Plutonium Finishing Plant, from 1986 through June 1989. The special study showed that, when considered as a group, the mean fecal excretion was statistically significantly different from control. Enhanced air sampling, which was initiated in response to the study, showed frequent but intermittent releases of plutonium in the workplaces, at levels below the detectability of normal air sampling. MDAs are listed for nonroutine plutonium excreta analysis. When modeled as chronic intake, the intakes and doses were low (less than 10 mrem committed effective dose equivalent)…* [ORAUT 2010e, pp. 19–20]

Since the modeled doses were low, NIOSH suggests modeling these intakes as routine rather than as being due to incidents (ORAUT 2010e, p. 20).

Plutonium at Hanford was a mixture of several isotopes, notably Pu-238, Pu-239, Pu-240, and Pu-241. Pu-238 and Pu-239/240 were measured separately only from 1983 onwards. Their ratio can be used to estimate the composition of the plutonium mixture, as noted by NIOSH (ORAUT 2010e, p. 21), and also to infer the activities of Pu-241 and Am-241. The ratios suggested by NIOSH in the TBD appear to be reasonable and claimant favorable (see ORAUT 2010e, pp. 20–22). Specifically, the assumption of 12% Pu-240 when there is no information about isotopic composition is generally reasonable and claimant favorable. For the coworker model, a set of default assumptions about the age of the plutonium have been suggested by NIOSH (ORAUT 2010e, Table C-8, p. 129). These assumptions are scientifically reasonable and claimant favorable. Before 1983, the measured quantity was total alpha from plutonium, which means the total of Pu-238 and Pu-239+240. In such cases, the information can be supplemented by available Am-241 data to infer how much Pu-241 and Am-241 were present at intake.

Finally, NIOSH also did comparisons of in-vitro versus in-vivo counts. There were 100 positive Am-241 chest count records analyzed together with the corresponding in-vitro bioassay records for Pu-238, 239 (100 sets). Each record was examined to determine if a positive urine or fecal sample were associated with the positive chest count.

Just over half (52) of the 100 sets of data points showed negative in-vitro bioassay results when there were positive chest counts. There were also cases where the in-vitro bioassay discovered the uptake and that was the reason that the chest count was initiated. This study made it apparent that in-vivo counting and in-vitro bioassay programs are complementary. They work together to identify incidents and evaluate internal doses due to them.

While SC&A will review issues associated with the U.S. Testing data quality for the 1987–1989 period separately (as stated at the beginning of this report), it is important to note that audits of the bioassay program were conducted routinely at least during the 1980s. Some results from the period prior to the 1987–1989 period (inclusive) covered by SEC-00155 are important for the plutonium program (and some others as well). Specifically, a 1982 audit report noted that plutonium measurements were systematically low in 1981 and that, despite improvements, the problem persisted into 1982. NIOSH uses the contractual value of 0.05 dpm/sample as the MDL; however, the actual MDL was closer to 0.1 dpm/sample. The underestimates of plutonium in urine extended to values higher than 0.1 dpm as well (Fleishman 1982, pdf p. 4 and p. 6). The problem for plutonium sampling appears to have been corrected by the 1984 audit (Spitz 1984). SC&A has not located similar audits for the 1970s. The data in the audits may provide a basis for corrections.

12.3 NIOSH Approach to Coworker Model for Plutonium

NIOSH has presented its approach to coworker modeling based on the plutonium measurements that are available for the period. NIOSH includes below MDA measurements in determining the intake values corresponding to various assumptions about solubility. The coworker model approach suggested is a standard one used by NIOSH and is not an SEC issue as such. NIOSH's coworker model for plutonium uses a linear distribution to fit the data below detection limit. The TBD notes that many plutonium samples are related to incidents; in such cases, workers were often sampled multiple times. NIOSH redacted the data in the following way for developing its coworker model:

> *If there were a large number of samples from a single worker, usually bunched after a specific time, these were removed. A specific number was not rigorously applied as the definition of large, but it was generally greater than about 20 in 1 year. In addition, once a person was selected to be removed, data for subsequent years in that worker's history were removed until the excretion was near or less than the reporting level.* [ORAUT 2010e, p. 118]

Removing incident-related samples for coworker modeling is appropriate. However, SC&A is concerned that in removing samples from subsequent years until "the excretion was near or less than the reporting level" may miss routine exposures that were high, for instance during intermittent production or processing campaigns or during waste-handling operations. This approach may bias the coworker model towards lower intake values.

Since the measurements for 1981 did not meet the contractual MDA limit of 0.05 dpm/sample, but rather only achieved an MDA closer to 0.1 dpm/sample, NIOSH should adjust its coworker model to reflect this fact. Similarly, NIOSH needs to investigate the correction factors for plutonium results in the period up to June 1984, and how a claimant-favorable approach to dose reconstruction for those with data and to unmonitored workers needs to be created. The TBD mentions exposures to Super S, but the coworker model only considers Types M and S (ORAUT 2010e, p. 137). Specifically, the TBD mentions in several places that Super S plutonium was present at Hanford (ORAUT 2010e, pp. 22 and 53).

Finally, NOISH's coworker model and intake estimation only goes up to 1988 (ORAUT 2010e, Tables C-9 and C-10, p. 131), though the SEC period extends to the end of 1990. It is important for NIOSH to ensure that this approach is claimant favorable, especially for separations workers.

12.4 Findings for Plutonium Modeling

Finding 14-1: NIOSH has not considered Type Super S plutonium for intake estimation.

Finding 14-2: NIOSH should take the different, non-contractual MDA for 1981 into account in its coworker model.

Finding 14-3: NIOSH should ensure that extending 1988 values to 1989 and 1990 is claimant favorable for separations workers.

Finding 14-4: NIOSH's method of redacting samples relating to incidents may bias coworker intake estimates towards a lower intake level.

13.0 ISSUE 16: CURIUM-244 AND AMERICIUM-241

13.1 Curium-244

Major work with curium appears to have ended in the late 1960s. There was a 1974 proposal to separate transplutonium radionuclides, including curium and americium isotopes, from waste generated at the Barnwell Nuclear Fuel Plant, which was being built at the time (Battelle 1974). However, the Barnwell plant never reprocessed spent fuel, and it appears that this project was not implemented.

There were some experiments with Cm-244 up to and including 1973, according to the TBD:

> *PNNL's Space Nuclear Systems Division reported on laboratory work in March 1969 on phase transformations in curium oxide in which a small sample of curium oxide was heated in a vacuum in a differential thermal analysis apparatus (Hansen 1969c, p. 4). The building where the work took place was not mentioned. One of the authors was interviewed briefly by phone. He said that he and a few others worked with milligram quantities for special studies in the 308 Building between about 1969 and 1973. All the work was done in gloveboxes. Each experiment was of short duration (a month or so), but there were multiple experiments. The curium was not from Hanford. Because quantities of curium and other higher order transplutonium elements were scarce, who, when, and how much of these special isotopes was made available to researchers was controlled by the AEC-wide Transplutonium Research Coordinating Committee. That committee arranged for delivery of the samples, which were used then shipped to the next researcher on the priority list. The researcher said there were no contamination spreads with the curium samples (Bihl 2009b).* [ORAUT 2010b, p. 49]

However, Hanford documentation indicates Cm-244 exposure potential and possible handling and processing well beyond 1973. For instance, this is indicated in the Monthly Report for June 1978:

> *One radiation occurrence involving the loss of containment and potential inhalation of ^{244}Cm was formally reported to RL. Other occurrences documented internally included a repeat of the above occurrence at 231-Z and inhalation of ^{90}Sr and ^{137}Cs by a technician at the 324 Building.* [Jech 1978a]

Similarly, the monthly report for October 1978 reported intakes of curium:

> *A series of inhalations of curium-244 has begun at 331 and is expected to continue for several weeks as are the Chromium 51 inhalations. This is not creating any undue problems.* [Jech 1978 b]

The context of these monthly reports indicates that these intakes may have occurred during cleanup or refurbishment of facilities. It may explain a single curium urinalysis done in June 1978. However, none were reported for October 1978.

13.2 Curium-244 Data

There is only one in-vivo data point for Cm-244 in the REX database in 1978. There were 15 in-vitro measurements reported in the 1970s (starting on July 1, 1972); but none of the measurements were made in 1973, when experimental work was done at Hanford. As noted, above, there was a measurement in June 1978, when an incident was noted; no measurement corresponding to the October inhalation incidents is in the REX database.

It is possible that the 1974 to 1979 and the scattered samples thereafter until 1981 (inclusive) were related to incidents during refurbishment and cleanup operations. There are no data for 1982 and also none for 1983 until October (inclusive). SC&A has not researched the reasons for the sampling in detail, but notes that exposures occurred well after the reported ending date of exposure potential related to curium processing. There appear to be ample routine urine data in the REX database for Cm-244 starting in November 1983.

13.3 NIOSH Approach to Curium-244

The TBD provides the following approach for Cm-244 after July 1, 1972:

> *Limited use of routine urinalysis was conducted starting in 1974. If an intake estimate is required, unmonitored workers should be assigned intakes at the 95^{th} percentile of the plutonium coworker intakes (constant distribution) prior to 1974 and at the 50^{th} percentile (with GSDs) from 1974 on.* [ORAUT 2010e, p. 60)

NIOSH has not provided any analysis to show how the various situations of curium exposure potential could reasonably be modeled by using the 95^{th} percentile of plutonium intakes. Furthermore, as noted above, Cm-244 data are too sparse for coworker modeling.

13.4 Americium-241

Americium-241 is created by the decay of Pu-241 (which is associated with plutonium-239/240) and hence can be inferred from plutonium data if the age and isotopic composition of the plutonium is known or can be assumed in a claimant-favorable manner. NIOSH has specified its

approach for Am-241 in plutonium mixtures in the TBD (ORAUT 2010e, Table 5-5).[7] However Am-241 separation operations were also conducted in Building 325 during the period under review in this report. The radiation dose due to such operations cannot be inferred from plutonium in-vivo or in-vitro data, since the objective of the process is to produce pure Am-241 unmixed with plutonium. According to the TBD, about 3 kilograms of pure Am-241 was separated in the A-Cell of Building 325 during the 1973 to 1976 period and shipped to Oak Ridge National Laboratory. This statement was based on a telephone interview, which referred to a set of slides that is not available (ORAUT 2010b, pp. 34–35).

13.5 Americium-241 Data

It should be noted that 3 kilograms of Am-241 represent a very large amount of alpha-emitting material—more than 10,000 curies. Table 12 shows the number of workers who were monitored for Am-241.

Note that there are very few measurements in 1975. Furthermore, as we have noted in some other cases, tank farm workers have very sparse monitoring data until 1977 or so. The reason for the sudden decline in monitoring in 1975 is unclear at this time. It is possible that it was related to a strike at Hanford in that year. We note that there were many measurements in the 200 and 300 Areas, in parts of which there was potential for americium exposure. The measurements appear to be a mix of routine and incident-related samples.

Table 12. Number of Workers Monitored for Am-241 by Area

Year	Number of Workers Monitored for Americium (In Vitro + In Vivo)							
	All Workers	100 Area	100N Area	200 Area	200 Tank Farms	300 Area	400 Area	700 Area
1972	218	12	10	***61***	***[redacted]***	***70***	***[redacted]***	***[redacted]***
1973	450	29	24	***111***	***[redacted]***	***190***	16	***[redacted]***
1974	618	45	38	***110***	***[redacted]***	***256***	12	***[redacted]***
1975	31	***[redacted]***	***[redacted]***	***12***	***[redacted]***	***9***	***[redacted]***	***[redacted]***
1976	730	39	33	***124***	***[redacted]***	***335***	21	***[redacted]***
1977	863	62	57	***159***	***[redacted]***	***353***	46	***[redacted]***
1978	1224	83	73	***295***	***17***	***486***	117	16
1979	1398	102	85	***386***	***20***	***485***	234	***[redacted]***
1980	1491	87	72	***429***	***24***	***628***	262	21
1981	1535	116	95	***494***	***24***	***699***	303	16
1982	1380	83	62	***437***	***31***	***778***	404	12
1983	1346	85	54	***544***	***47***	***711***	314	15
1984	1398	111	81	***614***	***50***	***719***	304	11
1985	1469	159	117	***715***	***64***	***738***	266	17
1986	1582	219	177	***859***	***87***	***738***	223	13
1987	1517	169	132	***886***	***82***	***690***	233	13
1988	1563	314	278	***1044***	***78***	***627***	222	24
1989	1819	374	336	***1279***	***75***	663	205	27
1990	2338	550	507	***1768***	***103***	732	208	29
All Years	7370	1136	1031	3203	187	2199	849	119

* The results presented in bold italics indicate areas and years with exposure potential (see Appendix A).

[7] The selection of the Am-241 to Pu-239 ratio is not an SEC issue and hence has not been reviewed in this report, since plutonium data for dose reconstruction are available.

13.6 NIOSH Approach to Americium-241

NIOSH has specified the following approach to estimating Am-241 dose for unmonitored workers:

> *Significant quantities of pure ^{241}Am or mixtures enriched in ^{241}Am were present in several Z-Plant facilities through 1976 and at times at a few other facilities…. Exposure prior to July 1, 1972 is covered by the SEC because it was determined to be infeasible to reconstruct doses. Bioassay monitoring via chest counts was used for significantly exposed workers from 1968 on and urinalysis was used for special monitoring after incidents with potential for intake. If an intake estimate is required from July 1, 1972 on, unmonitored workers should be assigned intakes at the same values as the plutonium coworker intakes using the 50th percentile values and the GSDs from Attachment C.* [ORAUT 2010e, p. 60]

Using plutonium as the reference radionuclide for Am-241 when the latter is a contaminant in plutonium is a reasonable approach (though NOISH should justify its choice of the 50th percentile value). However, plutonium is not an appropriate reference radionuclide for operations involving separation of americium or its processing apart from plutonium. NIOSH needs to specify a coworker model for unmonitored workers in such cases, especially until 1976 (inclusive), when the last major operation in which americium was not associated with plutonium took place.

13.7 Findings Relating to Curium-244 and Americium-241

Finding 16-1: Curium-244 exposure potential existed due to experimental operations in 1973 and due to other operations, probably related to refurbishment of facilities, later in the SEC period. SC&A has documented exposures due to incidents in 1978. It is unclear whether this potential continued into the 1980s. Routine sampling appears to have begun in November 1983.

Finding 16-2: Curium-244 data do not exist for 1973 and are sparse thereafter until October 1983.

Finding 16-3: A coworker model for Cm-244 may be feasible after 1984 (inclusive).

Finding 16-4: NIOSH has not provided a technical rationale for using plutonium data for Cm-244 dose reconstruction. This does not appear to correspond to documented situations with Cm-244 exposure potential.

Finding 16-5: NIOSH should develop a coworker model that is specific to Am-241, apart from its association as a trace contaminant in plutonium, especially for the period up to 1976. This may be difficult, given that much of the Am-241 in-vitro monitoring was in the context of incidents.

14.0 MATRIX ISSUE 19: LACK OF ADEQUATE MONITORING (PETITIONER ISSUE)

NIOSH has an extensive discussion of internal monitoring data in its revised TBD (ORAUT 2010e). SC&A has done an extensive review of the available data for completeness and

adequacy. The detailed analysis is presented in Appendix A of this report. The above discussion analyzes the data by radionuclide for the major radionuclides at the Hanford Site and details findings in each case.

As noted above, data are adequate for dose reconstruction and for coworker models in some cases. In other cases, they are not. In yet other cases, there are specific findings and suggestions for NIOSH; specifically to examine the feasibility of using available data to fill in gaps that exist. Some radionuclides other than those discussed above are discussed below in the order in which they appear in the SEC Issues Matrix (Appendix B).

15.0 MATRIX ISSUE 20: SKIN CONTAMINATION

Since external dose data records would reflect routine skin exposure, the issue of skin contamination is related to that of incidents and is discussed with Matrix Issue 22 below.

16.0 MATRIX ISSUE 21: MISSING AND DESTROYED RECORDS

SC&A made a request to DOE for a list of destroyed records. Since records are routinely destroyed according to a prescribed protocol, a list was made available to SC&A. It consists of a list of about 71,000 boxes of records that were destroyed. Almost all these records are either prior to the period being reviewed here (i.e., earlier than July 1, 1972) or are administrative records that are not relevant to this review. Some of the labels used for describing the contents of such boxes are as follows:

- Purchase orders
- Magnetic tapes (possibly backup tapes for records)
- Vouchers – Acct Pay

There are general ledger files and other records that appear to be administrative. There are a large number of boxes with dosimetry data, labeled “personnel badge film” and “BIOASSAY ELECTRO CA” that also bear the label “General Electric.” These are presumably records from the time that General Electric was the main contractor at Hanford (until 1964). These records are not directly relevant to the investigation of completeness and adequacy of data for this SEC review, since NIOSH has already stated that dose reconstruction is not feasible until June 30, 1972, on a number of counts. However, we note that for radionuclides that have a long residence time in the body, loss of records relating to the pre-1972 period could affect dose estimates in the period under consideration here if the incidents are not noted in the individual’s raw dose records. However, comparison of raw individual records to the electronic incident database reveals that the former is much more complete (See Section 17.0).

Unfortunately, a large number of the box descriptions have no date indicated in that column. There is a “To Date” column in the records list, but this appears to be the date on which the documents were boxed, rather than the latest document date of materials in the box.

A small number of boxes appear to have data relevant to the period under consideration, as well as a year indicating the date of the documents in the box. For example, there is a box of tritium data with the date:

- Box #53082 – “TRITIUM DATA 1976”

In other cases, which are more frequent, the box descriptions appear relevant, but there are no dates indicated as to the period in which the documents were created, as shown by the following examples:

- Five boxes labeled "Unusual incident" with no dates (box numbers 37722, 53692, 58218, 64877, and 64882)
- Two boxes titled "VAULT INVENTORIES" with no dates (box numbers 75016 and 75017)

There are some boxes that may be relevant, but whose titles are difficult to interpret. For instance, there are several boxes with the labels "WASTE MANAGEMENT ENVIRON W"; none of them have dates.

SC&A's review of the box titles, dates, and other date fields in the spreadsheet of destroyed documents indicates that some boxes with relevant personnel dosimetry data and incident data were destroyed. While most do not have date ranges for the documents in them, some box titles, such as Box #53082 mentioned above, are from the period being reviewed here.

It is not possible for SC&A to determine whether the data that may be relevant in the destroyed boxes is in the personnel files or in the REX database or both. Generally, external dose data seem to be reasonably complete in the REX database for the period under consideration and were declared by the Work Group to not be an SEC issue. Internal data are not complete and are inadequate in some cases, as discussed above. It is not possible, based on the review done here, to determine whether there are more data that could fill some of the essential gaps. NIOSH has done extensive data capture and SC&A has reviewed the available data, so it is likely that any duplicates would have been discovered in the extensive effort that NIOSH has made to compile information relative to internal dose reconstruction for the period under review.

16.1 Findings for Matrix Issue 21: Destroyed and Missing Records

Finding 21-1: A large number of records have been destroyed as a matter of government record-keeping practices. The vast majority of these records were administrative records of no relevance to dose reconstruction.

Finding 21-2: A small portion of these boxes appear to have contained data relevant to dose reconstruction, but most of that, in turn, appears to have been prior to the period under consideration. Some boxes that may be relevant have no dates indicating the period of the documents in the box. Finally, a small proportion of the boxes have labels that indicate they are relevant and a date that places some or all of the contents in the period under review here. SC&A has not been able to establish whether the destroyed boxes contained data that could fill in some of the gaps described above for internal dosimetry.

17.0 MISSING INCIDENT RECORDS

As discussed above, there are some incident records that have been destroyed. The contents of the destroyed boxes, and even the dates of those incidents, were not discovered during this investigation. SC&A took a couple of different routes to determining whether personnel records contain data on all incidents.

First, when researching the SRDB, SC&A came across descriptions of incidents. As noted in Observation 1 in Appendix A, SC&A found that workers were generally scheduled for bioassay when there were incidents. SC&A did not connect these cases to actual bioassay data to see if the measurements were actually done. We know from the Cm-244 examples that incidents were not always followed up by bioassay, at least as reflected in the REX database.

SC&A also attempted to determine whether the REX incident database contains information about incidents that are either mentioned in the individual claimant files supplied to NIOSH by the DOE or in the CATI conducted by NIOSH as part of the dose reconstruction process. The review was based on claimant records.

17.1 Incidents in REX Incident Database compared to Individual Records

To examine the extent and validity of the REX incident database, hardcopy records were examined for a subset of claimants who had documented incidents in the database during the SEC period. There were 40 claimants selected at random for examination; however, once the hardcopy records were examined, it was found that 10 of these workers spent some or all of their SEC employment at Pacific Northwest National Labs (PNNL). Therefore, an additional 10 claimants were selected who were identified as working only at Hanford. In addition, 1 of the original 40 random claims could not be opened via the NIOSH claimant database, so this claimant was removed from the analysis and replaced with another.

The incident database contained 63 separate incidents for the 50 claimants examined. Of the 63 incidents, 59 of these incidents (or ~94%) were reflected in the hardcopy records for the claimants. In the four cases where the incident was not reflected in the hardcopy records, the DOE_Response files appeared to be incomplete compared to the other claims reviewed. The files only contained x-ray records, internal monitoring, and annual dose totals, and did not contain the other documents typically included in the claimant records for Hanford, such as training certifications, visitor forms, mask fittings, monthly external dose reports, and lost dosimeter investigation forms. In three of the four cases, the incident was mentioned in the CATI report.

Conversely, the hardcopy records documented 92 separate incidents during the SEC period for the 50 claims examined. Of these 92 incidents, 33 (or about 36%) were not found in the electronic database. It is not clear why such a large portion of incidents were omitted from the database; it did not appear as though the severity of the incident had any effect on whether the incident was entered into REX. Table 13 contains specific information about the incidents identified in the electronic database, including date of the incident, whether it was included in the hardcopy records, a description of the incident (transcribed from the hardcopy record or CATI), and any additional comments.

Table 13. Summary of Incidents Reviewed

Incident Date	Incident Included in Hardcopy File?	Description of Incident From Hardcopy Record/CATI	Additional Comments
[redacted]/1973	No	From CATI report: "[Location] In the lab in 325 Bldg… Something got loose and he got 'crapped up' (i.e., contaminated) and he lost all his clothes and he had to be scrubbed until he was raw."	Incident is mentioned in CATI report. Hardcopy records appear to be incomplete.
[redacted]/1974	Yes	"While working in laboratory [redacted] 308 Building received coverall contamination… The concerned employee had inspected the gloves prior to starting his work but after 10 minutes of work he removed his hands from the glove box and noted that both gloves had ruptured. He remained at this location and had Operational Health Physics notified."	Claimant had 3 documented incidents on [redacted]/75, [redacted]/75, [redacted]/80 that were not included in the database. Claimant also had a documented incident on [redacted]/79 that was included in the database.
[redacted]/1980	Yes	"A [redacted] and [redacted] Operator entered the 221-T Canyon to observe removal of a B Plant jumper pan from the Multi-purpose transfer box for placement on the canyon deck at Section 12. Dose rates from the jumper pan were to be obtained after it had been removed to the deck. The CAM's in the canyon alarmed when the crane operator started lifting the jumper pan out of the Multi-purpose box. Personnel immediately left the canyon. CAUSE: Unexpected loose contamination in jumper pan that became airborne when pan was lifted by the crane."	The first DOE response file contained dose records for the wrong worker. The last name is the same, but the first name and middle initial differ.
[redacted]/1983	Yes	"Involved in an exposure incident at KE Basin. The worker is a [redacted] operator who runs a terminal in the KE Basin Radiation Zone. During slack periods [redacted] had manipulated the hooks and tongs used to access fuel drums in the basin. The tongs were contaminated. [Redacted] face and hairline were contaminated."	
[redacted]/1972	Yes	"Employee punched end of scissors through hood glove, through surgical gloves and into the heel of his left hand at the base of his thumb. Very little bleeding. No airborne contamination thought to be probable."	Claimant had a documented incident on [redacted]/72 that was not shown in the database. Claimant also had a documented incident on [redacted]/73 that was included in the database.

Table 13. Summary of Incidents Reviewed

Incident Date	Incident Included in Hardcopy File?	Description of Incident From Hardcopy Record/CATI	Additional Comments
[redacted]/1985	Yes	"Workers were moving contaminated waste and sorting it at 1C5N, 14-foot left front area. Respiratory protection was not being worn. Nasal contamination was detected on [redacted], skin contamination on [redacted] workers. A third worker was checked because he had been in the general area while the work was occurring."	Claimant had documented incidents on [redacted]/79 and [redacted]/81 that were not included in the database.
[redacted]/1974	Yes	"A [redacted] operator was found contaminated during a personnel survey in the 271-CR Change Room at completion of taking East Area Tank Farm catch tank readings and checking out FIC units."	Claimant had a documented incident on [redacted]/85 that was not included in the database.
[redacted]/1978	Yes	"Technician was polishing 244Cm doped waste fixation metallography sample in the glovebox in [redacted]. He had worked about 20 minutes on about six different samples of the same type. Upon removing hands from gloves, gross contamination on surgeon gloves (~1 M DPM) was detected. The surgeons gloves were removed, and the bare hands were removed. There was gross evidence of skin contamination and RM was notified. The glove break was caused by the metallography sample perforating the right glove."	Claimant had a documented incident on [redacted]/1978 that was included in the database. NOCTS lists the worker at [redacted] during the SEC period.
[redacted]/1986	Yes	"While working in [redacted], 100 Area, the worker incurred facial contamination of 500 cpm beta-gamma activity. A nose blow indicated 900 cpm activity; however, nasal smears did not indicate detectable activity (<200 cpm). Nuclides of concern were mixed fission and activation products, primarily Co60."	Date should actually be [redacted]/86 according to the hardcopy records.
[redacted]/1983	Yes	"A Certified [redacted] Operator and a [redacted] Technician were dispatched to flush the V-9-13 valve. The [redacted] operator installed the drain connecter between the V-9 valve and the drain header. As the [redacted] performed the required pre-flush survey, the [redacted] operator opened the V-9 flush valve and the connector Ball Valve as the [redacted] left the immediate work scene. A back spray of water from the drain contaminated both employees."	Claimant had documented incidents on [redacted]/73 and [redacted]/77 that were not included in the database.

Table 13. Summary of Incidents Reviewed

Incident Date	Incident Included in Hardcopy File?	Description of Incident From Hardcopy Record/CATI	Additional Comments
[redacted]/1974	Yes	"BNW [Battelle Northwest] Staff Members were demonstrating a ^{210}Po process to two AEC Canadian visitors. The ^{210}Po process demonstration was conducted within a glove box located in Room 604 of the 325 Building. The process, in part, involved removal of ^{210}Po samples from the glove box intermittently during the evening. Upon exit from Room 604, and upon completion of the work, at 11 PM, the Eberline Air Monitor alarmed. The operations personnel checked the room for a possible cause of the alarm. Finding no smearable contamination, both the BNW staff members and the visitors performed a personal survey and exited the room to go home... On 3/5/74 HEDL was requested to have all fans running. Word did not get to the power operators and the fans were shut down as a normal routine. The ^{210}Po glove box exhaust via four HEPA filters in a series prior to exhausting the 324 Building's main stack. It is assumed the reduction of exhaust resulted in less negative pressure within the glove box to an unsafe level for opening the glove box air lock."	Worker had a documented incident on [redacted]/75 that was not shown in the database. Worker also had documented incidents on [redacted]-85 and [redacted]-86 that were included in the database; however, the [redacted] incident occurred on both [redacted] and [redacted], though was only listed for [redacted] in the electronic database.
[redacted]/1973	Yes	"[Names Removed] were working in Glove Box [redacted]. DELETED finished connecting a thermocouple and removed his hands from the glove box and discovered contamination on his surgeon's gloves. [Claimant] removed his hands from the glove box and found both surgeon's gloves contaminated. Radiation Monitoring was contacted and placed the room on assault mask. The room air sample was counted and was less than assault mask levels... By all indications, one or more glove box gloves were ruptured from working with sharp objects inside the box. The apparent cause of the spread of contamination to eleven glove box gloves was failure of personnel using the gloves to always perform a survey of their hands and forearms each time the hands were withdrawn from the glovebox."	Worker had documented incidents on [redacted]/73, [redacted]/73, [redacted]/74, [redacted]/75, and [redacted]/79 that were not contained in the database. Records indicate the worker was at [redacted] during the SEC period.
[redacted]/1973	Yes	"A hood glove ruptured while [redacted] maintenance craftsmen were repairing the crucible cutter in the button line, hood 16."	Claimant also had an incident on [redacted]/73 that was also included in the database.
[redacted]/1973	Yes	"Contamination was found in the duct area (2nd floor) of 231-Z bldg. where [Name Removed] had been working."	Claimant spent some of the SEC period at [redacted].

Table 13. Summary of Incidents Reviewed

Incident Date	Incident Included in Hardcopy File?	Description of Incident From Hardcopy Record/CATI	Additional Comments
[redacted]/1984	Yes	The individual received a sliver in his right index finger while pulling a thermocouple out of a hood [redacted] facility during [redacted] refurbishing work. No contamination was detected on the sliver or on his finger; however, parts of the thermocouple were observed to be contaminated."	Claimant had a documented incident on [redacted]/72 that was included in the database. Claimant also had a documented incident on [redacted]/83 that was not included in the database.
[redacted]/1973	No	From CATI report (see comments): "Vacuum pump oil sprayed over the area when being maintained… [protective equipment] Double set of coveralls and mask… [duration of incident] 2 hours."	The incident is mentioned in the CATI interview with the claimant. It appears the claimant was an employee of [redacted] during the SEC period. The CATI interview states that the incident occurred at [redacted]. DOE Response files only contain annual dose totals and x-ray records.
[redacted]/1983	Yes	"With manipulator and boot removed from "[redacted]" hot cell, employee reached through the penetration port and tightened a light bulb inside the cell. Lab coat sleeve contamination."	Claimant had a documented incident on [redacted]/76 that was not included in the database.
[redacted]/1981	Yes	"Working on RTD's [Resistance Temperature Detectors] (thermocouples) No respiratory protection required or worn… Facial contamination."	
[redacted]/1985	Yes	"While preparing a standards solution in a hood, a glass vile containing Pu shattered rupturing the workers glove and contaminating her left thumb. Skin was intact but substantial decontamination was required."	Claimant was also involved in an incident on [redacted]/85 that was included in the database.
[redacted]/1973	Yes	"Employees became contaminated while bagging Pu waste out of a glove box. The tape did not seal and the bag dropped to the floor. Radeco air monitor about 20 ft. away from work area had no increase in activity."	Claimant had documented incidents on [redacted]/72 and [redacted]/78 that were not included in the database.
[redacted]/1972	Yes	"Employee received a puncture to his left ring finger from a syringe while cleaning a sludge pit. Puncture just barely broke the skin and no bleeding occurred. There was a visible mark on his finger."	Hardcopy records indicate the incident occurred in Area [redacted].

Table 13. Summary of Incidents Reviewed

Incident Date	Incident Included in Hardcopy File?	Description of Incident From Hardcopy Record/CATI	Additional Comments
[redacted]/1990	Yes	"[Redacted] workers entered the canyon for photography and observation of L cell. All wore respiratory protection. A portable air sampler was used to monitor airborne activity. The air sample indicated an air concentration of alpha activity (interpreted as plutonium) about 120% of that allowed by the protection factor for the respirators."	Hardcopy records indicate the incident occurred on [redacted]/90. Claimant had a documented incident on [redacted]/78 that was not included in the database.
[redacted]/1974	Yes	"The employees changed out a filter in a small exhaust line that serves the inhalation toxicology dog inhalation facility. No masks were worn. The filter and line are located in the 331 bldg. duct level. Upon removal from its holder the filter fell apart into small pieces. These pieces were picked up with a vacuum cleaner. Either a piece of the filter or a smear from the upstream side of the filter holder is required to obtain isotopic and particle size information."	
[redacted]/1974	Yes	"A technician who had been removing bolts from a flange inside a glove box in [redacted], discovered contamination on his coveralls when performing a personnel survey. He immediately evacuated the room and contacted operations and Radiation Monitoring."	Records indicate claimant was at [redacted] during the SEC period.
[redacted]/1972	Yes	"A Senior Chemical Technologist received a small injury to his right forefinger while bagging waste out of hood [redacted] of the [redacted]."	
[redacted]/1974	Yes	"Employee became contaminated while removing V-12 batch covers in the outlet pipe spaces. No mask worn."	Worker also had documented incidents on [redacted]/74, [redacted]/75, and [redacted]/79 that were also included in the database.
[redacted]/1984	Yes	"The worker was repairing a primary coolant return valve in a steam generator cell [redacted] Area. Respiratory protection was not worn. Upon exiting, skin contamination was detected."	
[redacted]/1980	Yes	"Employee was working in a greenhouse wearing a power air purifying air respirator, and the filter was knocked off."	

Table 13. Summary of Incidents Reviewed

Incident Date	Incident Included in Hardcopy File?	Description of Incident From Hardcopy Record/CATI	Additional Comments
[redacted]/1978	Yes	"Beta-gamma contamination of 4,000 c/m was detected on the exterior of a welder craftsman's nose during personnel surveys following exit from the 221-B Canyon. Investigation revealed the respirator worn by the employee was a Scott facepiece modified to provide deep-tinted lenses for welding activities as well as a clear lenses which could be exposed for normal viewing when the tinted lens was raised. The clear lens was inadequately secured/sealed causing air leakage around the lens to the employee's face rather than all the inlet air being filtered through the appropriate canister."	
[redacted]/1974	Yes	"[Claimant] was breaking up plutonium castings inside glove box [redacted]. He inadvertently cut through the glove box glove and his surgical glove breaking the skin of the ring finger of his left hand."	Claimant had documented incidents on [redacted]/75 and [redacted]/76 that were not included in the database. Records indicate claimant was at [redacted] during the SEC period.
[redacted]/1982	Yes	"Switched work from one non-contaminated valve to a contaminated valve. One person bumped hose on valve. Moving old valve to replace new. In with camera crew. Bumped hose on dirty pipe."	
[redacted]/1973	Yes	"The [redacted] technicians routinely bagged in a plutonium part in Room [redacted] conveyer system. One of the [redacted] technicians discovered contamination on his right coverall sleeve when performing a personnel check. He checked inside the can where the part was stored and discovered it contaminated. Radiation Monitoring was contacted and placed the room on assault masks."	Claimant had a documented incident on [redacted]/74 that was included in the database. Records indicate claimant was at [redacted] during the SEC period.
[redacted]/1988	Yes	"They were trying to unplug a line in SD valve pit using hot water. The operators sprayed cold water in to the pit on top of the hot water, this caused vapor to rise and some of it got into the cab of the crane contaminating [claimant's] coveralls. He was not wearing a mask at the time which is normal for this type of operation and is covered in RWP F1. He received a small amount of contamination in his nostrils and mouth."	
[redacted]/1982	Yes	"On [redacted]/82 at 0810 hours, a uranium fire occurred in the Peel Test Saw Area."	

Table 13. Summary of Incidents Reviewed

Incident Date	Incident Included in Hardcopy File?	Description of Incident From Hardcopy Record/CATI	Additional Comments
[redacted]/1980	Yes	"A [redacted] technician, working in [redacted] making mounts of samples, delivered the mounts and the analytical cards via the sample elevator to the counting room without first making radiological status surveys. The counting room attendant surveyed these finding contamination and notified Radiation Monitoring."	
[redacted]/1973	Yes	"An air sample that was removed from laboratory [redacted] Building on [redacted]/73 was found to be positive for plutonium contamination."	Claimant has a documented incident on [redacted]/74 that was not included in the database.
[redacted]/1973	Yes	"[Workers] were segregating and loading out polystyrene cubes into a shipping container for transporting to ARHCO for PuO2 recovery. The cubes had been surveyed by Radiation Monitoring. [Claimant] attempted to free two cubes that were stuck together but was unsuccessful and inserted them in a plastic bag. He surveyed his gloves immediately after bagging the cubes and found them contaminated... The technician checked the table and lead shielding they were using and found both contaminated. The table top was covered with a towel, and the contamination on the lead shielding was taped over."	Records indicate claimant was at [redacted] during the SEC period.
[redacted]/1983	Yes	"Worker became contaminated while inspecting a valve at [redacted]."	
[redacted]/1989	Yes	"[Claimant] incurred slight facial contamination and had detectable activity in nasal smears as a result of moving contaminated scaffolding in a pit."	
[redacted]/1974	Yes	"The subject employee's foot slipped while he was working from a ladder inside the primary side of [redacted] steam generator. When he slipped his right wrist was scratched on several places."	Claimant had a documented incident on [redacted]/77 that was not included in the database.
[redacted]/1989	Yes	"On [redacted]-89, at approximately 1050 hrs. a millwright knelt down on a contaminated damp rag to reinstall the impeller on the [redacted]. Upon exiting the [redacted] storage room, contamination was discovered on his right knee."	

Table 13. Summary of Incidents Reviewed

Incident Date	Incident Included in Hardcopy File?	Description of Incident From Hardcopy Record/CATI	Additional Comments
[redacted]/1974	Yes	"Employee became contaminated while working in the [redacted] of 327 bldg. Contamination was noticed at the beginning of work by a shoe cover survey."	Claimant had a documented incident on [redacted]/79 that was not included in the database.
[redacted]/1973	Yes	"A [redacted] operator incurred a contaminated injury to his thumb, left hand, while working in hood gloves at the sorting hood in [redacted]."	
[redacted]/1985	Yes	"Worker was contaminated while working on a check valve in the [redacted] Building, [redacted]. Beta-gamma contamination was found in nose, moustache, and cheek area."	
[redacted]/1981	Yes	"Steam generator inspection performed by employee, primary coolant sprayed."	Claimant had a documented incident on [redacted]/77 that was not included in the database.
[redacted]/1972	No	CATI report mentions an incident but it was in Building [redacted] not 232-Z, the date of the incident is not known	
[redacted]/1974	Yes	"Employee became contaminated during the changing of a line. A liter of distilled water was drained from a line connected to the tank. The contaminated water (thought to be nonradioactive) was then dumped into a crib sink located in Rm 601. Contamination was found on personal survey."	Claimant had documented incidents on [redacted]/73, [redacted]/75, [redacted]/76, [redacted]/82, and [redacted]/85 that were not included in the database.
[redacted]/1973	Yes	"Employee incurred a small cut to the base (palm) of his right hand. He was attempting to rearrange a package of waste in a burial drum."	Claimant had documented incidents on [redacted]/76 and [redacted]/80 that were not included in the database.
[redacted]/1978	Yes	"A pipefitter was removing lead wool packing from a pipe sleeve. He pried it out from sleeve. He became contaminated. Employee was wearing 2 pairs of coveralls, assault mask, and 2 pair of gloves."	
[redacted]/1979	Yes	"The subject employee was installing piping under the discharge elevator… with no respiratory protection… Personnel survey revealed [contamination]"	Employee also had a documented incident on [redacted]/79 that was not included in the database.

17.2 Findings Relating to Missing Incident Records

Finding 22-1: The individual records, consisting of a combination of the records supplied by DOE and the CATI reports, appear to document the vast majority of incidents. There does not appear to be a detectable pattern of not recording incidents.

Finding 22-2: The REX databases do not appear to contain the detail of information or the quantity of information available in the claimant records.

Note: SC&A has not attempted to review logbooks or to otherwise determine if there were incidents records in other records at Hanford that are not in the personnel files.

18.0 ISSUE 25: OTHER RADIONUCLIDES

A number of other radionuclides were handled, produced, or present at Hanford to which some employees had exposure potential. These include Cr-51 and Co-60, as well as fission products Ru-106 and Ce-144 that were separated. In addition, some personnel in the 400 Area had exposure potential to sodium-24, as noted in the TBD. Monitoring data for a number of radionuclides other than those discussed in detail above exist in the REX database; some, like sodium-24, more extensively than others, like Ce-144 or Ru-106. However, for radionuclides like Ce-144 and Ru-106, it should be possible to use MFP data. The in-vivo counter had the capability of detecting these radionuclides and others.

Sodium-24 measurements are available for the 1970s as well as the 1980s. However, some radionuclides, such as cobalt-60, only have in-vivo data from about 1984 onward. SC&A notes that more complete radionuclide monitoring seems to have been initiated in 1983 or 1984 to cover the more unusual radionuclides present at Hanford.

18.1 Quality of Data

As noted in Section 10.3, a 1982 audit of the quality of urinalysis indicates a failure to meet MDA levels for several radionuclides: ^{140}Ba-La, ^{22}Na, ^{24}Na, ^{137}Cs, ^{59}Fe, ^{106}Ru, ^{134}Cs, ^{239}Np, ^{95}Nb-Zr, ^{131}I (Fleishman 1982). Further, SC&A did not find any other audit report (Bihl 1986, Spitz 1984, Hickman 1982) that contained a discussion of the quality of monitoring for these radionuclides. Finally, SC&A has not located similar audit reports for the 1970s.

18.2 NIOSH's Approach to Other Radionuclides

NIOSH has proposed the following generic approach for dose reconstruction for the large number of miscellaneous radionuclides present at Hanford:

> *A large number of different radionuclides were present at Hanford at various times, but the available bioassay data for radionuclides in addition to those in this attachment were considered to be too few to be statistically reliable for intake estimation. Workers who were exposed to ^{137}Cs, ^{90}Sr, ^{24}Na, and ^{65}Zn could also have been exposed to other fission and activation products. From 1960 to 1988, intakes of most fission or activation products would have been detectable in whole-body counts, but the recording practice for fission and activation products other than 137Cs, 24Na, and 65Zn was not amenable to statistical analysis.*

> *Guidance for assigning intakes of additional radionuclides is provided in ORAUT-OTIB-0054 (ORAUT 2007a) and for specific buildings in Section 5.6.*
>
> *Assignment to unmonitored workers of radionuclides that were not analyzed in this study should be in accordance with guidance in Section 5.6.* [ORAUT 2010e, p. 141].

As noted in Section 10.4, this approach is suitable for reactor workers. NIOSH has also specified dose reconstruction approaches in Attachment C of ORAUT 2010e for sodium-24, zinc-65, and the specific fission products Sr-90, Cs-137 and Pm-147. However, as also noted in Section 10.4, NIOSH has not specified a coworker model for unmonitored 200 Area separations area workers or workers who handled wastes, including those in the 300 Area, including Buildings 324, 325, 327, and 3706.

18.3 Findings for Other Radionuclides

Finding 25-1: The MDA for several of the radionuclides in question in this section were not met in 1981. There are no other audit reports for the 1972–1986 period that address these radionuclides. (SC&A is examining some quality of data issues for the 1987 to 1989 period separately, as noted in the Overview section.)

Finding 25-2: Some of the unusual radionuclides, such as Co-60, only have a significant quantity of in-vivo data from about 1983 or 1984.

Finding 25-3: NIOSH should discuss the pre-1987 quality issues in the TBD relating to several fission products, as well as sodium-24, and specify how it will handle MDA and other problems that may have existed in years other than 1981. (SC&A is in agreement with NIOSH that sodium-24 is only relevant to the 400 Area for the period under consideration here (ORAUT 2010e, p. 53), and only during the period of operation of the FFTF.

Finding 25-4: While NIOSH has specified coworker models for a number of radionuclides and areas, it has not specified a coworker model for mixed fission and activation products in the 200 Area and in the waste handling and processing buildings in the 300 Area.

19.0 MATRIX ISSUE 26: DATA COMPLETENESS

SC&A did an extensive analysis of the completeness of Hanford internal dose data. The main parts of this analysis are in Appendix A. This appendix contains a compilation of the internal dose data by radionuclides for each year in the period under review—January 1, 1972, to December 31 1990. Hence, it should be remembered that the label "1972" only refers to the last half of that year. SC&A also sorted the data by area and by job type. Additionally, SC&A defined the areas according to whether there was exposure potential or not. This term was loosely defined in this context as the area where the radionuclide was handled or processed during that year in a form that workers might inhale relative to other areas where such a potential was relatively unlikely.

The percent of workers who were monitored for that category, as well as the median values of the monitoring results, are shown by radionuclide. In addition, the above discussion also contains the total number of workers who were monitored in each year by Area.

The discussion above by matrix issue also contains conclusions regarding whether the data are adequate for dose reconstruction. The findings from Appendix A are reproduced here for convenience.

19.1 Findings from Appendix A

Finding A-1: For the main radionuclides analyzed (Am, Cs, MFP, Pu, Th, and U), workers associated with the 200 Tank Farms were the most likely to be monitored during their employment.[8]

Finding A-2: 'Radiation monitors,' 'electricians,' 'operators,' 'pipefitters,' and 'science technicians' were consistently among the five job titles most likely to be monitored during their SEC employment.

Finding A-3: In general, the most commonly monitored job titles by area and year are as follows: 'managers and administrators' (100, 100-N, 200, and 300 Areas), 'operators' (200, 200 Tank Farms, and 300 Areas), and 'scientists' (300 Area).

Finding A-4: Records analysis for americium, cesium, mixed fission products, iodine, and uranium monitoring showed a significant decrease in worker sampling in 1975 (generally less than 1% of the worker population was monitored). Other significant decreases in worker monitoring include 1974 (iodine), 1976–1977 (mixed fission products), and 1985 (cesium). Thorium-232 was sparsely monitored throughout the period, and there are very few data points overall. No significant decreases in worker monitoring were identified for plutonium.

Finding A-5: Section 7 presents radionuclides not included in the main analysis because of the sparse available records; these include polonium, neptunium, radium, curium, californium/berkelium, and 'total actinides.' Polonium, curium, and 'total actinides' were mostly periodic sampling, while radium and neptunium were likely incident related.[9]

Observation A-1: Based on a review of the radionuclide-specific records in the SRDB, SC&A found that contamination incidents generally tended to be followed up by urinalysis and/or in-vivo counting of the individuals involved even if the initial nasal smears indicated no intake potential. However, it should be borne in mind that SC&A did not attempt to correlate incident records with individual personnel files. See also the discussion of Matrix Items 21 and 22 regarding missing or destroyed records in the main section of this report.

20.0 MATRIX ISSUE 27: BUILDING 324 LEAKS

This issue was added to the matrix in 2011 as a result of a comment made to the Advisory Board by an individual with knowledge of ongoing Hanford decommissioning operations. The concern was initiated by the discovery in November 2010 of very high radiation rates in the soil under Building 324 during decommissioning activities. The Board asked SC&A to review the issue for its relevance to the SEC period, July 1, 1972, to December 31, 1990, in case there were incidents

[8] The only exception to this is for iodine, because no workers identified with the Tank Farms had iodine monitoring associated with them.

[9] It is assumed that samples designated as 'special' via their respective 'reason codes' were incident related.

during that period that led to the contamination that would affect the feasibility of dose reconstruction with sufficient accuracy.

SC&A conducted a number of interviews with workers who had personal knowledge of the operations in Building 324 and the related operations in Building 325. A summary of these interviews is presented in Appendix D. These interviews complement the review that SC&A has done of the completeness and adequacy of monitoring records as described in this report and in Appendix A. They also complement interviews done earlier in the SEC process, which are provided in Appendix C.

The essentials of the incident are reviewed here for context, while more detail is available in Appendix D. The B-Cell in Building 324 was the location of a number of experimental and pilot programs in high-level waste management, notably the vitrification of high-level wastes. The wastes were sometimes artificially created by mixing specific fission products. In other cases, high-level wastes from Hanford were used and in yet other cases, high-level wastes from other locations were used. The high radiation levels found in 2010 appear to have originated in leaks of high-level waste into the soil in the mid-1980s. Onsite high-level waste, reportedly containing large amounts of Cs-137 from an on-site Hanford source, was being processed into glass logs as part of a feasibility demonstration for the Federal Republic of Germany (FRG). The material apparently reached the soil via a breach in the stainless steel liner of B-Cell. The breach was discovered during B-Cell remediation activities.

For one project in the 1970s, spent fuel from commercial reactors was dissolved in Building 324 B-Cell. The material was sent via underground pipes to Building 325 for recovery of uranium and plutonium; the high-level waste from the separations was returned via underground pipe to Building 324 B-Cell for vitrification. Interviewees are not aware of any leaks associated with the inter-building transfer line. Geoprobe measurements have not been performed.

Spills and gross contamination within B-Cell were anticipated, due to the nature of the work—wet chemistry processes with extremely high activity materials. Workers could not enter the hot cell, due to the dose rates; work was done remotely (e.g., with cranes and manipulators) or outside the cell. During the 1980s, B-Cell was used to fabricate isotopic radiation and heat sources for the Federal Republic of Germany (FRG). "Within the borosilicate glass matrix radiochemical constituents (^{137}Cs and ^{90}Sr) were immobilized to yield a product with a predetermined decay heat and surface radiation exposure rate" (Holton et al. 1989). A major spill of materials associated with this project reportedly occurred within B-Cell in 1986. This incident, which would have been documented as a contained spill (not a release) at the time, is considered to be the primary source of the high dose rates that have been detected in the soil under B-Cell. The spill was described in the interviews as follows:

> *Most of the contamination in B-Cell came from the FRG program. The biggest spill occurred in 1986, when 500 L of liquid cesium nitrate was spilled in B-Cell. This spill is considered the most likely source of the soil contamination. Liquid cesium nitrate was being transferred from one vessel to another. It was a vacuum transfer, so there was no way to measure the liquid volumes during the transfer. After the transfer, workers observed that the volume was lower than it should have been. They found out there was a crack in a weld on a jumper. About*

> *200,000 Ci of cesium had spilled on the floor of the hot cell. This was very well characterized material.* [Appendix D, Vol. II, of this report.]

The hot cell floor, lined with stainless steel, sloped towards a sump where spilled liquids could be collected and transferred to waste tanks in the high level vault. During decommissioning activities, the contractor identified a hole in the stainless steel liner at the floor of the sump (WCH 2010). This breach in the liner is believed to be the route by which contamination from inside the hot cell reached the soil. Recognizing the potential for soil contamination after the breach was identified, the contractor used underground radiation detectors (Geoprobes) to survey dose rates along various trajectories in the soil below the B-Cell. Both the B-Cell and Building 324 are intact.

Decontamination of B-Cell began in the late 1980s. Early efforts involved size-reducing contaminated equipment to fit in waste casks. Grout was used to stabilize materials within the casks; some of the grout spilled on the floor and became contaminated. It was during removal of contaminated grout from the floor and sump that the breach in the stainless steel liner was detected (WCH 2010). The building mission moved decisively into decontamination and decommissioning when PNNL transferred Building 324 to Babcock and Wilcox in the late 1990s. Residual materials in B-Cell and other areas of Building 324 were designated as waste, but the nature and form of the material raised regulatory concerns. DOE was found to have RCRA (Resource Conservation and Recovery Act) mixed waste in a non-permitted storage area. Of particular concern were residual materials from the FRG program, including the 1986 spill. Some of the spilled material had been absorbed into a layer of dust that had accumulated on the floor of B-Cell due to years of operation under negative pressure for radiological safety reasons. It was conservatively assumed that the spilled material had been absorbed into the dust layer (rather than draining to the sump) and had dried to a dispersible form (Hobart 1998). A specific Closure Plan was created and executed to remove the dispersible mixed waste from the Radiochemical Engineering Cells and waste vaults (DOE 1998).

While conducting a historical review of hot cell logbooks from Building 324, DOE discovered evidence of a prior soil contamination event (Langstaff 2001).

> *The discovery was an apparent leak from one of the lined hot cells or from piping embedded in the cell walls. When facility personnel were modifying the facility to accommodate a new process in B-Cell, they entered the crawl space below the airlock and between the High Level Vault and B-Cell. They needed to core the concrete and install stainless steel piping to the pipe trench where connections were then made to the process equipment in B-Cell. What they saw, when they entered the crawl space and looked into the open spaces on either side under A-Cell and C-Cell, were cracks in the A-Cell and C-Cell concrete floors and evidence of radioactive liquid leaking into the crawl space from above, through the cracks. They reported that extensive testing was done in the suspect hot cells to try to locate the source of the leak, but the testing was unsuccessful. Contaminated dirt was dug out and safely disposed. Catch trays were installed to contain the effluent from further leaks, should they occur.*

The contamination in the soil underneath B-Cell appears not to have created exposure potential for workers until the decommissioning operations after the SEC period under review here. With the building and hot cell intact, workers would not have had physical access to the external dose rates, and the material reportedly has not had a pathway to reach the air or water. Potential personnel exposures during decontamination, waste classification, and waste stabilization/removal efforts (from the late-1980s to the present) have not been assessed. Details of the earlier contamination event from the historical logbook review were not available to SC&A. This incident may justify further investigation. The timeframe of this discovery was described as "before the Point Beach fuel reprocessing," which would place it sometime in the mid- to late-1970s. The exposure potential and monitoring records of workers who discovered and managed the leaks under A-Cell and C-Cell also need to be investigated.

The interviewees reported a good safety culture in the B-Cell operations and good health physics practices. Workers generally wore their badges, and there was internal monitoring as well. SC&A reviewed the Cs-137, Sr-90, and mixed fission product in-vivo and in-vitro monitoring records in light of these incident descriptions (see Section 10). There appear to be ample internal monitoring data for these items in the 300 Area in the early to mid-1980s during the period when the spills are thought to have occurred, and also during the late-1980s when hot cell decontamination, waste characterization, and stabilization operations began. However, SC&A has not done a more fine-grained investigation of monitoring records of employees who were working in Building 324 at the time of the spill and decontamination. Similarly, monitoring data for personnel involved in the historical logbook incident have not been evaluated.

Two other things should be noted in this context. First, B-Cell operations appear to have involved ad hoc mixtures of fission products. Since monitoring records for individual fission products other than Cs-137 and Sr-90 are far less complete for the period in question (there are few Pm-147 bioassay records for the mid-to-late 1980s for instance), it may be important to understand the specific operations involved in B-Cell in this period, to find some way of enveloping the intake estimates based on available Sr-90, Cs-137, and mixed fission product data. Second, it is important to remember that the issue of the quality of data in relation to the U.S. Testing measurements from 1987 to 1989 is being separately investigated and is not covered here (see Section 1.0).

20.1 Findings for Issue 27

Finding 27-1: There were at least two incidents in which radioactive materials migrated from presumably contained hot cells and/or pipes to reach the soil. The material recently discovered under B-Cell is unlikely to have created internal exposure potential during the leak; however, the stabilization operations that began in the late 1980s may have created internal exposure potential. Furthermore, we note that the source of the leaks found under A and C cells is not well understood.

Finding 27-2: In general, there appear to be ample internal monitoring data for 300 Area workers for Cs-137 and mixed fission products and overall for Sr-90 during the 1980s, which is the period in question for the B-Cell incidents. However, it is important for NIOSH to verify whether the specific employees who worked in Building 324 at the time of the leaks, including the A and C cell leaks and their management, and during B-Cell the stabilization operations have adequate internal monitoring data for dose reconstruction. A detailed review of the logbooks and

incident records relating to B-Cell operations in the mid- to late-1980s and of the operations in A-Cell and C-Cell may also be warranted, given the scale of the contamination. For quality of data comments prior to 1987, see Section 10.

Finding 27-3: NIOSH should investigate whether there were ad hoc mixtures of fission products, for which there are scant data for the period, used in B-Cell feasibility studies during the mid-to-late 1980s. If such operations were done, NIOSH should specify a dose reconstruction approach for those operations.

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