NIOSH Response to ABRWH Request for Supplemental Information Related to the Rocky Flats SEC Petition

May 17, 2007

Executive Summary:
On May 4, 2007, the Advisory Board on Radiation Worker Health (ABRWH) requested that NIOSH provide the following supplemental information related to the Rocky Flats SEC petition:

1) Thorium Issue – SC&A has concluded that the NUREG-1400 approach is not appropriate or bounding. NIOSH contends that they have other process specific data that could be used to bound worker doses. NIOSH needs to demonstrate this by documenting this new approach and completing example dose reconstruction(s).

2) Building 881 – There was no Building 881 external monitoring data in the 1950's. NIOSH has provided information about the processes along with the data from the early 1960's suggest that their coworker model may be used to bound gamma and beta doses for Building 881 workers. NIOSH needs to demonstrate this by documenting this new approach and completing example dose reconstruction(s). In addition, the possibility of plutonium exposures in this building needs to be addressed.

3) Neutron Doses 1959 to 1970 – The current NIOSH approach relies on application of a central estimate of a building specific neutron photon ratio to estimate doses. The work group has remaining questions whether this approach will be bounding for all workers. NIOSH has additional data that may be used to estimate a bounding neutron photon ratio which could then be applied to bound worker doses during this time period. NIOSH needs to demonstrate this by documenting this new approach and completing example dose reconstruction(s).

The enclosed report has been prepared to respond to these requests. Supporting reference documentation has been provided at:

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I. ABRWH Request 1

"Thorium Issue – SC&A has concluded that the NUREG-1400 approach is not appropriate or bounding. NIOSH contends that they have other process specific data that could be used to bound worker doses. NIOSH needs to demonstrate this by documenting this new approach and completing example dose reconstruction(s)".

I.A. Background

Briefly, the following operations involving nontrivial quantities of thorium were conducted at Rocky Flats:

1. On seven occasions between March 1, 1962 and June 30, 1966, Rocky Flats received thorium metal parts originally fabricated at Y-12. These parts were used in weapons models. NIOSH originally considered the possibility that these parts could have been lightly machined at Rocky Flats, however subsequent interviews with five R&D machinists (included in this report) indicated this did not occur. Therefore, there is no airborne potential from handling these parts.
2. In 1960, three thorium ingots (approximately 80 kg each) were canned and pressed into desired shapes. A very detailed account of this operation has been located and provided to the Working Group (Calabra, 1961). Further detail was provided in the health physics logbooks covering this operation, including a list of personnel involved. In total, the project involved approximately 38 hours over a total of 8 working days. Limited urinalysis and air sampling was conducted during the operation, which indicated no internal exposures.
3. Removal of U^{232} daughters (including Th^{228}) from U^{233}. This involved 20 kg of U^{233}nitrate, which contained 47 ppm U^{232} as a contaminant. A very detailed account of this operation has been located and provided to the Working Group (Kirchner and Freiberg, 1965). Further detail was provided in the health physics logbooks covering this operation, including a list of personnel involved. This thorium strike was conducted on April 26-28, 1965. Air sampling was conducted during the operation. The health physics logbooks covering the operation, air sampling, and statements from the health physicist involved indicate that there were no releases during this operation.

The Rocky Flats Working Group has conducted extensive discussions on the limited thorium activities at Rocky Flats, supported by detailed investigations by NIOSH. On two occasions (March 7, 2007 and April 19, 2007), the Working Group indicated that the thorium issue constituted a TBD issue, rather than a SEC issue. The requirement for proof of principle was also explicitly discussed at these Working Group meetings, and the Working Group declined to request example dose reconstructions, indicating that the extensive weight of the evidence that had been assembled would suffice.

NIOSH originally proposed to use NUREG-1400 to bound the doses for these operations, as was proposed and accepted for small operations at Y-12. SC&A objected to the use of NUREG-1400 at Rocky Flats unless validation was provided that this methodology provided bounding intakes. NIOSH provided the requested validation using air data from Simonds Saw and Steel, and the torch cutting operation (part of the 1960 ingot project) at Rocky Flats compared to intakes predicted by NUREG-1400 for these operations, as suggested by SC&A. However, SC&A

raised objections to these comparisons, and continued to object to the application of NUREG-1400. The Board appears to have adopted SC&A's position on this issue on May 4, 2007. At that time, the Board requested that NIOSH provide bounding dose reconstructions using other process specific data. Therefore, NIOSH has produced two example dose reconstructions, one for each of the operations which had hypothetically nontrivial airborne exposure potential at Rocky Flats (the 1960 ingot operation, and 1965 thorium strike).

I.B. Interviews on machining/trimming of thorium metal parts at Rocky Flats

Telephone interviews conducted on January 16th and 17th, 2007 with five former Rocky Flats personnel and all were asked the following questions:

1. When did you start and how long did you work at Rocky Flats?
2. What were your responsibilities?
3. What can you tell us about the machining and or trimming of thorium parts at Rocky Flats?

<u>[Name Withheld]</u>

[Name Withheld] started in 1953 as a chemical operator. He was involved with rolling, forming, and machining operations at Buildings 776, 881, and 883. He was [Withheld] of building 444 from 1964 to 1986. In building 444 he was responsible for all rolling, forming and machining operations. During his tenure at Building 444 there was only beryllium and depleted uranium being machined. He was also involved with R&D and "special orders" and would have known if thorium was being machined. He clearly stated that to the best of his recall, there was no machining or trimming of thorium metal. When asked if there was hypothetically thorium machining done at RF how would that have been accomplished? He said all radioactive/pyrophoric metal with resultant turnings or chips would be been covered by a water-based oil emulsion. This would have minimized dispersion of chips and minimized potential fires.

<u>[Name Withheld]</u>

[Name Withheld] started in 1963 and worked [Withheld] years at Rocky Flats until [Withheld]. He left Rocky Flat for 2 years beginning in 1964 to attend [Withheld] and [Withheld] to get his masters degree. His master's thesis was [Withheld]. He is currently a consultant to LANL on machine production and gauging for new pit production and still holds an active "Q" clearance. While at Rocky Flats he was the [Withheld] for "non-traditional" machining. His responsibilities were R&D on machining techniques like electrochemical and electrical discharge machining. He clearly stated that in his position he never saw a piece of thorium metal at Rocky Flats. He said if he knew that some thorium was present, he would have gone to look because of his interest. His primary work was in Building 881 which he stated went "cold" in 1965. When asked what would be meant by "light machining" he stated at Rocky Flats that would have been no more than removal of 10 mils or less of material. He has excellent recall of R&D machining activities at Rocky Flats.

<u>[Name Withheld]</u>

[Name Withheld] started in 1953 worked [Withheld] years until [Withheld]. He was the liaison between R&D and production in the uranium facilities (883, 881, 444). He did not recall any machining of thorium. When asked what would be meant by “light machining”, he clearly stated that “it would be the minimal removal of material 30 mils of less and gram quantities removed”. He also said that if there were significant quantities thorium present, he would have known about it and would have remembered.

[Name Withheld]

[Name Withheld] started in1948 at Hanford and came to Rocky Flats in 1968 as a machinist. He worked for [Withheld] years at Rocky Flats. He was a supervisor and a General Foreman for production and in 1975 became the [Withheld]. In 1992 He was the [Withheld]. He had no recall that any machining of thorium metal took place at Rocky Flats.

[Name Withheld]

[Name Withheld]started in June, 1956 and worked at Rocky Flats until [Withheld] as machinist in the R&D area. He also had no recall of any machining of thorium at Rocky Flats.

Summary of conclusions with regard to machining of thorium parts at Rocky Flats

The ChemRisk Task 3/4 report clearly states that “There was light production of thorium parts in Building 881 in the 1950s to early 1960s. The report also states the “The major use has been fabrication of metal parts from natural thorium” and was also used as a “stand in” for the more expensive U or Pu components in various phases of development programs. It is not explicitly stated in the report itself whether “light production of thorium parts” refers to the ingot operation in 1960, or to some machining on the preformed Th metal parts received from Y-12. The interviews above indicate the former, as none of the workers interviewed recalls any machining of thorium parts. Furthermore, the handling of prefabricated parts from Y-12 occurred between 1962 and 1966, rather than early in the 1960s, which also indicates that the quote refers to the ingot operation.

I.C. Example dose reconstructions
I.C.1 1960 ingot operation
Step 1: cold-rolling of bare thorium ingots
Step 2: other machining (pressing, canning, cutting, etc.)
Step 3: decanning by flame-cutting with a torch

Step 1 (rolling) intake calculation:
The most directly-related data for use in the intake calculation comes from the Monthly Progress Report–Site Survey-July, 1960. This document reports the results of sampling taken during rolling, which observed 4.62 dpm/m^3. SC&A has noted that this data could be general air sample results, and has suggested that this is not appropriate for use in dose reconstruction. SC&A further suggested that data from Albert, 1960 be used instead. The Albert reference provides a measured breathing zone air concentration of 7.14×10^{-11} µCi/ml (2.64 Bq/m^3) for "rolling billet to slab". This value is for samples held for two weeks to allow for decay of short-lived airborne daughter species which would have negligible contribution to the dose. This value is approximately 35 times higher than the sample result collected during the rolling at Rocky Flats, therefore, NIOSH is hopeful that this can be agreed to be bounding. Using the Albert data as suggested by SC&A, the resulting intake for this step of the operation would be:

$$I = (2.64 \text{ Bq/m}^3) \times (1.2 \text{ m}^3/\text{hr}) \times (8 \text{ hr}) = 25.3 \text{ Bq}$$

Step 2 (other machining) intake calculation:
The most directly-related data for use in the intake calculation comes from the Monthly Progress Report–Site Survey-July, 1960. This document reports the results of sampling taken during "other operations", which observed 1.41 dpm/m^3. SC&A has noted that this data could be general air sample results, and has suggested that this is not appropriate for use in dose reconstruction. SC&A further suggested that data from Albert, 1960 be used instead. The Albert reference provides a measured breathing zone air concentration of 1.70×10^{-11} µCi/ml (0.63 Bq/m^3) for "lathe enclosed in hood". Interviews with site experts indicated that the equipment used for the ingot operation was the same equipment used for handling EU, which consisted of shrouded/hooded lathes, therefore this data would be appropriate. This value is for samples held for two weeks to allow for decay of short-lived airborne daughter species which would have negligible contribution to the dose. This value is approximately 27 times higher than the sample results collected the machining at Rocky Flats, therefore, NIOSH is hopeful that this can be agreed to be bounding. Using the Albert data as suggested by SC&A, the resulting intake for this step of the operation would be:

$$I = (0.63 \text{ Bq/m}^3) \times (1.2 \text{ m}^3/\text{hr}) \times (30 \text{ hr}) = 22.7 \text{ Bq}$$

Step 3 intake calculation:
The most relevant data for calculating an intake from the decanning operation is the air sample taken at 3 feet from the ingot while it was being cut. In SC&A's April 5, 2007 report, NIOSH's characterization of this sample as a breathing zone sample is questioned, and it is suggested that the intake be calculated instead by relying on welding data from SC&A's Bethlehem Steel analysis. NIOSH considers the suggested approach inadvisable for the following reasons:

1. the can was being removed from the ingot by flame-cutting (of the can) with a torch. It is not intuitively obvious to NIOSH why SC&A believes that a worker would position his face closer than 3 feet to the canned ingot during this operation, as doing so would present the very real possibility of severe burns. NIOSH continues to conclude that this sample is representative of the breathing zone experienced by the torch operator.
2. It is not intuitively obvious why welding data, which uses thoriated tungsten alloy electrodes rather than thorium metal used in the ingot operation, would be more appropriate than the samples from the actual operation itself. NIOSH investigated welding data and the predicted intakes were lower than for the process-specific samples.

The intake estimate below is based on the actual air sample taken at 3 feet from the ingot while the can was being removed with a torch.

I = (62 dpm/m^3) x (1.2 m^3/hour) x (2 hour) x (0.0167 Bq/dpm) = 2.5 Bq

Total intake:
The total intake from steps 1-3 above is 50.5 Bq. Since the identities of the individuals involved in the various steps of the ingot operation are known, and it is known that individual workers were not involved in all steps, an intake estimate reflecting the total of all steps would be bounding for any individual worker.

<u>Selection Criteria</u>

- Hypothetical Thorium Ingot Worker: worked 1959 through 1970 and was exposed to thorium in 1960.
- Unmonitored for thorium

<u>Cancer Description:</u>

Bone (ICD-9 170.0) 12/31/2000
Colon (ICD-9 153.9) 12/31/2000
Lung (ICD-9 162.0) 12/31/2000
Prostate (ICD-9 185.0) 12/31/2000

<u>Employment (Rocky Flats Plant)</u>

Start: 1959
End: 1970

<u>Work History</u>

NOCTS : DOB: 1930,
Diagnosis Date: 12/31/2000
Former Smoker
White-Non-Hispanic

Dosimetry Data: No thorium dosimetry data.

<u>Narrative</u>

Internal dose is caused by radioactive materials that are taken into the body. A chronic intake is an intake of radioactive material that occurs over an extended period of time (typically weeks or longer). An acute intake is an intake of radioactive material that occurs over a short period of time (typically minutes to hours). Regardless of the rate at which the intake occurs, the internal dose received from radioactive materials having long half-lives occurs over an extended period of time and is, therefore, considered chronic.

The internal dose to the prostate was determined by using the dose calculated for the highest non-metabolic organ.[3] The organ/tissue associated with this cancer is not included in the ICRP modeling of internal doses; so in accordance with NIOSH documentation, the largest dose to an exposed organ that is not described by the ICRP metabolic models was assigned as the appropriate internal dose (in this case, the adrenals).

A computer code, the Integrated Modules for Bioassay Analysis (IMBA), was used to estimate intakes of radioactive material and the subsequent annual organ doses. The IMBA Expert ORAU-Edition was used for this dose reconstruction. The ICRP 66 lung model with default aerosol characteristics was assumed, in conjunction with ICRP 68 metabolic models. It should be emphasized that intake dates, scenarios, and intake levels were based upon mathematical models and do not necessarily prove that such intakes occurred on the given dates. These dates and scenarios provide an acceptable explanation of exposure and dose based upon the bioassay data provided. This approach is in accordance with the provisions of the Radiation Dose Reconstruction Rule (42 CFR 82)[1] and guidance in the NIOSH Internal Dose Reconstruction Implementation Guideline.[2]

The energy employee assisted in the processing of thorium ingots, according to records received from the Department of Labor and information provided in the interview process. Employment records were reviewed, and no records of thorium monitoring were found. Based on air concentration data from similar thorium operations[4] an acute intake of 50.5 Bq of thorium-232 was assigned on January 1, 1960.

<u>Summary</u>
The doses below only capture thorium internal dose. These doses do not include external, medical, environmental, or internal doses from other radionuclides.

Bone:	6.214 rem
Colon:	0.018 rem
Lung:	61.079 rem
Prostate:	0.017 rem

These dose estimates were entered into IREP with a constant distribution.

<u>Probability of Causation (POC)</u>
These probably of causations are based on the dose from thorium internal dose only. These probably of causations do not include external, medical, environmental, or internal doses from other radionuclides.

Bone:	12.85%
Colon:	0.04%
Lung:	0.82%
Prostate:	0.03%

References

1. 42 CFR 82, *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act of 2000*; Final Rule, Federal Register/Vol.67, No. 85/Thursday, May 2, 2002, p 22314, SRDB Reference ID 19392.

2. NIOSH, (2002) *Internal Dose Reconstruction Implementation Guideline, Rev 0*, OCAS-IG-002, National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, Ohio, SRDB Reference ID 22402.

3. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0005, *Technical Information Bulletin: Internal Dosimetry Organ, External Dosimetry Organ, and IREP Model Selection by ICD-9 Code, Rev 02 PC-1*, February 10, 2006, SRDB Reference ID 22595.

4. Albert, R.E., Thorium – Its Industrial Hygiene Aspects, Academic Press, New York, 1966.

I.C.2 1965 thorium strike

Intake calculation:

The thorium strike occurred in Building 81, Room 266 on April 26-28, 1965. The source for this information is the health physics logbooks of the time, and personal communication with the health physicist involved in the operation. This individual provided a wealth of process details. The thorium strike was a wet chemistry process (Kirchner and Freiberg, 1965) which presented minimal airborne potential. It was conducted inside a reaction vessel, inside a dry box under negative pressure. Most importantly, he stated that due to the high external radiation fields, the individuals involved in this operation spent minimal time near the dry box where the chemical reaction was being performed. They approached the box only to perform the steps in the chemical process, then retreated.

In response to the Board's request for an example dose reconstruction based on process specific information, NIOSH has retrieved the air sampling data for this room on the relevant days. There were 10 fixed-head air samplers employed in the room during the thorium strike. The samplers were run for the entirety of both the day and night shifts on these days (16 hours per day). Interestingly, the maximum and average air concentrations measured by the sampling network in this room throughout the month of April indicate that the concentrations measured during the thorium strike are toward the low end of those routinely observed in this room. These sampling results, project documentation (Kirchner and Frieberg, 1965, and two HP logbooks covering the project) and personal communication with the project health physicist, and the fact that this was a wet chemistry process, all indicate that there was no release of material or intake potential from this project.

Under the conditions maintained on the thorium strike project (workers spending minimal time near the source, reaction contained in a reaction vessel and conducted inside a dry box under negative pressure) NIOSH considers data from fixed-head samplers to be representative of the atmosphere to which the workers were exposed. For the example dose reconstruction, NIOSH selected the highest of the air monitoring results, and applied it to the entire time period on all three days.

NIOSH considers this to be bounding for the following reasons: (1) the samples are not decay corrected to account for natural radon background, (2) it is assumed that the worker was exposed for 16 hours on each of three days, (3) the highest air sample from among the 10 samplers was selected. The following intakes were calculated:

April 26, 1965:

$I = (0.44\ RCG) \times [70\ (dpm/m^3)/RCG] \times (1.2\ m^3/hr) \times (16\ hr) \times (0.0167\ dpm/Bq) = 10\ Bq$

April 27, 1965:

$I = (0.45\ RCG) \times [70\ (dpm/m^3)/RCG] \times (1.2\ m^3/hr) \times (16\ hr) \times (0.0167\ dpm/Bq) = 10\ Bq$

April 28, 1965:

$I = (0.31\ RCG) \times [70\ (dpm/m^3)/RCG] \times (1.2\ m^3/hr) \times (16\ hr) \times (0.0167\ dpm/Bq) = 6.9\ Bq$

Total intake = 27 Bq

Example dose reconstruction:

Selection Criteria

- Hypothetical process operator: worked 1959 through 1970 and was exposed to thorium from April 26, 1965 through April 28, 1965.
- Unmonitored for thorium

Cancer Description:

Bone (ICD-9 170.0) 12/31/2000
Colon (ICD-9 153.9) 12/31/2000
Lung (ICD-9 162.0) 12/31/2000
Prostate (ICD-9 185.0) 12/31/2000

Employment (Rocky Flats Plant)

Start: 1959
End: 1970

Work History

NOCTS :	DOB: 1930, Diagnosis Date: 12/31/2000 Former Smoker White-Non-Hispanic
Dosimetry Data:	No thorium dosimetry data.

Narrative

Internal dose is caused by radioactive materials that are taken into the body. A chronic intake is an intake of radioactive material that occurs over an extended period of time (typically weeks or longer). An acute intake is an intake of radioactive material that occurs over a short period of time (typically minutes to hours). Regardless of the rate at which the intake occurs, the internal dose received from radioactive materials having long half-lives occurs over an extended period of time and is, therefore, considered chronic.

The internal dose to the prostate was determined by using the dose calculated for the highest non-metabolic organ.[3] The organ/tissue associated with this cancer is not included in the ICRP modeling of internal doses; so in accordance with NIOSH documentation, the largest dose to an exposed organ that is not described by the ICRP metabolic models was assigned as the appropriate internal dose (in this case, the adrenals).

A computer code, the Integrated Modules for Bioassay Analysis (IMBA), was used to estimate intakes of radioactive material and the subsequent annual organ doses. The IMBA Expert ORAU-Edition was used for this dose reconstruction. The ICRP 66 lung model with default aerosol characteristics was assumed, in conjunction with ICRP 68 metabolic models. It should be emphasized that intake dates, scenarios, and intake levels were based upon mathematical models and do not necessarily prove that such intakes occurred on the given dates. These dates and scenarios provide an acceptable explanation of exposure and dose based upon the bioassay data provided. This approach is in accordance with the provisions of the Radiation Dose Reconstruction Rule (42 CFR 82)[1] and guidance in the NIOSH Internal Dose Reconstruction Implementation Guideline.[2]

The energy employee assisted in the removal of uranium-232 and its associated daughters (specifically thorium-228) from uranium-233 metal, according to records received from the Department of Labor and information provided in the interview process. The energy employee's monitoring records were reviewed, and no records of thorium monitoring were found. Based on an analysis of the highest gross alpha job-specific air monitoring data, and the claimant favorable assumption that all alpha activity was thorium-228, an acute intake of 10 Bq of thorium-228 was assigned on April 26, 1965, 10 Bq of thorium-228 was assigned on April 27, 1965, and 6.9 Bq of thorium-228 was assigned on April 28, 1965. The most claimant favorable solubility type was used.

Summary

The doses below only capture thorium internal dose. These doses do not include external, medical, environmental, or internal doses from other radionuclides.

Bone:	0.754 rem
Colon:	0.004 rem
Lung:	0.559 rem
Prostate:	0.002 rem

These dose estimates were entered into IREP with a constant distribution.

Probability of Causation (POC)

These probably of causations are based on the dose from thorium internal dose only. These probably of causations do not include external, medical, environmental, or internal doses from other radionuclides.

Bone:	1.87%
Colon:	0.01%
Lung:	1.31%
Prostate:	0.01%

References

1. 42 CFR 82, *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act of 2000*; Final Rule, Federal Register/Vol.67, No. 85/Thursday, May 2, 2002, p 22314, SRDB Reference ID 19392.

2. NIOSH, (2002) *Internal Dose Reconstruction Implementation Guideline*, *Rev 0*, OCAS-IG-002, National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, Ohio, SRDB Reference ID 22402.

3. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0005, *Technical Information Bulletin: Internal Dosimetry Organ, External Dosimetry Organ, and IREP Model Selection by ICD-9 Code, Rev 02 PC-1*, February 10, 2006, SRDB Reference ID 22595.

4. Office of Compensation Analysis and Support, *Whitepaper on Thorium Exposures at the Rocky Flats Plant*, 2007.

II. ABRWH Request 2

"Building 881 – There was no Building 881 external monitoring data in the 1950's. NIOSH has provided information about the processes along with the data from the early 1960's suggest that their coworker model may be used to bound gamma and beta doses for Building 881 workers. NIOSH needs to demonstrate this by documenting this new approach and completing example dose reconstruction(s). In addition, the possibility of plutonium exposures in this building needs to be addressed."

II.A. Background:
NIOSH originally provided the analysis below on February 27, 2006, and it was discussed at the March 7 and April 19 Working Group meetings.

The unmonitored periods in the 1950s were for enriched uranium workers in Building 81, as discussed with SC&A by ORAUT personnel (Interview with Roger Falk, 5 December, 2006).

Based on a review of the external dosimetry worksheets posted in the project's Site Research Database, NIOSH has observed that workers in the enriched uranium (EU) operations in Building 81 were not monitored for external radiation exposures until the fourth quarter of 1960. In the fourth quarter of 1960, 328 workers were monitored, on a monthly exchange frequency, for penetrating and non-penetrating (skin) doses. Of the 328 monitored workers, 101 workers had a measured zero dose for both penetrating and skin doses for the quarter. For the 227 workers with at least one non-zero dose measurement, the following results were observed.

Table II.A.1: Comparison of 1960 measured and coworker doses for Building 81 workers

1960	Penetrating Dose (mrem)			Skin dose (mrem)		
	Median	95th Percentile	Maximum	Median	95th Percentile	Maximum
4th Quarter	15	75	135	60	430	710
Extrapolated[1] to One Year	60	300	540	380	1860	2840
Co-worker Dose[2]	1293	7121		1645	7728	

[1] Adjusted for partial monitoring in the quarter and multiplied by 4.
[2] Based on values in Table 7-1 in ORAUT-OTIB-0058, Rev. 01-D.

In 1961, the EU workers in building 81 were monitored on a quarterly frequency. Two hundred twenty six workers had a least one non-zero dose measurement in the year; 51 workers had a measured zero dose for both penetrating and skin doses for the year. For the 226 workers with at least one non-zero dose measurement, the following results, adjusted for partial monitoring in the year, were observed:

Table II.A.2: Comparison of 1961 measured and coworker doses for Building 81 workers

1961	Penetrating Dose (mrem)			Skin dose (mrem)		
	Median	95th Percentile	Maximum	Median	95th Percentile	Maximum
One Year	45	247	900	147	970	2320
Co-worker Dose	1527	7850		1923	8201	

In both 1960 and 1961, the co-worker doses, which would have been assigned had these workers not been monitored, are very generous compared to the monitored doses. Even limiting the analysis to the workers with positive measured dose (which overestimates the dose for the entire Building 81 population as a whole), the 95th percentile coworker penetrating dose overestimates the maximum observed dose by a factor of 13. Similarly, for nonpenetrating dose in 1960, the 95th percentile coworker nonpenetrating dose overestimates the maximum observed dose by a factor of almost 3. The co-worker data for 1961 also overestimate the observed doses in 1961: the 95th percentile coworker penetrating dose / maximum penetrating dose = 9, and the 95th percentile coworker nonpenetrating dose / maximum observed nonpenetrating dose = 4.

The practice in the 1950s was to monitor workers who had the potential to receive more than 10 percent of the "tolerance" limit. In the early 1950s, the tolerance limit was 3 rem in a 13-week rolling period for whole-body penetrating exposures, which extrapolates to 3,000 mrem/quarter and 12,000 mrem/year. When the EU workers were monitored in 1960 and 1961, the penetrating doses, even the maximum doses, were in fact less than 10 percent of these values. This demonstrates that the process leading to selection of low-potential-dose workers was accurate.

The recommendation of the IRCP used in the 1950s for the skin dose, as cited in ICRP Publication 2 (1959), page xvi, paragraph (13), was 8 rem accumulated during any 13 consecutive weeks. The ICRP stated, "This is derived from an average of 0.6 rem/week (the maximum permissible weekly dose formerly recommended for the skin of the whole body) which in 13 weeks amounts to 7.8 rems….". The ICRP further extrapolates this value to a yearly limit of 30 rem to the skin. Ten percent of these limits are 800 mrem/quarter and 3,000 mrem/year. When the EU workers were monitored in 1960 and 1961, the skin doses, even the maximum dose, are less than these values.

The building's machining capabilities were expanded with the construction of an additional machine shop in 1955 to support the hollow pit design, however this simply added to the original machining facilities which began operation in 1953. It is unlikely that the years between 1953 and 1955 yield such dramatic improvements in machining processes that average dose rates would have been significantly affected. Furthermore, the analysis above indicates that the coworker doses assigned overestimate even the maximum (*i.e.* 100th percentile) observed dose. It is not intuitively obvious how the expansion of Building 81 machining capabilities would have resulted in a lower maximum dose, since the original equipment continued to be used.

The weight of the evidence supports that coworker doses applied in earlier years would also be bounding of the doses received by unmonitored uranium workers in Building 81 in earlier years. This expectation is based on the following factors:

- The amount of enriched uranium processed in Building 81 steadily increased throughout the 1950s, and plateaued in the early 1960s, therefore the source term in the early 1960s was higher than the source term in the 1950s;
- There were no major changes in the Building 81 configuration (*e.g*. shielding improvements, etc.) which would have depressed the doses the workers received in the early 1960s relative to the doses received by workers in the 1950s.
- It may be true that industrial hygiene practices improved with time in this building as has been observed at other facilities. This could lead to decreases in exposures with time, however as discussed during the May 7th and April 19th Working Group meetings, it does not seem plausible that such improvements could have been of sufficient magnitude to overcome the degree of overestimation provided by NIOSH's coworker data, which overestimates even the maximum observed dose by a factor of at least three.
- The workers in Building 81 were not monitored because they were judged to have an exposure potential of <10% of the regulatory limit. This judgment was supported once the workers were monitored.

It can also be stated that the workers in 1960 and 1961 still were not required to be monitored according to the criteria applied for monitoring in the 1950s. In addition, a professional Health Physics staff was in place to make technical decisions based on field measurements and production levels at that time. Therefore, NIOSH remains confident that the application of OTIB-58 coworker doses throughout the 1950s bounds the external doses that could reasonably have been received expected to be received by unmonitored uranium workers in Building 81 prior to the fourth quarter of 1960, when these workers were unmonitored for external doses. Based on this analysis, it can also be stated with confidence that the decision not to monitor these workers was in accordance with the relevant regulatory requirements at that time.

II.B. Plutonium in Building 81:

The ABRWH also inquired about the possible presence of plutonium in Building 81. The Historical American Engineering Archive notes:

> "Beginning sometime after 1960 and continuing until 1977, Building 881 housed the chemical recovery operations for site returns and rejected enriched uranium weapon components. The first step was to remove surface plutonium contamination by bathing the returned parts in nitric acid. The used acid solution was collected, concentrated by evaporation, calcined to a dry oxide, and sent to Building 771 for recovery of plutonium. The cleaned parts were crushed in a press, processed, and used as feed material for the foundry."

Note that this process (1) began after the initiation of external monitoring for Building 81 workers in 1960, and (2) involved only surface Pu contamination, which would not present an appreciable external exposure hazard compared to the much larger mass of enriched uranium in the site returns.

The NIOSH/ORAU Team also conducted interviews with five site experts on this question, the results of which are presented below.

[Name Wothheld]:
[Name Withheld] indicated that they never did anything with Pu in B881 except a wash process to remove residual Pu from oralloy (enriched uranium) parts. This process used nitric acid to wash the parts and remove the small amounts of Pu that remained. The parts were then scanned and sent to the Y-12 plant. The resulting solution was precipitated and dried. If it had less than 500 ppm Pu, it was sent to Idaho, if not it went to B771. It was primarily a uranium compound with small amounts of plutonium. This process was carried out in B881 until 1976 when it was moved to B771, Room 174. Again [Name Withheld] pointed out this was primarily a uranium process.

[Name Withheld]:
[Name Withheld] also recalled the washing operation as the only plutonium in B881. He indicated the first wash was accomplished in the plutonium areas and B881 was a second low-level wash. The spray washing was accomplished in B881, room 266 in the second glovebox line from the north end. [Name Withheld] recalled that separate dosimeters were used on special projects and lists were kept of personnel involved. [Name Withheld] recalls that both external and internal dosimetry on special projects was reviewed and he recalls no over-exposures with any of the projects.

[Name Withheld]:
[Name Withheld] was the [Withheld] of chemical processing for enriched uranium in B881 from the time the building opened until 1962. He was quite certain that there was no plutonium in the building during his time there. When asked about the uranium part washing operation, he recalled it (after 1962) but did not recall it as a source of plutonium.

[Name Withheld]:
[Name Withheld] was the [Withheld] of chemical processing for uranium in B881 from 1962-1965. He recalls decontamination of the returned units as well. He characterized the plutonium contamination as a "nuisance situation." Spot welds on the oralloy shells were sometimes plutonium contaminated.

[Name Withheld]:
[Name Withheld] said that there were pits stored in a room on the south side of the "general" laboratory. They were stored in glove boxes until they were cleaned. There was some potential for exposure, but he termed it to be "fairly small." He recalls no instances of any exposure incidents as a result of the cleaning.

Conclusion:
The only known process involving plutonium in Building 881, the cleaning of returned EU weapons parts with minimal Pu surface contamination, began after the initiation of external monitoring in 1960. Furthermore, the quantities of Pu present were too small to present an external exposure hazard. These conclusions are based on interviews with four site experts as well as historical documentation, all of which give a consistent account of this process.

Therefore, NIOSH concludes that this process does not prevent the reconstruction of external doses for Building 81 workers with sufficient accuracy.

II.C. Example dose reconstruction:

At the Board's request, an example dose reconstruction for externally unmonitored uranium workers in Building 81 is included.

Selection Criteria

- Hypothetical Process Helper: worked 1959 through 1970 in 881 and was exposed to photons and electrons.
- Unmonitored for all years of employment

Cancer Description:

Colon (ICD-9 153.9) 12/31/2000
Kidney (ICD-9 189.0) 12/31/2000
Lung (ICD-9 162.0) 12/31/2000
Skin-BCC (ICD-9 173.0) 12/31/2000

Employment (Rocky Flats Plant)

Start: 1959
End: 1970

Work History

NOCTS :	Joe Description: 'Process Helper' DOB: 1930, Diagnosis Date: 12/31/2000 Former Smoker White-Non-Hispanic
Dosimetry Data:	No external dosimetry data.

Narrative

External dose is received from radiation originating outside the body and is typically measured by dosimetry worn on the body. Radiation dose measured on a film badge or a thermoluminescent dosimeter (TLD) may have been delivered quickly (acute exposure) or slowly over the period of time that the employee was exposed (chronic exposure).

The external dose to the kidney was determined by using the dose calculated for the liver.[2]

The energy employee worked as a process helper, primarily in Buildings 881, according to records received from the Department of Labor and information provided in the interview process. Their primary exposure would have been to photons and electrons. However, external electron radiation was only considered in this dose reconstruction for the skin, because it would not have added dose to the other cancer sites.

For the purpose of estimating probability of causation, all photon and electron doses are assumed to be acute.[1]

Radiation Type, Energy, and Exposure Geometry

The exposure geometry was assumed to be consistent with the specific dosimetry parameters applicable to the Rocky Flats Plant as described in the Technical Basis Document for the Rocky Flats Plant – Occupational External Dosimetry.[3] For determination of organ dose and to ensure claimant favorability, both 30–250 keV photon doses (based on the reported deep dose measurements) and electrons >15 keV (based on the reported shallow dose measurements) have been applied

In accordance with the NIOSH External Dose Reconstruction Implementation Guideline,[1] dose conversion factors (DCFs) appropriate for the era were used to calculate the organ dose from exposure to photon radiation. This exposure assumes 100% anterior-posterior geometry. A dose conversion factor (DCF) of 1 was used for all doses applied to the skin in this reconstruction per guidance in the Technical Information Bulletin: Interpretation of Dosimetry Data for Assignment of Shallow Dose.[4] For electrons, no additional factors which correct for organ sensitivity and clothing attenuation were applied.

Table II.C.1: External dose parameters

Building 881 – Exposure (1959 to 1970)	
Photons Energy Range	30-250keV
Photons Energy Fraction	100%
Photons Organ DCF (Colon)	1.060
Photons Organ DCF (Kidney)	1.064
Photons Organ DCF (Lung)	0.986
Photons Organ DCF (Skin)	1.000

No uncertainty correction factors were applied to photon or electron dose to minimize the estimated dose.

Dosimeter/Unmonitored Dose
No individual dosimeter results were available to reconstruct the energy employee's dose. Therefore, external dose was assigned in accordance with the Technical Information Bulletin: External Coworker Dosimetry Data for the Rocky Flats Plant and the Technical Information Bulletin: Supplementary External Dose Information for the Rocky Flats Plant.[5,6] These doses were assigned at the 95th percentile of coworker distribution to ensure that the unmonitored external dose was not underestimated.

<u>Summary</u>
The doses below only capture external dose. These doses do not include internal, medical, or environmental doses.

Colon: (63.765 rem)
Kidney: (64.010 rem)
Lung: (59.330 rem)
Skin-BCC: (66.873 rem)

<u>Probability of Causation (POC)</u>
These probably of causations are based on the dose from external dose only. These probably of causations do not include internal, medical, or environmental doses.

Colon (71.64%)
Kidney (68.92%)

Lung (61.52%)
Skin-BCC (80.12%)

References

5. NIOSH, (2006) *External Dose Reconstruction Implementation Guideline, Rev 2*, OCAS-IG-001, National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, Ohio, SRDB Reference ID 29929.

6. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0005, *Technical Information Bulletin: Internal Dosimetry Organ, External Dosimetry Organ, and IREP Model Selection by ICD-9 Code, Rev 02 PC-1*, February 10, 2006, SRDB Reference ID 22595.

7. ORAUT (Oak Ridge Associated Universities Team), ORAUT-TKBS-0011-6, *Technical Basis Document for Rocky Flats Plant – Occupational External Dosimetry, Rev 00*, January 20, 2004, SRDB Reference ID 20175.

8. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0017, *Technical Information Bulletin: Interpretation of Dosimetry Data for Assignment of Shallow Dose, Rev 01*, October 11, 2005, SRDB Reference ID 19434.

9. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0058, *Technical Information Bulletin: External Coworker Dosimetry Data for the Rocky Flats Plant, Rev 01 PC-1*, March 29, 2007, SRDB Reference ID 31084.

10. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0027, *Technical Information Bulletin: Supplementary External Dose Information for the Rocky Flats Plant, Rev 00*, May 19, 2005, SRDB Reference ID 19449.

III. ABRWH Request 3

"Neutron Doses 1959 to 1970 – The current NIOSH approach relies on application of a central estimate of a building specific neutron photon ratio to estimate doses. The work group has remaining questions whether this approach will be bounding for all workers. NIOSH has additional data that may be used to estimate a bounding neutron photon ratio which could then be applied to bound worker doses during this time period. NIOSH needs to demonstrate this by documenting this new approach and completing example dose reconstruction(s)."

III.A. Background:

The Neutron Dose Reconstruction Project (NDRP) was undertaken in the 1990s to address known limitations in Rocky Flats neutron dosimetry from the early years of operation. This project re-evaluated neutron doses for workers monitored for beta/gamma exposures in plutonium buildings from 1952-69. On May 4, the Board recommended the addition of a class to the SEC consisting of workers who were or should have been monitored for neutrons at Rocky Flats from 1952-1958. Therefore this discussion will focus on the 1959-1970 time period.

III.B. NDRP methodology

The NDRP recalculated neutron doses according to the following equation:

$D_{neutron} = D_{original} + D_{re\text{-}read} + D_{notional}$

$D_{neutron}$ = recalculated total neutron dose

$D_{original}$ = original doses from films which were unable to be re-read

$D_{re\text{-}read}$ = measured neutron doses from re-evaluated neutron films and track plates

$D_{notional}$ = unmonitored neutron dose estimated using neutron/gamma ratios

Original doses from films which could not be re-evaluated

There were a small number of films which could not be re-evaluated by the NDRP primarily because the films could not be located. In this situation, the NDRP let the original result stand. NIOSH has proposed to adjust these films by a film reading bias factor which reflects an adjustment for low-energy photons not detectable by NTA film, and for more accurate reading during the NDRP. SC&A has questioned the values used by NIOSH for this bias factor (1.99 for Building 71, and 1.13 for all other buildings). The original source of these correction factors was a report by Dr. James Ruttenber. In response to SC&A's concerns on this issue, NIOSH has re-evaluated these correction factors using films which were re-read by the NDRP. The two tables below show the results of NDRP re-reads for two situations (1) original film reading equal to zero, and (2) original film reading greater than zero. For the cases where the original reading was zero, NIOSH proposes to assign the 95th percentile daily neutron dose rate from the re-read films. For cases where the original reading was greater than zero, NIOSH proposes to assign the 95th percentile of the ratio of re-read to original readings. This approach is consistent with the co-worker methods employed by NIOSH in other situations, and is claimant-favorable. This will ensure that doses from original, unadjusted films will not be underestimated.

Table III.B.1: Re-read doses for original readings equal to zero

Years	N	r^2	50th percentile (mrem/cycle)	95th percentile (mrem/cycle)
1959-1969	36037	0.992	73	183

Table III.B.2: Re-read doses for original readings greater than zero

Years	N	r^2	50th percentile (re-read/original)	95th percentile (re-read/original)
1959-1969	34327	0.999	1.640	6.950

Re-read doses
From 1957-70, workers were monitored with NTA film. A total of 89,976 films were located for the NDRP. Of these, 87,286 were matched to workers. All available neutron doses measured with plates or films were re-evaluated by re-reading the films, many were re-read several times. Individual-specific calibration factors were calculated for each person re-reading films by comparison to calibration films exposed to known doses. There were two sets of calibration films (1) one set was exposed to a bare, unmoderated neutron source of PuF_4 (similar to the source term at Rocky Flats), and (2) the second set was exposed to a PuF_4 source moderated by 7 cm polyethylene. These two configurations yield spectra which would bookend the neutron fields experienced at Rocky Flats during the entire span of the NDRP (1952-69). No significant differences in calibration factors were observed between the two configurations. Prior to reading any films on any day, readers were required to read and pass an initial qualification test using calibration films. A separate routine quality control program was implemented to reread at least 10% of films that were read the previous day by each reader. NIOSH proposes to use the values for re-read films as determined by the NDRP in dose-reconstructions.

Notional doses
Notional neutron doses are neutron doses that are assigned to a worker who was potentially exposed to neutrons in a Pu-related building for a period of time but was not originally credited with a neutron dose for that time. Periods with no neutron monitoring data could result from (1) the worker was not monitored for neutrons, (2) the worker was monitored for neutrons, but doses could not be evaluated from the film, (3) the worker was not likely to have been exposed to neutrons during that period. Notional doses were assigned to the first two instances. If a worker was judged to have exposure potentials greater than 10% of the regulatory limit, they were monitored for beta/gamma exposure.

The NDRP calculated notional doses using neutron/photon ratios. In light of the Board's continuing concern with the application of n/p ratios, and the Board's explicit request for a new approach, NIOSH has revised the dose reconstruction approach for workers in plutonium buildings who were unmonitored for neutrons and/or gamma exposure. Rather than relying on a n/p ratio, which SC&A has questioned, the revised approach relies on coworker distributions of measured daily neutron and gamma dose-rates.

The badging policy in place during 1959-70 was that if a worker was judged to have an exposure potential greater than 10% of the regulatory limits of the time, they were required to be monitored. Workers judged to be at lower exposure potential were not necessarily required to be monitored (but sometimes were). The effect of monitoring only the workers judged to be at higher exposure potential would be to bias the coworker distributions higher than they would be if the entire population had been monitored. The application of these coworker distributions would therefore be claimant-favorable.

SC&A and the Working Group have noted that for the years 1960-64, some of the highest doses calculated by the NDRP were based entirely on notional dose. The conclusion has been drawn that this may indicate that the workers with the highest exposure potentials were not monitored. NIOSH does not concur with this conclusion. Rather, the notional doses calculated by the NDRP in these instances represent the results of applying a worker-favorable n/p ratio to individuals with high gamma doses. If the application of a n/p ratio is considered questionable, as the Board and SC&A have indicated, then dose estimates that rely on such a technique cannot form the basis of a conclusion that the highest exposed workers were not monitored. SC&A has noted that there is very little correlation between high gamma exposures and high neutron exposures (*e.g.* Figure 8 from SCA-SEC-TASK5-0052 Supplemental Report and associated text). NIOSH has also noted that individual badge readings with high gamma exposures do not always have high associated neutron badge readings. For example, the table below shows the highest 10 measured gamma doses in Building 71 in 1959, the highest 10 measured gamma doses in Building 91 in 1959, the associated measured neutron doses, and the observed n/p ratios compared to the ratios used to calculate notional dose by the NDRP. In every case, the observed ratio is lower than the ratio applied by the NDRP. This demonstrates that the high notional doses calculated by the NDRP are a result of an overestimation of the n/p ratio, rather than the workers with the highest exposure potential being unmonitored.

Table III.B.3: Highest 1959 gamma doses, associated neutron doses, and n/p ratios

Building	Year	Neutron dose	Gamma dose	Measured n/p	NDRP n/p
71	1959	72.00	1,613.00	0.04	1.40
71	1959	145.00	1,290.00	0.11	1.40
71	1959	123.00	1,180.00	0.10	1.40
71	1959	99.00	1,118.00	0.09	1.40
71	1959	133.00	1,063.00	0.13	1.40
71	1959	105.00	980.00	0.11	1.40
71	1959	144.00	907.00	0.16	1.40
71	1959	148.00	870.00	0.17	1.40
71	1959	154.00	735.00	0.21	1.40
71	1959	79.00	731.00	0.11	1.40
91	1959	52.00	85.00	0.61	3.60
91	1959	42.00	85.00	0.49	3.60
91	1959	54.00	80.00	0.68	3.60
91	1959	40.00	75.00	0.53	3.60
91	1959	27.00	75.00	0.36	3.60
91	1959	84.00	75.00	1.12	3.60
91	1959	84.00	75.00	1.12	3.60
91	1959	81.00	75.00	1.08	3.60
91	1959	30.00	75.00	0.40	3.60
91	1959	87.00	60.00	1.45	3.60

Due to the Board's continuing concerns and explicit request for a new approach, NIOSH has developed coworker distributions of daily neutron and gamma dose rates. The gamma dose rate distributions are based on the exposures observed from β-γ film results, and the neutron dose rate distributions are based on the exposures observed from the re-read NTA film results. These coworker distributions do not rely on n/p ratios, which should address the Board's concerns on this issue. Values for 50^{th} and 95^{th} percentiles have been generated, which NIOSH proposes to apply in accordance with the various guidance documents governing assignment of coworker data.

A significant overestimating factor in this approach is that NIOSH has chosen to rely on the distribution of individual cycle data, rather than annual doses for individual workers. The data show that the highest badge readings are dispersed across numerous individual workers throughout a given year, as opposed to a few workers consistently showing the highest badge results. NIOSH's reliance on individual cycle data has the effect of applying the 50^{th} or 95^{th} percentile badge readings from the entire year for the entire monitored population during the entire time workers were unmonitored. If NIOSH had instead relied on annual doses from individual workers for generation of the coworker distributions, the assigned doses would be lower (data not shown) because high badge readings tend to be averaged out over the course of a year. This should mitigate the need for a job-type analysis, as proposed by SC&A.

Table III.B.4: Coworker gamma and neutron dose rates

Building	Year	N	r^2	50% (mrem/yr)	95% (mrem/yr)	N	r^2	50% (mrem/yr)	95% (mrem/yr)
		Gamma				Neutron			
71	1959	4738	0.90	1356	6779	2331	0.99	2659	8034
71	1960	6507	0.87	574	3546	3480	1.00	4380	9229
71	1961	3110	0.86	1330	4849	1669	1.00	4198	9334
71	1962	4715	0.81	1069	4105	2916	0.94	4041	11250
71	1963	11496	0.81	574	3337	10116	0.99	2008	5847
71	1964	14151	0.89	261	2320	12414	0.99	1734	4563
71	1965	6186	0.92	523	4000	5477	0.99	1030	2687
71	1966	6034	0.87	1192	6037	5188	0.98	937	2413
71	1967	6853	0.90	907	5614	6104	0.96	808	3941
71	1968	8212	0.88	678	3468	6493	0.97	991	6935
71	1969	7712	0.88	590	4278	5580	1.00	1590	4824
71	1970	1811	0.90	240[b]	4278[a]	2734	0.99	1675	5110
76	1959	6651	0.83	1616	6153	442	0.99	1637	4380
76	1960	5474	0.75	1981	5840	542	0.97	1753	6726
76	1961	4529	0.71	2451	5319	0	NA	1753[a]	6726[a]
76	1962	5889	0.72	1721	4484	0	NA	1753[a]	6726[a]
76	1963	4793	0.75	1616	4563	0	NA	1753[a]	6726[a]
76	1964	1565	0.79	1741	5079	10	0.87	704	2037
76	1965	2945	0.83	913	5342	1434	0.96	777	1545
76	1966	3206	0.77	1898	7324	1978	0.98	852	1743
76	1967	4808	0.89	706	6486	2048	0.99	971	2774
76	1968	4668	0.88	283	2759	1657	0.99	954	3441
76	1969	4942	0.83	65	1570	714	0.98	1217	2292
76	1970	2385	0.84	120[b]	1102	131	0.72	1703	2738
77	1959	3073	0.89	261	2868	64	0.98	1755	3539
77	1960	2861	0.87	130	3598	0	NA	1947[a]	3793[a]
77	1961	3248	0.79	1121	5214	0	NA	1947[a]	3793[a]

Building	Year	N	r^2	50% (mrem/yr)	95% (mrem/yr)	N	r^2	50% (mrem/yr)	95% (mrem/yr)
		Gamma				Neutron			
77	1962	4253	0.78	479	2764	0	NA	1947[a]	3793[a]
77	1963	3576	0.78	815	4343	111	0.98	1947	3793
77	1964	1112	0.77	965	4958	266	0.95	2268	3865
77	1965	1488	0.82	754	3682	995	0.99	1013	2173
77	1966	1674	0.78	1278	5519	1438	0.99	999	2086
77	1967	1334	0.86	1454	5299	1238	0.99	1048	1966
77	1968	1246	0.85	586	2772	863	0.97	969	1811
77	1969	2439	0.86	88	1991	448	0.98	717	1325
77	1970	800	0.81	120[b]	2392	57	0.70	2060	2873
91	1959	1497	0.88	240[b]	521	574	1.00	808	1787
91	1960	1954	0.94	240[b]	261	313	0.88	617	1546
91	1961	2011	0.98	240[b]	521	102	0.91	1501	2307
91	1962	1982	0.99	240[b]	519	71	0.88	2138	3132
91	1963	2218	0.99	240[b]	587	91	0.84	1104	4849
91	1964	1862	0.95	240[b]	417	72	0.98	1186	2152
91	1965	1375	0.97	240[b]	706	97	0.99	1180	2285
91	1966	755	0.91	118	1662	49	0.97	1189	1669
91	1967	766	0.94	240[b]	1276	0	NA	1189[a]	1669[a]
91	1968	895	0.94	240[b]	665	20	0.95	669	1073
91	1969	739	0.96	240[b]	483	38	0.98	1108	2237
91	1970	374	0.91	209	1322	0	NA	1108[a]	2237[a]
All	1959	16304	0.86	782	5788	3456	1.00	2112	7039
All	1960	17456	0.82	433	4745	4379	0.93	3963	8812
All	1961	14063	0.77	1051	5058	1821	0.97	3989	9229
All	1962	17532	0.75	730	3964	3032	0.94	3937	11106
All	1963	23448	0.80	548	3807	10646	0.99	1981	5788
All	1964	25823	0.86	339	3285	13033	0.99	1721	4471
All	1965	14215	0.87	393	3852	8617	0.99	965	2470
All	1966	13853	0.83	900	5958	9166	0.99	907	2178

Building	Year	N	r^2	50% (mrem/yr)	95% (mrem/yr)	N	r^2	50% (mrem/yr)	95% (mrem/yr)
		Gamma				Neutron			
All	1967	18053	0.89	482	5137	10154	0.97	873	3134
All	1968	19632	0.88	281	2869	10173	0.96	965	5044
All	1969	19356	0.87	135	2997	7803	1.00	1348	4356
All	1970	6898	0.81	120[b]	1200	4697	0.99	1314	4248

NA = not available

a = data in given year and building insufficient to generate estimate. The higher of the preceding or following year values assigned.

b = 50th percentile was zero, therefore value calculated as missed dose from badge exchange frequency identified from cycle data.

III.C. Example dose reconstruction

Selection Criteria

- Hypothetical Process Helper: worked 1959 through 1970 in 771 and was exposed to photons and neutrons.
- Monitored for photons and partially monitored for neutrons.

Cancer Description:

Colon (ICD-9 153.9) 12/31/2000
Kidney (ICD-9 189.0) 12/31/2000
Lung (ICD-9 162.0) 12/31/2000
Skin-BCC (ICD-9 173.0) 12/31/2000

Employment (Rocky Flats Plant)

Start: 1959
End: 1970

Work History

NOCTS :	Joe Description: 'Process Helper' DOB: 1930, Diagnosis Date: 12/31/2000 Former Smoker White-Non-Hispanic
Dosimetry Data:	Photon dosimetry from June 1, 1959 through December 31, 1970. Neutron Dosimetry from July 2, 1962 though December 31, 1970 with some gaps.

Narrative

External dose is received from radiation originating outside the body and is typically measured by dosimetry worn on the body. Radiation dose measured on a film badge or a thermoluminescent dosimeter (TLD) may have been delivered quickly (acute exposure) or slowly over the period of time that the employee was exposed (chronic exposure).

The external dose to the kidney was determined by using the dose calculated for the liver.[2]

The energy employee worked as a process helper, primarily in Buildings 771, according to records received from the Department of Labor and information provided in the interview process. Their primary exposure would have been to photons and neutrons.
For the purpose of estimating probability of causation, all photon doses are assumed to be acute and all neutron doses are assumed to be chronic.[1]

Radiation Type, Energy, and Exposure Geometry

The records supplied by the Department of Energy and the interview process indicate the energy employee worked at the 771 facilities. The energy employee's exposure geometry was assumed to be consistent with the specific dosimetry parameters applicable to the Rocky Flats Plant as described in the Technical Basis Document for the Rocky Flats Plant – Occupational External Dosimetry.[3]

In accordance with the NIOSH External Dose Reconstruction Implementation Guideline,[1] dose conversion factors (DCFs) appropriate for the era were used to calculate the organ dose from exposure to photon and neutron radiation. This exposure assumes 100% anterior-posterior geometry. Plutonium specific DCFs were applied for <30 keV photons.

In the NIOSH External Dose Reconstruction Implementation Guideline,[1] organ dose conversion factors are tabulated by averaging the energy specific values from ICRP 74 (1986)[9] over the IREP photon energy range. The lowest photon energy interval in the Interactive RadioEpidemiological Program (IREP) is categorized as less than 30 keV. Plutonium emits several X-rays in this energy range; however, a simple average as used in the Implementation Guideline may not result in the most accurate dose conversion factor. For plutonium work, the average X-ray energy is approximately 17 keV. As a result, using 20 keV as a claimant-favorable single-point estimate is most appropriate. Since the low energy photon dose to glovebox workers, laboratory technicians, maintenance workers, metallurgical operators, and D & D workers is predominantly in the anterior-posterior (AP) geometry,[3] single-point estimate values using anterior-posterior (AP) geometry were calculated for 16 organs listed in ICRP 74.[9] Some workers (site support personnel, chemical operators when not working with gloveboxes, support personnel, and radiation technicians) were estimated to have received varying amounts of non-AP dose.[3] Since there is significant uncertainty in the individual exposure geometry and AP geometry is generally claimant favorable or neutral compared to other geometries for most cancers, an AP geometry is applied for all <30 keV photon exposures.

A dose conversion factor (DCF) of 1 was used for all doses applied to the skin in this reconstruction per guidance in the Technical Information Bulletin: Interpretation of Dosimetry Data for Assignment of Shallow Dose.[4] For neutrons, additional correction factors (which incorporate the energy range fractions) and ICRP 60 correction factors were applied in accordance with the Technical Basis Document for the Rocky Flats Plant – Occupational External Dosimetry.[3]

Table III.C.1: External dose parameters

Building 771 – Exposure (1959 to 1970)						
	Photon		Neutron			
Energy Range	<30 keV	30-250keV	<10 keV	10–100 keV	100 keV – 2 MeV	2–20 MeV
Energy Fraction	100%	100%	—	—	—	—
ICRP 60 CF	—	—	0.085	0.034	1.361	0.327
Organ DCF (Colon)	0.0150	1.0597	2.0117	0.9612	0.5037	0.9666
Organ DCF (Kidney)	0.0410	1.0638	2.0384	0.9972	0.6641	1.0466
Organ DCF (Lung)	0.0300	0.9860	1.5234	0.7509	0.5791	1.0042
Organ DCF (Skin)	1.000	1.000	1.000	1.000	1.000	1.000

No uncertainty correction factors were applied to photon or neutron dose to minimize the estimated dose.

Dosimeter Dose
Individual dosimeter results were used to reconstruct the energy employee's dose. Corrections to the reported doses were applied as described above. The photon doses based on measured and coworker data were estimated using algorithms from the Technical Information Bulletin: Supplementary External Dose Information for the Rocky Flats Plant.[6]

The recent re-evaluation of individual neutron dosimetry data provided detailed neutron dosimetry data and was used as reported,[7] per guidance in the Technical Information Bulletin: Use of Rocky Flats Neutron Dose Reconstruction Project Data in Dose Reconstructions.[8]

For non-affected original neutron dosimetry data that was not re-evaluated by the Neutron Dose Reconstruction Project (NDR Project),[7] doses were adjusted based on an analysis of all re-evaluated dosimetry at the 95th percentile. An adjustment factor of 6.95 for all non-zero data and 183 mrem for each zero were applied.

Coworker Dose Assignment
During the periods that the energy employee was on site and not monitored (i.e., there was no reported gamma dose or NDRP Notional dose was reported), external dose was assigned in based on external daily dose rates derived for coworker dosimetry data.[5] These doses were assigned at the 95th percentile of coworker distribution to ensure that the unmonitored external dose to the organ was not underestimated. This results in a coworker dose assignment of 0.675 rem of shallow dose, 2.840 rem of deep dose, and 36.302 rem of neutron dose.

Missed Dose
A potential missed dose was assigned to each actual or potential dosimeter cycle where a zero was reported to provide a claimant-favorable estimate of the potential external doses received. A missed dose represents the dose that could have been received but may not have been recorded due to the dosimeter detection limits or site reporting practices.

The total number of gamma dosimeter cycles where a zero was assigned was 7. This number was chosen to ensure that a best estimate of instances of a zero badge reading was accounted for in this dose reconstruction. Based on limit of detection information provided in the Technical Basis Document for the Rocky Flats Plant,[3] this results in a potential missed dose of 0.148 rem to the colon, 0.149 rem to the kidney, 0.138 rem to the lung, and 0.140 rem to the skin from 30–250 keV photon radiation. The calculated missed dose was applied as the geometric mean with associated geometric standard deviation for the purpose of calculating probability of causation.

The total number of re-evaluated neutron zero dosimeter reported from the NDR Project was assigned per guidance in the Technical Basis Document for the Rocky Flats Plant.[3] The total number of re-evaluated neutron zero dosimeter cycles assigned was 20. This number was chosen to ensure that a best estimate of instances of a zero badge reading was accounted for in this dose reconstruction. Based on limit of detection information provided in the Technical Basis Document for the Rocky Flats Plant,[3] this results in a potential missed dose for of 2.786 rem to the colon, 3.359 rem to the kidney, 2.939 rem to the lung, and 4.176 rem to the skin. The calculated missed dose was applied as the geometric mean with associated geometric standard deviation for the purpose of calculating probability of causation.

Summary

The doses below only capture external dose. These doses do not include internal, medical, or environmental doses.

Colon: (79.971 rem)
Kidney: (93.412 rem)
Lung: (82.509 rem)
Skin-BCC: (119.441 rem)

Probability of Causation (POC)

These probably of causations are based on the dose from external dose only. These probably of causations do not include internal, medical, or environmental doses.

Colon (56.05%)
Kidney (56.30%)
Lung (49.02%)
Skin-BCC (77.03%)

References

1. NIOSH, (2006) *External Dose Reconstruction Implementation Guideline, Rev 2*, OCAS-IG-001, National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, Ohio, SRDB Reference ID 29929.

2. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0005, *Technical Information Bulletin: Internal Dosimetry Organ, External Dosimetry Organ, and IREP Model Selection by ICD-9 Code, Rev 02 PC-1*, February 10, 2006, SRDB Reference ID 22595.

3. ORAUT (Oak Ridge Associated Universities Team), ORAUT-TKBS-0011-6, *Technical Basis Document for Rocky Flats Plant – Occupational External Dosimetry, Rev 00,* January 20, 2004, SRDB Reference ID 20175.

4. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0017, *Technical Information Bulletin: Interpretation of Dosimetry Data for Assignment of Shallow Dose, Rev 01,* October 11, 2005, SRDB Reference ID 19434.

5. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0058, *Technical Information Bulletin: External Coworker Dosimetry Data for the Rocky Flats Plant, Rev 01 PC-1,* March 29, 2007, SRDB Reference ID 31084.

6. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0027, *Technical Information Bulletin: Supplementary External Dose Information for the Rocky Flats Plant, Rev 00*, May 19, 2005, SRDB Reference ID 19449.

7. ORAUT (Oak Ridge Associated Universities Team), *Neutron Dose Reconstruction Protocol*, ORISE 05-0199, SRDB Reference ID 17126.

8. ORAUT (Oak Ridge Associated Universities Team), ORAUT-OTIB-0050, *Technical Information Bulletin: Use of Rocky Flats Neutron Dose Reconstruction Project Data in Dose Reconstructions, Rev 00*, December 13, 2005, SRDB Reference ID 20223.

9. ICRP (International Commission on Radiological Protection), 1996, *Conversion Coefficients for Use in Radiological Protection Against External Radiation*, ICRP Publication 74, Annals of the ICRP Vol 26(3/4), Pergamon Press, Oxford, England, SRDB Reference ID 7979.

Attachment 1: Energy Employee's Monitoring Data

Year	Building	Measured Dose (mrem)				
		SKIN	PEN	Gamma	Neutron (non-affected)	Neutron (re-read)
1959	71	931	363	363	0	0
1960	71	1151	975	975	0	0
1961	71	672	608	608	0	0
1962	71	1345	1104	1104	0	168
1963	71	2129	1840	1269	0	2572
1964	71	1258	891	891	0	1633
1965	71	1359	1145	1065	80	743
1966	71	3055	2714	2263	66	606
1967	71	2314	1577	1120	0	682
1968	71	1846	1097	795	50	863
1969	71	2089	1289	885	110	567
1970	71	1498	1086	690	176	326

Year	Building	Unmonitored Period (days)		Zeros		
		Gamma	Neutron	Gamma	Neutron (non-affected)	Neutron (re-read)
1959	71	151	368	0	0	0
1960	71	0	364	0	0	0
1961	71	0	363	0	0	0
1962	71	0	270	1	0	0
1963	71	0	87	1	0	2
1964	71	0	0	0	9	9
1965	71	0	0	2	1	2
1966	71	0	0	2	1	2
1967	71	0	0	0	0	3
1968	71	0	0	1	1	0
1969	71	0	0	0	2	0
1970	71	0	0	0	2	2