DRAFT

ADVISORY BOARD ON RADIATION AND WORKER HEALTH
National Institute for Occupational Safety and Health

Review of the Rocky Flats Plant Special Exposure Cohort (SEC) Petition, SEC-00030

Second Supplemental Report on the Rocky Flats SEC Petition

Contract No. 200-2004-03805
Task Order No. 5
SCA-SEC-TASK5-0052, Second Supplemental Report

Prepared by
S. Cohen & Associates
1608 Spring Hill Road, Suite 400
Vienna, Virginia 22182

Saliant, Inc.
5579 Catholic Church Road
Jefferson, Maryland 21755

June 2007

S. Cohen & Associates: **Technical Support for the Advisory Board on Radiation and Worker Health Review of NIOSH Dose Reconstruction Program**	Document No. SCA-SEC-TASK5-0052 Second Supplemental Report Effective Date: June 1, 2007 Revision No. 0 – Draft (Corrected)
Review of the Rocky Flats Plant Special Exposure Cohort (SEC) Petition, SEC-00030 – Second Supplemental Report on the Rocky Flats SEC Petition	Page 2 of 66
Task Manager: ________________________ Date: ____________ Joseph Fitzgerald	Supersedes: N/A
Project Manager: ________________________ Date: ____________ John Mauro, PhD, CHP	

TABLE OF CONTENTS

LIST OF TABLES

FIGURES

EXECUTIVE SUMMARY

This second supplemental report on the Rocky Flats SEC petition by SC&A is a targeted review of the following issues:

- Thorium dose reconstruction methods proposed by NIOSH in its May 17, 2007, report (NOSH 2007)
- Application of the external dose coworker model to Building 81 workers who worked there during the 1950s
- Possible presence of plutonium in Building 81
- Review of neutron dose reconstruction methods for 1959–1970 proposed by NIOSH in NIOSH 2007

THORIUM

There are four thorium related issues that SC&A followed up on:

(1) Routine machining and rolling of thorium metal
(2) Post-incident cutting of thorium metal in September 1960
(3) Thorium-228 strikes to remove it from uranium-233
(4) Small thorium sources

SC&A also made an observation to follow-up on the issue of whether magnesium-thorium alloy was brought to Rocky Flats in large amounts.

SC&A's principal conclusion in its prior reviews of the topic was that NIOSH's proposed use of a Nuclear Regulatory Commission document that provides methods for determining whether a workplace should have air monitoring, NUREG-1400, had not been demonstrated to provide bounding intake estimates for machining and other operations. SC&A had also noted certain data limitations relative to thorium rolling operations. Our conclusions regarding routine metal operations are as follows:

- NOISH's proposed use of data from the industry to complement Rocky Flats data on thorium rolling provides a suitable method for determining intakes.
- Similarly, the use of industry-wide data in a claimant-favorable manner regarding possible machining operations of metal mock-ups from Y-12 is also appropriate.

With regard to the other thorium-related issues, SC&A conclusions are as follows:

(1) **Torch-cutting of thorium**: NIOSH's use of a Rocky Flats air sample taken 3 feet from the torch-cutting of thorium is not claimant favorable and does not represent a breathing zone sample for manual torch-cutting of thorium. The intake value used does not take

into account NIOSH's earlier assessment of the cobble-cutting operation at Bethlehem Steel. That assessment should be used as a complement to the Rocky Flats torch-cutting sample. NIOSH has already performed all the elements of the analysis needed to yield claimant-favorable value for intake.

(2) **Thorium-228 strikes, April 1965**: NIOSH has not demonstrated the relationship of the air sample values used for estimating intakes during the April 1965 thorium strike to the breathing zone, even though they are the highest among collected area samples (for each day of the April 26-28, 1965 operations). Data regarding the locations of the samples are not in the air sampling datasheets, but may be available elsewhere. These data and use of adjustment factors that relate general air samples to breathing zone concentrations, as was used in the Bethlehem Steel site profile revision, would help to resolve this issue.

(3) **Thorium-228 strikes, 1966–1977**: According to a history of U-233 operations at Rocky Flats, (1) there were some thorium-228 strikes in the 1966–1977 period and (2) the U-232 concentrations (and hence maximum Th-228 concentrations) in these later operations was considerably smaller than the 1965 operations. NIOSH did not explicitly discuss these in its May 2007 report, but indicated later that it is acquiring air concentration data for a 1967 thorium strike. NIOSH has also indicated that later operational and air concentration data would show that the 1965 thorium strike provides a bounding case for thorium strike intakes. Air concentration and/or other operational data and source term information from the 1966-1977 period may allow the April 1965 strike to be established as one representing a bounding intake relative to the others, in the absence of incidents. The data were not available to SC&A at the time of finalization of the analysis in this report (May 29, 2007).

(4) **Small thorium sources**: There were numerous small sources of thorium, less than 500 grams each, used in various parts of Rocky Flats. The NIOSH 2007 report has addressed routine machining and rolling operations satisfactorily (see item 1 above), but did not extend that analysis to cover small thorium sources. NIOSH's demonstration application of NUREG-1400 for thorium molds, provided in December 2006 (see SC&A 2007b, Attachment 20), was not demonstrated as a bounding intake. The use of thorium air concentration data as a check on the use of NUREG-1400 would provide an appropriate approach for small sources. The use of NUREG-1400 for small sources for intake estimation was approved by the Board for Y-12.

(5) **Observation regarding thorium-magnesium alloy:** Two rather different positions in regard to the thorium-magnesium alloy at Rocky Flats now exist. The first is a scenario based on Rocky Flats site expert statements regarding lack of evidence of receipt of such shipments, and other considerations (e.g., inventory). The second scenario is based on statements by a Dow Madison worker that there were large and regular shipments of thorium magnesium alloy to Rocky Flats. The Board asked NIOSH to investigate this issue for Dow Madison, as a follow-up to the NIOSH recommendation that Dow Madison workers between 1957 and 1960 (250 days or more employment) be included in the SEC. These two positions may or may not come into conflict, depending on the outcome of NIOSH's Dow Madison-related investigation. They have quite different

radiological implications for some aspects of work at these sites and related estimation procedures for radiation exposure. SC&A notes that data are available for dust generated by alloys containing a few percent thorium, notably thoriated welding rods, which may be applicable to processing of magnesium-thorium alloy in metal form. If shipments to Rocky Flats from Dow Madison occurred, that is the form in which it would have been shipped. SC&A also notes that NIOSH has informed the Board that it is preparing a complex-wide assessment of exposure from thoriated welding rods, for which data have been discussed in the context of Rocky Flats. Finally, SC&A understands that NIOSH is investigating whether the Mg-Th alloy was shipped to the Department of Defense facility called the Rocky Mountain Arsenal, which is in the same general region as Rocky Flats and/or the nearby Lockheed Martin aerospace facility (see Attachment 1).

BUILDING 81, 1950s EXTERNAL GAMMA AND BETA DOSE

Building 81 workers were not monitored for external gamma and beta dose in the 1950s. NIOSH has proposed to use the external coworker model for these workers and has shown that the 95th percentile value of dose in that model is much greater than the measured external gamma and beta doses in Building 81 during the last quarter of 1960 and during 1961. SC&A has reviewed the comparison and concurs with NIOSH regarding the relative values of average measured dose compared to coworker dose. However, some questions remain. SC&A's findings are as follows:

(1) **Use of the coworker model for 1950s Building 81 workers**: SC&A finds that the application of coworker data to Building 81 workers for the 1950s, when there was essentially no external dose monitoring in that building, would generally be claimant favorable if the production processes had not changed and/or working conditions were demonstrated to be radiologically comparable. However, there were extensive changes in production processes in Building 81 in the late 1950s and early 1960s. NIOSH has not analyzed the effects of these changes on exposure potential and has not demonstrated the comparability of working conditions. The application of the coworker model may turn out to be claimant favorable were such an analysis to be done; but the many significant changes that occurred were not acknowledged or discussed in the NIOSH 2007 report.

(2) **Finding regarding plutonium in Building 81**: Plutonium was present in Building 881 as part of the operation of decontaminating enriched uranium parts. A portion of the residues from the cleaning process contained plutonium of sufficient purity and in significant enough quantities for it to be shipped to the Savannah River Site. The amounts involved were also significant enough that the exhaust air plenum became appreciably contaminated. NIOSH has not demonstrated that the use of the shallow and deep photon dose coworker model is applicable to workers involved in cleaning the enriched uranium parts and processing and handling the plutonium residues in Building 81.

NEUTRON DOSE RECONSTRUCTION, 1959–1970

NIOSH has proposed a three-part model for estimating the neutron doses for unmonitored individuals with potential for neutron exposure:

- Replace the original doses, which were originally read as zeros and were not reread as part of the NDRP, with 183 mrem per badge cycle.
- Use a 95th percentile correction factor of 6.95 on all original non-zero readings that could not be re-read. All neutron badge re-readings in the 1959–1970 period were used in a single distribution to derive this value.
- NIOSH proposes to use the 50th or 95th percentile value of neutron dose rates from individual badge cycles according to its coworker model protocols to estimate neutron dose for those periods when workers with exposure potential were not monitored. NIOSH refers to these reconstructed neutron doses as “notional” dose. In this report, SC&A has reserved the term “notional” dose to refer to estimates of neutron dose made in the Neutron Dose Reconstruction Project (NDRP). The method for estimation of neutron dose for unmonitored periods or unmonitored workers proposed by NIOSH in NIOSH 2007 is referred to explicitly as estimates for unmonitored workers or periods.

SC&A has reviewed all three parts of NIOSH’s proposed method. Its findings are as follows:

(1) **Finding regarding zero original recorded doses where badges were not re-read**

The 95th percentile value of dose rate of 183 mrem/day in Table III.B.1 is in error; it was intended to be per badge cycle (see Attachment 3). A value of 183 mrem per badge cycle would be more than the building-specific 95th percentile values in most cases for buildings other than Building 71. But for Building 71, it is less than the building-specific 95th percentile value in most years. The NIOSH approach of using only the re-read values of all neutron doses originally recorded as zero for all years together is not appropriate since many of the original zeros do not reflect actual neutron measurements in the 1967-1970 period.

(2) **Findings regarding correction factors for non-zero original readings that were not re-read**

a. A uniform correction factor applied to all years and all workers affected by the problem of non-re-read badges with greater than zero original recorded dose, as suggested by NIOSH, is not supported by the data or an evaluation of the badge-reading, archiving, and other practices relating to neutron dose reading and estimation in the 1959–1970 period.

b. The reading of neutron badges in the pre-1963 period involved significant errors due to the technical limitations of the reading protocol, notably the small area of the badge that was read. Some of the underlying reasons for these errors are different from those that affected later differences between the re-read value of dose and the originally recorded value of dose. Empirical lognormal 95th percentile values of correction factors for the re-read doses of the affected workers for 1959 and 1962 are significantly higher than the 95th percentile value of 6.95 proposed by NIOSH.

c. The correction factors for 1965 are higher than other early years, possibly due to the workers being "overwhelmed" by the neutron badge reading workload.[1] The empirical lognormal 95th percentile correction factor (19.4) for the re-read doses of the affected workers is much higher than the 95th percentile value of 6.95 proposed by NIOSH. (The high 95th percentile values for correction factors in 1969 and 1970 are covered in the next two findings.)

d. Scientifically defensible correction factors for the 1967-1970 period cannot be developed by cumulative application of the entire NDRP database for the non-re-read portions of worker neutron dose records. The original neutron dose readings in this period in the NDRP database and the workers' DOE neutron dose files consist of two fundamentally different kinds of data: (1) values of dose that were read from the badges and (2) doses calculated from area n/p ratios. The area measurements were not archived. A great deal of work would be needed to go back to the dosimetry log sheets to separate the calculated from the original measured doses. This work is essential to determine whether and how correction factors that meet the test of scientific reasonableness can be developed.

e. The number of workers who are affected by the non-re-read of doses (including zero doses) increased greatly in 1968, and continued increasing through 1969 and 1970. This was likely due to non-archiving of data in 1969 and 1970. The reason for the jump in 1968 is unknown at the present time. As many as 1,735 workers were affected in 1970.

(3) Finding regarding neutron dose estimates for unmonitored periods

The 95th percentile measured doses proposed to be applied to unmonitored workers at risk of neutron exposure are likely to be very claimant favorable for filling in monitoring gaps for the vast majority of workers in the 1959–1970 period (as distinct from issues associated with non-re-read doses, discussed above). However, for the period 1961–1964 and possibly for 1959 and 1960, it is appears that some of the workers at highest risk of neutron exposure may not have been monitored for the entire year. The problem of *establishing* that the stated approach is claimant favorable in these instances and for these time periods appears to be difficult and has not yet been solved.

(4) Finding regarding workers with exposure potential, but no neutron dose monitoring

There are some areas and buildings where there was a potential for neutron exposure where there do not appear to be any dose measurements. These include the oralloy cleaning and plutonium residue recovery area and the criticality experiment area in

[1] The characterization is that of Roger Falk (SC&A 2007a, Attachment 3).

Building 81. There may also be other such areas at Rocky Flats. SC&A has not done wider review of this issue since it presumes that NIOSH is preparing such a list pursuant to the Board's request made during the May 2–4, 2007 meeting in Denver.

(5) **Finding regarding ending date of NTA film use**

Two official documents (Inkret, no date but 1989 or after, and Baker 2002) contain conflicting statements about when the use of NTA film completely ended at Rocky Flats. The former indicates that some use continued up to and including June 1972, while the latter indicates that all NTA film was phased out by the end of 1970.

(6) **Finding regarding changes in procedures**

Changes in dose reconstruction procedures, coworker models, and workbooks relating to Rocky Flats would have to be made before the proposed approaches can be applied to estimate neutron exposure. This includes changes to the neutron part of the external coworker model (ORAUT-OTIB-0058), and dose reconstruction workbooks, such as the one related to missed dose calculation. SC&A has not evaluated the amount of work that it would take to accomplish this.

Observation from SC&A 2007a:

The NDRP had extensive quality control procedures for the re-reading of neutron dosimeters. As SC&A noted in its April 30, 2007, report:

> [T]*here was no independent check of the readings of the person against whom all correction factors were developed. Furthermore, the independent checker was assumed to have no bias in his readings, despite the fact that he himself had developed the calibration standard in the 1960s against which the accuracy of his reading was established. It should be noted that the last two points have nothing to do with the valuable insights of* [NAME], *or his competence and professionalism. He has provided very useful technical and historical insights to SC&A in the interviews that were conducted as part of the neutron dose review. They are noted here for technical reasons. It is highly unusual to assume that one person has no error or bias in his readings, when all others had errors and biases. It is even more unusual to make such an assumption without independent validation of the assumption. Furthermore, this assumption of no bias and zero expected error in the final re-read dose was used as a basic part of the statistical model in the NRDP.*

Observation 1: The Board's SEC criteria require data validation by NIOSH, but contain no explicit guidance regarding this particular type of situation. Here there were extensive efforts to establish the quality of the reading of the badges by individual readers in order to correct for biases that were detected in the course of the program. However, the calibration of the entire process of developing the correction factors was never

> ***independently validated. As a result, the re-read doses have an essential element of validation against systematic error missing, despite the extensive quality control measures that were taken during the NDRP and the correction factors that were developed for individual readers.*** [SC&A 2007a, p.47]

1.0 INTRODUCTION

During its May 2–4, 2007, meeting in Denver, Colorado, the Advisory Board on Radiation and Worker Health (hereafter called "Board" or ABRWH) asked NIOSH to further investigate certain issues. NIOSH prepared a report on these topics dated May 17, 2007 (NIOSH 2007) for the Board's consideration. This SC&A review is principally of that NIOSH report and topics closely connected with it. Specifically this review covers the following topics:

- Thorium dose reconstruction methods proposed by NIOSH in its May 17, 2007, report (NOSH 2007)
- Application of the external dose coworker model to Building 81 workers who worked there during the 1950s
- Possible presence of plutonium in Building 81
- Review of neutron dose reconstruction methods for 1959–1970 proposed by NIOSH in NIOSH 2007

A technical conference call between the Working Group, SC&A, and NIOSH to clarify the status of certain thorium-related items was held on May 25, 2007. The minutes of that call are in Attachment 1.

This report should be read in conjunction with SC&A's main report on the Rocky Flats SEC petition (SC&A 2007). Specifically, Section 6.3 of SC&A 2007 covers thorium issues and Chapter 8 of SC&A 2007 covers data completeness questions, including those in relation to Building 81 (also called Building 881). For neutron-related issues, it should be read in conjunction with SC&A's first supplemental report on neutron dose reconstruction for the 1952–1970 period (SC&A 2007a).

It should be noted that this review has taken into account data and NIOSH analyses on the issues noted above available to SC&A up to and including May 29, 2007.

2.0 THORIUM DOSE RECONSTRUCTION METHODS FOR ROCKY FLATS

NIOSH has proposed dose reconstruction methods for the three activities involving the largest potential thorium radiation source terms at Rocky Flats:

(1) Possible exposure from machining of thorium-232 metal of mock-ups received from Y-12 that may have been done at Rocky Flats[2]

(2) Exposure during certain thorium ingot operations during 1960.

(3) Exposure during operations to remove thorium-228 that had built up as a contaminant in U-233 that was to be processed into metal buttons at Rocky Flats. This operation was known as a "thorium strike."

The dose reconstruction issues for each of these are different and we will consider each separately. NIOSH has not proposed anything explicit in relation to the various small sources of thorium-232 at Rocky Flats that is different from the prior implicitly proposed use of a Nuclear Regulatory Commission guidance document, NUREG-1400. SC&A has made some prior comments on that issue and some follow-up is provided here. Finally, the Board made a determination to follow up on a thorium-related issue regarding the Dow Madison (Illinois) plant that may have some implications for Rocky Flats. SC&A has provided an observation on this point (without analysis), since it connects with a prior discussion relative to the Rocky Flats thorium source term.

2.1 MACHINING OF THORIUM-232 MOCK-UPS AND ROUTINE INGOT ROLLING

In its April 5, 2007, report, SC&A provided an extensive discussion of the available literature on machining of thorium and resultant air concentrations (SC&A 2007, Sections 6.3.2.2 and 6.3.2.3, pp. 166–173). In reviewing comparable operations, SC&A concluded that since the nature of the possible machining was known,[3] it would likely be possible to use the available data for creating a bounding dose approach for the Rocky Flats machining of thorium metal mock-ups. SC&A has reviewed the proposed NIOSH approach in "Step 1" and "Step 2" (NIOSH 2007, p. 5) and concurs that this represents a plausible approach for placing an upper bound on thorium from the relevant machining operations.

The empirical approach suggested by SC&A is described in a manuscript, *Thorium, Its Industrial Hygiene Aspects*, authored by Roy Albert and published by Academic Press in 1966. Based on

[2] NIOSH 2007 states that expert evidence indicates there was actually no machining. Prior discussions have alluded to light machining work. The dose reconstruction method was presented by NIOSH assuming that there was machining.

[3] It is to be noted that this Rocky Flats situation is in contrast to Y-12, where NIOSH could provide no data or information on the nature of operations relating to much larger thorium-232 source terms (see ABRWH meeting, Washington, D.C., June 15, 2006, transcripts, page 268, available on NIOSH/OCAS website.)

our review of the literature, SC&A believes that this manuscript remains, to this day, the most authoritative reference on the industrial hygiene aspects of thorium.

For "Step 1" relating to machining, NIOSH proposes to use a value of 1.70 x 10^{-11} µCi/ml (0.63 Bq/m^3). This value is based on the Alberts manuscript, which is an authoritative document on this topic covering processing of thorium up to the time of its publication in 1966.

Also, in its May 17, 2007 report, NIOSH refers to a measured breathing zone concentration 7.14 x 10^{-11} µCi/ml (2.64 Bq/m3), obtained from the Albert manuscript, as the airborne thorium dust loading observed in the breathing zone of workers involved in the rolling of ingots equipped with local ventilation. This value reflects six measurements of gross alpha activity counted 2 weeks after collection to allow short-lived radon progeny to decay away. This dust loading is 35 times higher than the concentration derived using the NUREG-1400 methodology. It appears to be a scientifically defensible and claimant-favorable approach for assigning doses from thorium machining operations of the type that have been discussed as possibly occurring with the mockup.

As a check on this approach, the following presents a brief summary of the data provided in the Albert manuscript. Chapter 10 of the manuscript addresses the inhalation hazards of thorium in industry, and Section 6 of Chapter 10 specifically addresses rolling, forging, and machining of thorium metal. Table 10.4 of the manuscript presents data on the concentration of thorium in the breathing zone of workers involved in melting, machining, and forging thorium. Table 1 presents excerpts from this table that address various steps associated with machining thorium. (It is assumed that thorium melting was not performed at Rocky Flats; data associated with thorium melting are therefore not included in this table). As may be noted, the value selected by NIOSH is among the highest observed breathing zone values associated with forging operations, and therefore, seems to be a scientifically sound and claimant-favorable value.

Table 1. Excerpts from Table 10.4 of Albert (1966): Concentrations in Breathing Zone Air Samples (µCi/ml)*

Operation Sampled	No. of samples collected	Alpha Decay		Beta decay	
Machining		After 24 hrs	After 2 wks	After 24 hrs	After 2 wks
Machining ingots and electrode stubs					
Lathe equipped with local exhaust hose	6	2.49E-9	3.12E-10	1.97E-9	4.59E-10
Lathe enclosed in hood	5	3.9E-10	1.70E-11	5.18E-10	3.1E-11
Sawing ingot (dry)	1	3.5E-11	Note**	1.08E-10	Note**
Crushing and pressing turnings	2	9.59E-10	2.72E-10	1.54E-9	9.67E-10
Forging					
Removing ingot from heating furnace	2	1.64E-11	Note**	1.66E-11	Note**
Forging into billet	4	3.90E-11	1.94E-11	5.17E-11	1.29E-11
Rolling billet into slab	5	9.5E-11	7.14E-11	1.07E-10	6.57E-11

* After R.R Lowery, Radiation Hazards Encountered in Arc Melting Thorium, U.S. Bureau of Mines Report Investigation, 5969 (1962)

** Not measured

2.2 1960 INGOT OPERATIONS

SC&A has reviewed NIOSH's proposed use of data from other sites as a complement to the air monitoring data during the routine rolling operations and concurs that it is a reasonable approach to derive a plausible bounding dose estimate.

However, in the case of the failed rolling operation in September 1960, when a canned thorium ingot was cut with a torch, NIOSH has repeated the use of an air sample and questioned SC&A logic in concluding that it was not a breathing zone sample:

> *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.*
>
> $I = (62\ dpm/m^3) \times (1.2\ m^3/hour) \times (2\ hour) \times (0.0167\ Bq/dpm) = 2.5\ Bq$ [NIOSH 2007, pp. 5–6, emphasis added]

SC&A's concern that this was not a breathing zone sample is explained in its April 5, 2007, report as follows:

> *The flame-cutting of an ingot on September 22, 1960, was documented and some air concentration data are available (Attachment 20). However, the number of samples is rather limited—four in all (Air Sample records 1960). NIOSH has identified one of these as a "breathing zone" sample (Attachment 20); however, the raw data card itself only stated that the sample was taken "3 ft from thorium ingot while it was being cut."* ***This is more than an arm's length****; it* [is] *farther than the operator would be from the ingot during the cutting operation; hence, the sample is unlikely to reflect a true breathing zone concentration. In such*

> *circumstances, a short distance of a foot or two can make a considerable difference in air concentrations.* [SC&A 2007, pp. 165–166, emphasis added]

The stretched arm of a 5-ft 10-in man is typically about 30 or 31 inches, shoulder to finger tips, well short of 3 feet. A manual cutting posture would put the face at ~1 foot from the job, sometimes closer. In a similar situation, welders protect themselves with face shields. It is unclear how the Rocky Flats worker who cut the thorium with a torch protected himself,[4] but it is not technically justifiable to assume that a sample taken at a distance of 3 feet from a manual torch cutting operation was a breathing zone sample. Available information in the logbook does not indicate a remote cutting operation. SC&A also has noted that this sample had a very low air flow rate, which would reduce its representativeness of the location that was sampled.

The air concentration value indicated by the sample was 0.63 Bq/m^3, which is about 0.15 mg/m^3 of Th-232 (specific activity = 0.11 microcuries per gram). In reviewing the cutting of uranium cobbles at Bethlehem Steel, SC&A had suggested reviewing air concentration data connected to welding operations, where transients can reach as high as 850 mg/m^3 (SC&A 2005, p. 49). It is recognized, of course, that such concentrations are not sustained for hours and that welders protect themselves with face shields, which would reduce air concentrations actually experienced.

NIOSH has done its own review of cobble cutting in the context of revising the Bethlehem Steel Site Profile. In that context, NIOSH assumed a uranium concentration for the person cutting the cobble of 600 MAC for 2 hours, which amounts to 30 mg/m^3 (NIOSH 2006, p. 24) or about 200 times greater mass concentration than the one air sample taken during the cutting. SC&A is not suggesting that this value be used for the specific Rocky Flats situation at issue. This is because, among other possible considerations, the thorium being cut was in a steel can, for instance. The specifics of the Rocky Flats situation, including the Rocky Flats air sample taken at three feet, should be considered in light of the analysis done for Bethlehem steel to yield a more robust calculation. It is noted that all the elements necessary to the calculation have been performed by NIOSH.[5]

Finding regarding the thorium ingot cutting operation in September 1960: NIOSH's use of a Rocky Flats air sample taken 3 feet from the torch-cutting of thorium is not claimant favorable and does not represent a breathing zone sample for manual torch-cutting of thorium. The intake value used does not take into account NIOSH's earlier assessment of the cobble-cutting operation at Bethlehem Steel. That assessment should be used as a complement to the Rocky Flats torch-cutting sample. NIOSH has already performed all the elements of the analysis needed in order to yield a claimant favorable value for intake.

---

[4] A Rocky Flats Health Physics logbook entry of September 14, 1960, states "Discussed use of respirators in 83 for Th processing," but there is no indication of the outcome of the discussion or whether respirators were actually used in the operations that followed. See Health Physics Logbook, 1960–1963, on the NIOSH "O Drive" at "NIOSH_Data on 'cocsvr01' (O:)/AB Document Review/Rocky Flats/Logbooks/Log 8-29-60—6-12-63"

[5] SC&A notes in passing that the probability of causation for lung cancer in the sample dose reconstruction, as reported on page 8 of NIOSH 2007 appears to be in error. It is too low for the estimated lung dose (p. 7).

2.3 THORIUM-228 STRIKES

A thorium-228 "strike" is a term that is used to refer to the removal of thorium-228 from uranium-233, which was one of the materials processed at Rocky Flats. This was done by chemical processing (fluoride precipitation). U-233 generally has some contamination with uranium-232. U-232 in turn has a decay chain, the first radionuclide in which is thorium-228. Th-228 and some of its decay products are strong gamma-emitting radionuclides that build up rapidly in a sample of U-233 (on a time scale of months).[6] The amount of Th-228 that builds up in a given time in a U-233 sample is directly proportional to the amount of U-232 in that sample. Even though it is present in trace quantities, Th-228 increases the processing hazards associated with U-233. Thorium strikes were carried out on U-233 samples in which Th-228 (and hence radium-224 and thallium-208) had built up sufficiently to pose processing hazards.

The removal of Th-228 was a wet process involving fluoride precipitation. The thorium strikes were done in a "dry box" ventilated environment. Further, according to the NIOSH report, the workers carrying out the thorium strike worked under conditions where external exposure was sought to be minimized and where potential for radionuclide intakes was "minimal":

> *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 [a site expert interviewed by NIOSH] 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.* [NIOSH 2007, p. 9]

NIOSH has provided a sample dose reconstruction for "the" thorium strike operation conducted during April 26–28, 1965. It is based on the highest of the area air samples taken on each of the three days in the room where the operation was carried out.

SC&A has reviewed the air concentration data for Room 266 for the month of April 1965, when the operation was carried out. SC&A concurs with NIOSH that it used the highest samples on each date on the dates in question, and that "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" (NIOSH 2007. p. 9). That is, the maxima and averages on the three days are toward the low end of the maxima and the averages (respectively) compared to the air concentrations on other days in the same room.

From sample data for the dates of the operation, April 26–28, 1965, one can note that the air concentrations measured at the J and K sampling heads were much higher than at most other sampling locations. Since radon daughter products would be quickly homogenized in a small

[6] The half-life of Th-228 is about 1.9 years. The subsequent decay chain consists of very short-lived radionuclides that build up on a time scale of days.

room,[7] it appears that the air concentrations are more likely to be related to workplace related emissions. From the data it appears that sampling heads J and K may have been closest to the workplace.

NIOSH has used the highest, non-decay-corrected air concentration value for each day[8] and assumed three 16-hour working days to derive an intake estimate that it states is a bounding value. Using these three assumptions would result in a bounding value for that operation *if* the air concentration value could be related to the breathing zone. As it stands, the relationship of the overestimation created by claimant-favorable assumptions of very long working days and a non-decay-corrected air concentration value to any potential underestimation caused by the use of even the highest area sample is unknown. This is because the location of the area sampler relative to the worker is unknown, or at least not specified in the dose calculation. The gradients of air concentration in the room were quite large. The range of measured air concentrations was as follows:

- 2.1% to 44.4% of the maximum allowable concentration on April 26, 1965,
- 3.3% to 44.9% on April 27, 1965, and
- 2.7% to 30.7% on April 28, 1965.

This indicates the need to relate the location of the sampler head to the breathing zone of the workers involved in the operation. It is unclear if the highest air samples were taken at locations that were nearer the workstation or to the area where the workers retreated after approaching the chemical reaction vessel in the dry box. The NIOSH procedure for adjusting area air sampling data to breathing zone concentrations at Bethlehem Steel would likely provide a useful approach in this case as well. NIOSH may need to establish the locations of the samplers, which are not stated in the sheets containing the raw data.

Finding regarding the April 1965 thorium strike: NIOSH has not demonstrated the relationship of the air sample values used for estimating intakes during the April 1965 thorium strike to the breathing zone. Even though they are the highest among collected area samples (for each day of the April 26–28, 1965 operations), their relationship to workers' breathing zones has not been established. Data regarding the locations of the samples are not in the datasheets, but may be available elsewhere. These data and use of adjustment factors that relate general air samples to breathing zone concentrations, as was used in the Bethlehem Steel site profile revision, would help to resolve this issue.

The NIOSH 2007 report did not provide any data for any other thorium strikes. The history of U-233 operations at Rocky Flats (ICF Kaiser 1999) makes it clear that these operations were conducted at times between 1965 and 1977. It notes the following regarding U-233 operations that followed the first one in 1965:

> *Inventory records indicate that kilogram (kg) quantities of ^{233}U were also received, processed, and shipped at RF [Rocky Flats] over the next three years, 1966–1968. Smaller quantities, typically less than 1 kg, show up on inventories*

[7] The room is stated to be small by NIOSH (see Attachment 1).
[8] At sampler head J on April 26, 1965 and at sampler head K on April 27 and 28, 1965.

during the period 1969–1973, where projects included casting small metal ^{233}U disks. During 1974–1977, kg quantities of ^{233}U again arrived and were processed at RF, however by 1974, uranium processing had been stopped in Building 881. Two special order projects worked on between 1974 and 1977 again involved manufacturing a number of components from 233 metal….

The ^{232}U contamination in this metal [produced at Rocky Flats by a "thermit reaction"] was substantially lower, running around 7–8 ppm, compared with 50 ppm in 1965. Still, gamma radiation levels were fairly high and a fluoride precipitation step was used on feed material, and from time to time on in-process material, to remove the "hot" daughter products and reduce the external radiation hazard to workers. [ICF Kaiser 1999, p. 9]

This U-233 history notes that the U-232 contamination was highest in the 1965 operation. Hence, it is possible that the air concentrations from the 1965 operation, appropriately interpreted, could serve as a bounding intake estimate, provided there were no incidents or process upsets in later operations. The NIOSH (2007) report discusses only the 1965 thorium strike, which is referred to as follows: "The thorium strike occurred in Room 266, Building 81…." (NIOSH 2007, p. 9).

The question of thorium strikes following the 1965 operation was discussed during the May 25, 2007 conference call. NIOSH stated that it is acquiring air concentration data for a thorium strike in 1967. If the source term data are also available, this would provide some confirmation of the relationship of the 1965 air concentration data to other thorium strikes.

However, NIOSH stated on May 25, 2007 that such strikes were not needed later due to the low U-232 concentrations in the incoming U-233:

[NIOSH]: In terms of the ICF Kaiser reference indicating the removal of "hot" daughter products to reduce the external radiation hazard to workers, Brant noted that that the same document (on page 4) indicates that "U233 processed in 1965 contained approximately 50 ppm U232, while that processed in 1976-77 contained only 7-8 ppm U232". The U-233 used in this later project was to support an operation at NTS, in which Mel Chew was directly involved. Mel recalls that because this later metal had much lower U-232 content, it was not necessary to do Th strikes on it. Ken Freiberg also recalled the same thing. [May 25, 2007 Conference Call minutes, Attachment 1]

A statement to the effect that later U-233 samples had 7-8 ppm does occur in the ICF-Kaiser, as quoted above, but it also notes that thorium-228 strikes occurred after 1965 both prior to U-233 processing. and "from time to time on in process material." SC&A has been unable to reconcile this statement in the ICF-Kaiser history published in 1999 (quoted at length above) with the NIOSH interpretation of it and with associated site expert recollection, both quoted above.

Finding in regard to thorium strikes during 1966–1977: According to a history of U-233 operations at Rocky Flats, (1) there were some thorium-228 strikes in the 1966–1977 period and (2) the U-232 concentrations (and hence maximum Th-228 concentrations) in these later operations was considerably smaller than the 1965 operations. NIOSH did not explicitly discuss these in its 2007 report, but indicated later that it is acquiring data for a 1967 thorium strike. NIOSH has also indicated that later operational and air concentration data would show that the 1965 thorium strike provides a bounding case for thorium strike intakes. Air concentration and/or other operational data and source term information from the 1966-1977 period may allow the April 1965 strike to be established as one representing a bounding intake relative to the others, in the absence of incidents. The data were not available to SC&A at the time of finalization of the analysis in this report (May 29, 2007).

2.4 SMALL SOURCES OF THORIUM AT ROCKY FLATS

In light of the issues related to the lack of suitable demonstration that NUREG-1400 yielded a bounding dose for thorium at Rocky Flats, SC&A had recommended that other approaches be developed for estimating potential intakes from the small thorium sources (less than 500 grams) or that the use of NUREG-1400 be validated for small sources:

> *NIOSH's attempt at validating the use of NUREG-1400 does not meet the criteria of 42 CFR Part 83, as discussed above. The most recent validation attempts using weighted average air concentration data from Simonds and one air sample from RFP may provide a starting point for a use of NUREG-1400 at RFP for small sources, but a convincing demonstration has not yet been made. It may be possible to choose a single value of air concentration from among the extensive data on air concentrations for various operations that would bound all RFP small operations.*
>
> *It is likely that a suitable approach for small uses of Th-232 (i.e., those each less than 500 g) can be developed, but this has not yet been done.* [SC&A 2007, p. 174]

NIOSH addressed the routine machining and rolling operations and provided plausible bounding dose estimates using methods other than NUREG-1400. However, NIOSH did not extend this analysis to small thorium sources.

The status of the analysis of small thorium operations was discussed during the May 25, 2007 conference call (Attachment 1). NIOSH pointed to a prior example of the use of NUREG-1400 for mold coatings (Attachment 20, SC&A 2007b) as being the approach that it would take. Such an approach would be consistent with the Board's approval of a similar approach for small sources at Y-12. However, NIOSH had indicated that an appropriate comparison to other data (in that case from Y-12 itself) would be made in the process of developing the bounding approach for small, non-production type of sources. Dr. James Neton, the Scientific Director of the Office of Compensation Analysis and Support, described NIOSH's approach as follows during the June 8, 2006 Working Group meeting:

> *At this point we are working with the concept that these smaller amounts of thorium, that is, the 11 grams, the 16 grams, the less than 500 [grams], in our opinion were not related to production activities, but they were laboratory-type amounts that were used particularly in the Assay Analytical Lab, appear to have been used for calibration sources standards testing, that sort of thing.*
>
> *So it wouldn't really fall in the production category and we are developing approaches -- we think we can develop approaches to bound exposure so these small quantities. There are a number of ways to go with this. One approach is to use something like New Reg 1400 [NUREG-1400] that, for those of you who aren't familiar with it, is a document that talks about air sampling in the work place. It was issued in 1993 and it had some -- actually, bounding analyses one can do based on the quantity of source that are present and what fraction becomes re-suspended from the air, and then you could modify the amount in the air based on certain prophecies and confinement practices, that sort of thing; identify the nature of the material, whether it was liquid, solid, gas.*
>
> *We think that we can put a bound on exposures in these laboratory-type buildings. That, coupled with the fact that we do have a large amount of air sample data after the SEC period when large quantities of thorium were being processed, there's both air sample and fecal data that one could use to bound exposures from what we would consider to be a -- certainly a less error-intensive environment, you know. There wouldn't be generated as much airborne activity as a laboratory process. So that's where we stand with this right now.* [ABRWH Working Group 2006, pp. 20-21]

SC&A has suggested a similar approach for the use of NUREG-1400 for small sources at Rocky Flats. The Working Group accepted the approach and Board indicated approval as well at its June 14-16 meeting in Washington, D.C. in not including small sources in the portion of the Y-12 SEC that was based on lack of adequate thorium monitoring data. (ABRWH 2006, pp. 260–298, and ABRWH 2006a, pp. 10–15).

Finding in regard to small thorium sources: There were numerous small sources of thorium, less than 500 grams each, used in various parts of Rocky Flats. The NIOSH 2007 report has addressed routine machining and rolling operations satisfactorily, but did not extend that analysis to cover small thorium sources. NIOSH's demonstration application of NUREG-1400 for thorium molds, provided in December 2006 (see SC&A 2007b, Attachment 20), was not demonstrated as a bounding intake by a comparison to actual operations. The use of thorium air concentration data as a check on the use of NUREG-1400 would provide an appropriate approach for small sources. The use of NUREG-1400 for small sources for intake estimation was approved by the Board for Y-12 on a similar basis.

2.5 ROCKY FLATS, DOW MADISON AND THE THORIUM SOURCE TERM

In its April 2007 report, SC&A raised the possibility, based on a worker interview, that large amounts of magnesium-thorium alloy (thorium content less than 4%) may have been shipped from Dow Madison to Rocky Flats. NIOSH, based on interviews with site experts including high level managers, concluded that if any such alloy was shipped to Rocky Flats, it was in small amounts in already manufactured form. In light of the lack of corroborating evidence for large-scale shipments and in light of site expert statements, SC&A found that NIOSH had not provided conclusive evidence on the issue, but that no other corroborating information for the shipments was available. In light of Rocky Flats expert evidence from several experts, SC&A concluded the following:

> *A difference of interpretation remains between NIOSH and SC&A regarding the magnitude and nature of the magnesium-thorium alloy source term due to contradictory interview statements and lack of documentation to resolve the large differences implicit in the statements made by site experts from both the Dow Madison and RFP sites. However, subsequent followup with RFP petitioners and former RFP workers produced no corroborating information to substantiate Dow Madison shipments of magnesium-thorium alloy to Rocky Flats, nor did investigations find any further information about its applications there.* [SC&A 2007, p. 164]

It is to be noted in this context that NIOSH is preparing a complex-wide dose reconstruction approach for thoriated welding rods, which consist of a tungsten-thorium alloy with a few percent thorium metal (SC&A 2007, p. 164).

At its May 2–4, 2007, meeting, the Board asked NIOSH to investigate magnesium-thorium alloy shipments from Dow Madison to DOE facilities, based in part on information from the same Dow Madison worker that precipitated the original concern that large amounts of magnesium-thorium alloy were shipped to Rocky Flats. The request included an investigation into the post-1960 period, when the worker in question stated he was personally familiar with shipments of thorium-magnesium alloy to Rocky Flats. The Board action was in response to the NIOSH decision to recommend an SEC based on potential exposure to thorium at Dow Madison during 1957–1960. Thorium magnesium alloy was mentioned in the NIOSH Evaluation Report, but only in the context of commercial operations, inspected by the AEC (NIOSH 2007a, p. 9 and p. 13). Hence, two rather different positions in regard to the thorium-magnesium alloy now exist:

(1) A scenario based on Rocky Flats site expert statements regarding lack of evidence of receipt of such shipments, and other considerations (e.g., inventory)

(2) A scenario based on the Dow Madison site expert evidence, upon which the Board has kept open the issue of potentially very large and regular shipments from Dow Madison to Rocky Flats

(6) **SC&A observation regarding magnesium-thorium alloy:** Two rather different positions in regard to the thorium-magnesium alloy at Rocky Flats now exist. The first is a scenario based on Rocky Flats site expert statements regarding lack of evidence of receipt of such shipments, and other considerations (e.g., inventory). The second scenario is based on statements by a Dow Madison worker that there were large and regular shipments of thorium magnesium alloy to Rocky Flats. The Board asked NIOSH to investigate this issue for Dow Madison, as a follow-up to the NIOSH recommendation that Dow Madison workers between 1957 and 1960 (250 days or more employment) be included in the SEC. These two positions may or may not come into conflict, depending on the outcome of NIOSH's Dow Madison-related investigation. They have quite different radiological implications for some aspects of work at these sites and related estimation procedures for radiation exposure. SC&A notes that data are available for dust generated by alloys containing a few percent thorium, notably thoriated welding rods, which may be applicable to processing of magnesium-thorium alloy in metal form. If shipments to Rocky Flats from Dow Madison occurred, that is the form in which it would have been shipped. SC&A also notes that NIOSH has informed the Board that it is preparing a complex-wide assessment of exposure from thoriated welding rods, for which data have been discussed in the context of Rocky Flats. Finally, SC&A understands that NIOSH is investigating whether the Mg-Th alloy was shipped to the Department of Defense facility called the Rocky Mountain Arsenal, which is in the same general region as Rocky Flats and/or the nearby Lockheed Martin aerospace facility (see Attachment 1).

3.0 BUILDING 81 EXTERNAL GAMMA AND BETA DOSE IN THE 1950–1959 PERIOD

There was essentially no external gamma or beta dose monitoring for Building 81 workers during the 1950s.[9] NIOSH has compared 1960 data and 1961 data for Building 81 workers to the doses that would be assigned under the external dose coworker model developed for Rocky Flats and shown that the latter as consistently much higher than the measured doses. NIOSH has argued that this fact, together with a number of other factors, support the use of the coworker model as the bounding dose estimate for workers in Building 81 the 1950s:

> *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.* [NIOSH 2007, p. 15]

SC&A has frequently noted that the quantity of production in a facility is relevant to population dose, but is generally not relevant to individual dose, unless smaller quantities lead to part-time work for some or all workers. The increase in production at Rocky Flats was accomplished by building new facilities and by increasing the number of workers, and not by going from part-time to full-time production work. Working conditions, the nature of the facilities, industrial hygiene methods, and methods to detect, report, and evaluate incidents are all basic to potential and

---

[9] In this chapter, the terms "dose," "monitoring" etc., relate to gamma and beta dose

actual exposures. There are many situations in which individual exposures are high with low production and vice versa due to variations in working conditions. Further, individual exposures within a facility usually depend on the type of job done by a particular worker.

SC&A concurs with NIOSH that the average exposures in the last quarter of 1960 and in 1961 in Building 81 were less than 10% of the then-prevailing regulatory limit. The 95th percentile of the coworker doses are also much greater than the maximum recorded exposures. On the face of it, the 95th percentile values of coworker dose would be suitable for application to the 1950s, provided the nature of the jobs and working conditions could be established to be broadly similar.

The large margin between the coworker dose and the maximum measured shallow and deep doses in 1960 and 1961 indicate that the use of the coworker model would be generally claimant favorable for Building 81 workers in the 1950s, if all other things were generally equivalent from a radiation exposure perspective. However, there is evidence that conditions were likely to have been substantially different during the two time periods In particular, the Historic American Engineering Record for Rocky Flats indicates that significant process changes did occur in the late 1950s and early 1960s in Building 881:

> *The dissolution process yielded a uranyl nitrate solution, from which a uranium peroxide was precipitated. Once filtered, the precipitate formed a yellow, cake-like substance that was heated (calcined) to produce an orange uranium oxide. The dissolution, precipitation, and calcination processes were originally performed as batch processes. By the late 1950s to early 1960s, the processes became one continuous operation. The orange oxides were converted to uranium tetrafluoride, a green salt. The conversion was conducted by placing the orange oxides into monel (copper-nickel alloy) containers, heating to reduce the compound, and adding anhydrous hydrogen fluoride. The green salts were transferred to a sealed metal bomb reactor for final reduction to uranium metal. Building 881 operations initially produced enriched uranium buttons approximately 3 kg in size; however, with process improvements, these operations were able to produce buttons up to 15 kg in size.* [HAER 881]

Rocky Flats workers contributed to these changes, which are described in the official history as "improvements:"

> *Enriched uranium recovery processes used at the Plant were based upon those developed at the Los Alamos Scientific Laboratory and the Oak Ridge Reservation during and after World War II. The processes were refined at the Oak Ridge Reservation Y-12 Plant in the several years preceding the construction of the Rocky Flats Plant.*
>
> *Plant personnel contributed many unique improvements to enriched uranium recovery processes. Improvements were made to the continuous dissolution processes of the following materials: sand and slag from foundry operations; and skull oxide (material recovered form foundry crucibles). Improvements were*

> *made in the other continuous processes for: peroxide precipitation; calcination of uranium peroxide; and leaching of powdered solids. Site personnel developed improved processes for graphite incineration; oralloy parts decontamination; and achieved a 15-kilogram (kg) scale reduction of uranium tetrafluoride to metal.* [HAER 881]

The processes used in the early to mid-1950s were, therefore, those that dated back to the Manhattan Project and the years that immediately followed World War II. The changes made in the late 1950s and early 1960s appear to have been in the context of scaling up production at Rocky Flats, which occurred in the same time period. New or refined processes would require new processing equipment or changes to existing processing equipment; they would also require changed production procedures. It is likely that job descriptions and details of certain kinds of work changed in this context. It would be surprising if such significant changes did not result in a change in radiological conditions for many or most workers in Building 881. In any case, an assumption that dose rates experienced by individual workers did not materially decrease cannot be an *a priori* or default assumption. NIOSH has not investigated the effects of these changes; rather it has limited its remarks to just one set of changes:

> *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.* [NIOSH 2007]

This NIOSH statement does not recognize the significant nature of the process changes that occurred in the late 1950s and early 1960s. The pattern of badging of Building 881 workers in Building 881 in terms of the new processes, procedures, and equipment versus the prior arrangements is unknown. Specifically, SC&A is concerned that given that many workers were still not monitored in the first part of that 1960s, it is not at all clear that the workers who were monitored in the last quarter of 1960 did jobs that were radiologically comparable to most of the 1950s—that is, the period(s) until the many changes were made in the building.

NIOSH has also not analyzed whether certain groups of workers, such as foundry workers who may have had similar jobs in the early 1960s and in the 1960s, were badged for entire year in 1961 or even at all. Finally, sub-critical experiments were conducted in Building 81 during the 1950s and early 1960s, until 1964 (see Section 4 below). While these involved few workers and were conducted at night, it is not clear whether these workers were badged in 1960 or 1961.

Finding regarding use of the coworker model for 1950s Building 81 workers: SC&A finds that the application of coworker data to Building 81 workers for the 1950s, when there was essentially no external dose monitoring in that building, would generally be claimant favorable if the production processes had not changed and/or working conditions were demonstrated to be radiologically comparable. However, there were extensive changes in production processes in Building 81 in the late 1950s and early 1960s. NIOSH has not analyzed the effects of these changes on exposure potential and has not demonstrated the

comparability of working conditions. The application of the coworker model may turn out to be claimant favorable, were such an analysis to be done; but the many significant changes that occurred were not acknowledged or discussed in the NIOSH 2007 report. The necessary analysis for establishing the use of the coworker model for Building 81 for the 1950s has not yet been performed.

Documents indicate that cleaning of oralloy parts occurred in Building 881, but that residues with high concentrations of plutonium were recovered as a result. The ChemRisk Report on the history of Rocky Flats operations, published by the Colorado Department of Health, confirms that cleaning of HEU parts with plutonium contamination occurred in Building 881:[10]

> *For some time, the 881 chemical recovery operations included an "oralloy leaching" operation, in which returned or rejected enriched uranium parts were subjected to a spraying of hot nitric acid to remove residual plutonium surface contamination. Some amount of uranium would also be removed by the acid leaching. Associated solutions were evaporated, and the concentrate precipitated with ammonia gas, calcined to a dry oxide form, and analyzed for plutonium content. Oxide that was sufficiently high in plutonium content was sent to the Savannah River Plant, while that which was low in plutonium content was sent to the Oak Ridge Y-12 Plant for recovery of the uranium. Over time, the exhaust system associated with the oralloy leach process accumulated a build-up of plutonium, which was eventually removed with the plenum filters and treated as plutonium waste.* [ChemRisk 1992, p. 68]

SC&A has not come across a quantitative estimate of the overall amount of plutonium that was recovered in the cleaning process. However, it is to be noted that sufficient amounts were recovered to make it worthwhile to send to the Savannah River Plant. Materials accounts at Rocky Flats and Savannah River Site would provide a partial account of the source term (since some went with the uranium to the Y-12 Plant.

NIOSH acknowledged the presence of plutonium in Building 881 in its Rocky Flats SEC Petition Evaluation Report:

> *The original building was designed and built for processing enriched U. Small quantities of other radioactive materials such as U-233 and Pu were also handled.* [NIOSH 2006a, p. 24]

However, NIOSH has not analyzed the implications of plutonium-rich residues for the workers involved in handling them. The personnel processing the plutonium residues from the cleaning process would have the potential for various kinds of radiation exposure.[11] In the present context of the non-monitoring of Building 881 employees for external deep and shallow dose in the 1950s, a specific analysis of the 1960 and 1961 data for Building 881 is needed in order to

---

[10] Enriched uranium work in Building 881 ended in the early 1960s.

[11] In its April 5, 2007, report, SC&A concluded that the NIOSH internal dose coworker model was appropriate. The use of this model is indicated for workers involved in the oralloy cleaning process who were not monitored for internal exposure to plutonium.

ensure that plutonium recovery workers were monitored in those years. If they were, then the coworker model would be shown to be claimant favorable for those operations for shallow and deep photon dose and beta dose. (The estimation of neutron doses to workers with a potential for neutron exposure who were not monitored is covered separately in Section 6 of this report).

Finding regarding plutonium in Building 881: Plutonium was present in Building 881 as part of the operation of cleaning enriched uranium parts. A portion of the residues from the cleaning process contained plutonium of sufficient purity and in significant enough quantities for it to be shipped to the Savannah River Site. The amounts involved were also significant enough that the exhaust air plenum was appreciably contaminated. NIOSH has not demonstrated that the use of the shallow and deep photon dose coworker model is bounding (or more accurate than bounding) for the workers involved in cleaning the enriched uranium parts and processing and handling the residues in Building 881.[12]

[12] Neutron exposure issues in Building 881 are covered in Section 6.

4.0 NEUTRON DOSE ESTIMATION, 1959–1970, INTRODUCTION[13]

The Rocky Flats Plant had the potential to expose workers to a variety of radiation types and sources. Exposure to neutrons was one of these radiation types. There was particular potential for exposure to neutrons in laboratory and industrial-scale operations, notably those involving plutonium processing and parts fabrication. There were a variety of sources of neutrons at Rocky Flats:

(1) Neutrons were generated by spontaneous fission and (alpha, n) reactions in all situations involving plutonium in significant amounts.

(2) Laboratory and other neutrons sources, such as californium-252 neutron sources, were present at Rocky Flats.

(3) Sub-critical experiments were carried out in various locations throughout almost the whole period at issue here (1959–1970). These had the potential for neutron exposure.

(4) Special projects were carried out with radionuclides such as curium-244.

In this section, the terms "monitoring," "badges," and the like refer to neutrons, unless otherwise specified.

SC&A's supplemental report presented a detailed analysis of NIOSH's neutron dose estimation procedures for the 1952–1958 period and for 1959–1970 (SC&A 2007a). During the May 2–4, 2007, meeting, the Board recommended the addition of workers who were monitored or should have been monitored for neutrons at Rocky Flats for the 1952–1958 period, though the buildings and activities associated with that description remain to be defined. This section reviews the new procedures for neutron dose estimation for the 1959–1970 period that have been suggested by NIOSH in its report to the Board for the June 11–12, 2007 meeting (NIOSH 2007). The issues regarding neutron dose measurements are connected with the use of the NTA film dosimeter. Thermoluminescent neutron dosimeters were introduced in 1971.

Prior to review of the new methods that NIOSH has suggested, it is helpful to review the basic kinds of data that are available:

(1) Many workers at risk of neutron exposure were monitored during the 1959–1970 period. Data are available from the 70s-series buildings and some other areas.

(2) Many workers with neutron exposure potential in this same period were not monitored.

(3) As part of the Neutron Dose Reconstruction Project that was initiated in 1994 (ORISE 2005), 87,000 thousand badges were re-read. The vast majority of the original readings were found to be in error, some by an order of magnitude or more.

[13] In the rest of this report, the terms "dose," badge," "monitoring," etc. refer to neutrons unless otherwise specified.

(4) Generally, the badges of these workers during the 1959–1968 period were archived (though there seem to be a larger number of badges in 1968 that were not re-read compared to earlier years).

(5) Between 1959 and 1964, a significant fraction of workers included in the NDRP project who were at risk of neutron exposure were not monitored for neutron exposure (although they were monitored for photon exposure).

(6) Between 1967 and 1970 many of the neutron badges that were issued were not read in order to improve the quality of the reading that was being done. The workers whose badges were not read were assigned a dose based on their gamma exposure reading multiplied by a neutron-to-photon ratio that was calculated at the time from area surveys.[14] These calculated doses were entered into the workers individual dose.

(7) The area survey data used to estimate the neutron-to-photon ratios were not archived and so cannot now be recovered.

(8) In 1969, it was decided not to archive neutron film. A large number of NTA dosimeters issued in 1969 and 1970, including many that were never read, were discarded and never recovered for re-reading during the NDRP project. The year 1968 also has a larger fraction of non-re-read badges compared to earlier years.

Prior to reviewing the new methods suggested in NIOSH 2007, there have been four basic components to NIOSH's neutron dose estimates (see SC&A 2007a, including the Attachments, for details):

(1) The original badges that were located and connected to a worker were re-read, and this dose was made part of the worker's dose record and DOE file.

(2) The readings of the original badges that were not re-read (because they could not be located or for other reasons) were multiplied by a factor of 1.99 for Building 71 and 1.13 for other buildings.[15] This value of dose was added to the workers dose record. This means that in those cases where the original reading was zero, a zero was entered.

(3) For short gaps in the dose record when workers were not monitored, the worker's own nearby dose readings were used to estimate the dose during the period of the gap. This was part of what was called the "notional dose."

(4) For large gaps (including a full year of non-monitoring), another element of a "notional" dose was estimated. The average neutron dose for that building for a particular year was divided by an average photon dose for that building (using paired n/p data). The resulting

[14] These calculated doses are to be distinguished from the notional doses that were calculated as part of the NDRP, many using n/p ratios. But these ratios were estimated differently.

[15] In contrast to the NIOSH procedure, the NDRP itself did not use any correction factors for original dose that was not re-read. That portion of the original dose was added to the re-read dose without correction.

n/p ratio was multiplied by the worker's gamma dose during the gap in the dose record to yield a "notional" dose estimate. This was the other part of the "notional" dose.

Elements 3 and 4 of the dose estimate were combined to yield a total "notional dose" that filled the entire gap for the year for a particular worker. If there were no monitoring records for that year, the entire year's notional dose was based on the n/p ratio and the gamma dose. (See ORISE 2005 for details.)

In its April 30, 2007, report on neutron dose estimates (SC&A 2007a), SC&A made a number of findings relating to the NDRP neutron dose estimates. For instance, SC&A noted that workers with zero gamma dose could still have significant neutron doses. In such cases, and others with low gamma dose readings, multiplying an n/p ratio by the gamma dose would yield an underestimate of the worker's dose. Further, the use of a building average n/p ratio did not appear to be reliable for reconstructing individual worker dose estimates, since it might yield underestimates for some job types, while providing overestimates in other cases. SC&A also noted that the NDRP itself had called the "notional dose" method, notably the portion derived from n/p ratios, as "somewhat speculative."[16] SC&A's analysis also showed that NIOSH's correction factors used to adjust the original dose would likely result in underestimates in most cases. These included both the times when the original reading was non-zero and those when the original reading was zero.

At its May 2–4, 2007, meeting, the Board asked NIOSH to provide it with a different approach to estimate neutron doses for the 1959–1970 period, in light of the outstanding questions relating to the NDRP approach. NIOSH 2007 contains a new approach that does not rely on building-specific neutron-to-photon ratios to estimate neutron dose during periods of no monitoring. NIOSH has also proposed new correction factors for replacing original doses that could not be re-read.

The NIOSH estimation procedure for badges that were not re-read is reviewed in Section 5. Section 6 covers the new NIOSH procedure for estimating dose during unmonitored periods. Finally Section 7 outlines some of the changes in dose reconstruction procedures for Rocky Flats that would likely be necessary, if the NIOSH proposals are actually used for individual dose reconstruction.

It is important to note that SC&A references in the following sections to NIOSH's estimation procedures or NIOSH's proposals for estimating neutron doses do not imply that NIOSH is actually going to use these methods. The NIOSH 2007 report presents these methods in the context of the Board's request for them. What will actually occur in neutron dose reconstruction in practice for the 1959-1970 period cannot be inferred from the state of decision-making as yet, so far as SC&A is able to discern. Hence, the following analysis takes the NIOSH methods discussed in NIOSH 2007 at face value in reviewing them, without reference to the actual methods that may be employed.

---

[16] It was deemed relatively the most speculative for the early years, 1952–1958 (SC&A 2007a), for which the Board has recommended an addition to the SEC for workers who were monitored or should have been monitored for neutrons.

5.0 ORIGINAL DOSE RECORDS THAT WERE NOT RE-READ

The readings of neutron dosimeters of the NTA type were determined to contain significant errors both during a review undertaken at Rocky Flats in the mid-1960s and during the Neutron Dose Reconstruction Project (NDRP), which was initiated in 1994. A large part of the work of the NDRP was to recover and re-read these neutron dosimeters. However, not all the dosimeters were recovered. These are the non-re-read badges. Hence, the problem arises as to what value of dose to assign for those badges known to be issued (according to workers' dose records) but which could not be found, or, if found, could not be associated definitively with particular workers. In such cases, a value for the dose as originally recorded is known—it is in the worker's dose record. But this value is also likely to be in error. Hence some procedure to estimating a value of dose corresponding to the non-re-read badges is necessary.

The problem falls into two categories for arithmetic reasons. If the original dose was not zero, then it can be multiplied by a correction factor that quantitatively reflects the degree to which the original readings were estimated to be in error. If the original badge reading was zero, this approach will not work, since it will yield a dose estimate that is still zero when it is known that re-reading of badges that were originally thought to reflect zero dose resulted in non-zero dose results, which were relatively high in some cases.

NIOSH has proposed one method for handling the zero original dose problem and another for the non-zero original dose situation. Both are reviewed in this section.

5.1 REPLACING ZERO ORIGINAL DOSE READINGS[17]

In its April 30, 2007, report, SC&A pointed out that original zero neutron readings of badges could sometimes result in rather large doses when the badges were found and re-read. NIOSH has proposed the following method to estimate the dose in those cases where a badge with an original zero dose reading was not re-read:

> *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.* [NIOSH 2007, p. 21]

Table III.B.1 of the NIOSH report states that the 95th percentile daily neutron dose rate is 183 mrem/day (NIOSH 2007, p. 21) for original zero recorded doses for the 1959–1969 period. This daily rate is larger than the high end of daily neutron dose rates recorded at Rocky Flats and is in error. The NIOSH dose reconstruction demonstration used a value of 183 mrem *per badge*

[17] The SC&A calculations in this section are based on neutron dose data obtained from matched pair data in the NDRP database. That is, there are about 76,000 records of neutron badges that were re-read as part of the NDRP that have a corresponding gamma dose reading as well for the same period – hence the term "matched pair data." SC&A did not have the entire database of 87,000 neutron badge re-readings as a discrete file that was necessary to check the exact details of the NIOSH values. Apparently it has not been complied in that form, but must be derived from available data. The derivation procedure is not specified in NIOSH 2007. However, the sample of 76,000 badge re-readings analyzed by SC&A is more than sufficient to review the NIOSH analysis and provide reliable conclusions about whether it is claimant favorable.

cycle rather than per day. SC&A confirmed with NIOSH that the value is to be interpreted as being per badge cycle (see the e-mail exchange documented in Attachment 3)..

A value of 183 mrem per badge cycle would yield about 6 mrem per day for a monthly badge cycle and about 13 mrem/day for a 14-day badge cycle. The latter was typical for Building 71, while the former was typical of other neutron areas.

SC&A evaluated the re-read neutron data by year and building to show that the 95th percentile values of the daily dose rate are dependent on the year and the building. A one-size fits all value for the dose rate does not reflect the 95th percentile values in several cases, while in others it is greater than the value more reflective of work in a particular building.

The data show that badge cycles were highly variable by year, even within a building for different workers (or work locations) within the same building and the same year. One approximate comparison with the NIOSH value of 183 mrem per badge cycle can be made by multiplying the 95th percentile value of the daily neutron dose rate for that year and building with the typical number of days per badge cycle for that rate of dose at that time. Since the number of days per badge cycle can vary a great deal for the same daily dose rate in some cases, the values per badge cycle corresponding to the for 95th percentile dose rates can vary substantially. Table 2 shows the 95th percentile values for daily neutron dose and the badge cycle values calculated in this way for Building 71 by year and compares them to the NIOSH value of 183 mrem per badge cycle.

Table 2: 95th Percentile Values for Daily Neutron Dose, Building 71, 1959–1969

Year	Average days per cycle	Range of days/cycle	95th pc dose mrem per day	Badge cycle for ~95 pc dose, days	95th dose per cycle, min, mrem	95th dose per cycle, max, mrem	95th pc/ 183 min	95th pc/ 183 max
1959	15.11	7 to 30	23.46	14 to 24	328	563	1.8	3.1
1960	7.00	6 to 8	24.86	6 to 8	149	199	0.8	1.1
1961	14.00	7 to 15	25.00	14 to 15	350	375	1.9	2.0
1962	19.65	13 to 91	30.43	13 to 14	396	426	2.2	2.3
1963	14.52	13 to 31	15.64	13 to 14	203	219	1.1	1.2
1964	14.60	7 to 75	12.37	13 to 15	161	186	0.9	1.0
1965	30.56	28 to 40	7.30	28 to 31	204	226	1.1	1.2
1966	30.40	28 to 31	6.60	28 to 31	185	205	1.0	1.1
1967	27.64	10 to 31	10.71	14 to 30	150	321	0.8	1.8
1968	36.50	6 to 38	14.48	6 to 17	87	246	0.5	1.3
1969	29.50	8 to 88	13.43	14 to 15	188	201	1.0	1.1

The second to the last column in Table 2 compares the lowest computed value of dose per badge cycle to the 183 mrem per badge cycle used by NIOSH in its example dose reconstruction. The NIOSH value is about equal to or greater than the lowest value in all cases except 1959, 1961, and 1962. The last column compares the highest computed value with the NIOSH value of 183 mrem per day per badge cycle. The NIOSH value is lower in most cases. The computed value is more than 50% higher than the NIOSH value in 4 out of 12 cases.

Table 3 shows similar calculations as that in Table 2, except that it relates to Building 91. In this case the average badge cycle duration has been used for simplicity, since the variation in badge cycle durations is not great in most cases. The NIOSH value of 183 millirem per badge cycle is generally greater than the computed 95th percentile value. This is because the value is derived from the entire re-reading of zero doses for all buildings. The number of NTA badges actually issued in the 1959–1969 period was dominated by Building 71, where the daily dose rates among the workers with higher exposure were generally higher than the counterparts in other buildings. Hence a 95th percentile value based on the entire database would tend to be dominated by Building 71 and yield values higher than the Building-specific 95th percentile for the other buildings (all other things being equal, and assuming the methods are valid).

Table 3: 95th Percentile Values for Daily Neutron Dose, Building 91, 1959–1969

Year	Average days per cycle	Range, days/cycle	95th dose (mrem) per day	95th dose (mrem) per average cycle	[95th dose (mrem per average cycle]/183 mrem
1959	30.79	21 to 36	4.13	127	0.69
1960	30.06	27 to 35	2.79	84	0.46
1961	29.77	27 to 36	6.28	187	1.02
1962	30.14	27 to 35	8.64	260	1.42
1963	30.33	21 to 42	4.69	142	0.78
1964	31.34	21 to 42	5.93	186	1.02
1965	30.75	28 to 39	5.93	182	1.00
1966	29.85	28 to 31	4.54	136	0.74
1967	N/A	N/A	N/A	N/A	N/A
1968	30.05	28 to 32	2.94	88	0.48
1969	28.50	25 to 29	5.64	161	0.88
1959-69:		21 to 42			

The above SC&A analysis is based on all matched-pair neutron badge re-readings, rather than only on the re-readings of zero data. The NIOSH value of 183 mrem per day is based on the re-reading results of only those badges that originally showed zero readings (see Attachment 3). SC&A was not able to reproduce the 183 mrem/badge cycle figure since the precise database from which it was derived was not available to SC&A. The 95th percentile value obtained by SC&A based on matched pair data was about 217 mrem per badge cycle. The difference is likely attributable to the fact that NIOSH used measurements only from the re-read badges that were originally recorded as zero.

Finally, the use of a dataset defined by all neutron doses that were originally recorded as zero over the entire 1959–1969 period in order to determine a 95th percentile value is not scientifically appropriate. The problem arises from the fact that a number of the original zeros are from the 1967–1969 period, when many or most neutron badges were not read. As is discussed in Section 5.2 below, a value of dose computed from photon dose multiplied by a neutron-to-photon ratio between zero and 1 was used in cases where the NTA film was not read. The NDRP database does not distinguish between zeros that were actual original readings of NTA film from the computed values. In those cases where the photon dose was zero to 9 mrem, a zero neutron dose was recorded. These recorded neutron zero are not comparable to the zero readings. As a result, the set of originally recorded zero readings does not actually represent the workers with actual zero original readings. Nor would the application of the resultant 183 mrem per badge cycle to every recorded zero be replacing an original zero reading in many cases in the 1967–1970 period. A dose rate determined from all annual re-read data by building and by year would be more appropriate.

Finding regarding zero original recorded doses where badges were not re-read: The 95th percentile value of dose rate of 183 mrem/day in Table III.B.1 is in error. NIOSH has stated that the value should be changed to 183 mrem per badge cycle (see Attachment 3). A value of 183 mrem per badge cycle would be more than the building-specific 95th percentile values in most cases for buildings other than Building 71. But for Building 71, it is less than the building-specific 95th percentile value in most years. The NIOSH approach of using only the re-read values of all neutron doses originally recorded as zero for all years together is not appropriate since many of the original zeros do not reflect actual neutron measurements in the 1967–1970 period.

5.2 CORRECTION FACTORS FOR NON-ZERO ORIGINAL READINGS[18]

For doses that had non-zero original recorded doses, NIOSH has proposed to apply a 95th percentile value of all correction factors over all years to the original dose. This value is shown in Table III.B.2 and is 6.950 (NIOSH 2007, p. 22). This is based on all non-zero re-read doses for all years. NIOSH's explanation for the choice was as follows:

> *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.* [NIOSH 2007, p. 21]

In its April 30, 2007, report, SC&A analyzed the correction factors for the badges that were not re-read that had non-zero original recorded dose for 3 years, 1959, 1965, and 1969 (SC&A 2007a, pp. 48–53). Only the workers who were affected by the problem—that is, only workers who actually had non-re-read original doses that were not zero—were included in the analysis. A detailed example table was presented for 1959 (Table 8, SC&A 2007a, p. 50). It is reproduced here for convenience as Table 4.

[18] For the purposes of this section, we accept the re-read dose as the correct dose. There were many quality checks in the NDRP re-reading process, but there were some issues as well, which were discussed in SC&A's April 30, 2007, report (SC&A 2007a).

Table 4. Original and Re-read Neutron Doses, and Ratio of Re-read to Original, 1959

Original NeutronDose	Non-Replaced OriginalNeutronDose	Affected Orig dose	NDRP Neutron Dose	NDRP/Affected
120	80	40	652	16.30
120	40	80	1101	13.76
160	80	80	674	8.43
147	80	67	523	7.81
760	160	600	4219	7.03
1119	120	999	4227	4.23
1146	187	959	4051	4.22
240	40	200	705	3.53
600	360	240	763	3.18
360	40	320	1010	3.16
2362	160	2202	5415	2.46
520	200	320	548	1.71
5867	267	5600	8756	1.56
200	200	0		
160	160	0	579	
160	160	0	786	
120	120	0	568	
80	80	0	799	
80	80	0		
40	40	0	628	
40	40	0	632	
40	40	0	602	

Data taken from: O-drive - AB Doc - Rocky Flats - NDRP - Copy of NDRP_BE_20070319 - *tblNDRPData*
Source: SC&A 2007a, Table 8.

This table is important because it demonstrates that the correction factor of 6.95 that NIOSH has selected may not be claimant favorable for many workers. It presents the actual data for the 13 workers who had original film badge readings that were greater than zero and then the badges were reread. For example, for the first person (i.e., the first row in Table 4), the neutron dose that was originally measured for this worker for the badges that were recovered was 40 mrem. Column 2 represents value of dose on the original badges that were not found or not re-read for some other reason. Column 4 presents the results of the re-read of the film badges that were available for re-reading for this worker. The re-read neutron dose was 652 mrem. Hence, the ratio of the re-read-to-original neutron dose on the re-read badges for this worker in this year is 16.3 (i.e., the value in column 5). The implications of this table are that for 5 of the 13 workers that comprise the population or workers in 1959 that had positive original film badge readings and that were reread, the ratio of 6.95 would not be bounding if the badges that were not recovered were representative of the ones that were recovered. In order to develop a valid correction factor, a statistical analysis would be necessary that would require a characterization of the badge reading protocols of the time and how they evolved.

SC&A's analysis of data for 1959, 1965, and 1969 was presented in its April 30, 2007, report. It showed that the empirical lognormal 95th percentile values for the correction ratios found for these 3 years *for the workers affected by the problem of non-re-read badges* were much higher than the overall 95th percentile value computed by NIOSH cited above. SC&A has now extended this analysis to the entire 1959-1970 period. The results are shown in Table 5. It is to be noted that the 95th percentile values of the correction factor are highly variable by year. Furthermore, the number of affected workers goes up dramatically from none or a few dozen up to and including 1965, to several hundred in the 1966 to 1970 period. When the workers affected by non-re-read zero badges are taken into account, the total number of affected employees in 1969 rises to 605, and in 1970 to 1,735.

Table 5. 95th Percentile Values for Individual Correction Factors for Non-Zero, Re-Read Neutron Badges, Affected Workers Only

Year	Correction ratio, 95th percentile value (Note 1, except 1964)	Range of correction factors, all affected workers	r^2 for linear regression of correction factor with re-read dose	Comments and number of affected workers (Note 3)
1959	15.5	1.6 to 16.3	r^2 = 0.16;	Slight negative correlation; 13 workers
1960	N/A	N/A	N/A	No affected workers
1961	7.7	N/A	N/A	One worker only
1962	13.4	0.5 to 18.6	r^2 = 0.004	No correlation, 19 workers; three original readings > re-read.
1963	4.5	1.1 to 15.3	r^2 = 0.09	Slight negative correlation. 87 workers.
1964	8.4 (Note 2)	1.7 to 13.3	See comment	Only three workers affected
1965	19.4	1.88 to 40.42	r^2 = 0.14	Slight negative correlation; 30 workers
1966	2.7	0.7 to 5.4	r^2 = 0.37	Moderate negative correlation. Most correction factors less than 2.0. Affected workers = 211
1967	4.1	0.4 to 48	r^2 = 0.00	No correlation. 95th percentile affected by a single large ratio; omitting this, it yields a 95th percentile of 3.0. Affected workers = 66. Spread in correction factors of over 2 orders of magnitude.
1968	7.6	0.4 to 40	r^2 = 0.03	Almost no correlation. 434 workers. Spread in correction factors of 2 orders of magnitude.
1969	22.0	0.5 to 221	r^2 = 0.01	Essentially no correlation; 438 workers. Spread in correction factors of over 2 orders of magnitude.
1970	16.7	0.22 to 61	r^2 = 0.018	Essentially no correlation. 489 workers. Spread in correction factors of over 2 orders of magnitude.

Note 1: Empirical lognormal 95th percentile value. Values rounded to one decimal place, except as indicated.
Note 2: Simple arithmetic mean.
Note 3: Number of affected workers = number of workers with some non-zero original dose that was not re-read. Correlation refers to that between correction factors (re-read/corresponding original) and re-read neutron dose.

The annual figures for the numbers of affected workers, along with the cumulative doses in each category, were given in Table 7 of SC&A 2007a. That table is reproduced below for convenience as Table 6.

Table 6. Non-replaced Original Neutron Dose

Year	Total #annual Entries	Total # of workers w/NonReplaced OrigNeutronDose	Total OrigNeutron Dose [1]	Total NonReplaced OrigNeutronDose	Total NDRP Neutron Dose reread	Orig dose affected by NDRP	NDRP reread/ affected orig	Ratio of NonReplaced to OrigNeutronDose Orig.
1959	819	22	14,441	2,734	37,238	11,707	3.18	***0.19***
1960	1087	1	40	40	4,344	0		***1.00***
1961	1407	2	187	107	1,891	80	23.64	***0.57***
1962	1695	64	58,648	47,618	30,167	11,030	2.73	***0.81***
1963	1804	88	165,302	18,067	268,499	147,235	1.82	***0.11***
1964	1959	4	1,049	328	7,344	721	10.19	***0.31***
1965	1929	30	4,306	747	21,099	3,559	5.93	***0.17***
1966	1981	234	134,911	18,164	196,278	116,747	1.68	***0.13***
1967	1858	69	91,800	16,140	87,024	75,660	1.15	***0.18***
1968	2046	451	293,738	55,440	504,354	238,298	2.12	***0.19***
1969	2322	605	166,126	48,877	386,937	117,249	3.30	***0.29***
1970	2098	1735	303,923	185,605	352,886	118,318	2.98	***0.61***

[1] - The "total original dose" includes only the total dose for the workers who had some part of their original dose that was not re-read.
Source of data: O-drive - AB Doc - Rocky Flats - NDRP - Copy of NDRP_BE_20070319 - *tblNDRPData*
Source: SC&A 2007a, Table 7, p. 49.

The NIOSH 95th percentile value of the correction factor is estimated from all re-read badges for all years. There are two assumptions implicit in this aggregation:

(1) The source of the reading errors is the same throughout the 1959–1970 period.

(2) The population of the workers affected by non-re-reading of badges each year is (statistically) the same as that for whom badges were found and re-read throughout the period.

In other words, the data can be aggregated in the manner done by NIOSH *only if the overall distribution of all re-read badges with original non-zero dose is substantially the same as the annual distributions for the non-re-read badges with non-zero dose.* The following factors need to be analyzed to determine whether this hypothesis is correct:

- Did the badge reading practices change over the years? Did the initiation of a review of neutron badge reading practices in 1966 and the start of new norms regarding which badges would be read affect the correction factors?
- Were there likely sources of systematic error in badge reading within any given year?
- Did the estimation of neutron doses for many workers by area n/p ratios and photon doses affect the eventual result regarding correction factors?
- Did the non-archiving of neutron badges in 1969 and 1970 affect the correction ratios?

These are complex questions. We will consider each in turn.

5.2.1 Badge Reading Practices

Badge reading practices changed several times in the period. The table below, reproduced from the NDRP report, shows that there were several changes between 1959 and 1967, in terms of the area of the badges that were read, the protocol for determining the area to be read, and the value(s) used for dose per track per square millimeter of badge area.

Table 3.1 History of NTA Film Evaluation Methods

	1958–1959	1960	1961	1962	1963	1964	1965	1966	1967–1970
Area	1 mm^2 3 mm^2	1 mm^2 3 mm^2	1 mm^2 3 mm^2	1 mm^2 3 mm^2 10 mm^2	10 mm^2	10 mm^2	10 mm^2	10 mm^2	10 mm^2
Positive	> 2 x Blank	> 2 x Blank	> 1.5 x Blank	> Blank + 1.65 x sqr(Blank)	> Blank + 1.65 x sqr(Blank)	> 2 x Blank	> 2 x Blank All	All	> Blank
CF (mrem/track/mm^2)	40	40	40	40 100	100	100 70	70 40	110	Custom

Source: ORISE 2005, p. 4.

The result of the shift to reading 10 mm^2 of area for all badges in 1963 can be seen in Table 4 above and in Attachment 2, which shows all the correction factors for the affected workers for that year. In the years 1959 to 1962, most of the correction factors of the affected individuals[19] were greater than 2, while in 1963, over 50% of them were less than 2. The 95th percentile value of the correction factor dropped from 15.5 and 13.4 respectively in 1959 and 1962 (the 2 years for which an there were sufficient affected workers to compute a 95th percentile) to only 4.5 (which is less than NIOSH's 95th percentile value of 6.95 for the entire 1959–1970 period).

In 1964, only three workers were affected by the problem of non-reading of original badges. However, it is clear that the correction factors rose again in 1965, despite continuation of the 1963 protocol of reading 10 mm^2 square of the badge data. The statements of Roger Falk,[20] the principal scientist who worked on the NDRP and who was responsible for review of the neutron badge reading program in 1966, throw considerable light on this change. By the time the review was initiated, the quality of the badge reading had again deteriorated, but this time it was not because of the small area of the reading, but because the amount of work – presumably related to a combination of the new reading protocol instituted in 1963 and the larger number of badges

[19] The term "affected individuals" in this context refers to those workers who (1) were issued badges that were not re-read as part of the NDRP and (2) had non-zero neutron readings entered in their dose records at the time of the original data entry.

[20] The statements in question were made during interviews with Roger Falk when he was an ORAU site expert, working in his capacity as a government contractor. The interviews are documented in SC&A 2007a.

issued – overwhelmed the staff available to do the reading. The changes instituted in 1967 as a result of the review were discussed by SC&A and NIOSH in a conference call on April 17, 2007:

> ***Roger [Falk]:* …** *All the film badges prior to 1967 were read at the time that the badges were handed in. Then in 1967, one of the issues was that the* ***dosimetry technicians were overwhelmed by the number of films that they were expected to read. The answer to that problem determined then was that if we are going to do a quality read, then we can't read that many films. So we had to determine which workers were at risk and do a quality read on those films. For the rest, the assigned neutron dose was based on the gamma dose.*** *When the NDRP project found films [that were not read at the time], we read all of them. So the NDRP project now has a film-read dose that replaces the notional doses assigned in real time [in the 1967–1970 period].* [SC&A 2007a, Attachment 3, pp. 77–78, emphasis added]

In light of the fact that the technicians were "overwhelmed" with the laborious job of neutron badge reading, it is reasonable to assume that the increase in the correction factor (indicating an increase in the errors in the original reading) was in large measure due to this problem. Note that in the year of the review itself, 1966, the quality of the original reading, as indicated by the correction factors, was much better than in 1965. The subsequent year also had a 95th percentile correction factor of less than 5, which is also less than NIOSH's 95th percentile for the entire period. SC&A notes that the number of badges that were not re-read (most of which were presumably not found) took a sudden (unexplained) jump from 30 in 1965 to 234 in 1966, the year the review was initiated, and fell back in 1967 to 69 (see Table 6 above).

Both the number of affected workers and the 95th percentile value of the correction factor increased again in the 1968–1970 period. There is a persuasive explanation for the changes in 1969 and 1970; it may also extend to a part of 1968 (see Sections 5.2.3 and 5.2.4 below).

5.2.2 Intra-year Source of Systematic Error

The process of re-reading the neutron badges during the NDRP showed that systematic reading errors were specific to individuals and to the experience of individuals:

> *It became apparent that, over time and under time pressure, the normalized reads tended to be generally lower than would be obtained by best practice. It was observed that reads by some individuals over some time periods appeared to be on average lower or higher than reads by other individuals. The amount by which reads tend to be lower (or higher) depended on the particular reader and the stage of that particular reader's training and production experience.* [ORISE 2005, p. 28]

In view of the fact there were large, individual-dependent errors in a project where the readers' quality was being checked constantly and, except for the principal reader, independently, it is likely that individuals reading the badges under much less rigorous conditions would have introduced systematic errors that were very different from one another. These intra-year errors would be expected to be greater at the time that only a small area of the badge was being read (1959–1962), compared to later years, all other things being equal. This is reflected in the higher correction factors for 1959 and 1962 than for 1963–1967 (See Table 3 above), except 1965, when the workers were "overwhelmed" with a very high workload.

The experience of the NDRP indicates that there were likely to have been individual-dependent reading errors throughout the 1959–1970 period. For such errors, correction factors for individual readers would be the most appropriate. Of course, it is not now possible to develop such correction factors for non-re-read badges.

The many changes in badge reading protocol over time and the likelihood of *different* systematic individual errors in badge reading argue against pooling of the correction factors from various years. This may also be a partial explanation for the general lack of a strong negative correlation between the correction factors and the original dose reading.[21]

5.2.3 Estimated Dose Entries versus Original Dose Readings

When it was decided not to read all neutron badges starting in 1967, area neutron to photon ratios were estimated and were used together with workers' photon doses to estimate the neutron dose. The area neutron and photon surveys were not archived – that is the data are not available today and were not available to the NDRP. The fact that calculated doses and actual readings are now mixed up in the NDRP dose records is a critical factor in evaluating the problem of determining correction factors for the 1967–1970 period. This makes the data in the NDRP files during the 1967–1970 period fundamentally different from the prior era. In light of this, we quote the April 17, 2007 exchange with Roger Falk on this topic at length:[22]

> ***Arjun [Makhijani]:*** *So the column that says "original dose" in the data is not the badge reading?*
>
> ***Roger [Falk]:*** *It could be the reading or it could be the notional dose that was assigned.* ***You can't distinguish which type from that report. You would need to go to the original dosimetry worksheet to discern that.***
>
> ***Ron [Buchanan]:*** *So, we had the original reading that was the dose of record. And you did not re-read that in 1967; you filled the gaps with notional dose in 1967. And you added that to the originally read dose and the total appeared as the "original dose?"*
>
> ***Roger:*** *I am not sure I followed that. Basically at the time (starting in 1967), we determined which of the neutron films would be read and which workers would be*

[21] The correlation coefficients between the correction factors and the re-read values of neutron dose are similar to those for the correction factors and the original dose. The former are shown in Table 3. One would normally expect larger errors when the total number of tracks (and hence total dose) was small – that is the errors should be somewhat negatively correlated with the badge reading.

[22] All personnel identified in the following quote – Arjun Makhijani, Roger Falk, and Ron Buchanan – made the statements cited in their capacity as government contractors (SC&A, ORAU, and SC&A, respectively). The interview is documented in SC&A 2007a.

assigned the neutron dose. It [the decision to read a worker's neutron film] was based on where the worker was actually working and on the worker's gamma dose. We tried to do a quality read for those workers who were truly at risk, and then assign a neutron dose to workers who were at lesser risk [whose badges were not evaluated].

Arjun: *So it was sort of like the 1969 policy for gamma dose, when it was decided not to read some badges of workers who were thought to be at lesser risk?*

Roger: *That is correct, except that a neutron dose was assigned to the worker at that time.*

Ron: *I am talking about original dose from 1952 to 1966. The "original dose" in those years was partly a notional dose?*

Roger: *No. All the film badges prior to 1967 were read at the time that the badges were handed in. Then in 1967, one of the issues was that the dosimetry technicians were overwhelmed by the number of films that they were expected to read. The answer to that problem determined then was that if we are going to do a quality read, then we can't read that many films. So we had to determine which workers were at risk and do a quality read on those films. For the rest, the assigned neutron dose was based on the gamma dose.* ***When the NDRP project found films [that were not read at the time], we read all of them.*** *So the NDRP project now has a film-read dose that replaces the notional doses assigned in real time [in the 1967–1970 period].*

Ron: *So the 1952–1966 original doses that are listed were all original readings and they [the non-affected neutron doses] were not changed.*

Roger: *Right.*

Ron: Then in 1967, you read films of workers at high risk carefully and the rest were assigned n/p ratio-derived doses and that is the original dose that appears in the record.

Roger: Yes.

Ron: *Was it that some workers had none of the badges read during a year or was it that their badges were read in some quarters and not in others?*

Roger: *It was based on where they worked and the magnitude of their gamma dose for each exchange period. We also tracked the process operators who were working in the high-neutron (fluorinator) areas during that exchange period and read their neutron film regardless of what their gamma dose was. For workers who were not assigned to high-neutron areas, the reading of their film was not*

> *done unless their gamma was over a pre-determined level.* ***Otherwise, they were assigned neutron dose based on gamma doses [and n/p ratios]. This data was not archived.***
>
> ***Ron:*** *So the same workers would have some assigned and some measured doses in any year?*
>
> ***Roger:*** *It could change month by month, for example, if they were on a monthly cycle. And if their gamma dose was above a certain level, their NTA film was read.*
>
> ***Brant [Ulsh]:*** *What happened in the NDRP for the film badges that were not read at that time?*
>
> ***Roger: The neutron films that were not read at that time [and were archived] were read in the NDRP.***
>
> ***Ron:*** *How was the notional dose calculated at that time?*
>
> ***Roger:*** *It [the neutron:gamma ratio] was based on building surveys that we had at the time. It was based on a composite survey of the buildings at the time, rather than the NDRP approach. It was based on n/p ratios determined from neutron and photon (gamma) surveys of the work areas.* [SC&A 2007a, Attachment 3, pp. 77–78, Emphasis added]

Hence, according to the lead scientist of the NDRP, Roger Falk,[23] the NDRP data for the 1967–1970 period that are labeled as "original" readings are not all actual badge readings. Some of them are actual readings, while the rest are doses that were calculated at the time from n/p ratios determined by area photon and neutron surveys. This means that the "original readings" contain two very different kinds of numbers that are likely to be from different distributions. For those badges that were found and re-read, the comparison to the "affected original" readings should therefore take into account the difference between these two kinds of "readings."

The increase in the range of correction factors from the 1959–1966 period to the 1967 period is likely due largely to the mixture of the two types of numbers that are in the original neutron data. A history of Rocky Flats dosimetry, written in or after 1989, reproduces the protocol that was used to assign neutron dose when the badge was not read. It is reproduced below in Figure 1. It shows that a constant n/p ratio of 0.5 was applied to all gamma doses greater than or equal to 20 mrem. For doses between 10 and 20 mrem, a dose of 10 mrem was assigned, with an implicit n/p ratio between 0.5 and 1. Otherwise the neutron dose was recorded as zero. This was done for each badge cycle when the neutron film was not read. In other words, the n/p ratio used was between 0 and 1, depending on gamma dose. Given that individual gamma badge readings are not well correlated with neutron dose, the use of a constant n/p ratio for photon doses over 20 mrem would likely result estimated doses that would have large errors that would, moreover, be

[23] Roger Falk made the statement referred to here in his capacity as government contractor (ORAU). The interview is documented in SC&A 2007a.

relatively unconnected with the neutron badge reading. This provides the explanation for the huge range of correction factors in each in year in the 1967–1970 period: it spans two orders of magnitude or more in each year and covers three orders of magnitude over the entire period. The ranges of correction factors in the 1967–1970 period are about 3 to 10 times greater than those found in the 1959–1966 period. Given the lack of correlation between individual gamma and neutron badge readings, an examination of the original dosimetry worksheets will likely reveal that the correction factors of those badges that were actually read originally had a smaller spread than those re-reading values that were compared to original doses that were calculated using an n/p ratio between 0 and 1.

PERSONNEL DOSIMETRY
(From R.B. Falk notebook, March 12,1971)'

A. Procedures for Assignment of Neutron Dose

1. A neutron dose is assigned when a neutron film is issued but is not evaluated with the microscope.

2. All neutron film is microscopically evaluated for persons with a gamma dose greater or equal to 200 mrem. If the film readout yields a neutron dose less than
50 mrem, a minimum dose of 50 mrem will be assigned.

3. For film not read, the neutron dose assigned is one-half the gamma dose for gamma dose ≥ 20 mr.

a. For gamma doses in the range of 10 to 19, the assigned neutron dose is 10 mrem.

b. For gamma doses in the range of 0 to 9, the assigned neutron dose is 0 mrem.

4. Neutron film for persons known to be working in high-neutron areas will be evaluated microscopically.

Figure 1. Neutron Dose Assignment Protocol
Source: Inkret, no date, p. 3 (pdf file page 7)

It should also be noted that the range of n/p ratios of 0 to 1 is much lower than was determined for average building-by-building n/p ratios in most cases during the NDRP. This provides a likely explanation for the large number of high correction factors (>10) in the 1968–1970 period, with more than 80 cases each in 1969 and 1970. This point is also relevant to the analysis in Section 5.1 above, as noted there.

For the neutron badges that were recovered, the re-reading can be treated as a correct dose (apart from questions associated with the independent verification of the principal reader—see Section 6 below, which affects policy related to the entire neutron badge re-reading project). For 1967–1970 neutron badges that were not found, the original dose that was not an actual reading but calculated from an n/p ratio cannot be corrected by any application of a correction factor, since these factors are not correlated or connected to the neutron dose that was on the original badge in a way that can now be determined.

Further, according to Roger Falk's statement on April 17, 2007,[24] the area neutron and photon surveys were not archived. This means that the data from which the n/p ratio range of 0 to 1 was calculated are missing. It may be possible to come up with other means of developing correction factors for the original dose values that were estimated, for instance, by compiling a data base for all such values where the badges were found and examining the re-reading results by building and job type. However, this would be a non-trivial job, since it would require going into the original dosimetry logs for ~2,000 workers and creating a badge-cycle-by-badge cycle database.

As things stand, there is a data integrity problem in the NDRP database for the 1967–1970 period that undercuts its utility in determining correction factors for neutron doses for that period for workers whose badges were not re-read. The "original" dose database contains two very different types of numbers that need to be separated and studied before any scientifically supportable statements can be made about potential corrections. It is to be noted that in its April 30, 2007 report, SC&A noted that among the years it analyzed (1959, 1965, and 1969) it concluded that it appeared difficult to assign a scientifically supportable correction factor for 1969 and that a preliminary analysis indicated that the same might be true of 1970. SC&A is now extending that conclusion to the 1967–1970 period, due to the reasons discussed above.

5.2.4 Non-Archiving of Badges, 1969 and 1970

The matter of estimating correction factors for 1969 and 1970 is further complicated by the fact that many of the badges were not archived. This practice started in 1969, according to Roger Falk, who also stated that it was related to the impending change from NTA film to TLD (SC&A 2007a, p. 79). However, since that change took place in 1971, it is unclear why the 1969 and 1970 badges were not archived. Further, when the TLD came into use in 1971, the glow curves were also not archived (SC&A 2007a, p. 79). SC&A has not investigated the issue of the non-archiving of neutron dose data from a certain point onward in the later 1960s. Given that the number of workers whose badges were not re-read for some reason in the NDRP took a leap upward in 1968 (see Table 6 above), it is possible that the policy of not archiving neutron badges was actually started some time in 1968.

The lack of archiving increased the scale of the problem of non-re-read badges from 1967 to the 1969–1970 period, and possibly 1968 as well. By 1970, the number of affected workers had risen to 1,735 (including zero and non-zero original readings). For comparison, the number of affected workers in the 1959–1965 period was less than 100 in all cases, and a few dozen or less in most of those years. As noted above, it is unclear why it went up to 234 workers in 1966, the year that the internal review of neutron dose reading appears to have been initiated.

The magnitude of the problem in the 1968–1970 period of the non-reading of badges is far greater than that in the earlier period, when a smaller number of workers is affected, except 1966, when the quality of reading was better than in most other years for the badges that were recovered.

---

[24] Roger Falk made the statement referred to here in his capacity as government contractor (ORAU). The interview is documented in SC&A 2007a.

Findings regarding correction factors for non-zero original readings:

(1) **A uniform correction factor applied to all years and all workers affected by the problem of non-re-read badges, as suggested by NIOSH, is not supported by the data or an evaluation of the badge-reading, archiving, and other practices relating to neutron dose reading and estimation in the 1959–1970 period.**

(2) **The reading of neutron badges in the pre-1963 period involved significant errors due to the technical limitations of the reading protocol, notably the small area of the badge that was read. Some of the underlying reasons for these errors are different from those that affected later differences between the re-read value of dose and the originally recorded value of dose. Empirical lognormal 95th percentile values of correction factors for the re-read doses of the affected workers for 1959 and 1962 are significantly higher than the 95th percentile value of 6.95 proposed by NIOSH.**

(3) **The correction factors for 1965 are higher than other early years, possibly due to the workers being "overwhelmed" by the neutron badge reading workload.[25] The empirical lognormal 95th percentile correction factor (19.4) for the re-read doses of the affected workers is much higher than the 95th percentile value of 6.95 proposed by NIOSH. (The high 95th percentile values for correction factors in 1969 and 1970 are covered in the next two findings.)**

(4) **Scientifically defensible correction factors for the 1967–1970 period cannot be developed from the NDRP database for the non-re-read portions of worker neutron dose records. The original neutron dose readings in this period in the NDRP database and the workers' DOE neutron dose files consist of two fundamentally different kinds of data: (1) values of dose that were read from the badges and (2) doses calculated from area n/p ratios. The area measurements were not archived. The ratios or 0 to 1 that were used would produce underestimates, in some cases serious underestimates of neutron dose. A great deal of work would be needed to go back to the dosimetry log sheets to separate the calculated from the original measured doses. This work is essential to determine whether and how correction factors that meet the test of scientific reasonableness for this period can be developed.**

(5) **The number of workers who are affected by the non-re-read of doses (including zero doses) increased greatly in 1968 and continued increasing through 1969 and 1970. This was likely due to non-archiving of data in 1969 and 1970. The reason for the jump in 1968 is unknown at the present time. As many as 1,735 workers were affected in 1970.**

[25] The characterization is that of Roger Falk (SC&A 2007a, Attachment 3).

6.0 THE NEW NIOSH APPROACH TO ESTIMATING DOSE FOR UNMONITORED WORKERS

6.1 NEUTRON DOSE ESTIMATES FOR UNMONITORED WORKERS

In view of the objections to the method of using n/p ratios, NIOSH has proposed a different method to estimate neutron dose for periods when workers were not issued neutron badges. NIOSH has described the new method as follows:

> *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.* [NIOSH 2007, p. 24]

A part of NIOSH's argument that the badge data could be used in the way suggested above is that the badged workers were the ones with high exposure potential:

> *The badging policy in place during 1959–1970 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.*

The issue of the correctness of the judgment of Rocky Flats personnel in relation to who was at risk of neutron exposure was the topic of considerable discussion in the course of the review of the Rocky Flats Evaluation Report. NIOSH initially acknowledged that that judgment may have been in error but then retracted that acknowledgement later on. SC&A has concluded that a significant misjudgment did take place as reflected in the failure to monitor workers in Building 71 in the early years. It is also likely that some of the workers with high exposure potential were not monitored in the 1959–1964 period. We discuss each of these points below.

The history of Rocky Flats by Ed Putzier, written in 1982, is quite clear regarding the early misjudgment of the health physics management in not monitoring Building 71 workers:

> *At the time I was interviewed [1952], I was told by the person* ***who was eventually to be our director that handling plutonium was only an alpha radiation problem.*** *By the time I reported for work [mid-1952], his technical advisor had found out different and the person in charge of radiation dosimetry had obtained a stack of Oak Ridge-type badges….For workers in Building 991, a piece of NTA (nuclear track) film was added since some of the NDT operations did involve some generation of neutrons…from a gamma neutron reaction and not that they were handling plutonium, which gave off neutron radiation also.*
>
> …
>
> *Early neutron and gamma dose evaluation for Building 991 personnel was done by readout of the NTA film at Los Alamos….By early 1956, we had our own equipment and convinced our management that we did indeed have measurable quantities of neutrons associated with plutonium operations. And by 1956, Building 771 personnel were monitored for neutrons.* Putzier 1982, p. 34 of the pdf file, emphasis added][26]

It appears that the operational failure may have been at the management level, rather than in the field since the technical advisor was aware early of the neutron exposure potential of plutonium. However, that it took 4 years to actually get some neutron monitoring into place in Building 771 indicates that gaps between health physics technical understanding and actual monitoring practice could and did exist. Hence, while the intent may have been to monitor personnel with exposure potential for more than 10% of the dose limits, the practice may have been, and sometimes apparently was, short of this precept. SC&A has also shown in other contexts that the non-reading of badges where workers were thought to be at relatively low risk did not correspond to the 10% guideline (and may not have been intended to correspond to that guideline) and that such practices may have been put in place due to resource considerations.

In the specific case of neutrons, the increase in the area of the badges that was to be read was put in place as a correction for the errors caused by reading too small an area in earlier years. But when the larger area to be read was combined with a larger number of badges (~1965) the technicians were "overwhelmed" with the amount of reading work. Instead of increasing the number of technicians, the number of badges to be read was decreased and an estimated dose was entered into the record. Likewise, a similar policy was adopted with regard to beta-gamma badges in 1969, when large numbers of badges that were issued were not read (SC&A 2007).

[26] Very little of the Building 771 data prior to late 1958 is available.

It is not the purpose of the above to analyze the cause of the problems in monitoring coverage, but simply to point out the existence of some important gaps and to analyze their implications for the SEC evaluation process. The issue in the present context is whether the gaps involved workers with a high exposure potential in the 1959–1970 period and whether some of these workers had higher exposure potential than workers who were monitored.

NIOSH continues to claim that the doses estimated by the NDRP are claimant favorable. For NIOSH therefore, the fact that some NDRP notional doses are greater than the highest dose measurements is not to be taken as an indication that the highest exposed workers may not have been monitored. SC&A has reviewed NIOSH's analysis in Table III.B.3 (NIOSH 2007) and concluded that the *systematic* choice of workers with high gamma doses to estimate the n/p ratios biases the results in favor of showing that the n/p ratio method is claimant favorable. The test in Table III.B.3 does not indicate anything about the general nature of the results as it relates to applying Building average n/p ratios to estimate neutron dose.

By contrast, SC&A used a random selection of cases in its investigation. The analysis is presented in SC&A 2007a, Section 8. Overall, that preliminary analysis indicated that n/p ratios may yield underestimates of the actual dose in many (but not all) cases, though it would sometimes yield best estimate results and at other times it would yield overestimates. Further analysis has confirmed this preliminary conclusion.

We arranged annual total gamma and neutron doses derived for all paired data by worker and by year. We used the NDRP Building n/p ratios to estimate doses and then compared the estimated results to the actual measured dose. The results generally indicated that in a large proportion of cases, sometimes somewhat less than half and sometimes more than half, the estimated dose was less than the measured dose, sometimes considerably less than measured dose, even when gamma doses were not originally recorded as zero.[27] In the balance of cases, the estimated dose was slightly to greatly higher than the measured dose. Table 7 shows some examples of overestimates and underestimates for Building 71 for 1964. About two-thirds of the estimated doses were less than the measured doses.

Table 7. Some Examples of Underestimates and Overestimates using the NDRP n/p ratio =3.1, Building 71, 1964, mrem and Ratio

Gamma dose	Measured neutron dose	Notional neutron dose	Ratio, notional/measured
1849	3833	5732	1.50
1657	3445	5137	1.49
1509	3147	4678	1.49
1434	2991	4445	1.49
1309	2756	4058	1.47
792	1687	2455	1.46
927	1978	2874	1.45
1614	3453	5003	1.45
1240	2659	3844	1.45

[27] These recorded gamma doses were replaced by 1mrem in the NDRP.

Table 7. Some Examples of Underestimates and Overestimates using the NDRP n/p ratio =3.1, Building 71, 1964, mrem and Ratio

Gamma dose	Measured neutron dose	Notional neutron dose	Ratio, notional/measured
33	71	102	1.44
547	2632	1696	0.64
339	1632	1051	0.64
11	53	34	0.64
304	1468	942	0.64
238	1154	738	0.64
268	1300	831	0.64
629	3067	1950	0.64
162	794	502	0.63
913	4521	2830	0.63

Note: Measured dose is the dose as re-read by the NDRP.

It can be seen from Table 7 that (1) the low estimates of notional dose tend to be associated in this case with lower gamma doses, and (2) that the measured neutron doses are not so different, averaging about 2600 mrem in the cases where the notional dose is an overestimate and 1,847 where it is an underestimate.

NIOSH has stated that the Board and SC&A should not reject the use of n/p ratios and also use them to make judgments about monitoring practices:

> *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.* [NIOSH 2007, p. 23]

SC&A does not agree with this conclusion. SC&A has shown that the n/p ratio method sometimes gives overestimates and sometimes underestimates. The frequency of underestimates is quite large, sometimes ~50% or more; sometimes less. This is to be expected since the method uses a building average n/p ratio. This shows two things:

(1) The n/p ratio method in the NDRP does not systematically yield a claimant favorable method as claimed by NIOSH.

(2) Since the n/p ratio often underestimates the measured dose, it is likely that some of the NDRP notional dose estimates (but not all) among the workers with 100% notional dose would be underestimates.

From the second conclusion we can further deduce that *if there are many notional doses that are all higher than the highest measured doses*[28]*, at least some of the workers who had among the highest exposure potentials were not monitored.*

For 1965 and later years, the highest neutron doses were generally the measured ones, with small exceptions. This indicates that the problem of non-monitoring of some workers at high risk of exposure was likely confined to the 1959–1964 period.[29] The charts for 1959–1965 were provided in SC&A 2007a. Figures 2 though 5 show the corresponding charts for 1966 through 1969.

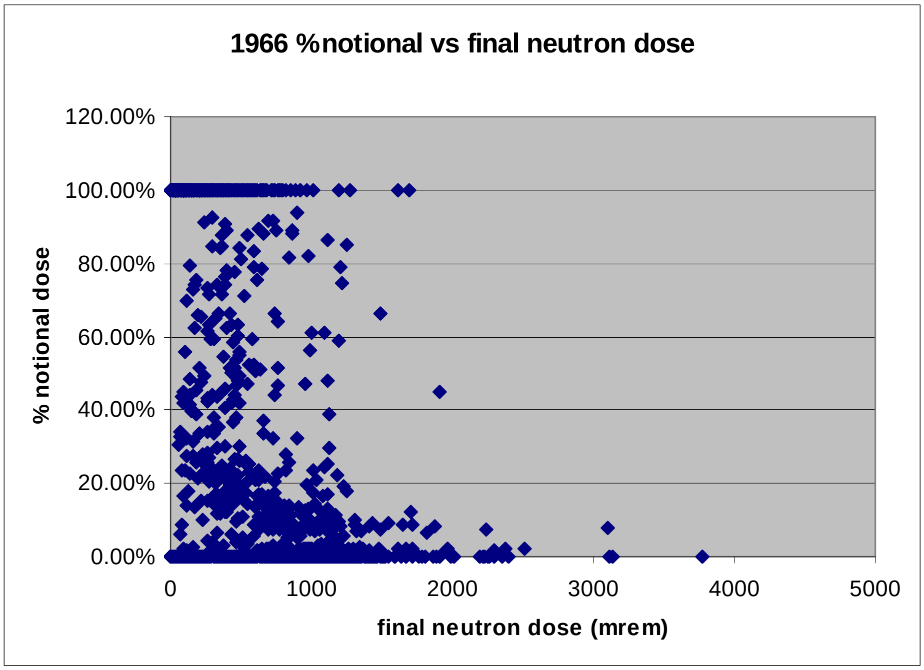

Figure 2. 1966 % Notional Dose versus Final Neutron Dose

[28] In order to make use of the analysis, only workers with 100% measured must be compared with those with 100% notional dose. It is not possible to sort out situations where the total dose is a mixture of measured and notional components.

[29] Inkret (no date, but written in 1989 or later, as determined from internal references to dates of events) states that all Building 71 workers were monitored for neutrons starting in 1959 or 1960. However, the cumulative badge cycles in 1959 for all workers in Building 71 was only about 2,000, indicating a full-time monitoring equivalent of only ~100 to 150 workers. The average badge cycle in Building 71 was ~20 days; for most workers it was 14 days.

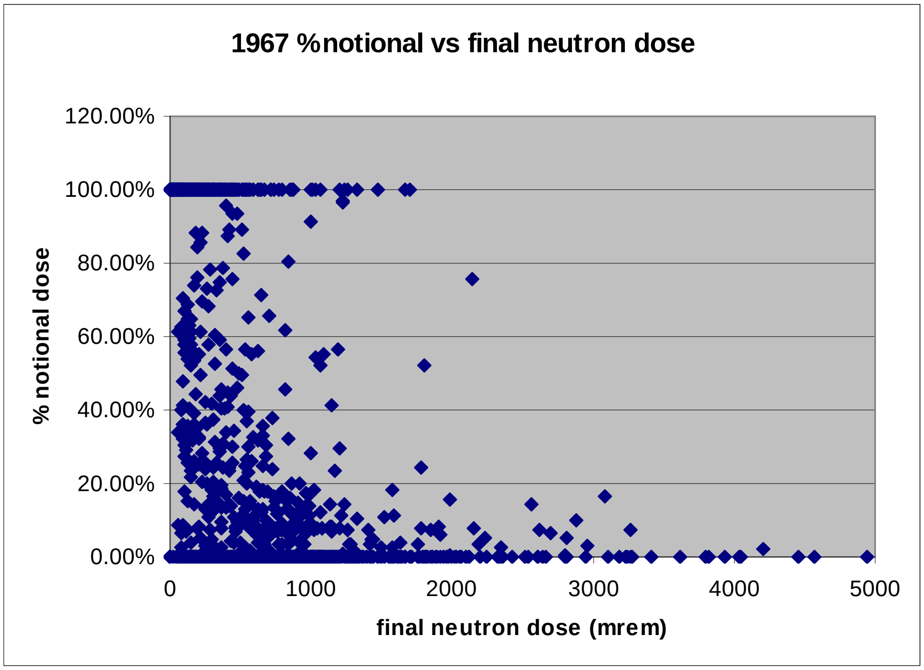

Figure 3. 1967 % Notional Dose versus Final Neutron Dose

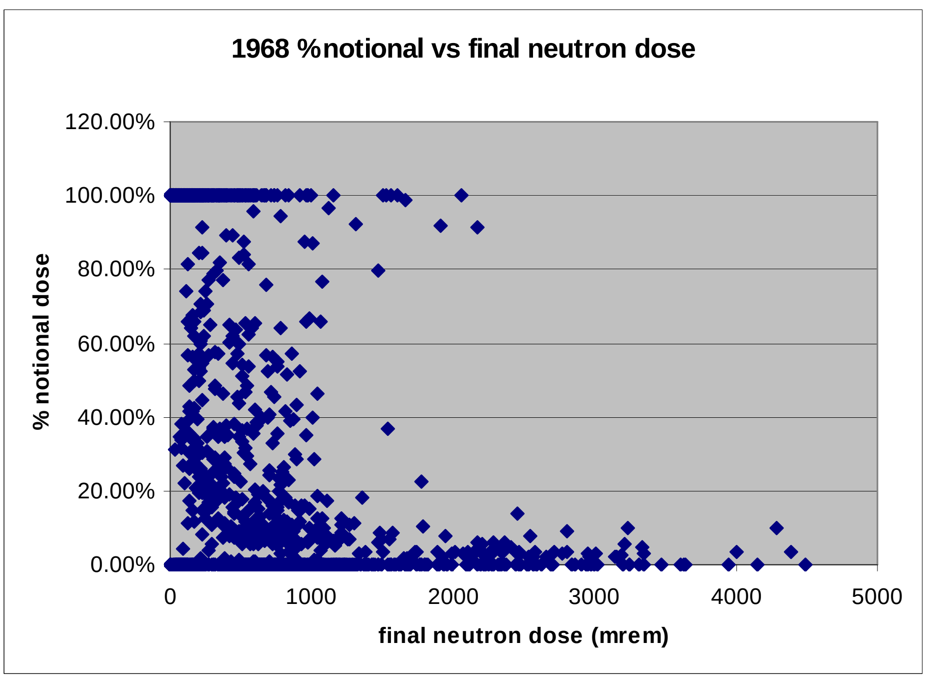

Figure 4. 1968 % Notional Dose versus Final Neutron Dose

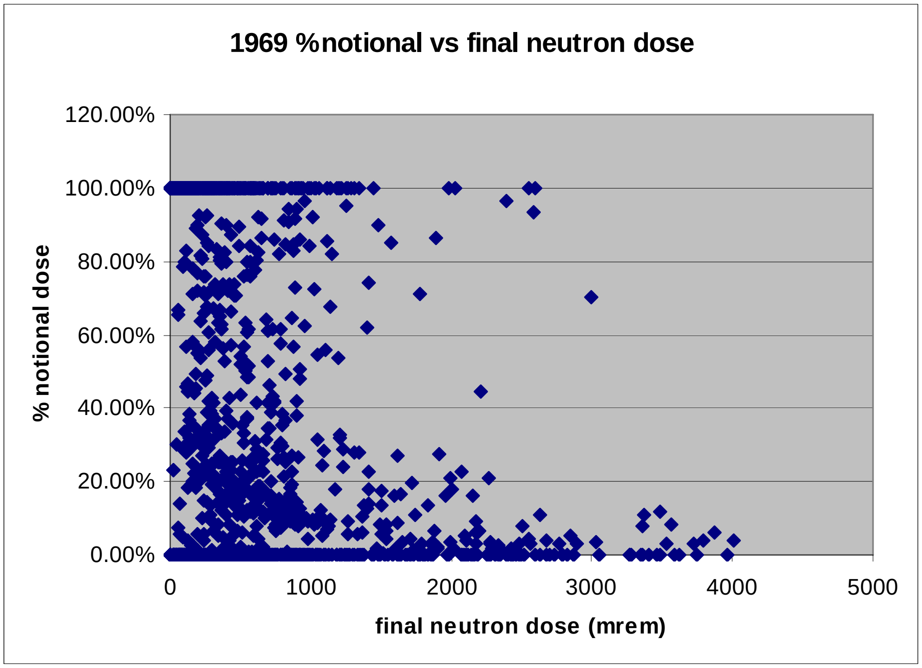

Figure 5. 1969 % Notional Dose versus Final Neutron Dose

In all these cases, the highest doses are the measured doses. This indicates that when the monitoring increased in 1965, the coverage of the workers with high exposure potential was more complete.

Some caution is needed in interpreting the charts for 1967–1970 because the final neutron dose has disparate elements in it, including the original estimated doses for badges that were never recovered. The charts are provided as indicators of the differences between the 1959–1964 period and the 1965–1970 period in regard to the results from the n/p method compared to measured dose.

While SC&A does not concur with NIOSH's analysis that notional doses estimated using the NDRP method are systematically claimant favorable, the alternative approach outlined in NIOSH 2007 to estimate neutron doses using 95th percentile readings of the badges is likely to yield claimant favorable results for a large majority of workers.[30] This is because workers did change work stations over badge cycles. The neutron exposure potential varied from one badge cycle to the next, making it very likely that the estimated dose will be claimant favorable *if* NIOSH consistently applies the 95th percentile value of individual badge results. The other caveat is whether the population of monitored workers who were exposed is comparable to or greater than those not monitored.[31] This appears to have been the case in the 1965–1970 period. The evidence for the 1959–1964 period is more complex.

[30] NIOSH continues to refer to estimates by this method as "notional" dose. SC&A has tried to reserve that term for dose estimates that go by that name in the NDRP report (ORISE 2005).

[31] It is sufficient to establish comparable exposure conditions in this context if a 95 percentile is consistently applied. This would still yield a systematic overestimate if the total number of badge cycles exceeds a handful.

SC&A's analysis indicates that some of the workers who were not monitored in the 1961–1964 period may well have been at higher exposure risk than those who were. The evidence is more mixed for 1959 and 1960. A building by building or job by job analysis would be needed to arrive at a supportable statement for 1959 and 1960. It is quite possible that the method proposed by NIOSH would yield claimant favorable doses even in those cases where the most exposed personnel were not monitored, if the 95th percentile values for individual badge cycle measurements are consistently used. The difficulty is that in the face of a lack of monitoring of workers and highly varying exposure conditions, it is very difficult to make a definitive statement that includes all those members of the proposed class who have high exposure potential in every year.

SC&A has spot checked some of the values of values of estimated dose in Table III.B.4 and was able to reproduce them from the underlying data.

Finding regarding the notional dose approach: The 95th percentile notional doses proposed to be applied to unmonitored workers at risk of neutron exposure are likely to be very claimant favorable for filling in monitoring gaps for the vast majority of workers in the 1959–1970 period (as distinct from issues associated with non-re-read doses, discussed above). However, for the period 1961–1964 and possibly for 1959 and 1960, it is appears that some of the workers at highest risk of neutron exposure may not have been monitored for the entire year. The problem of *establishing* that the stated approach is claimant favorable appears to be very difficult and has not been solved.

6.2 OTHER ISSUES RELATED TO UNMONITORED WORKERS

There are some neutron dose data Buildings 71, 76, 77, 86, 91, and 21, 22, 23.[32] However, there were also neutrons in other areas for which SC&A has located no data. SC&A raises the question here since the adequacy of the approach for estimating doses for unmonitored workers in the above-named buildings needs to be demonstrated for buildings without neutron data. As noted, the proposed approach of using 95th percentile badge-cycle values is likely to be claimant favorable under the vast majority of circumstances. The issue here is that the circumstances need to be defined and related to Table III.B.4 in NIOSH 2007.

For instance, subcritical experiments were carried out in the regular production areas including Building 81 until 1964. According to the history of the Critical Mass Laboratory:

> *The year of the first subcritical experiment at Rocky Flats, sometime in the 1950s, is not known; but these were called "in situ" experiments. They were subcritical approaches toward criticality performed on location in* ***one or another production building around Rocky Flats where the very same components under study were being manufactured.*** *In these experiments, fissile components were carefully stacked by hand in an intentional approach toward criticality but without actually attaining that state. Although they always remained safely well subcritical, critical parameters would be determined from an extrapolation of data. The parameter watched was the ever-increasing reactivity of the assembly*

[32] These three are considered together in the NDRP.

> *– closely related to another parameter called multiplication. These experiments were inherently more risky to personnel because workers were physically present while fissile material was being added. For that reason, they were performed "off shift" when not many workers would be in the building. Perhaps the philosophy "Risk the few, but spare the many" seemed noble at the time. Several experimental programs involving both **enriched uranium** and plutonium in solid, powder, and solution forms were studied by this intriguing method* [Rothe 2005, pp. 52–53, emphasis added].

Since enriched uranium was processed in Building 81, the workers who participated in those experiments were at risk of neutron exposure.

As discussed above in Section 3, plutonium was present in one room in Building 81, where the cleaning of enriched uranium parts was done. The residues often contained high enough concentrations of plutonium to be packaged and shipped to the Savannah River Plant. There may have been potential for neutron exposure in this room, notably in the operations of handling and packaging the residues.

The history of the Critical Mass Laboratory also mentions that subcritical experiments were carried out outside that laboratory, which started operation in 1964.

Finding regarding areas with neutron exposure potential but no neutron monitoring: There are some areas and buildings where there was a potential for neutron exposure where there do not appear to be any dose measurements. These include the oralloy cleaning and plutonium residue recovery area and the criticality experiment area in Building 81. There may also be other such areas at Rocky Flats. SC&A has not done wider review of this issue since it presumes that NIOSH is preparing such a list pursuant to the Board's request made during the May 2–4, 2007, meeting in Denver.

6.3 PERIOD OF USE OF NTA FILM

The NDRP covered the period up to and including 1970 in its recovery and re-reading of NTA film. The transition to TLDs appears to have occurred mainly in 1971; however the history of Rocky Flats dosimetry indicates that use of NTA film may have gone on beyond that for those workers who were on longer (more than semi-monthly) badge cycles:

> *1971–1972 This was a transition period during which film dosimeters were replaced by thermoluminescent dosimeters (TLD). In January 1971, all beta and gamma film was replaced with Harshaw TLD-700 lithium fluoride ribbon (100% ^{7}Li) and the semi-monthly exchange group neutron film was replaced by TLD-600 lithium fluoride ribbon (96% ^{6}Li). All neutron dosimeters were TLD by July 1972.* [Inkret, undated]

In contrast, a 2002 dosimetry history indicates that the TLD-600 neutron dosimeter had been fully implemented by the end of 1970:

> *By the end of 1970 Rocky Flats had acquired sufficient TLD 700s and TLD 600s to fully load and implement the new Harshaw TLD holder.* [Baker 2002]

Finding regarding the end of NTA film use: Two official documents (Inkret, no date but 1989 or after, and Baker 2002) contain conflicting statements about when the use of NTA film completely ended at Rocky Flats. The former indicates that some use continued up to and including June 1972, while the latter indicates that all NTA film was phased out by the end of 1970.

6.4 OBSERVATION FROM SC&A 2007A

Observation from SC&A 2007a:

The NDRP had extensive quality control procedures for the re-reading of neutron dosimeters. As SC&A noted in its April 30, 2007, report:

> [T]*here was no independent check of the readings of the person against whom all correction factors were developed. Furthermore, the independent checker was assumed to have no bias in his readings, despite the fact that he himself had developed the calibration standard in the 1960s against which the accuracy of his reading was established. It should be noted that the last two points have nothing to do with the valuable insights of* [NAME], *or his competence and professionalism. He has provided very useful technical and historical insights to SC&A in the interviews that were conducted as part of the neutron dose review. They are noted here for technical reasons. It is highly unusual to assume that one person has no error or bias in his readings, when all others had errors and biases. It is even more unusual to make such an assumption without independent validation of the assumption. Furthermore, this assumption of no bias and zero expected error in the final re-read dose was used as a basic part of the statistical model in the NRDP.*
>
> *Observation 1: The Board's SEC criteria require data validation by NIOSH, but contain no explicit guidance regarding this particular type of situation. Here there were extensive efforts to establish the quality of the reading of the badges by individual readers in order to correct for biases that were detected in the course of the program. However, the calibration of the entire process of developing the correction factors was never independently validated. As a result, the re-read doses have an essential element of validation against systematic error missing, despite the extensive quality control measures that were taken during the NDRP and the correction factors that were developed for individual readers.* [SC&A 2007a, p.47]

7.0 CHANGES IN DOSE RECONSTRUCTION PROCEDURES AS A RESULT OF THE NEW NIOSH NEUTRON DOSE APPROACH

The May 17, 2007, changes proposed by NIOSH in the dose reconstruction process for assigning neutron dose to unmonitored, or undermonitored, workers for the period 1959–1970 will necessitate changes in the documents governing dose reconstruction. SC&A did a brief review of the procedural changes that would be needed to accommodate the proposed changes in neutron dose reconstruction methodology. NIOSH's recently proposed process would:

- Eliminate the previous n/p method of estimating an unmonitored worker's neutron dose. That method consisted of multiplying the worker's recorded photon dose by an n/p value (which was derived for a specific building for a given year).

- Replace the previous method with one that uses a given percentile (i.e., 50th or 95th) of the neutron dose results that were obtained from workers badged for neutrons for a specific building for a given year. These badge results are on a badge-exchange basis, as opposed to an annual average, to better reflect the variations in neutron doses with job types and time dependence.

- Remove the use of the reading bias correction factor of 1.99 for Building 71 and 1.13 for all other buildings for unaffected (i.e., non-reread) Original Neutron Dose when using NDRP dose records.

- Replace the previous reading bias correction factor with a 50th percentile value of 1.640 or 95th percentile value of 6.950 (derived from 1959–1969 reread vs. unaffected data analysis) for workers with NDRP unaffected neutron doses greater than zero. If the NDRP unaffected neutron dose was recorded as zero, then the worker will be assigned a claimant-favorable neutron dose of 73 mrem/badge cycle (50th percentile value) or 183 mrem/badge cycle (95th percentile value).

- Notional doses in the worker's NDRP dose records (part of which were derived from n/p values) would be replaced by coworker data as described in the second bullet point above. At this time, it appears that NIOSH would only replace the n/p derived portion of the notional dose and leave the dose derived from the worker's adjacent neutron dose readings as they presently are.

These changes in neutron dose assignment procedures most likely will require the revision of related documents, such as TBDs and OTIBs. Some of these documents are:

(1) TKBS-0011-6, especially parts 6.7.3.4 and 6.7.3.5 concerning NTA film reading bias factors and the use of the NDRP n/p data.

(2) OTIB-0027, Section 3.0 and Tables 4-1 and 4-2.

(3) OTIB-0050, Sections 3 and 4 will have to be rewritten concerning notional doses.

(4) OTIB-0058, sections concerned with 1959–1969 neutron dose assignments, including Tables 7-1 and 7-2.

(5) The following workbooks and guidelines would be subject to change:
- Complex Wide Coworker Data 1.10
- Revised OTIB-0058 Guidance 6-13-06
- RFP_OTIB-0058 Coworker dose Tool 1.00
- RFP_Missed Zero Calculation Workbook 1.14
- RFP_Calculation Workbook 2.24
- RFD_BE Words for DRs_5-16-06
- Basic Guidelines for RFP Dose Reconstruction V 1.10 (4/5/06).

For claims involving neutron exposure at the RFP during 1959–1970, the DR process and report would need to be changed to incorporate the recently proposed NIOSH method. Additionally, any DRs that have been performed in the past would need to be re-evaluated if they involved neutron exposure at the RFP during 1959–1970. These are the most obvious documents that could be affected by the proposed method; other documents may also be affected if the new method is implemented.

SC&A has not evaluated the time and resources it would take to implement the needed changes.

8.0 REFERENCES

42 C.F.R. pt. 83, 2000. Code of Federal Regulations, Title 42, Part 83: *Procedure for Designating Classes of Employees as Members of a Special Exposure Cohort under the Energy Employees Occupational Illness Compensation Program Act of 2000*.

ABRWH 2006. *Transcript of the Meeting of the Advisory Board on Radiation and Worker Health*, June 15, 2006. Meeting held in Washington, D.C., June 14-16, 2006.

ABRWH 2006a. *Transcript of the Meeting of the Advisory Board on Radiation and Worker Health*, June 16, 2006. Meeting held in Washington, D.C., June 14-16, 2006.

ABRWH Working Group 2006. *Transcript of the Meeting of the Working Group of Advisory Board on Radiation and Worker Health*, June 8, 2006. Meeting held by conference call, June 8, 2006.

Albert, R.E. 1966, *Thorium, Its Industrial Hygiene Aspects*, Academic Press.

Baker 2002. Baker, Steve, *Historical Timeline of External Dosimetry Equipment Used at Rocky Flats Since 1952 – SCB-031-02*, Kaiser-Hill Company, February 12l 2002.

Buffer, P. (Date unknown). *Rocky Flats Site History: Events Leading to the Creation of the Weapons Complex and Events at the Rocky Flats Site from the 1930s to Present*, on the web at http://rockyflats.apps.em.doe.gov/references/199-Rocky%20Flats%20History%20Thru%201-2002.pdf

Flack, S. and R. Meyer 2004, *Technical Basis for the Rocky Flats Plant—Site Description*, ORAUT-TKBS-0011-2, Rev. 00, Oak Ridge Associated Universities, Oak Ridge, Tennessee. January 10, 2004.

HAER 881. Historic American Engineering Record, Rocky Flats Plant, Manufacturing and General Support HAER No. CO-83-Q (Rocky Flats Plant Building 881) (Rocky Flats Plant B. On the web at http://www.lm.doe.gov/land/sites/co/rocky_flats/HAER/base/Buildings/881.htm

Inkret, W.C. no date. *Dosimetry History at Rocky Flats*, Dose Assessment: Los Alamos National Laboratory, published in 1989 or later.

NIOSH 2006, *Technical Basis Document: Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation, Lackawanna, New York; Period of Operation: 1949–1952*, Rev. 00, OCAS-TKBS-0003, July 27, 2006.

NIOSH 2006a. *SEC Petition Evaluation Report, Petition SEC-00030*, Revision #0, (Petition relating to the Rocky Flats Plant), April 7,2006

NIOSH 2007. *NIOSH Response to ABRWH Request for Supplemental Information Related to the Rocky Flats SEC Petition*, May 17, 2007

NIOSH 2007a. *SEC Petition Evaluation Report Petition SEC-00079*, Revision # 0, (Petition relating to the Dow Chemical Company Madison Site), April 13, 2007.

ORISE (Oak Ridge Institute of Science and Education) 2005, *Technical Base Document for the Neutron Dose Reconstruction Project: Neutron Dose Reconstruction Protocol*, ORISE 05-0199, Oak Ridge, Tennessee. February 7, 2005.

Putzier, E.A. 1982, *The Past 30 Years at the Rocky Flats Plant*, Rockwell International, Golden, Colorado, November 1982.

Rothe, Robert E. *A Technically Useful History of the Critical Mass Laboratory at Rocky Flats*, LA-UR-05-3247, Los Alamos National Laboratory, Los Alamos, New Mexico, May 2005

SC&A 2007. *Review of the Rocky Flats Plant Special Exposure Cohort (SEC) Petition, SEC-00030, Volume 1: Main Report*. SCA-SEC-TASK5-0052. S. Cohen & Associates, Vienna, Virginia. April 5, 2007.

SC&A 2007a. *Supplemental Report on Neutron Doses at Rocky Flats, 1952–1970*, SCA-SEC-TASK5-0052 Supplemental Report, Revision 1. S. Cohen & Associates, Vienna, Virginia. April 30, 2007.

SC&A 2007b. *Review of the Rocky Flats Plant Special Exposure Cohort (SEC) Petition, SEC-00030, Volume 2: Attachments*, SCA-SEC-TASK5-0052, S. Cohen & Associates, Vienna, Virginia, April 27, 2007.

Smith, M., 2006, *External Coworker Dosimetry Data for the Rocky Flats Plant*, ORAUT-OTIB-0058, Rev. 00, Oak Ridge Associated Universities, Oak Ridge, Tennessee, April 6, 2006.

Smith, M., 2007, External Coworker Dosimetry Data for the Rocky Flats Plant, ORAUT-OTIB-0058, Rev. 01, Oak Ridge Associated Universities, Oak Ridge, Tennessee. January 8, 2007.

ATTACHMENT 1: MINUTES OF MAY 25, 2007, Conference Call

RFP working group technical issue conference call, May 25, 2007, on Rocky Flats thorium-related issues for clarification

Notes are not verbatim, but closely represent what was said.

Participants:

Working Group: Mark Griffon

NIOSH/ORAU: Brant Ulsh

SC&A: John Mauro, Joe Fitzgerald

1) Thorium strike

Joe Fitzgerald indicated that SC&A understands that NIOSH's May 17, 2007 response to the ABRWH provided a demonstration of dose estimation for thorium strikes based on the April 1965 strike. However, SC&A is aware of at least one more documented strike, as well as the possibility of a number of others as inferred in the 1999 ICF Kaiser history of U-233 operations. While the provided bounding analysis for the 1965 strike may be applicable for it, it is not clear whether and how it would be bounding for the others.

Brant responded by noting that NIOSH has requested similar air monitoring results for a second thorium strike (identified as taking place in January 1967 based on interviews with [NAME], notations in the Kittinger-Vogel logbook, and [NAME] *Thorium Use at Rocky Flats* document) and the methodology would be the same as that done for the 1965 strike. Brant noted that the 1965 strike involved approximately 20 kg of U-233 containing 47 ppm of U-232, making it the bounding case in terms of source term. The personnel involved, the wet chemistry process, the equipment used and the location were the same as the 1965 strike. However, Mark Griffon said the analysis of the 1967 strike would need to be confirmatory of this preliminary conclusion because size of source term, alone, would not establish that it is bounding from a worker exposure standpoint. Brant expects to receive the air sampling data by June 1.

In terms of the ICF Kaiser reference indicating the removal of "hot" daughter products to reduce the external radiation hazard to workers, Brant noted that that the same document (on page 4) indicates that "U233 processed in 1965 contained approximately 50 ppm U232, while that processed in 1976-77 contained only 7-8 ppm U232". The U-233 used in this later project was to support an operation at NTS, in which [NAME] was directly involved. Mel [Chew] recalls[33] that because this later metal had much lower U-232 content, it was not necessary to do Th strikes on it. [NAME] also recalled the same thing.

[33] Mel Chew made the statement referred to in his capacity as a government contractor (ORAU).

In terms of representativeness of air monitoring samples, Brant noted that NIOSH chose the highest of the samples taken from 10 fixed head samplers for its dose estimation, recognizing that while there is no way of confirming how representative of breathing zone this would be, strikes involved a wet chemistry process conducted inside a reaction vessel, which was in turn inside a sealed glovebox, in a relatively small room with multiple samplers, and under short occupancy times due to the high external exposure levels associated with them, would thereby have mitigated some of the uncertainties associated with reliance on area air monitoring results.

2) "Small" thorium sources

Joe indicated that SC&A's April 5, 2007 report contained a finding on small thorium sources at RFP (typically laboratory scale sources) that indicated that "it is likely that a suitable approach for small uses of Th-232 (i.e., those each less than 500 g) can be developed, but this has not yet been done." Brant responded that while the Board's direction at its last meeting did not include demonstration of that specific issue, NIOSH has provided data from the inventory ledgers and has established that 7 kg of thorium was documented as "material unaccounted for" in the ledgers as of December 1967, which noted "This represents 7 kgs consumed by the Analytical Laboratories over a period of years. Thorium nitrate is utilized as a titrating agent in the analysis of fluorine." The actual mass of thorium would be about half this quantity, as the chemical form involved was thorium nitrate. Mark asked if this was the only "small operation". Brant referred to [NAME]'s report which discussed the possible use of Th oxide as a mold coating in limited experiments. Thorium oxide is listed on the inventory sheets in maximum quantities of 8 kg beginning April 1957, and carried in inventory with declines of a kg here and there until June, 1965. This is similar in magnitude to the other "lab sources". Brant indicated that NIOSH provided a NUREG-1400 based analysis of the mold coating operation in one of the previous reports (couldn't recall which one). In the past the Board has not required explicit consideration of these small lab sources. Mark indicated that NIOSH could apply either NUREG-1400 (as it did for similar quantities at Y-12) or an alternative approach (as provided in its response to the Board) to bound associated doses.

3) MgTh alloy

Joe indicated that while SC&A planned to allude to this issue based on statements made at the last Board meeting, there is no new information or analysis to offer the Board regarding disposition of shipments of the material from Dow Madison, including possible receipt at RFP. He mentioned that anecdotally, he had heard recently that such shipments may have actually been sent to Rocky Mountain Arsenal and that these two facilities may be getting confused. Brant acknowledged that there is some circumstantial evidence of receipt and use of MgTh alloy at Rocky Mountain Arsenal and at a nearby Lockheed Martin facility involved with aerospace work, but that there is nothing conclusive at this point. Mark requested that this possibility be discussed with [NAME] (the Dow Madison worker) by NIOSH.

A final point of clarification was raised by John Mauro, who indicated that the cutting of canned thorium using torches may not necessarily involve extensive melting of the thorium, itself, given that the cutting would be largely confined to the stainless steel can. This would lead to reduced thorium metal fumes and would make this activity less analogous to the cutting of cobbles at Bethlehem Steel, a comparison that SC&A has been examining.

ATTACHMENT 2: 1963 CORRECTION RATIOS FOR RE-READ BADGES

This attachment provides an example for comparison regarding the changes in correction factors that were likely due, in part at least, to the change in badge reading protocol.

1963	1963	1963	1963	1963
OriginalNeutronDose	**NonReplacedOriginalNeutronDose**	**Affected Orig.**	**NDRPNeutronDose**	**NDRP/Affected**
320	190	130	1,992	15.32
72	37	35	310	8.86
560	120	440	2,998	6.81
920	450	470	2,323	4.94
810	90	720	3,326	4.62
970	120	850	3,784	4.45
540	170	370	1,634	4.42
450	80	370	1,555	4.20
580	80	500	2,091	4.18
600	220	380	1,417	3.73
410	120	290	1,073	3.70
670	180	490	1,727	3.52
730	120	610	1,881	3.08
1,520	120	1,400	4,250	3.04
1,650	300	1,350	3,834	2.84
820	140	680	1,904	2.80
1,420	80	1,340	3,661	2.73
1,200	240	960	2,567	2.67
1,820	150	1,670	4,440	2.66
2,190	220	1,970	4,947	2.51
1,370	140	1,230	3,084	2.51
1,340	130	1,210	3,020	2.50
850	160	690	1,716	2.49
2,040	340	1,700	4,208	2.48
1,410	140	1,270	3,123	2.46
1,860	340	1,520	3,695	2.43
1,020	140	880	2,087	2.37
1,330	150	1,180	2,797	2.37
1,470	160	1,310	3,001	2.29
1,100	80	1,020	2,336	2.29
1,850	100	1,750	3,927	2.24
2,100	170	1,930	4,249	2.20
2,630	1,160	1,470	3,234	2.20
1,270	80	1,190	2,587	2.17
940	180	760	1,638	2.16
570	110	460	975	2.12
1,840	80	1,760	3,730	2.12
2,310	280	2,030	4,124	2.03
1,970	220	1,750	3,544	2.03
1,010	100	910	1,749	1.92
2,870	290	2,580	4,926	1.91
2,760	280	2,480	4,720	1.90
2,020	90	1,930	3,652	1.89

1963 OriginalNeutronDose	1963 NonReplacedOriginalNeutronDose	1963 Affected Orig.	1963 NDRPNeutronDose	1963 NDRP/Affected
1,730	290	1,440	2,692	1.87
2,640	310	2,330	4,308	1.85
1,230	150	1,080	1,989	1.84
3,300	170	3,130	5,760	1.84
3,450	600	2,850	5,189	1.82
1,900	90	1,810	3,293	1.82
2,110	120	1,990	3,601	1.81
1,310	90	1,220	2,182	1.79
820	100	720	1,287	1.79
2,300	130	2,170	3,875	1.79
2,290	230	2,060	3,671	1.78
2,580	910	1,670	2,852	1.71
1,360	150	1,210	2,062	1.70
1,470	250	1,220	2,062	1.69
1,070	250	820	1,369	1.67
2,350	120	2,230	3,718	1.67
1,980	110	1,870	3,104	1.66
2,780	150	2,630	4,341	1.65
3,430	440	2,990	4,756	1.59
1,190	210	980	1,520	1.55
950	210	740	1,143	1.54
2,170	170	2,000	3,027	1.51
2,740	270	2,470	3,528	1.43
1,410	110	1,300	1,848	1.42
2,600	80	2,520	3,571	1.42
2,120	160	1,960	2,771	1.41
2,560	300	2,260	3,181	1.41
2,980	120	2,860	4,015	1.40
3,010	200	2,810	3,937	1.40
3,000	220	2,780	3,782	1.36
3,090	160	2,930	3,952	1.35
3,110	180	2,930	3,823	1.30
3,440	320	3,120	4,059	1.30
3,900	220	3,680	4,783	1.30
2,310	150	2,160	2,784	1.29
3,540	240	3,300	4,245	1.29
3,470	80	3,390	4,058	1.20
3,240	350	2,890	3,440	1.19
3,310	150	3,160	3,697	1.17
3,330	390	2,940	3,427	1.17
3,890	160	3,730	4,244	1.14
3,330	100	3,230	3,493	1.08
1,660	450	1,210	1,306	1.08
2,490	80	2,410	2,568	1.07
180	180	0	350	

ATTACHMENT 3: E-MAIL EXCHANGE WITH NIOSH REGARDING TABLE III.B.1 IN NIOSH 2007

From: Arjun Makhijani [mailto:arjun@ieer.org]
Sent: Wednesday, May 30, 2007 9:03 AM
To: Ulsh, Brant A. (CDC/NIOSH/OD)
Cc: joef@saliantsolutions.com; griffonm@comcast.net; jmauro@scainc.com; kbehling@scainc.com
Subject: factual question re Table III.B.1

Hi Brant

I just needed a quick confirmation or clarification about the 183 mrem figure in Table III.B.1 Is it the 95 percentile of the NTA film re-readings that had zeros recorded originally? Or is it the 95 percentile of all re-readings? We have been interpreting it as the 95 percentile of zeros alone. I wanted to make sure that we are interpreting it correctly.

Also it appears that there is an error in that table and it should be mrem/badge cycle rather than mrem/day. Right? The sample DR seems to use it as a value per badge cycle ("183 mrem per zero").

I would really appreciate a reply ASAP. Thanks so much.

Arjun

From: "Ulsh, Brant A. \(CDC/NIOSH/OD\)" <bau6@cdc.gov>
To: "Arjun Makhijani" <arjun@ieer.org>
Cc: <joef@saliantsolutions.com>,
<griffonm@comcast.net>,
<jmauro@scainc.com>,
<kbehling@scainc.com>
X-OriginalArrivalTime: 30 May 2007 15:02:05.0937 (UTC)
FILETIME=[7CCF4E10:01C7A2CB]
X-ELNK-Received-Info: spv=0;
X-ELNK-AV: 0
X-ELNK-Info: sbv=0; sbrc=.0; sbf=0b; sbw=000;

Arjun:
You are correct on both counts: Table III.B.1 is based only on badges originally read as zero, and the units should be 183 mrem/cycle not per day.

Brant

This e-mail is intended for the use of the recipient(s) named above. It may contain information that is **protected by the Privacy Act, privileged, or confidential**, and it should not be disseminated, distributed, or copied to persons not authorized to receive such information.