**REVISED 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

## Supplemental Report on Neutron Doses at Rocky Flats, 1952 to 1970

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

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


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| ***Review of the Rocky Flats Plant Special Exposure Cohort (SEC) Petition, SEC-00030 – Supplemental Report on Neutron Doses at Rocky Flats, 1952 to 1970*** | Page 2 of 91 |
| Task Manager: ________________________ Date: ___________ Joseph Fitzgerald | Supersedes: 0 – Draft |
| Project Manager: ________________________ Date: ___________ John Mauro, PhD, CHP | |

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# EXECUTIVE SUMMARY

Workers in several buildings at Rocky Flats were at risk of neutron exposure. The risk arose mainly in the context of working with plutonium in Buildings 71, 76, 77, and 91, though there were also other buildings with some exposure risk, such as Buildings 21, 22, and 23. For a variety of reasons, including non-monitoring of many workers at risk, inaccurate reading of early neutron dosimeters, and incomplete coverage of the neutron energy spectrum by the dosimeters, it was realized in the mid-1960s that the neutron dosimetry records at Rocky Flats were incomplete and in error to varying degrees. These problems affect the period from 1952 to 1970. A project to re-evaluate Rocky Flats neutron doses was begun in the 1990s and a report was produced in 2005 that forms the basis of NIOSH's Rocky Flats neutron dose reconstruction for most workers in the buildings in question for the 1952 to 1970 period. This Neutron Dose Reconstruction Project (NDRP) resulted in the generation of neutron dose estimates that were put into the individual dose records of the workers included in the study. Basically, everyone monitored for gamma radiation exposure was included in the NDRP.

Neutron monitoring in the 1952–1958 period was, for the most part, confined to a group of workers in Building 91, where workers were thought by the Rocky Flats Health Physics professionals of the time to be at highest risk of exposure. Los Alamos provided 20 glass track dosimeters per badge cycle (monthly) and read them through 1956. In 1957 and 1958, an outside contractor performed the work of reading neutron dosimeters and the dosimeter was changed to neutron track film, known as NTA film. The NDRP and NIOSH concluded that the early monitoring was too limited in coverage and too sparse to provide a basis for estimating doses for unmonitored workers at risk of neutron exposure. SC&A concurs with this conclusion.

Lacking sufficient data for the 1952 to 1958 period, itself, the NDRP used 1959 neutron and photon data to estimate n/p dose ratios, aggregated by building. The average neutron dose for all workers in a building in a given year was divided by the average gamma dose, to yield a constant ratio for that building and that year. The method of estimating neutron dose for each year in the 1952 to 1958 period for unmonitored workers was to multiply the measured gamma dose from the year in question for that worker by the 1959 neutron-to-photon (n/p) ratio for the building in which the worker worked.

SC&A examined the NDRP neutron dose reconstruction model for the 1952 to 1958 period in several ways. The first was to evaluate whether the workers monitored in the period were the most exposed, so it could be determined whether some basis existed for evaluating whether the calculated doses (called "notional" doses) met the test of "sufficient accuracy" required by 42 CFR 83. Failing that, SC&A examined whether some other data from the 1952 to 1958 period were available to validate the use of 1959 building data in combination with individual gamma dose measurements. SC&A also examined the use of the n/p model to estimate neutron dose. Since the neutron badges had to be re-read, the process for checking the re-readings was also examined. Finally, SC&A examined the validity of back extrapolating 1959 n/p ratios to the 1952 to 1958 period.

Available data and dose estimates from the 1952 to 1958 period indicate that Building 91 monitored workers were sometimes the most exposed, but that at other times, Building 71 workers may have been the most exposed. The latter were not monitored for most of the period. (The terms dose, monitoring, badge, etc., as used here refer to neutron exposures unless otherwise mentioned.) Evaluation of exposure conditions in 1959, said by NIOSH to be essentially similar to the 1952 to 1958 period, indicated that Building 71 dose rates were the highest and Building 91 dose rates were the lowest among production buildings. This means that no benchmark for validating the back-extrapolation of n/p ratios from 1959 is available. Furthermore, there are no neutron area monitoring data or other records from 1952 to 1958 that would enable the NDRP dose estimation procedure for Building 71 for this period to be validated. In light of the practice of workers following a batch of plutonium from start to completion of processing, the use of such data for validation would probably be quite difficult.

For Building 91, there are data for the 1952 to 1956 period as well as 1959 data. These data indicate that exposures, as measured by the average daily dose rate experienced by monitored workers, were higher in the early period and lowest in 1959. Hence, the available neutron exposure data indicate that working conditions changed between the early period and 1959, making the back-extrapolation using 1959 n/p ratios questionable at best. A detailed study of the n/p ratios by job type for 1959 and for 1952 to 1956 would be needed to establish the validity of the back-extrapolation for Building 91.

NIOSH has stated that a shift in plutonium processing batch size from the 200 to 220 gram range to 1,200 grams in 1957 did not materially affect the n/p ratio. An examination of the NIOSH Site Profile for Rocky Flats and other data shows that the change in batch size occurred in the context of other changes that may have substantially changed exposure conditions, and hence, the n/p ratio. These changes included the following:

- An expansion of Building 71 during 1956–1957 as part of preparations for a large-scale expansion in production
- A new plutonium chemistry line in Building 71, which included a change in plutonium handling methods
- The construction of Building 76 and Building 77 during 1956–1957
- A transfer of plutonium metal working operations from Building 71 to Building 76
- A transfer of weapon assembly operations from Building 91 to Building 77
- A change in weapon design to a hollow pit

Furthermore, there were also new job types added during the latter part of the 1952–1958 period. Specifically, a plutonium waste incinerator was added to Building 71 in 1958.

NIOSH has stated that these changes would not adversely affect claimants in that they result in claimant-favorable n/p ratios and dose estimates. However, the specific effect of these changes on the n/p ratio or on dose estimates has not been quantitatively analyzed by NIOSH or the NDRP. The many changes need to be carefully investigated for their effect on the comparability of the n/p ratio between 1959 and the 1952 to 1958 period. Indeed, given that the changes occurred within the 1952 to 1958 period, an assumption of a constant n/p ratio in Building 71 for the whole period does not appear to be justified.

In summary, the use of 1959 data for estimating 1952 to 1958 neutron doses for unmonitored workers at risk of such exposures has not been validated. Substantial and significant changes in job types, facilities, processes, production methods, source term, and weapon design occurred in the 1956 to 1958 period. In the April 24, 2007, conference call held just before this report was finalized, NIOSH agreed that there had been extensive changes and added detail to the changes described by SC&A. NIOSH asserted that the changes resulted in 1959 n/p ratios being claimant favorable when applied to the earlier period. However, neither the NDRP nor NIOSH have quantitatively evaluated the many complex changes that occurred for their impact on the n/p ratio. Available data and information regarding facility changes in Building 71 and Building 91 indicate that the use of 1959 n/p ratios with the assumption that earlier conditions were similar is not scientifically appropriate at the present time. Extensive analysis, most likely involving detailed classified investigations, would be required just to determine the feasibility of a derived method for back-extrapolation. Given that there are essentially no comparable individual dose data (since Building 91 changed between 1956 and 1959) and no field data between 1952 and 1958, it is unclear whether any amount of effort could result in a scientifically defensible method of estimating the neutron doses of unmonitored workers in these two buildings. The evolution of Buildings 76 and 77 during 1957 and 1958 would also have to be studied for its comparability to 1959. This has not been done in the NDRP.

For the 1959–1970 period, data for gamma and neutron doses exist for the various buildings and the issues are somewhat different. Building n/p ratios aggregate all job types and may not be suitable for application for estimating individual worker dose. The goal of the NDRP was to develop best estimates of dose, and according to NIOSH, claimant-favorable choices were made in the process, as well. SC&A tested this assertion by estimating notional doses from n/p ratios for workers who had at least 6 months of monitoring data. While the numbers were too small for statistical significance, in most cases, the notional dose was less than the measured dose, and in many cases it was over 50% less than the measured dose. This indicates that the NIOSH assertion of claimant favorability of notional dose as estimated by use of n/p ratios alone for the entire year may not be generally valid and needs to be corroborated with a detailed analysis for application to individual dose estimation. Such an analysis was not presented in the NDRP, though it may have been done. Furthermore, an analysis of n/p ratios by job type would be needed to determine whether the use of an average building ratio is the source of the underestimation.

SC&A investigated the process of re-reading neutron badges during the NDRP. There was extensive training and quality control of badge re-reading during the project. A part of this was necessitated by the fact that badge reading was found to have systematic errors that varied by individual badge reader and by the experience of the reader. Correction factors were developed for badge readers by reference to the reading of a single person, who was treated as the "gold standard." However, no independent calibration of this "gold standard" was done. The calibration badges had been prepared by the same person in the 1960s, who stated that he had not looked at his prior results before reading them as part of the NDRP. While the expertise of this reader is well-known and established, the lack of a blind calibration procedure raises questions about the accuracy of the badge readings in a context where (1) the corrections that had to be made to the original readings were often very large (sometimes more than an order of magnitude), and (2) a systematic, though varying, bias in readings was generally observed in badge readers.

As one indication of the many difficulties in the whole process of estimating notional doses, the NDRP, itself, called the estimates “somewhat speculative.” The technical expert of that project felt that, of the estimates in the various periods, the estimates for the 1952 to 1958 period were the “more speculative” ones (see Attachment 3).

Finally, SC&A investigated the issue of the portions of the original neutron dose record that could not be re-read. The NDRP method of simply adding this to the total estimated neutron dose is incorrect and raises questions of data integrity (since the NDRP dose is now part of individual workers’ dose records). NIOSH uses a building-specific correction factor of 1.99 for Building 71 and 1.13 for other buildings. The SC&A analysis of the correction factors for re-read doses for individuals by year compared to the corresponding originals indicates that these factors are not claimant favorable for many workers. Moreover, the correction factors depend on the year of the original dose reading. The estimation of a correction factor for individual dose estimation appears quite complex. Claimant-favorable correction factors could be quite high in many cases (~20 or higher). In at least one year, 1969, SC&A found that it would be quite difficult to justify a specific scientifically defensible correction factor. A large number of workers—605—are affected. A preliminary analysis by SC&A indicates that there may be a similar problem for 1970, when there were over 1,700 workers who had some portion of their original dose that was not re-read.

**FINDINGS**

Finding 1: The available data indicate that the limited number of workers who were monitored in Building 91 were not necessarily among the highest exposed workers, though they may have been in some cases. There was some monitoring of Building 71 workers in 1957–1958, but only some data from late 1958 are available, which appear to be similar to 1959. Hence, for practical purposes, Building 71 can be considered to have no significant neutron monitoring data from 1952 to late 1958. Since there is no basis for comparison for essentially the entire period, available monitoring data for Building 91 for the 1952–1958 period cannot be used to develop bounding estimates of unmonitored workers at risk of neutron exposure in Building 71.

Finding 2: Available data and estimates indicate that the judgments made in the early 1950s regarding the monitoring of workers in Building 91 and non-monitoring in Building 71 were in error at least some of the time in that the available data and estimates indicate that the highest exposed workers during 1952 to 1956 were likely sometimes in Building 91 and sometimes in Building 71. This means that Building 91 doses from the 1952 to 1958 period cannot be used to develop a bounding dose estimate for workers at risk of neutron exposure in that period, even apart from the questions associated with back-extrapolation of 1959 data to the earlier period. Evidently, the same is also true of Building 91 doses in 1959.

Finding 3: The 1952–1958 data were regarded by the NDRP as an insufficient basis for assigning doses to workers who were not monitored in that period. SC&A concurs with this finding.

Finding 4: There were several changes at Rocky Flats in the 1955 to 1958 period that were likely to materially affect gamma and neutron doses, and therefore their ratios. These factors were not quantitatively investigated in the NDRP or by NIOSH as part of the decision to use 1959 building n/p ratios for estimating 1952–1958 individual neutron doses. NIOSH's claim, made on April 24, 2007, that the 1959 n/p ratios are claimant favorable if used for 1952–1958 neutron dose estimation has no analytical or scientific foundation at present. It would require a detailed investigation of the effect of the extensive differences between 1959 and earlier years. In view of the lack of data for validation of Building 71 dose estimates for the 1952–1958 period, it is unclear whether any amount of effort could result in a scientifically defensible method of estimating the neutron doses of unmonitored workers in Building 71.

Finding 5: The results derived from the use of the 1959 Building 91 n/p ratio for the 1952 to 1958 period have not been validated. The data for Building 91 strongly indicate a lack of comparability between Building 91 neutron exposure in 1959 and earlier years, notably the 1952–1956 period. The neutron dose rate in 1959 was much lower than the rates in earlier years, which were themselves very variable. They appear related, at least in part, to the changes in the work that was done in Building 91 due to the transfer of assembly operations to Building 77. The factors that caused the lower dose rates in the later years in the 1950s were not analyzed in the NDRP. The NIOSH claim that the back-extrapolation of 1959 n/p ratio would be claimant favorable does not have a scientific foundation at present, since a quantitative analysis of the transfer of operations and other changes on the n/p ratio has not been done. An extensive analysis would be necessary before it can be determined whether it is reasonable to use the Building 91 1959 n/p ratio for the earlier period. In view of the sparse and highly selective monitoring in the early period in Building 91 (oriented to a particular group of workers thought to be at special risk), it is unclear whether such an analysis can provide a scientifically defensible result.

Finding 6: Development of n/p ratios by job is necessary to test whether the method of using building n/p ratios for estimating neutron doses is adequate for all groups of workers in a building.

Finding 7: The uncertainties associated with estimating notional dose from building n/p ratios are important for the period from 1959–1964; they are much less so for 1965–1969. In the latter period, workers with the higher doses generally appear to have some monitoring data.

Finding 8: The use of building n/p ratios as a method for making a best estimate or claimant-favorable estimate has not been adequately demonstrated. It may not yield best estimates of bounding doses for all members of the proposed class.

Finding 9: The model chosen by the NDRP of a direct proportionality of neutron to gamma dose, with a zero gamma dose corresponding to a zero neutron dose, does not adequately reflect the nature of the paired neutron-gamma measurements. Hence, it is unclear if the variance calculated by the NDRP method can be used to put a bound on doses in a defensible manner.

Finding 10: The upper-bound factor of 10 for Building 91 to replace calculated n/p values based on measurements is not justified. This arbitrary upper bound should be abandoned and replaced with the calculated values for those years when the calculated value is higher.

Finding 11: The NDRP total neutron dose poses a problem of data integrity in those cases where an original dose that was not re-read was added to the re-read and notional dose.

Finding 12: The NIOSH correction factors of 1.99 and 1.13 that are used for non-re-read dose are not claimant favorable in many cases and several years. Assignment of a suitable correction factor that would be scientifically defensible and claimant favorable is quite complex.

Finding 13: In one of the three years analyzed by SC&A, 1969, the correction factors for re-reading neutron badges appear to be relatively independent of dose and are highly variable. It is not clear how a scientifically defensible correction factor could be developed for 1969 or for other years that may have a similar problem to bound individual dose or make a dose estimate more accurate than that.

Finding 14: It is not clear whether and how the cases where there is a positive original dose that could not be re-read, along with a zero original dose that was re-read, can be integrated into an analysis of correction factors.

# 1.0 INTRODUCTION

This report supplements the SC&A report on the Rocky Flats Special Exposure Cohort petition (SC&A 2007). SC&A noted in that report that it would prepare a supplemental report on neutron exposure, since certain issues relating to the estimation of bounding dose relevant to 42 CFR 83 were still pending on April 5, 2007, when SC&A submitted its report to the Board. During the working group conference call of April 19, 2007, SC&A also committed to providing comments on remaining SEC-significant findings raised in the conclusions of its April 5 report (SC&A 2007, p. 20), which are provided in a companion cover letter transmitting this report. The main part of this report covers NIOSH's neutron dose estimation procedures for the 1952–1970 period. The last section is devoted to brief comments on the other issues.

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. While many of the details are classified, some of the principal sources of neutrons are reasonably clear from the nature of the materials present:

(1) Neutrons generated by spontaneous fission of various radionuclides were present at Rocky Flats, notably plutonium-240. Hence, all situations involving plutonium in significant amounts would have the potential for neutron exposure. These would have included chemical processing of plutonium, plutonium metallurgical operations, handling and movement of plutonium parts, and subassembly and assembly of devices.

(2) Neutrons generated by (alpha,n) reactions, notably those with plutonium alpha particles interacting with fluorine. Areas with plutonium tetrafluoride ($PuF_4$) provide a principal example of situations with potential for neutron exposure.

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

(4) Some neutrons would also be expected to be generated in uranium areas, but the neutron flux would be very low in the absence of fluoride compounds such as $UF_6$. NIOSH has stated that such compounds were not present at Rocky Flats (Attachment 3).

The methods used to measure neutron dose until 1971—coated glass plate dosimeters and neutron track film dosimeters (NTA film)—suffered from significant limitations regarding coverage of the neutron energy spectrum and accuracy of reading of the plates and films. These are discussed in the report of the Neutron Dose Reconstruction Project (NDRP) (ORISE 2005) and in the external dose portion of the Rocky Flats Site Profile (Langsted 2004).

All workers who were at risk of exposure to neutrons who had gamma monitoring (or neutron monitoring) were included in the NDRP (see Attachment 2). That means that workers who were thought not to be at risk of exposure to gamma radiation (defined as less than 10% of the annual dose limit) would not be included in the NDRP. The NDRP was created to investigate historical monitoring practices, to re-read available neutron badges, and to make neutron dose estimates for time periods when no data were available for workers at risk. In practice, workers with gamma monitoring who were in certain buildings (Buildings 71, 76, 77, 91, 21, 22, and 23) were included in the NDRP. Neutron doses were estimated for each year for each individual in the project for the 1952–1970 period. The results were made part of the individual workers' radiation dose records; they are treated essentially on a par with external dose measurements for the purpose of dose reconstruction. Doses that were estimated to fill gaps in the monitoring record of individual workers were called "notional doses" in the NDRP to distinguish them from measured doses, which were obtained from a re-reading of the original glass track dosimeters and NTA film that could be recovered. The fraction of badges recovered for different years varied from nearly all the badges to none. NOISH developed a coworker model to be applied to workers exposed to neutrons who were not part of the NDRP (Attachment 3).

Neutron monitoring[1] was sparse in the early years (1952–1958) at Rocky Flats. The vast majority of workers at risk of neutron exposure were not monitored. Moreover, the individual workers who were monitored generally did not have a full year's coverage. Rather, workers tended to be monitored for some badge cycles and not in others. Finally, essentially all the workers who were monitored in the 1952–1958 period were in Building 91. Apart from the latter part of 1958, when monitoring records are available for Building 71, no monitoring records for any building other than Building 91 are available for the 1952–1958 period. Within that period, there were also changes in the neutron dosimeter, an outside contractor read the badges, changes in weapon design, and there were facility expansions, including an expansion of Building 71. For some parts of the analysis, the period under review is therefore divided into two sub-periods. The first period was from 1952–1956, when Los Alamos issued glass track neutron dosimeters and also read them. In the second period, 1957–1958, NTA film was introduced and a contractor read the film.

This monitoring pattern in the early period was defined by the health physics staff at Rocky Flats, because the monitored group of workers was judged to have the highest potential for neutron exposure. An assumption regarding the accuracy of such judgments often underlies some of the basis of NIOSH's dose reconstruction methodologies, notably coworker models. In this particular case, the doses received by the monitored group of workers in Building 91 relative to other workers are important because if they were established to be the highest, it would provide a guideline for establishing whether estimated doses for non-monitored workers meet the criterion of dose reconstruction with sufficient accuracy.

Los Alamos issued about 20 glass track badges per badge cycle. Los Alamos also read the badges. All the badges were issued to workers in Building 91. However, individual workers were not consistently monitored for the whole year. Hence, individual worker neutron dose records in this period generally are incomplete even for workers who were monitored.

Monitoring coverage increased from 1959 onward (inclusive) in terms of the number of workers who were covered and in building coverage. For 1959 onward, data are available for the main plutonium buildings named above (71, 76, 77, 91, and together for 21, 22, and 23). Overall for

[1] The terms "monitoring" or "badges" when used alone in this report refer to neutron monitoring or neutron badges (respectively), unless otherwise specified. Similarly, the term "dose" is used to refer to neutron dose, unless otherwise specified.

the period from 1957 to 1970, the NDRP retrieved 90,000 NTA films, of which 87,000 were matched to workers and re-read, and 76,000 were matched to individual workers' neutron dose records in order to estimate neutron doses for the time periods for which there were monitoring gaps.

Due to changes in the manner in which neutron badges were read, we will spilt the 1959–1970 period into two sub-periods; 1959–1966 and 1967–1970. Towards the end of the first period, it was realized that reading a large number of neutron badges was creating a problem of quality of the results. Therefore, from 1967 onward, only the neutron dosimeters of the workers thought to be most at risk were read more carefully than before, while the others were not read. The 1967 and 1968 films were recovered and re-read during the NDRP. However, many of the 1969 and 1970 films were not archived, so these badges could not be re-read.

# 2.0 COMPARISON OF BUILDING 91 AND BUILDING 71 DOSES, 1952–1958

In a conference call on March 28, 2007 (Attachment 1), regarding validation of the estimated doses for the 1952–1958 period, NIOSH stated that Building 91 workers were judged to have the highest neutron exposure potential at the time. SC&A used two methods to test which group of workers may have received the highest dose. First, SC&A compiled the top 10 doses in each year in the 1952–1958 period, and determined whether the dose was estimated (notional) or measured. Second, SC&A compared the measured doses in 1959 in the various buildings to one another to examine the relative dose rates in Building 91. Both analyses are indicative only, since no definitive analysis is possible with the available data.

The data and estimates regarding whether the monitored or unmonitored workers were the most exposed in the 1952–1958 period are mixed. For instance, in 1953, the top 10 exposures were estimated to have been received by workers with some monitoring data. For 1955 and 1956, the contrary was true. In both years, the top 10 estimated doses were all notional doses assigned to workers who were not badged. They were all in Building 71, where there was no neutron monitoring in those two years.[2] These Building 71 doses were all notional doses. In the other years in the period, the results were that some of the most exposed were monitored, while others were not.

Table 1 shows the number of dose estimates among the top 10 that consisted completely of notional dose—that is, the number of dose estimates that were made up entirely of estimated doses for workers who were not monitored during that year. It should be remembered that even people who were monitored often had some notional doses. Over half (53%) of the top 10 dose estimates were of workers who had no (neutron) monitoring whatsoever. It was the goal of the NDRP to make best estimates of individual neutron dose, while making some claimant-favorable assumptions. Hence, this comparison would provide one way of testing the hypothesis that Building 91 workers were at highest risk of neutron exposure for the period.

This test is not definitive since there are questions about the NDRP dose estimates, as discussed in this report.[3] Furthermore, NIOSH has stated that there are some claimant-favorable aspects to notional dose estimation. Therefore, Table 1 provides only an indicative but not definitive test of whether the monitored Building 91 workers were at highest risk in practice; the indicated result is that they were likely not at highest risk in many or most situations. In fact, in 1955 and 1956, the top few dozen estimated doses were all for workers in Building 71, who were assigned 100% of their dose as part of the NDRP process. That is, all of these doses were "notional doses." Another way of looking at it is that during the 1952 to 1958 period, the unmonitored workers appear to have been the ones at highest risk of neutron exposure in many cases; in other cases monitored workers had the highest doses.

[2] There may have been some monitoring in 1956, but no data are available.

[3] SC&A has not done a comparison of estimated doses for this period for this reason, but restricted the analysis to dose ranking.

**Table 1: Number of Workers with 100% Notional Dose in the Highest 10 Neutron Dose Estimate Category, 1952–1958**

| Year | # with 100% notional dose |
|---|---|
| 1952 | 3 of 10 |
| 1953 | 0 of 10 |
| 1954 | 7 of 10 |
| 1955 | 10 of 10 |
| 1956 | 10 of 10 |
| 1957 | 5 of 10 |
| 1958 | 2 of 10 |
| Total | 37 of 70 (53%) |

It is also instructive to look at plots of dose estimates for workers as a function of what proportion of the dose estimate was based on measurements and what fraction was "notional dose" estimated using the NDRP model (see below).

Figure 1 shows the scatter plot of percent notional dose versus the total estimated neutron dose for 1955. It is clear that for this year, the highest estimated doses were systematically among those who were not monitored at all during that year—that is, those who had 100% notional doses. As discussed below, notional doses for the 1952–1958 period were estimated from 1959 monitoring data. Again, given the questions regarding the estimation of notional doses, this comparison does not yield definitive results.

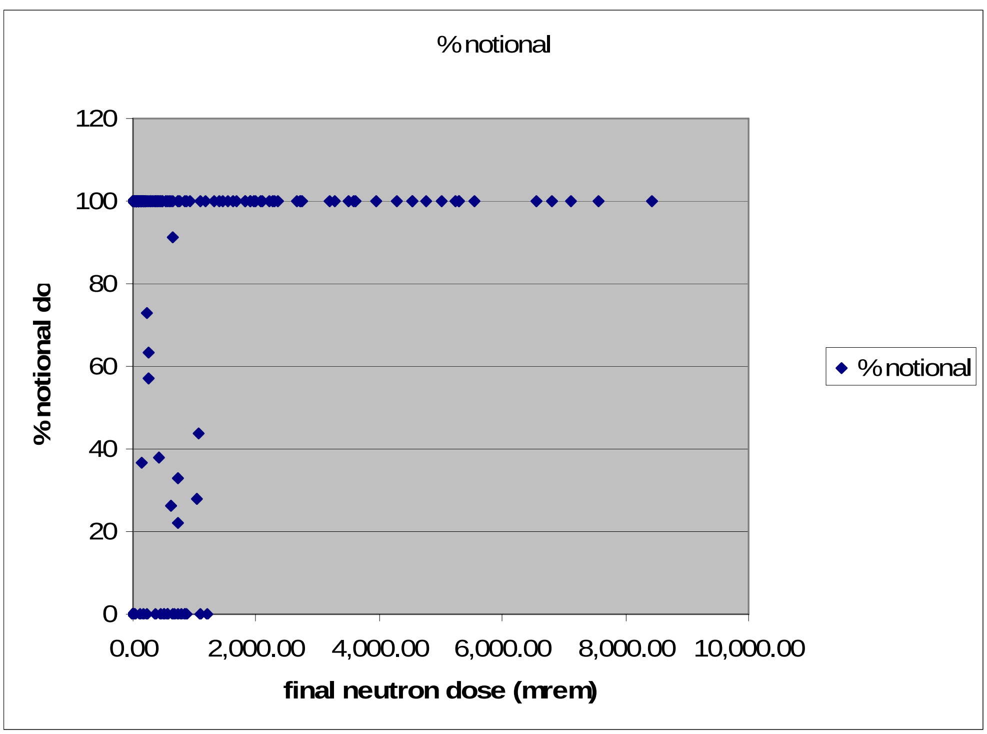


**Figure 1: Neutron Dose versus Percent Notional Dose, 1955**

Neutron doses for the 1952–1958 period for the vast majority of workers in the NDRP were estimated primarily by multiplying the gamma dose for the time period for which neutron dose was being estimated by a constant factor called the neutron-to-photon (n/p) ratio for the building in which the worker was located:

$$\textit{Notional dose, period } T = (\textit{Bldg. n/p ratio})_{1959} * (\textit{gamma dose during } T) \qquad \textit{Eq. 1}$$

Hence, 1959 is a critical year to examine closely for relevance to the 1952–1958 period. The first point to examine in the context of the above analysis is whether Building 91 neutron doses were typically greater than or less than neutron doses in other buildings in 1959. This provides an additional perspective on the above-ranking comparison for the 1952 to 1958 period.

Since many workers were monitored only for part of the year, it is most useful to look at measured dose rates to obtain a comparison of neutron exposure potential in the various buildings. This avoids the problem of comparing doses estimated from the n/p ratio model, about which there are considerable questions, most notably for the 1952 to 1958 period, with measured doses.[4] Hence, the NIOSH compilation of paired neutron and photon measured doses was used for this comparison. The neutron dose used was as re-read by the NDRP.

An examination of the data for 1959 reveals that Building 91 had the lowest average daily exposure of all the production buildings with neutron exposure potential (Buildings 71, 76, 77, and 91).[5] The highest average recorded daily neutron exposure was in Building 71, which had essentially no paired monitoring data that has been recovered prior to late 1958. Specifically, **in 1959, Building 71 had the highest average daily dose of about 10.1 mrem per day (paired data only), while the daily dose in Building 91 was about 2.2 mrem per day, or about 4.6 times lower. Clearly, in 1959, Building 71 workers as a group were at much higher risk of larger neutron exposure than Building 91 workers as a group.** Table 2 shows the average daily neutron dose in 1959 by building, calculated from paired neutron-gamma data.

**Table 2: 1959 Average Daily Neutron Dose by Building, mrem/day**

| Building | Average daily dose |
|---|---|
| 71 | 10.1 |
| 76 | 5.4 |
| 77 | 5.3 |
| 91 | 2.2 |

During the working group meeting on Rocky Flats of April 19, 2007, NIOSH stated that the judgment of the health physics professionals who decided to monitor Building 91 workers because they were thought to be most at risk was in error, since workers who were at significant risk in Building 71 were not monitored.[6] SC&A's analysis points in the same direction.

[4] The issue of back-extrapolation from 1959 to 1952–1958 is dealt with separately.

[5] Buildings 21, 22, and 23 were not production buildings. They had about the same daily recorded average neutron dose (2.64 mrem/day) as Building 91.

[6] The working group meeting transcript was not available at the time of this writing. SC&A took notes on this and some other points during the meeting. This statement is based on those notes.

However, in the next conference call, NIOSH revised this judgment in that workers thought to be at highest risk were monitored, but those who actually received the highest doses were not the ones who were at highest risk, because of the good health physics protection provided by health physics (Attachment 4).

SC&A concludes that it is not possible to substantiate the decision-making process of the professionals at the time without clear documentation, which may be classified, if it exists at all. Some Building 91 measured doses were among the highest compared to estimated Building 71 doses, and the reverse was also true for the 1952–1956 period. There cannot be a definitive conclusion on this point with the available data. SC&A stands on the essence of its earlier conclusion that the decision not to badge Building 71 workers was likely an error of judgment, because the indications are that some of them were among the highest exposed workers during this period. Lack of monitoring and lack of field monitoring data for Building 71 has created a situation where it is not possible to validate or benchmark notional doses in any way.

**Finding 1:** The available data indicate that the limited number of workers who were monitored in Building 91 were not necessarily among the highest exposed workers, though they may have been in some cases. There was some monitoring of Building 71 workers in 1957-1958, but only some data from late 1958 are available, which appear to be similar to 1959. Hence, for practical purposes, Building 71 can be considered to have no significant neutron monitoring data from 1952 to late 1958. Since there is no basis for comparison for essentially the entire period, available monitoring data for Building 91 for the 1952–1958 period cannot be used to develop bounding estimates of unmonitored workers at risk of neutron exposure.

**Finding 2: Available data and estimates indicate that the judgments made in the early 1950s regarding the monitoring of workers in Building 91 and non-monitoring in Building 71 were in error at least some of the time in that the available data and estimates indicate that the highest exposed workers during 1952 to 1956 were likely sometimes in Building 91 and sometimes in Building 71. This means that Building 91 doses from the 1952 to 1958 period cannot be used to develop a bounding dose estimate for workers at risk of neutron exposure in that period, even apart from the questions associated with back-extrapolation of 1959 data to the earlier period. Evidently, the same is also true of Building 91 doses in 1959.** [7]

[7] NIOSH has not proposed to use Building 91 doses from 1959 for other buildings in the 1952–1958 period. This statement that this cannot be done is merely to make the conclusion of the analysis presented here explicit.

# 3.0 1952–1958 DATA

Aspects of the 1952–1956 neutron data other than those discussed above, when Los Alamos issued the glass track dosimeters, are as follows:

- The original badge readings were generally found to be systematic underestimates when they were re-read as part of the NDRP.
- There were too few gamma and neutron paired data (zero for most areas) to reliably estimate n/p ratios from the data of the time.
- During re-reading, most, but not all, dosimeters were located.

The following additional facts apply to 1957–1958:

- Los Alamos stopped supplying glass track badges and reading them.
- NTA film was introduced and was read by an external contractor.
- The vast majority of the film could not be recovered for re-reading.
- There are essentially no comparison data for the 1957–1958 period against which to check notional dose or n/p ratios, except possibly for January 1957 and late 1958 data, according to Roger Falk (Attachment 2).[8]

The total number of workers for whom some data are available (including those who had just one or two badge cycles in a year) and whose neutron badges could be recovered and paired with gamma data were ~15 for 1952–1954 and ~30 for 1955 and 1956. Recovered data for 1957 and 1958 (other than December 1958) were even more sparse. Almost all of the available data (other than for late 1958) are for Building 91.

**Finding 3: The 1952–1958 data were regarded by the NDRP as an insufficient basis for assigning doses to workers who were not monitored in that period. SC&A concurs with this finding.**

As a result of the sparse nature of the 1952–1958 data, the limited coverage of buildings, and other factors, the notional doses for unmonitored workers between 1952 and 1958 (i.e., the vast majority of workers at risk of neutron exposure) were estimated by the NDRP by multiplying n/p ratios for a particular building (as estimated in the NDRP for 1959) with the individual's gamma dose for the period for which the neutron dose is being estimated (see Equation 1 above). This

[8] As noted, the available paired neutron and gamma data for the period are essentially all from Building 91, except for late 1958, which appears to belong in the same period as 1959 from the considerations above. There appear to be some other scattered data for 1957 and 1958 that are not in the main NDRP table of matched neutron gamma pairs.

was done for Buildings 71, 76, 77, and 91.[9] Hence, the validity of the use of 1959 n/p ratios for the earlier period is critical to the reconstruction of the neutron doses for the 1952 to 1958 time period. This issue is addressed in the next section.

[9] For other buildings or for workers not stationed in these buildings, but who went into them, the NDRP uses an aggregate ratio for these four buildings under the rubric "Other Buildings" (ORISE 2005, Table 11.1). Building 78 is assigned the higher of the ratios for Buildings 76 or 77. This procedure was also followed for cases with a combined "76, 77, 78" building designation (ORISE 2005, Table 11.1, Noted).

# 4.0 1959 NEUTRON AND GAMMA DOSE DATA AND ITS USE FOR 1952–1958 NEUTRON DOSE ESTIMATION

In 1959, there are some neutron dose data for all the production buildings discussed above – 71, 76, 77, and 91. These data were paired with gamma dose data for each building to estimate n/p ratios. This constant n/p ratio for each building was applied to the measured gamma doses for individual workers to estimate a neutron dose for each year for workers included in the NDRP. These estimates are in each worker's dose record and are used by OCAS for dose reconstruction.

There are several issues regarding the use of 1959 data for estimating neutron doses in the 1952 to 1958 period, using the n/p ratio approach described above. The NDRP report has a detailed description of the method to assign neutron doses for 1952–1970. The following factors are fundamental to the credibility of the methods adopted in the NDRP to assign neutron doses to workers for the 1952–1958 time period.

- The establishment of the similarity of working conditions for workers in a building in general and for groups of workers within that building between 1959 and the 1952–1958 period.

- If conditions changed, the demonstration of the scientific and statistical validity of the conclusion that 1959 n/p ratios are claimant favorable when applied to the conditions prevailing in the various buildings in each year in the 1952 to 1958 period.

- Validation of the back-extrapolation approach for each building to be reasonably certain that the approach would yield a bounding dose.

- The accuracy and validity of the re-reading of the neutron badges (which by 1959 were NTA badges).

- The problem of badges that could not be re-read for a variety of reasons, such as an inability to locate them or an inability to match them to a particular worker.

- The validity of the statistical model used to develop the n/p ratio approach.

- The general issue of the use of building n/p ratios multiplied by the gamma to dose to estimate neutron doses.

# 5.0 BACK-EXTRAPOLATION FROM 1959 TO THE 1952–1958 PERIOD

NIOSH has stated that 1959 data can be back-extrapolated to the 1952–1958 period because of the essential similarity of working conditions. According to NIOSH, the only material change that occurred in the period was the change in plutonium batch size from about 200 grams to 1,200 grams. NIOSH also stated that a change in batch size would not materially affect the n/p ratio:

> *Arjun [Makhijani]: Were there workers at Plant C* [which includes Building 71] *who are at significant risk of neutron exposure?*
>
> *Roger [Falk]: Yes, they did have the potential for neutron exposure. But there was a batch size change in 1957. Before that year, the batch size was 200 or 220 grams of plutonium; then in 1957 the batch size changed to 1,200 grams per batch. So you have a change of a factor of five or six.*
>
> *Roger: The change in batch size would be expected to have only minimal impact on n/p ratio.*

During the working group meeting of April 19, 2007, NIOSH also stated that the change in batch size would not affect the validity of back-extrapolating from 1959 to the 1952–1958 period, and that this was the only known material change in conditions. NIOSH stated that the other conditions, such as shielding, stayed the same and that it did not see any conditions that would affect the validity of the back-extrapolation.[10]

In point of fact, there were several changes that could affect the validity of the back-extrapolation. These changes require technical investigation as regards their effect on the n/p ratio. For instance, were the changes in batch-size accompanied by changes in the geometry of the containers used for the processing in a manner that affected the n/p ratio? Did such changes affect different work locations in different ways? The most important point is that the change in batch-size did not occur in a vacuum as an isolated technical decision. It occurred in the context of an expansion of Rocky Flats, as well as a change in the design of the plutonium pit that was being produced there. Both these points are noted in Volume 2 of the Rocky Flats site profile:

> ***1956–1957***
> *This period saw the construction of Buildings 447, 776, 777, 883, 997, 998, and 999; and the expansion of Buildings 444, 881, and 771[also called Building 71].* ***These additions were directly related to the change of the weapon concept to a hollow unit and anticipated production increases.*** (Flack and Meyer 2004, p. 7, emphasis added)

Hence the change in batch size in 1957 occurred during an expansion of Building 71 (among others). It follows that a large amount of new plutonium processing equipment was installed in 1956 and 1957 at Rocky Flats. The NDRP did not investigate how much of the work in 1959

[10] The transcript of the working group meeting was not available at the time of this writing. SC&A notes of some of the points during the conference call have been used in this paragraph.

was on new equipment and how that might change the n/p ratio between the pre-1956 period and 1959. Neither the NDRP nor NIOSH have addressed issues such as the automation of production, training of workers, increasing experience of workers, and other issues connected with a large increase in the scale of production.

The matter of the expansion in 1956–1957 was discussed during the April 24, 2007, conference call with NIOSH and Roger Falk (Attachment 4). During that time, it became apparent that the nature of the changes was extensive and affected major portions of the operations in Building 71 and Building 91:

- A new chemistry line was added in Building 71. This dominated the n/p ratios in 1959.

- The Building 71 operation was changed from remote-controlled to manual. In the early years, the remote-controlled operation gave rise to frequent clogging of the lines, which have to be manually cleared by maintenance. This was a part of "lessons learned" and the change was an attempt to reduce maintenance dose. Roger Falk opined that the increase in the dose from manual operations would be greater than the decrease due to elimination of frequent manual unclogging of the lines.

- Metal operations were transferred from Building 71 to Building 76, a new building built in 1956–1957.

- Weapons assembly operations were transferred from Building 91 to Building 77.

There were also other major changes that could have materially affected the back-extrapolation. For instance, a new plutonium waste incinerator was installed in Rocky Flats in 1958:

> *In 1958, an incinerator used for burning plutonium-contaminated waste was installed in Building 771. The incinerator was the only one of its kind in the country and perhaps in the world. Designed and built by plant personnel, the prototype functioned like an industrial incinerator but its real heart was a series of filters, scrubbers and heat exchangers designed to purify toxic gases and other byproducts of the burning process.* [Buffer, no date, p. 4]

According to the Rocky Flats site profile, there was also a "major facility expansion" at Rocky Flats in 1955 (Flack and Meyer 2004, p. 7). However, the site profile is lacking in details of this facility expansion and in which buildings it occurred. Roger Falk stated that the reference to the major facility change in 1955 was likely the funding and design of the facilities built in 1956 and 1957. SC&A has not independently investigated the changes referred to in 1955.

Finally, there was a plutonium fire at Rocky Flats in 1957 that started in a stainless steel glovebox. The TBD lacks detail as to whether this led to glovebox redesign and whether such redesign may have been integrated into the expansion of Building 71. Roger Falk stated that the fire accelerated the various changes discussed above, including the transfer of metalworking operations from Building 71 to Building 76 (Attachment 4).

It is clear that the changes in types of work, the equipment, radiological conditions, and other factors were so large that the new configurations and equipment would drive the 1959 n/p ratios. Therefore, even if the NIOSH argument that the change in plutonium batch size, by itself, had only a minimal effect on the n/p ratio, the other changes would be expected to produce significantly different radiological conditions for both neutron and gamma exposure in 1959 compared to the earlier period. Furthermore, the operations in Buildings 76 and 77 were in new equipment that was built in 1956 and 1957.

Neither the NDRP nor NIOSH have quantitatively evaluated the effect of the large changes in Buildings 71 and 91 on the back-extrapolation of n/p ratios from 1959 to the earlier period. In the April 24, 2007 conference call, NIOSH asserted that the changes would be expected to result in claimant-favorable n/p ratios for the purpose of calculating 1952–1958 neutron doses. However, SC&A notes that the goal of the NDRP was to produce best estimates. This was affirmed by Roger Falk during the conference call of April 12, 2007, when he also stated that where a choice had to be made, it was done in a claimant-favorable way (Attachment 2).

As things stand, the NIOSH claim that the 1959 n/p ratios were claimant favorable when applied to the 1952–1958 is without demonstrable analytical or scientific foundation. Therefore, it cannot be considered scientifically credible unless it is supported by an extensive analysis of the many significant changes discussed above. This has not been done. At present, the net effect of the changes on the 1959 n/p ratio as it would apply to the earlier period has not been evaluated and is unknown.

Moreover, it is unclear whether any amount of effort could result in a scientifically defensible method of estimating the neutron doses of unmonitored workers in Building 71 in the 1952–1958 period. This is because of the near total absence of any comparable data from the period with which to directly validate the NDRP approach for estimating notional neutron doses for the 1952 to 1958 period for Building 71. For instance, area neutron monitoring data and dose rates may help in such an exercise, but such data do not exist. And if they did, they may be difficult to use for validation due to the practice of workers following a plutonium batch from start to finish. However, if they did exist, they might provide dose rates that could be combined with interviews as a partial validation approach. We note that the NDRP tried, but could not find a way to validate the approach, as noted by Roger Falk during the March 28, 2007, conference call (Attachment 1):

> *Ron [Buchanan]: Are there area neutron measurements from area monitoring or calibration modeling?*
>
> *Brant [Ulsh]: You are not going to find neutron surveys. There are calibration surveys.*
>
> *Roger [Falk]: But we have not found that for the 1950s. The first study was for 1962.*
>
> *Ron: Los Alamos was doing calibration, but there is no documentation that they went to Rocky Flats.*

*Roger: We searched very diligently for validation data. We did not find anything for the 1950s that would allow us to do our own benchmarking.*

*Brant: Did you do experiments that would be expected to bound conditions at Rocky Flats?*

*Roger: The process where they put Pu through the flouridator was the highest neutron source.*

*Brant: We don't have field surveys. But there is a laboratory study from the 1960s.*

*Roger: The Mann-Boss study was in 1962, and I did my studies in 1967 and 1968.*

*Arjun [Makhijani]: Let me get this accurately for the notes. Here is what I understood you to say, Roger. You tried hard to find some field data on neutron exposure for the plutonium areas where workers were not monitored in the 1950s to validate your NDRP notional dose assignments. Despite these efforts, you were not able to find any. Right?*

*Roger: Yes, that is right. We discussed this topic in the formal interview that you conducted with me.*

SC&A again discussed the question of validation of the NDRP approach of using 1959 n/p ratios for the 1952 to 1958 period with NIOSH and Roger Falk on April 25, 2007. This reaffirmed SC&A's conclusion that there are no data on which the back-extrapolation of a 1959 n/p ratio for Building 71 can be validated for use in the 1952 to 1958 period.

We will address Building 91 in the next Section.

**Finding 4: There were several changes at Rocky Flats in the 1955 to 1958 period that were likely to materially affect gamma and neutron doses, and therefore their ratios. These factors were not quantitatively investigated in the NDRP or by NIOSH as part of the decision to use 1959 building n/p ratios for estimating 1952–1958 individual neutron doses. NIOSH's claim, made on April 25, 2007, that the 1959 n/p ratios are claimant favorable if used for 1952-1958 neutron dose estimation has no demonstrable analytical or scientific foundation at present. It would require a detailed investigation of the effect of the extensive differences between 1959 and earlier years. In view of the lack of data for validation of Building 71 dose estimates for the 1952-1958 period, it is unclear whether any amount of effort could result in a scientifically defensible method of estimating the neutron doses of unmonitored workers in Building 71.**

# 6.0 VARIABILITY OF WORKING CONDITIONS WITHIN THE 1952–1958 PERIOD, BUILDING 91

The changes at Rocky Flats discussed above occurred at various times within the 1952 to 1958 period. *A priori*, this argues against the application of a single n/p ratio per building to the entire period. Since data are available for the 1952–1956 period and for 1959 for Building 91, an indicative check is possible for this building. It cannot be definitive, since the data for the 1952–1956 period are sparse.

Building 91 badges were issued monthly during 1952 to 1956, and also during 1959. Figure 2 shows a scatter plot of Building 91 paired neutron and gamma 1959 data (zero gamma doses are set equal to 1, following the NDRP practice). A linear regression line (non-forced) is also shown. It is clear that individual neutron doses are uncorrelated with the corresponding gamma doses ($r^2$ = 0.007). A very nearly constant value of about 60 mrem per badge, independent of the gamma dose, is returned by the linear regression (the intercept is about 66 mrem).

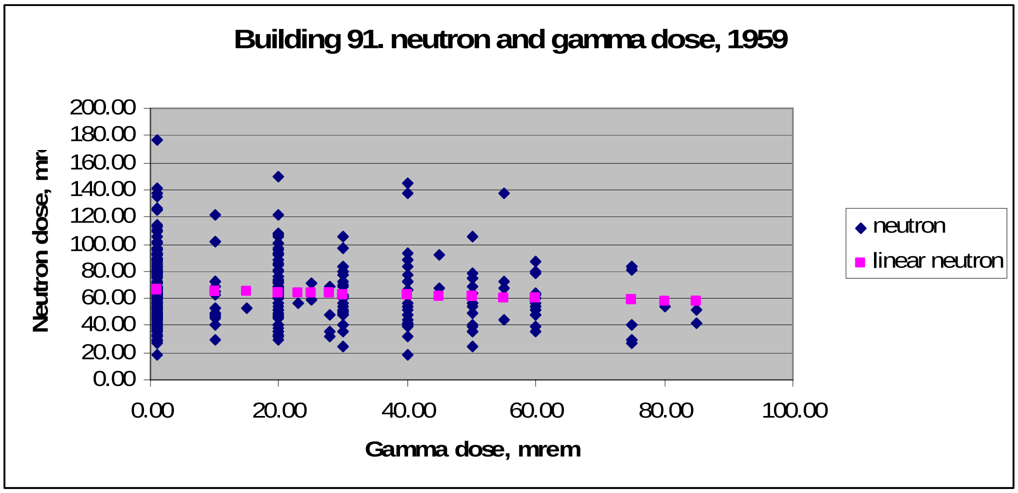


**Figure 2: Neutron and Gamma Dose Scatter Plot, 1959, with a Non-forced Linear Regression shown ("linear neutron")**

In addition, the data for 1952 to 1958 generally show a lack of correlation between neutron and gamma doses. Figures 3 through 7 show scatter plots of the paired neutron and gamma data and the corresponding regression lines. Except for 1953, where there is a slight negative correlation ($r^2$ = 0.035), the individual neutron and gamma badge readings are essentially uncorrelated, with $r^2 << 0.01$ in all cases.

One feature of these plots that is important for a comparison of working conditions is the typical neutron readings for individual badge cycles (all of them being about 1 month). The readings show a wide variation over the period, with the highest individual readings occurring in 1953, followed by 1952. Generally, the lower readings per badge cycle occur in 1959.

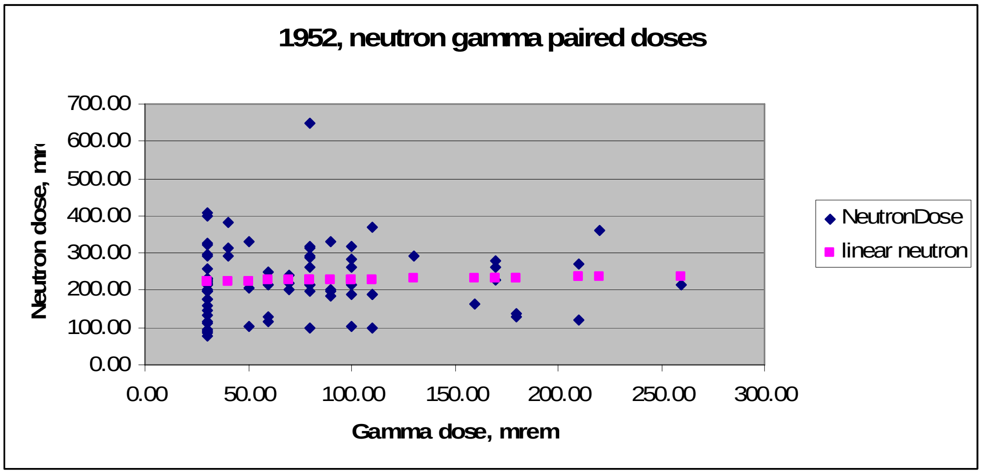


**Figure 3: Neutron and Gamma Dose Scatter Plot, 1952, with a Non-forced Linear Regression shown ("linear neutron")**

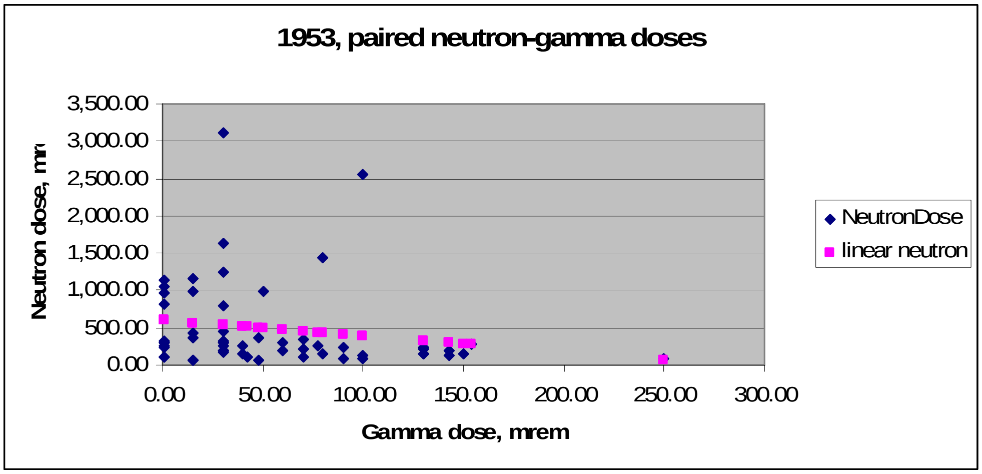


**Figure 4: Neutron and Gamma Dose Scatter Plot, 1953, with a Non-forced Linear Regression shown ("linear neutron")**

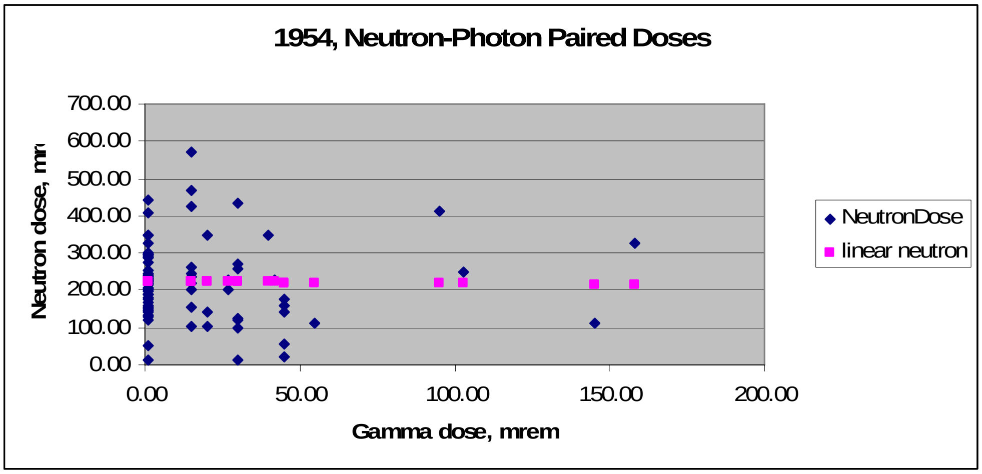


**Figure 5: Neutron and Gamma Dose Scatter Plot, 1954, with a Non-forced Linear Regression shown ("linear neutron")**

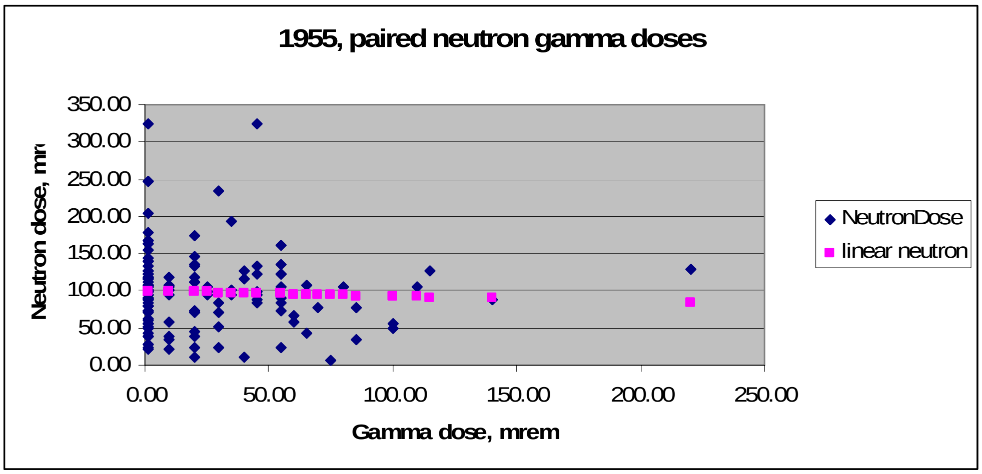


**Figure 6: Neutron and Gamma Dose Scatter Plot, 1955, with a Non-forced Linear Regression shown ("linear neutron")**

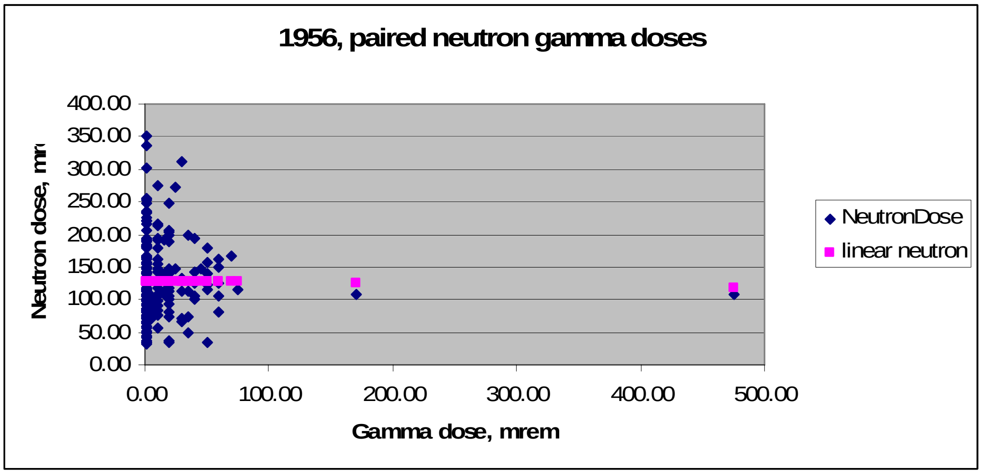


**Figure 7: Neutron and Gamma Dose Scatter Plot, 1956, with a Non-forced Linear Regression shown ("linear neutron")**

A similar result is obtained if one compares the neutron dose values per day for the various years under consideration. Table 3 shows the average values of neutron dose per day in the period for Building 91.

**Table 3: Average Daily Neutron Exposure, 1952–1959, mrem/day, Building 91**

| Year | mrem/day |
|---|---|
| 1952 | 6.79 |
| 1953 | 14.45 |
| 1954 | 5.55 |
| 1955 | 2.66 |
| 1956 | 4.07 |
| 1959 | 2.20 |

It is evident that typical or average exposures were declining overall in the first few years (except for the transition from the startup year of 1952 to 1953). This could be due to changes in working conditions, the nature of the source term, and/or the addition of workers into the monitoring program. The latter occurred in 1955 and 1956, when the number of workers in Building 91 covered by neutron monitoring approximately doubled compared to the 1952–1954 period, as indicated by the recovered paired badged data. There are only very scattered data for Building 91 for 1957 and 1958.

During the working group meeting on Rocky Flats of April 19, 2007, NIOSH acknowledged that the judgment of the health physics professionals who decided to monitor Building 91 workers because they were thought to be most at risk was in error, since workers who were at significant risk in Building 71 were not monitored.[11] SC&A's analysis points in the same direction.

NIOSH made a somewhat different statement in a conference call on April 24, 2007. It withdrew its conclusion that the judgment of the health physics professionals of the time was in error, and stated that the workers who got the highest doses were different from the ones judged to be at highest risk, because the latter were well protected from the risks. At the same time, NIOSH's site expert, Roger Falk, stated that the neutron exposure risk came from a special neutron source, which was the cause of concern (Attachment 4). This would explain the higher dose rates in the early years. However, the statement appears to be at variance with NIOSH statements in the same conference call that while workers in Building 91 were monitored for neutrons because they were thought to be at high risk, the actual exposures were lower due to sound health physics protection (Attachment 4). SC&A's analysis indicates that Building 91 exposures may have been on the high side relative to Building 71 in some areas and times during 1952–1958, but not others. This analysis, presented above in Section 2, is only indicative rather than definitive, for reasons previously discussed.

High neutron dose rates may have been experienced by a particular segment of workers in Building 91 in 1952 and 1953. The cause of the significant decline in the average measured dose rates in 1954 is unclear if the same group of workers was of concern in that year. The sharp drop in average dose rates in 1955 and 1956 also occurred prior to the transfer of assembly operations to Building 77 (since Building 77 had not yet gone into operation). In view of the increase in the number of monitored workers in 1955 and 1956 compared to earlier years, it is possible that a different group of workers was monitored, as well. Other explanations, such as better radiological protection, more experience in handling the neutron source, or a change in the neutron source are also possible. A detailed, most likely classified investigation would be necessary to analyze the changes in neutron dose rates in Building 91.

As discussed above, weapons assembly operations were transferred from Building 91 to Building 77 in 1957 (see Attachment 4). This means that work in 1959 in Building 91 was fundamentally different than in earlier years, when the assembly took place in Building 91 and the neutron source was handled there. There appears to have been monitoring of a very small group of specialized workers in Building 91 in the early years, making inferences for other groups of workers from their experience essentially impossible. Furthermore, Building 77 assembly operations took place in a new building with new equipment; this experience is unlikely to be a satisfactory guide for the early Building 91 period.

Of course, an investigation of gamma doses is also needed if the net effect of the various changes that occurred during the 1956–1958 period on the n/p ratio is to be determined. But in view of the fact that individual neutron and gamma badge readings are approximately uncorrelated for essentially the whole period, the changes in neutron dose alone are also significant and indicate a lack of comparability of working conditions between 1959 and the 1952–1956 period. This lack of comparability is likely to be at least partly or largely due to the change in the work done in Building 91 in 1957–1958 period.

[11] The working group meeting transcript was not available at the time of this writing. SC&A took notes on this and some other points during the meeting. This statement is based on those notes.

**Finding 5: The results derived from the use of the 1959 Building 91 n/p ratio for the 1952 to 1958 period has not been validated. The data for Building 91 strongly indicate a lack of comparability between Building 91 neutron exposure in 1959 and earlier years, notably the 1952–1956 period. The neutron dose rate in 1959 was much lower than the rates in earlier years, which were themselves very variable. They appear related, at least in part, to the changes in the work that was done in Building 91 due to the transfer of assembly operations to Building 77. The factors that caused the lower dose rates in the later years in the 1950s were not analyzed in the NDRP. The NIOSH claim that the back-extrapolation of 1959 n/p ratio would be claimant favorable does not have a scientific foundation at present, since a quantitative analysis of the transfer of operations and other changes on the n/p ratio has not been done. An extensive analysis would be necessary before it can be determined whether it is reasonable to use the Building 91 1959 n/p ratio for the earlier period. In view of the sparse and highly selective monitoring in the early period in Building 91 (oriented to a particular group of workers thought to be at special risk), it is unclear whether such an analysis can provide a scientifically defensible result.**

# 7.0 JOB TYPES

The comparability of radiological conditions in 1959 to the 1952–1958 period depends, in part, on the constancy of the main job types that were being done across the 1952–1959 period. Furthermore, the averaging of the neutron and photon doses over a whole building to estimate an n/p ratio has in it an implicit assumption that individual doses can be computed from building averages with sufficient accuracy. NIOSH has stated that the 1959 workers were not specialized at a single workstation in Building 71, but rather followed a particular plutonium batch from the start of processing to the finish. This would appear to justify the use of a single building n/p ratio, at least implicitly.

However, the 1959 data indicate more than one job type in relation to neutron exposures. For instance, an examination of the average neutron dose rates experienced by individual workers in 1959 in Building 71 indicates that some workers' dose rates cluster around ~10 mrem/day, while others are in the ~1 to 2 mrem/day range. This indicates (but does not prove) that more than one job type existed from the point of view of neutron exposure conditions. An analysis of the neutron and gamma dose data by job type is highly desirable to establish the reasonableness of using a single building n/p ratio for estimating individual dose.

The issue of job types for 1952 to 1958 dose estimation is complicated by the changes that occurred in that period. For instance, the addition of an incinerator in 1958 in Building 71 created new job types. The expansions, new design of the weapon, the addition of a new incinerator, and the changes in the methods of handling plutonium likely created new job types, at least from the standpoint of exposure conditions. For instance, the frequent clogging of plutonium lines in the early years necessitated manual clearing and likely high exposure potential situations. This was addressed during the expansion of Building 71 by a redesign of plutonium handling from remote to manual. Roger Falk has stated that this would increase dose from routine operations while decreasing maintenance-related dose. The net effect was stated by Roger Falk to be an increase in neutron dose. However, the actual net effect is unknown, since there are essentially no data from the 1952 to 1958 period against which to compare the 1959 doses and hence determine the net effect.

A study of the ratios of paired daily neutron and exposure rates would be needed to determine if there are distinct job categories, so far as n/p ratios are concerned. This would appear to be a prerequisite to determining the validity of using a building n/p ratio for estimating individual notional neutron dose. The NDRP did not carry out such an analysis. It did consider several approaches and selected building n/p ratios. The averaging of job types is implicit in such a selection, and there is a potential for underestimating dose for some groups of workers, notably those in situations with relatively high neutron dose rates and low gamma dose rates. Paired neutron-gamma data make it clear that such situations were quite common. Figure 8 shows such paired data for Building 71 for 1959. A linear regression line is also shown (though the correlation is poor, $r^2 = 0.025$).

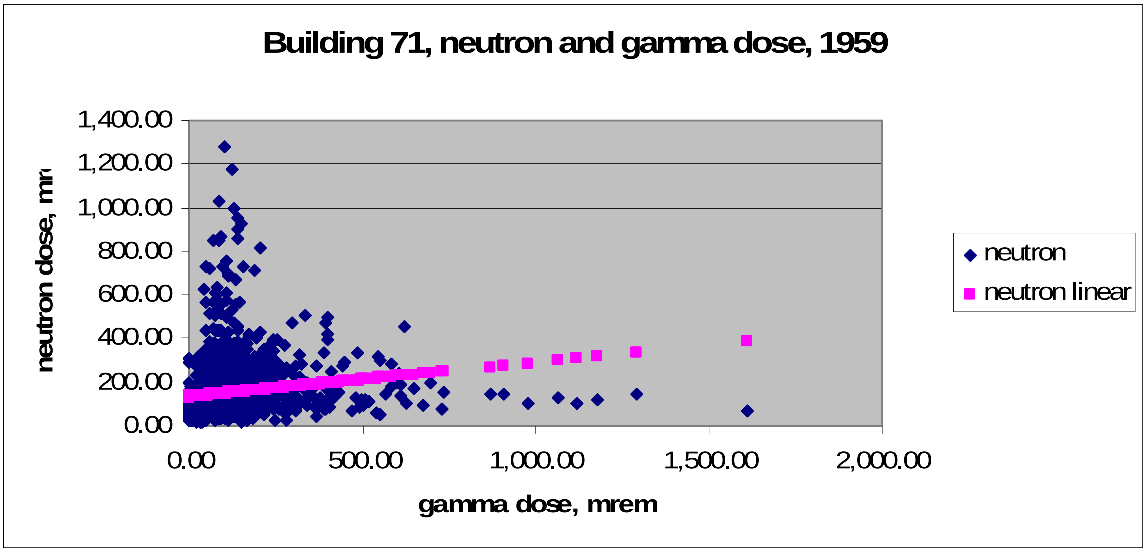


**Figure 8: 1959 Matched Pairs for Building 71**

It is clear that a low gamma dose (less than LOD) could be accompanied by high neutron doses of a few hundred millirem even in a single badge cycle and vice versa.

The choice made by the NDRP to aggregate neutron and gamma doses by building and take the ratio of the averages is inherently oriented towards reducing variability by averaging building doses. However, this approach masks the real individual variations in neutron and gamma exposure by the very reason of its reduction of variability by a resort to building averages. This is demonstrated by the more uncertain results yielded by the n/p ratio method of estimating neutron dose, compared to the method of using the individual's own nearby dose to fill intra-year gaps (ORISE 2005, Section 12.5.2).

The necessity for a job-type analysis is also indicated by the lack of systematic claimant favorability in the notional dose estimated by the n/p method compared to the actual measured dose (see Section 8).

**Finding 6: Development of n/p ratios by job is necessary to test whether the method of using building n/p ratios for estimating neutron doses is adequate for all groups of workers in a building.**

# 8.0 1959–1970 NOTIONAL DOSES

The 1959–1970 period is different from the 1952–1958 period in that neutron and gamma dose are available for all production buildings at issue here, as well as Buildings 21, 22, and 23. The amount of data tends to increase with time as more workers were brought into the monitoring program. The NDRP neutron dose estimates for this period consist of the sum of three components:

- A measured dose component, which is the amount of dose as registered on NTA badges as re-read by the NDRP.
- The non-re-read portion, which is the amount of dose that could not be re-read for a variety of reasons, including non-recovery of a badge or inability to match a badge to a year or worker.
- A notional dose, estimated in one of two different ways, to fill gaps in neutron monitoring. The notional dose could be for an entire year if there are no badge data for that person for that year, or it may consist of a partial year estimate to fill in gaps that are less than 1 year.

We will deal with the first two items in subsequent sections. In this section we consider notional doses. The NDRP considered a variety of ways to fill in gaps in a worker's neutron monitoring record and settled on a combination of two methods:

- Intra-year gaps that were short that could be filled by the worker's own nearby measured doses.
- Full year gaps or long gaps within the year that were filled in by multiplying the average building n/p ratio for a whole building for an entire year to the gamma dose measured during the period of the gap.

The two were combined by time-weighting them—the weighting given to the nearby dose is the proportion of the time for which the worker had neutron monitoring in that year. Hence, if there is no monitoring, the entire dose is estimated from the n/p ratio. (ORISE 2005, Appendix IV). The goal of the NDRP was to make best estimates of worker neutron doses by re-reading badges and filling in the gaps in the most accurate way possible:

> *The purpose of the Neutron Dose Reconstruction Project (NDRP) is to provide to current and former radiation workers of the Rocky Flats Environmental Technology Site (hereafter designated as Rocky Flats) the best reasonably achievable assessment of the neutron exposure they received while performing work in the plutonium production facilities from 1952 through 1970.*
>
> *This protocol describes the methods and technical basis used by the NDRP to reassess these neutron doses, either by rereading neutron films and plates used to monitor workers for neutron exposures or by estimating the neutron doses for*

> *periods of time when a worker was not monitored for neutron exposures in a plutonium-related building.* [ORISE 2005, p. 1]

Roger Falk stated that claimant-favorable choices were made on occasion during the process. A simple test can reveal whether the estimated notional dose is a best estimate with claimant-favorable features built in when there are uncertainties.

SC&A randomly chose one worker from Building 71 and one from Building 91 for each year in the 1959–1969 period, with the restriction that the worker have at least 6 months of paired neutron-gamma dose data (the NDRP did not calculate notional doses for 1970). SC&A then computed a notional dose for the worker for the same period using the n/p ratio provided by the NDRP for that building and that year. This was done to determine whether the notional dose was comparable to or greater than the measured dose (as re-read by the NDRP). The NDRP itself seems to have done such a test, but the results of such a comparison for individual doses are not provided in ORISE 2005. Table 4 shows the results of the analysis.

**Table 4: Ratios of Notional to Measured Neutron Doses for Individual Workers, 1959–1970**

| Year | Building 71 notional/ measured | Building 91 Notional/ measured |
|---|---|---|
| **1959** | 65% | 150% |
| **1960** | 83% | 49% |
| **1961** | 94% | 74% |
| **1962** | 91% | 63% |
| **1963** | 39% | 99% |
| **1964** | 22% | 53% |
| **1965** | 77% | 80% |
| **1966** | 23% | 94% |
| **1967** | 26% | (See Note 1) |
| **1968** | 46% | 115% |
| **1969** | 70% | 374% |
| ***% of years bounded: (Note 2)*** | ***0%*** | ***30%*** |

Note 1: No data were available for Building 91 for 1967.
Note 2: "Bounded" is defined as 100% or more. If the 99% value for 1963 is included by rounding up, the percentage for Building 91 would be 40%.
Data taken from: O-drive - AB Doc - Rocky Flats - NDRP - Copy of NDRP_BE_20070319 - *tblBetaGammaNeturon Matches and tblNDRPData*

For Building 71, the notional dose was 90% or more of the measured dose in only 2 out of 11 cases in consecutive years (1961 and 1962). It was below 50% of the measured dose in 5 out of 11 cases, all in the period 1963–1969. In the latter period, the notional dose was less than 50% of the measured dose in 5 out of 7 years. A strict bounding (ratio equal to or greater than 100%) was obtained in only 3 out of 21 cases (4 out of 21 if the 99% value is rounded up).

The results for Building 91 were somewhat better, with the notional dose being greater than 90% of the measured dose in half the cases, and less than 50% in only one case, where it was close—

49%. The SC&A analysis is illustrative only, and should not be interpreted as a statistically significant result. However, it provides a sufficient basis to question whether the building n/p ratios would provide a uniformly claimant-favorable or best-estimate dose. In a technical conference call with SC&A (April 24, 2007), NIOSH claimed that the NDRP dose was not intended to be a bounding estimate, but rather a best estimate (Attachment 4). This analysis indicates that the portion of the notional dose estimated from n/p ratios may not meet this test. SC&A also notes that the NDRP has presented no statistical analysis comparing individual measured doses to doses estimated using the n/p notional dose method to test whether the goal of actually producing an individual best estimate was uniformly fulfilled. The analysis above in Table 4 indicates that such an analysis is necessary before notional dose estimates can be regarded as best estimates that are claimant favorable when parameter choice is an issue.

The NDRP itself recognized the notional dose as "somewhat speculative" (as a whole), with the portion being calculated from n/p ratios as being more uncertain than that calculated from a worker's own nearby dose in the year in question. The latter approach is not available for the 1952–1958 period for most workers. Of all the notional dose assignments, the estimates for the period 1952–1958 were considered by Roger Falk, the expert whose judgments are at the center of the NDRP, to be the most speculative of the lot (relatively speaking). According to the draft notes of the April 17, 2007, conference call:

> ***Roger [Falk]:*** *Yes, I agree that notional doses are basically estimates and they are our best shot at estimating the unmonitored neutron dose. They are more speculative the farther back we extrapolate. So the 1952–1958 period would be the more speculative part. As you got more and more workers monitored with NTA film in the 1960s, the method of using the average neutron dose as the estimator of the notional dose becomes more important [more heavily weighted in the notional dose estimate, discernable from the weighting factors in the notional dose equations in a worker's "Individual Timeline" [NDRP report]. Then the notional dose becomes less and less speculative.*

We have already discussed one source of the problem—a lack of n/p ratios by job type. The fact that workers were moving with a batch of plutonium did not smooth out exposure sufficiently for all job types to have been similarly exposed, since there appear to be clusters of dose rates among workers, rather than a general dose rate with a small variance that applies to the whole building. Furthermore, the clustering of neutron dose rates does not appear to increase in the 1960s when the transition took place to specialized work at a single workstation, in contrast to a worker following a batch of plutonium from start to finish. This indicates that production of different types, maintenance, handling, and other work connected to processing of plutonium at Rocky Flats was more complex than is represented by a building n/p ratio, so far as individual dose estimation is concern.

The notional dose estimates with the largest element of uncertainty are the ones that are estimated entirely or almost entirely from a building n/p ratio. This proportion of workers in this category varied by year. Since monitoring coverage took a sharp jump in 1964, the coverage from 1965 onward would be expected to be better. Figures 9 though 14 show that for most years from 1959 to 1964, a large number of workers had their entire neutron dose estimated from a building n/p ratio, including those with the higher estimated doses. In 1959 and 1960, the results were more mixed.

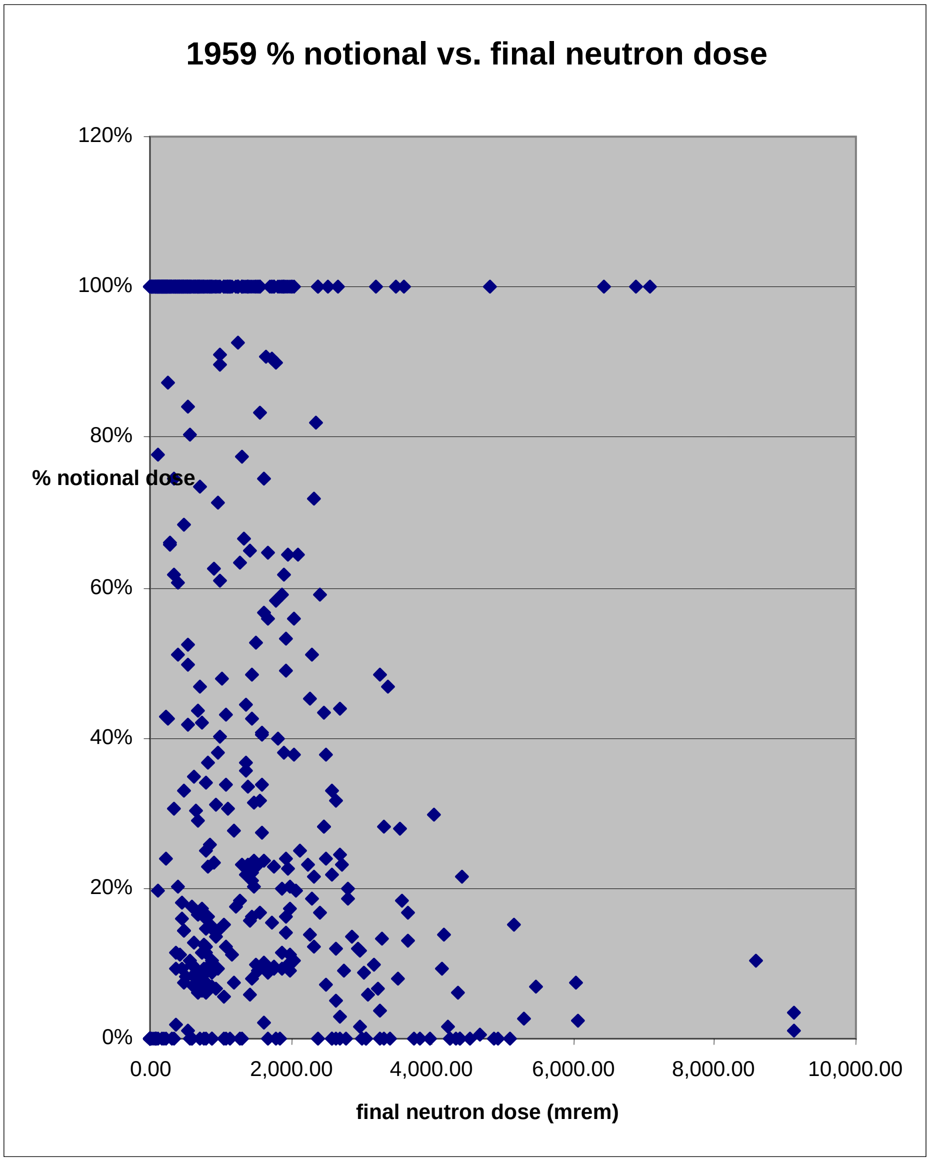


**Figure 9: Percent Notional Dose compared to Total Neutron Dose Estimate, 1959**

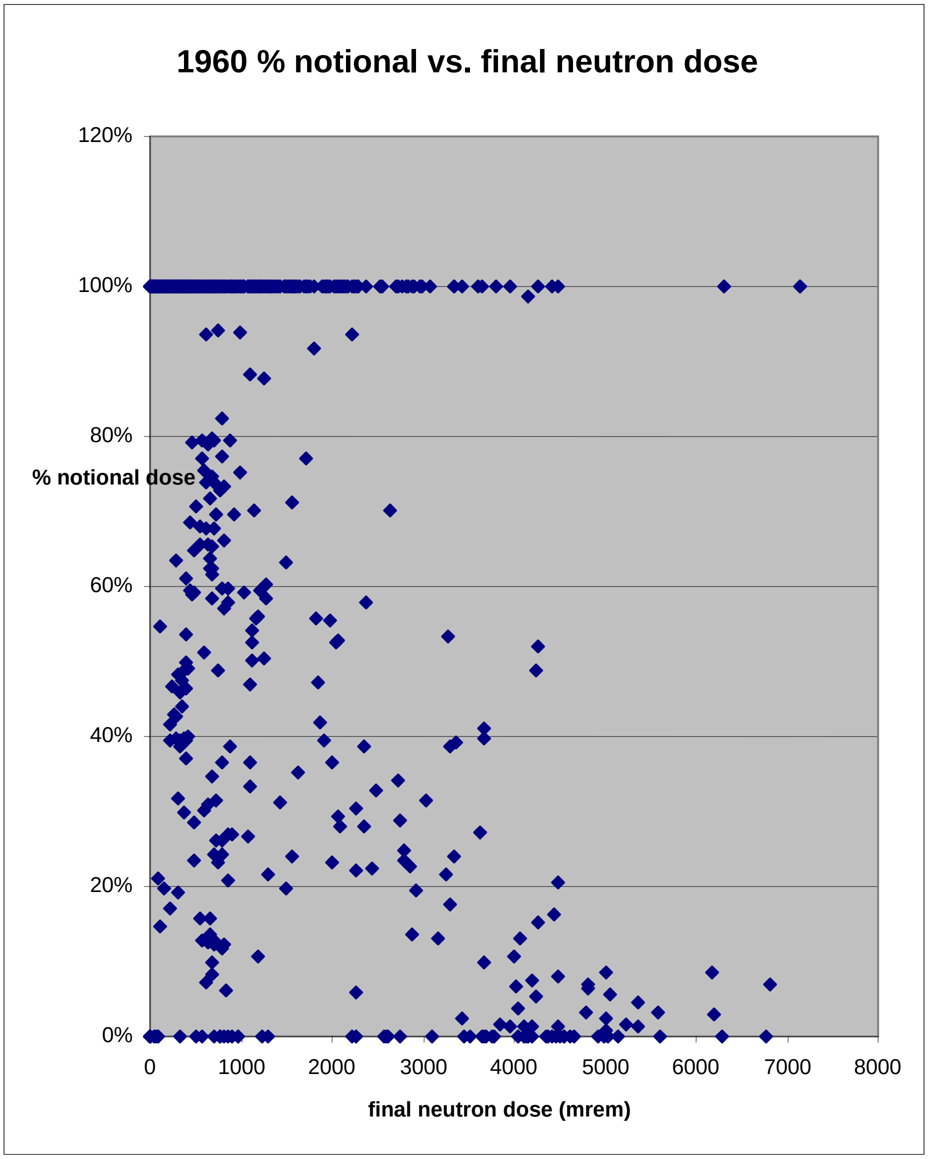


**Figure 10: Percent Notional Dose compared to Total Neutron Dose Estimate, 1960**

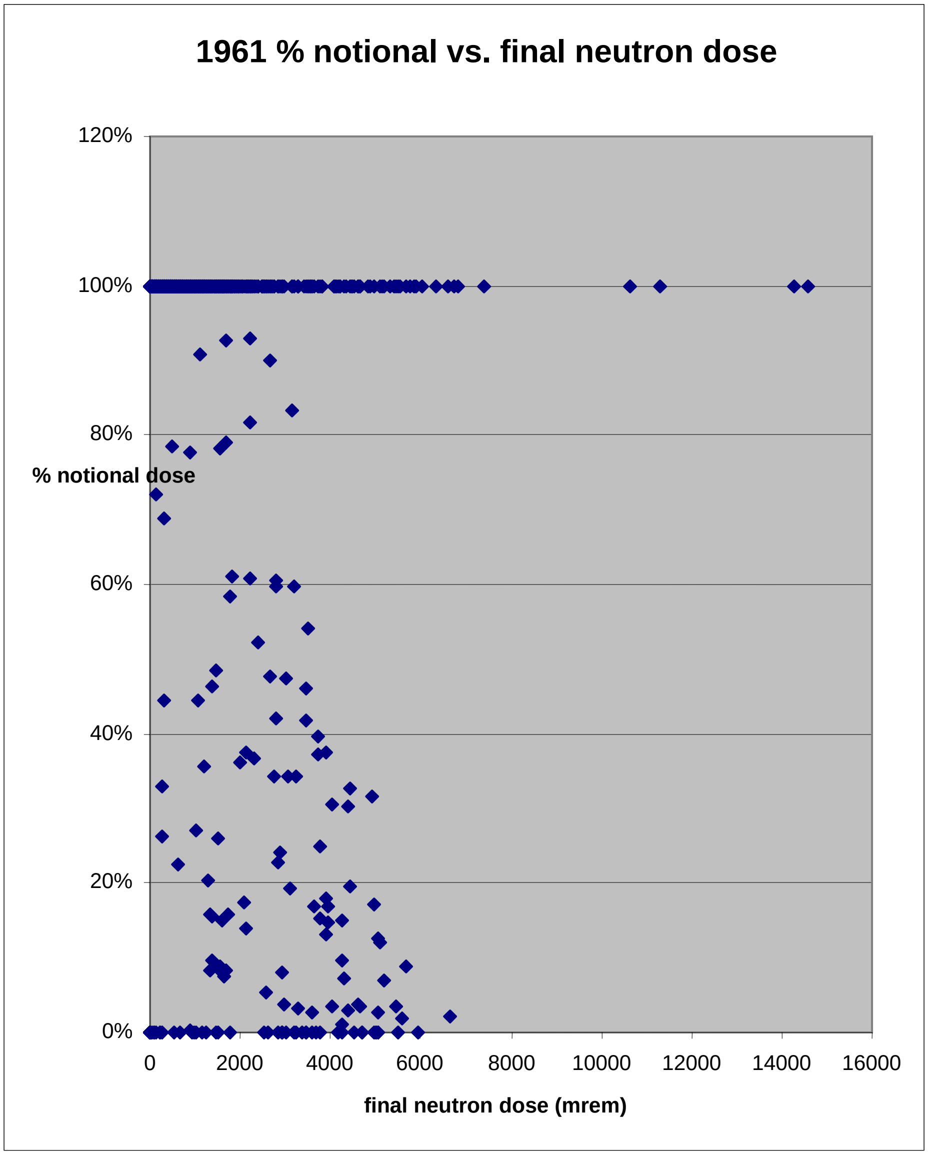


**Figure 11: Percent Notional Dose compared to Total Neutron Dose Estimate, 1961**

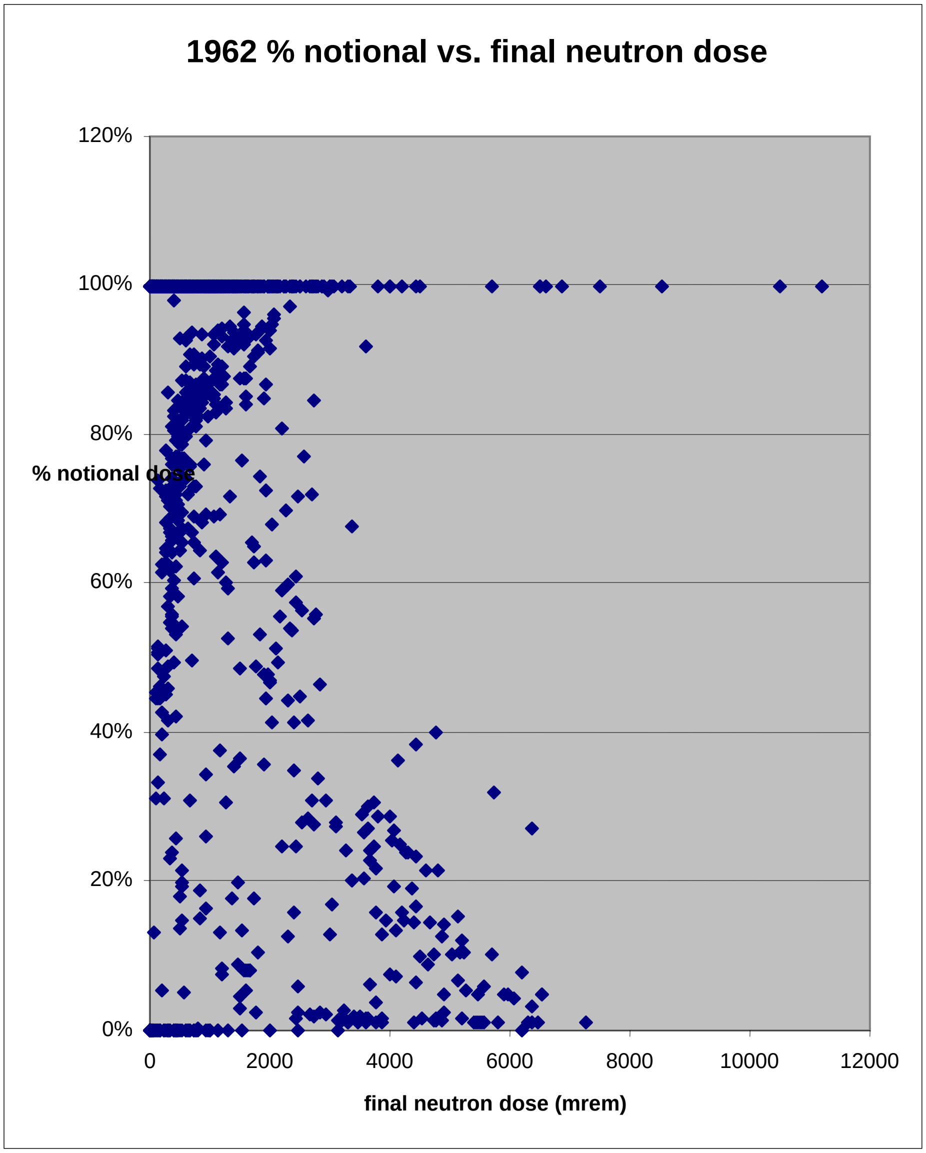


**Figure 12: Percent Notional Dose compared to Total Neutron Dose Estimate, 1962**

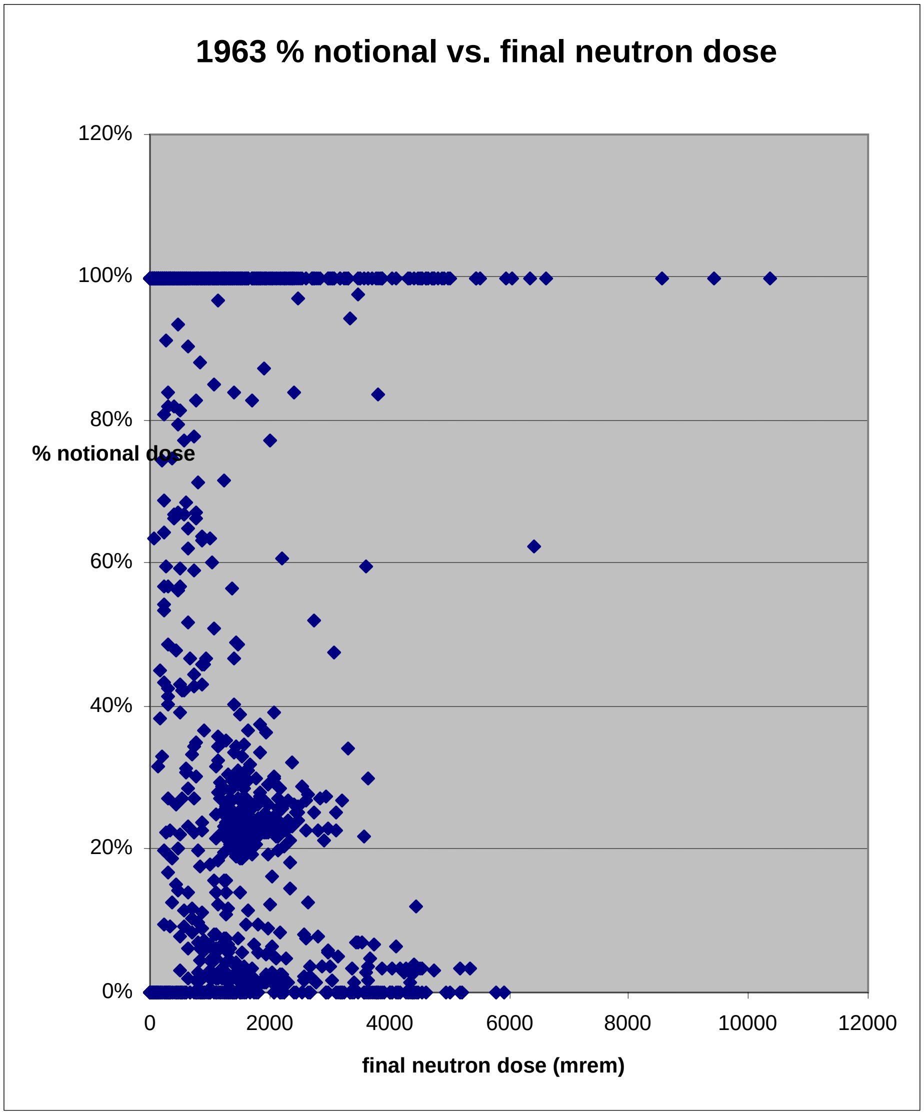


**Figure 13: Percent Notional Dose compared to Total Neutron Dose Estimate, 1963**

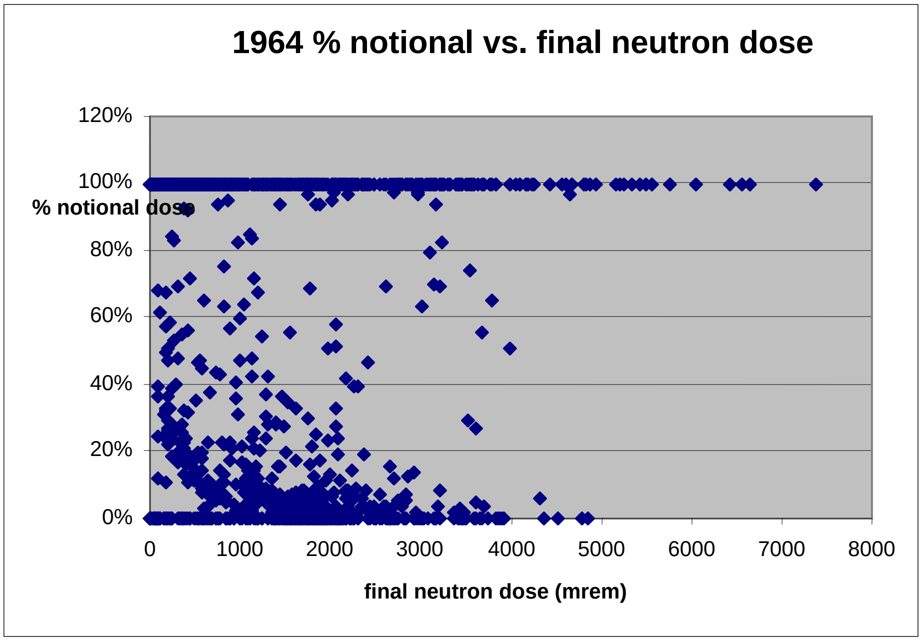


**Figure 14: Percent Notional Dose compared to Total Neutron Dose Estimate, 1964**

When many of the high dose estimates are 100% notional doses, it indicates that there may have been gaps in coverage of the more exposed workers in this period. As noted before, a conclusion based on a comparison of notional dose with measured dose (the 0% notional dose dots in the above figures) is of limited significance, due to the uncertainties in the n/p ratio method and some claimant-favorable features that may be in the notional dose estimate. Nonetheless, the contrast with 1965 is interesting, because the same comparison yields a different result. In that year, the highest estimated exposures were for those workers who have full-year or partial-year monitoring, while the ones with no monitoring generally had lower total estimated doses. This is shown in Figure 15.

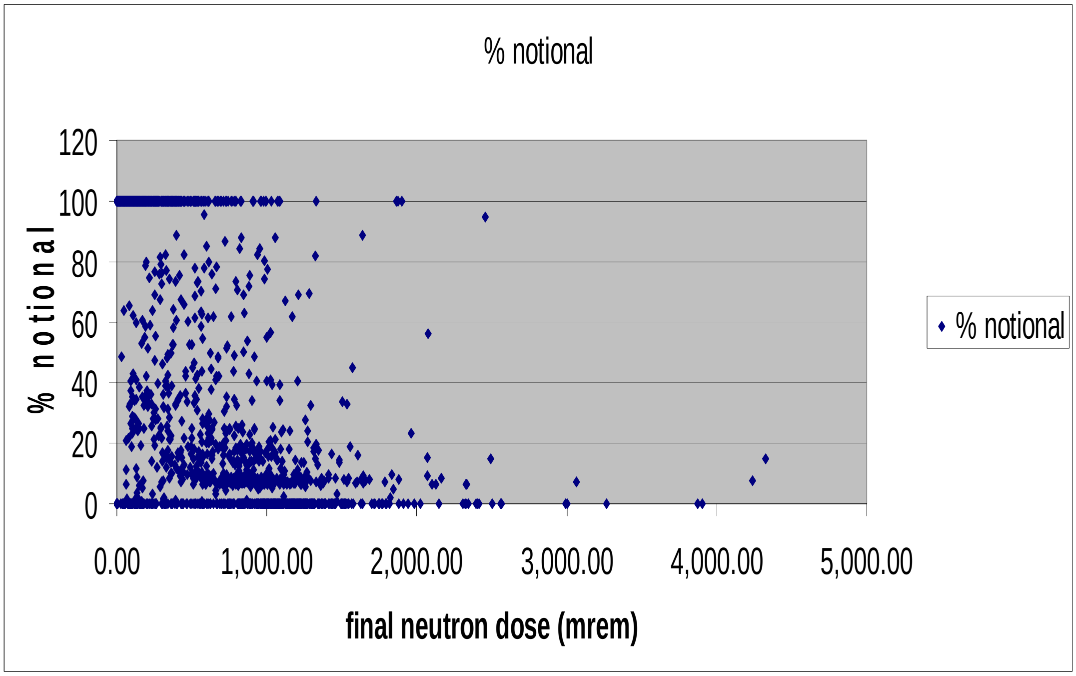


**Figure 15: Percent Notional Dose compared to Total Neutron Dose Estimate, 1965**

A similar pattern is evident in the other years in the 1966-1969 period (no notional doses were calculated for 1970).

There are also some statistical questions associated with the n/p ratio approach to estimating notional dose adopted by the NDRP beyond the question of aggregation at the level of a building. The model assumes that individual neutron doses are proportional to individual gamma doses. However, when an individual n/p ratio was tested as a predictor of the individual's own neutron dose in a nearby period, the results were unsatisfactory, which is one reason why the building n/p ratio was developed (ORISE 2005, Section 12 and Appendix IV).

The basic equation of proportionality is given as follows:

$$N_i = \beta g_i + e_i,$$

where $\beta$ is the n/p ratio, $N_i$ is the true dose and $g_i$ is the gamma dose for measurement i (ORISE 2005, Section 12.5).

In the model adopted by the NDRP, the expected value of the error is zero for the true dose (which is not known) and for the measured dose. The analysis of paired measurements shows that this is not even close, since paired gamma and neutron data are not closely correlated. For instance, the r-squared for paired data for 1961 for Building 71 is only 0.022, while that for 1963 is 0.16. As noted above, the value for 1959 is 0.025.

Moreover, non-forced linear regressions generally show a substantial intercept (see Figure 8), indicating a positive neutron dose when the gamma dose is zero. Hence, the NDRP model does not adequately reflect the realities of the measured dose data, even if the model adopted might reduce errors overall.

As a final point, the n/p ratios in the NDRP for Building 91 for 1961–1964 differ significantly in some cases from those calculated by SC&A from the NDRP database. Table 5 shows the two sets of Building 91 ratios.

**Table 5: Annual Average n/p ratios for Building 91, 1959–1964**

| Year | Bldg. | # of data pts | SC&A Calculated n/p (paired values) | NRDP n/p value | SC&A/NDRP ratio |
|---|---|---|---|---|---|
| 1959 | 91 | 387 | 4.03 | 3.6 | 1.1 |
| 1960 | 91 | 282 | 8.21 | 6.8 | 1.2 |
| 1961 | 91 | 102 | 16.19 | 7.4 | 2.1 |
| 1962 | 91 | 71 | 23.94 | 10[a] | 2.4 |
| 1963 | 91 | 72 | 13.64 | 10[a] | 1.4 |
| 1964 | 91 | 67 | 12.87 | 10[a] | 1.3 |

[a] - A value of 10 was chosen by NDRP as a reasonable upper bound for the n/p ratio for these 3 years.

SC&A has not been able to determine the reason for the differences for the 1959–1961 period. For 1962 to 1964, the NDRP truncated the upper bound and adopted a ratio of 10 as a reasonable upper bound. This was partly based on an experiment with an unshielded bare $PuF_4$ done by Roger Falk:

> ***Roger [Falk]:*** *The ratio of 10 was set as a reasonable upper bound for what a credible ratio could be. It was based on my measurements with a bare plutonium fluoride source. It looked like the ratio was about 13 for an unshielded* $PuF_4$ *source. So the ratio of 10 was chosen as an arbitrary upper bound for the assigned n/p ratio.* (Attachment 3)

It is acknowledged that in plutonium operations, $PuF_4$ would be the most copious source of neutrons. However, it is not clear that it would yield the highest n/p ratios for building, much less individuals. The ratio depends on gamma dose as well. The ratio of almost 24 for Building 91 is a calculated value from the data for 1962. This points to a situation of very low gamma doses with relatively high neutron doses. If some of the low gamma dose was produced by subtraction of background, that correction should have been made. There is no basis to reject a calculated value and replace it by an "arbitrary upper bound."

**Finding 7: The uncertainties associated with estimating notional dose from building n/p ratios are important for the period from 1959 to 1964; they are much less so for 1965 to 1969. In the latter period, workers with the higher doses generally appear to have some monitoring data.**

**Finding 8: The use of building n/p ratios as a method for making a best estimate or claimant-favorable estimate has not been adequately demonstrated. It may not yield best estimates of bounding doses for all members of the proposed class.**

**Finding 9: The model chosen by the NDRP of a direct proportionality of neutron to gamma dose, with a zero gamma dose corresponding to a zero neutron dose does not adequately reflect the nature of the paired neutron-gamma measurements. Hence, it is unclear if the variance calculated by the NDRP method can be used to put a bound on doses in a defensible manner.**

**Finding 10: The upper bound of 10 for Building 91 to replace calculated n/p values based on measurements is not justified. This arbitrary upper bound should be abandoned and replaced with the calculated values for those years when the calculated value is higher.**

# 9.0 BADGE RE-READING

Re-reading of the original neutron badges was necessary, because it was discovered in the mid-1960s that the original badge readings were likely to be considerably in error. A part of this problem appears to have arisen from the large number of badges that had to be read as Rocky Flats expanded its operations and after Los Alamos withdrew from the Rocky Flats neutron dosimetry program.

Table 4 shows the cumulative original readings of the neutron badges, the portions that could not be recovered ("Non-replaced total"), and the portions that were recovered and re-read, and the revised readings that were used in the NDRP program as the basis for assigning neutron dose to the individual concerned and the estimation of n/p ratios. (Building details are not shown.). Table 4 covers only the 1959–1966 period, since the errors in the original reading of the NTA film were generally the largest in this period.[12]

**Table 6: 1959–1966 – Original, Re-read, and Total Estimated Cumulative Neutron Dose, person-mrem/yr**

| Year | Original total | Non-replaced total | Re-read original | NDRP dose (re-read dose) | NDRP total/ Re-read total | Final neutron dose |
|---|---|---|---|---|---|---|
| **1959** | 69,763 | 2,734 | 67,029 | 429,536 | 6.41 | 799,083 |
| **1960** | 16,900 | 40 | 16,860 | 415,584 | 24.65 | 904,719 |
| **1961** | 10,141 | 107 | 10,034 | 321,165 | 32.01 | 1,409,608 |
| **1962** | 352,004 | 47,618 | 304,386 | 566,056 | 1.86 | 1,607,275 |
| **1963** | 432,159 | 18,067 | 414,092 | 1,015,623 | 2.45 | 1,948,319 |
| **1964** | 105,621 | 328 | 105,293 | 1,062,347 | 10.09 | 2,064,176 |
| **1965** | 147,100 | 747 | 146,353 | 836,846 | 5.71 | 1.086,245 |
| **1966** | 559,434 | 18,164 | 541,314 | 836,291 | 1.54 | 1,052,676 |

Note: The original totals include all original measured doses (in contrast to Table 6 – see note to Table 7).
Source of data: O-drive - AB Doc - Rocky Flats - NDRP - Copy of NDRP_BE_20070319 - *tblNDRPData*

It is to be noted that Table 6, and Table 7 below, are designed to examine the re-reading process in the NDRP, not the NIOSH dose reconstruction process. For 1959, the re-read badges were almost 6.5 times the original reading. For 1961, the average ratio of the re-read total to the original total was about 32. The lowest ratio for these years was 1.54 in 1966. This table provides a characterization of the magnitude of the errors that were originally made. It throws light on three points:

- The large magnitude of the errors, which were systematic errors, continued for many years in the health physics program. While there were undoubtedly parts of the health physics program where the work was done accurately, the large and persistent errors in neutron dosimetry point up the need for verification of the judgments of health physics professionals when critical matters relating to dose reconstruction are concerned.

[12] Nearly all of the 1957 NTA film for 1957 and about 88% of the 1958 film was not recovered or could not be re-read. (Note that the percentages relate to the proportion of the originally recorded dose that could not be re-read rather than the number of dosimeters.) The errors were generally smaller in the 1967 to 1970 period.

- It follows, therefore, that the protocols for re-reading during the NDRP should be carefully examined to ensure that appropriate quality controls were part of the program.

- The problem of the badges that could not be found or could not be re-read for other reasons needs to be addressed.

We take up the second and third points for evaluation here for the 1959–1970 period.

**Badge Re-reading Protocol**

The NDRP had extensive training and quality assurance for the personnel who re-read badges. The procedures are described in the NDRP report (ORISE 2005) and also have been discussed in working group meetings. During the process of re-reading and quality assurance, it was found that the re-reading contained significant errors as well, with many readers underestimating the dose while others overestimated the dose. In other words, the re-reads had systematic biases, dependent on the individual, that needed correction.

A procedure was developed to establish correction factors for each individual reader. A central feature of this procedure was that one master reader, Roger Falk, was assumed to be the "gold standard" whose readings would not have any error or bias. This was discussed in some detail during the April 12, 2007, conference call (Attachment 2):

> *Roger [Falk]: I was the one expert reader.*
>
> *Arjun [Makhijani]: You were the only one?*
>
> *Roger: Yes.*
>
> *Arjun: Did anyone verify your reading of the badges?*
>
> *Roger: No.*
>
> *Arjun: So it seems that there was no independent check of your work.*
>
> *Brant [Ulsh]: It wasn't just the reader being compared to Roger's reading of the films. There were a set of films exposed to known doses, and individual reader calibration factors were calculated.*
>
> *Roger: Both of us [reader and Roger] read the same production films [to determine reader modification factors]. I was considered the gold standard. Arjun is largely correct. The readings of the individuals were ratioed against mine. I read more thoroughly. So the bias [in a re-reading of the badge] for each film reader was adjusted by checking against a thorough reading by myself. [Note: This process is discussed in Section 12.2 of the NDRP protocol.]*

*John [Mauro]: Were there blind batches given to you to read that were exposed to neutrons to check. Was that done – were you given blind calibration films as a check?*

*Roger: There were two sets of calibration films, but I was not blind to that. But I disciplined myself to be blind during reading of those films.*

Therefore, there 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 Roger Falk, 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.**

The issue of the badges that could not be re-read is addressed in the next section.

# 10.0 NON-REPLACED BADGE READINGS

The NDRP re-reading did not cover all neutron badges for the period. For instance, most badges for 1957 and 1958 were not recovered or could not be paired with workers. As a result, many workers with neutron monitoring data had only a part of their neutron data re-read. Given the rather large errors in the original readings, notably in the 1959–1966 period, the issue of un-read badges is an important one in dose reconstruction. The NDRP simply added the part of the original dose that could not be re-read without correction to the re-read dose. It did not correct the non-re-read portion, because it decided it could not. When asked about this problem, Roger Falk noted the following:

> *Roger: The rationale was that we could not make a judgment as to what the error [in the original neutron dose] was for the film we could not re-read. Therefore, we let the original reading stand unless we determined a neutron dose from a re-read film; then we could update that [original neutron dose]. It was not within the scope of what the project set out to do because we did not have enough supplemental information to modify the [original neutron dose] value without a film that could be re-read.* [Attachment 3]

This presents a methodological problem in dose reconstruction for those workers who were monitored or partially monitored, but whose badges could not all be recovered or attributed to them. This problem occurs because the NDRP added doses known to be underestimates by a significant amount (up to a few thousand millirem) to a best estimate of dose. Hence, despite some claimant-favorable assumptions, the result may well be an underestimate. This would apply to monitored workers whose badges could not all be re-read. The problem is beyond an issue of whether the resultant dose is claimant favorable. **Adding a value for non-re-read dose that is known to be in error with a high probability and that is likely to be a considerable underestimate in many or most cases (notably before 1967) raises an issue of the integrity of the final value of the estimated dose. This issue is similar to the problem of putting a zero in dose records when badges were not read, which was done in 1969 and is discussed in SC&A's main report (SC&A 2007).** In addition, there is the issue of whether and how the non-re-read portion of the original dose can be corrected.[13]

Table 7 shows the non-replaced neutron dose for the 1959–1970 period and the number of workers affected by the problem.

[13] In this analysis, we assume for simplicity that the re-reading gives the correct dose.

### Table 7: 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*

In some years, the number of workers affected was very small—just one in 1960 and two in 1961. On the other hand, hundreds of workers were affected in 1966, 1968, and 1969. In 1970, the total number of workers with non-re-read badges was 1,735. This last number, as well as the high number of 1969 (605 workers) is likely due to the fact that a large part of the NTA film was not archived after a decision was made that Rocky Flats would switch to TLDs. That change to TLDs for neutron monitoring occurred in 1971 (Attachment 3). It is unclear why the actual practice of not archiving the film began about 2 years before that.

Even though the NDRP did not correct the portion of the original dose that could not be re-read, NIOSH does apply a correction factor to this portion in its dose reconstruction protocols. For Building 71, NOSH uses a factor of 1.99; for other buildings the correction factor is 1.13.

We will now examine whether and how the non-re-read portion of the dose can be corrected and, hence, whether the NIOSH correction protocol addresses the problem appropriately.

Table 8 shows the annual dose data for the 22 workers for whom part of the original neutron badge record could not be re-read, along with the full original dose, the part of the original dose that was re-read, and the re-read dose. It also shows the ratio of the re-read dose to the original readings of those badges. The ratio for those workers who had a value of zero neutron dose in the original record is not given, for obvious reasons. We elected not to follow the NDRP practice of assigning a small positive dummy dose for gamma readings that were recorded as zero in order to enable the calculation of a ratio. (NDRP used 1 mrem.)

**Table 8: 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*

It is immediately evident that the errors in the original reading varied a great deal, ranging from 1.56 to 16.3 (ratio of re-read value to the corresponding original value). The empirical lognormal mean of the finite ratios in Table 8 is 4.6, and the corresponding 95th percentile value is 15.5. Both of these are much higher than the correction factors of 1.99 and 1.13 used by NIOSH. Moreover, while the re-read dose and the corresponding original dose are correlated, the correction ratio has only a modest negative correlation with either the re-read dose or the corresponding original dose ($r^2$ = 0.16 and 0.19 respectively). Figures 16 and 17 show scatter plots and linear regressions for the ratio against these two variables.

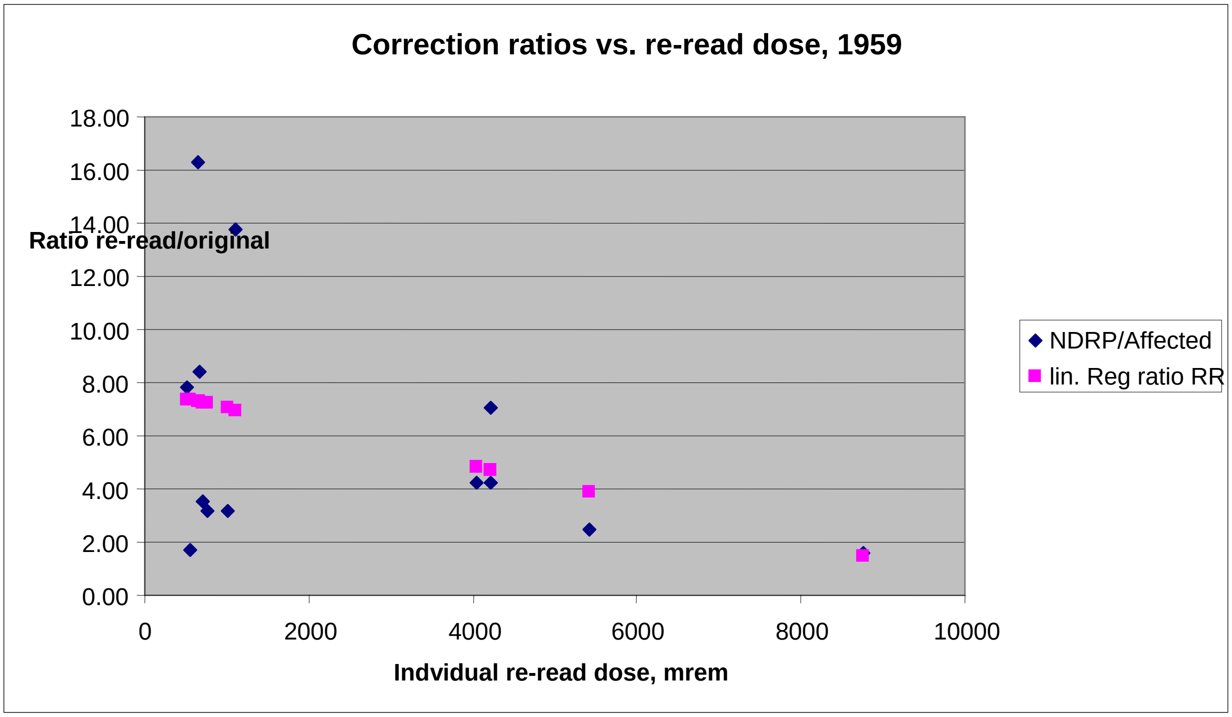


**Figure 16: Correction Ratios vs. Re-Read Dose, 1959**

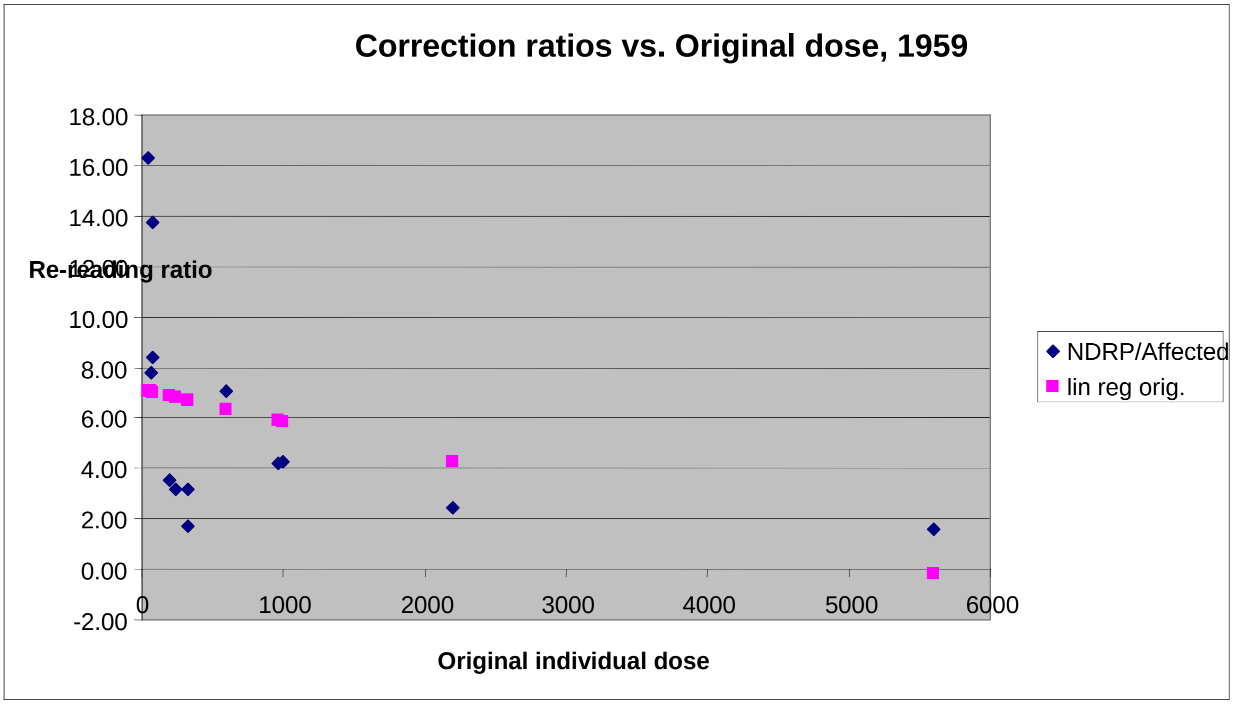


**Figure 17: Correction Ratios vs. Original Portion of the Dose that Was Re-Read, 1959**

The modest negative correlation indicates that the correction factors are smaller for larger doses, as is clear from both graphs. The correction factors indicated by the linear regression line in

Figure 16 are considerably higher at most levels of re-read dose than those used by NIOSH to correct the non-re-read portion of the original neutron dose. For instance, the correction factor for a re-read dose of 4,000 mrem is more than 4, based on the linear regression. A claimant-favorable choice, taking account of the variability in the correction ratio, would be higher.

The 1965 data are rather similar to 1959 in terms of the results of the analysis. The empirical lognormal mean of the correction ratio = 6.3 and 95$^{th}$ percentile = 19; there is a modest negative correlation of the correction ratios with re-read or corresponding original dose: $r^2$ = 0.14 and 0.2, respectively.

The data for 1969 point to a larger problem than one of finding a suitable correction factor for non-re-read doses for that year. First, the number of workers with non-read dose is large—605. Of these 605 workers, 438 had non-zero original doses that were re-read. The ratios of the re-read to the corresponding original doses vary from less than 1 in 11 cases (0.5 to 0.95 – i.e., the original doses were higher than the re-read doses) to 221, a variation of well over 2 orders of magnitude. More importantly, the correction ratios are not correlated with the re-read dose ($r^2$ = 0.01) and very weakly correlated with the corresponding original dose ($r^2$ = 0.06). Figure 18 shows the scatter plots and linear regression of the correction ratio versus the re-read dose (note the log scale on the vertical axis). The empirical lognormal mean of the ratios is 4.7 and the 95$^{th}$ percentile value is 22. The correlation does not improve significantly when the five highest values of the ratio are dropped ($r^2$ = 0.03).

A choice of a correction factor becomes problematic in this case. In theory, any number in the range of correction factors could apply to any original non-re-read dose. The potentially arbitrary nature of the correction raises issues of the scientific credibility of the result. Moreover, since hundreds of workers are involved, it would not suffice to use a 95$^{th}$ percentile correction factor, since that is likely to underestimate the corrected dose for some workers. A preliminary analysis by SC&A for 1970 indicates a result similar to 1969. Over 1,700 workers had non—re-read portions of their original neutron dose in that year.

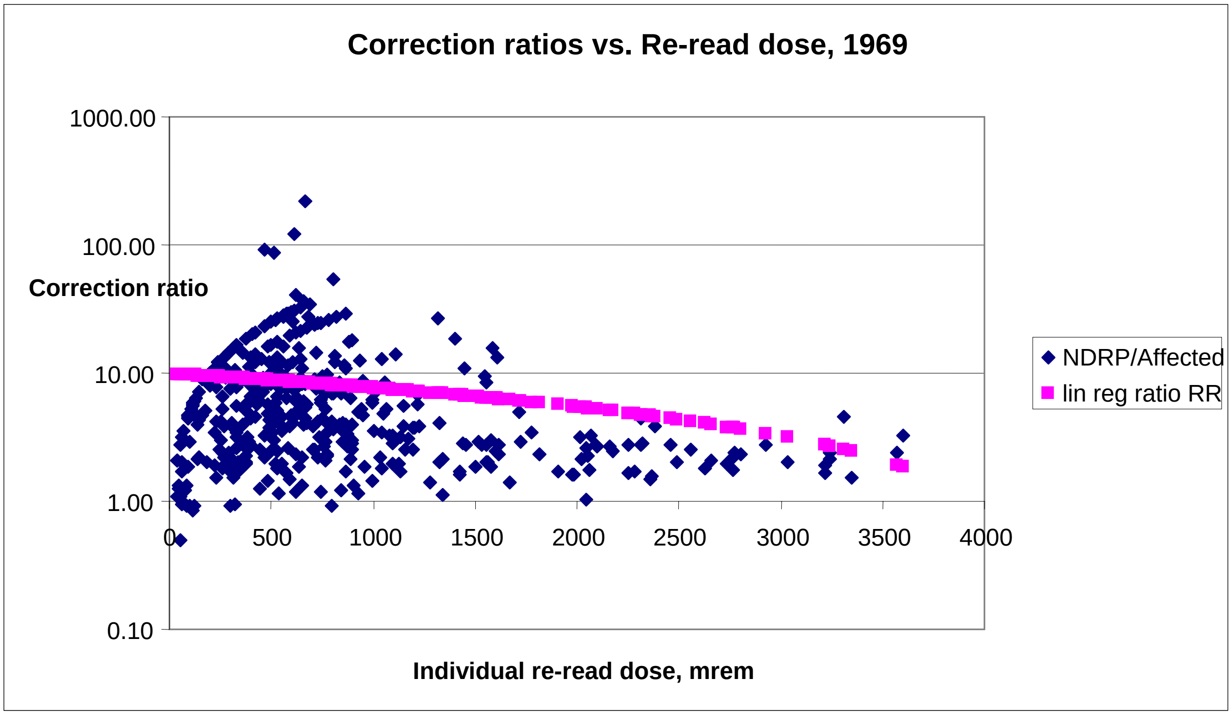


**Figure 18: Correction Factors versus Re-read Dose, 1969, with a Linear Regression Plot**

In addition to these issues, there is a problem where there were non-zero doses that were not re-read, and all of the re-read badges originally had zero dose. Most of the latter resulted in a positive re-read dose. There were 167 such cases in 1969. As noted, an individual correction factor cannot be calculated for such cases. These cases cannot be easily integrated into any overall analysis of the problem of determining a correction ratio that would be technically defensible.

**Finding 11: The NDRP total neutron dose poses a problem of data integrity in those cases where an original dose that was not re-read was added to the re-read and notional dose.**

**Finding 12: The NIOSH correction factors of 1.99 and 1.13 that are used for non-re-read dose are not claimant favorable in many cases and several years. Assignment of a suitable correction factor that would be scientifically defensible and claimant favorable is quite complex.**

**Finding 13: In one of the three years analyzed by SC&A, 1969, the correction factors for re-reading neutron badges appear to be relatively independent of dose and are highly variable. It is not clear how a scientifically defensible correction factor could be developed for 1969 or for other years that may have a similar problem to bound individual dose or make a dose estimate more accurate than that.**

**Finding 14: It is not clear whether and how the cases where there is a positive original dose that could not be re-read but a zero original dose that was re-read can be integrated into an analysis of correction factors.**

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# ATTACHMENT 1: MARCH 28, 2007, CONFERENCE CALL MINUTES

**SC&A Conference Call with NIOSH, March 28, 2007, on Neutron Coworker Model compared to 1952–1958 Measured Dose Data**
**Final with Corrections**

The notes represent a substantive summary and are not verbatim.

**Present on the call**:

Working Group: Mark Griffon

NIOSH/ORAU: Brant Ulsh, Roger Falk, Jenni Hoff, Matt McFee, Karin Jessen, Matt Smith, Mutty Sharfi, Keith McCartney

SC&A: Joe Fitzgerald, Ron Buchanan, Arjun Makhijani, John Mauro

**Joe [providing background for call]**: SC&A has had the chance to review neutron data provided by NIOSH in mid-March. In particular, SC&A has evaluated 1952–1958 n/p ratios for which we requested information last year. However, we are now running out of time. If we can resolve the issues, it will be reflected in the report; and if not, they will remain open after the SC&A report is issued. Ron has been the one doing the comparisons on neutron dose. We need clarification and it would be very helpful if you can provide it.

**Brant:** First comparison was of 1952 to 1958 measured doses to coworker data. And you got the data from the spreadsheet that NIOSH put up with the individual claimant data, right?

**Ron:** Yes. NIOSH has proposed to use the 1959 coworker model for unbadged workers in the 1952–1958 period. So we decided to do a comparison to see how well the coworker data matched up with the measured data. We got a lot of data just a couple of weeks back. I did the comparison, using claimant data, at the 50$^{th}$ and 95$^{th}$ percentile. I looked at the yearly allotted neutron and photon dose prescribed by the ORAUT-OTIB-0058 coworker model (Table 7-2) and prorated it for the number of days of neutron monitoring. I expected a match at the 50$^{th}$ percentile.

**Brant:** It is good to get your arms around the scope of the problem. How many people might this affect? We have 1,100-odd dose reconstructions that we have done at Rocky Flats. People in the NDRP have their doses assigned from measured or other methods. Claimants represent a subset of workers, of course. But among them, I found there were only 9 claimants with employment at Rocky Flats during 1952 and 1958 who did not have NDRP data for at least 1 year.

**Arjun:** The number of claimants is not relevant.

**Mark:** The SEC class applies to all workers and it is irrelevant that at this point few claimants worked during the time period being discussed. You may get a lot more claims if you grant an SEC for the 1950s.

**Brant:** It provides important perspective that we are only talking about 9 out of over 1,100 claimants at this point for whom this could even be an issue. It would be a different matter if we were talking about hundreds of claims. I put this issue on the table, and you can make of it what you want.

**Ron:** For claimants, most of these were neutron and photon badging periods and used matching data.

**Brant:** The appropriate comparison is going to be to 95th percentile. It will be based on individual exposure potential. I see neutron doses in the order of hundreds of millirem. For these workers, we would use the 95th percentile in most cases. But it is not appropriate to compare partial-year coworker to badge-exchange by badge-exchange, as pointed out in the NDRP protocol, and in my March 16th e-mail. Benchmarking n/p ratio is best done no finer than annually.

**Ron:** I know that you don't compare the individual exchange cycle, but these were not individual exchange cycles. These are mostly on multiple badge-exchange cycles.

**Brant:** Thanks for that clarification, however, the point remains that both the consultant statistician to the NDRP and the NDRP's Advisory Board recommended that comparisons be done at resolutions no finer than annually.

**Mark:** The conclusion of the NDRP was that you don't want to derive an n/p ratio from individual badge-exchange cycles. This is a different analysis, comparing coworker to measured data.

**Roger:** The point that the statistician was making is that the variability in individual exchange cancel out and give you a convergence to the mean. That is the point that the consulting statistician raised.

**Arjun:** If you take all the 25 records together, then the median ratio of the ratios of coworker neutron dose to measured dose is only 7%. The measured data are not from the same distribution as the coworker data.

**Brant:** That is so—they are not the same distribution. The NIOSH spreadsheet of neutron data from 1953 to 1958 is for workers with high exposure potential. In order to get a valid ratio, you have to exclude people who have zero measured data. The NIOSH spreadsheet has workers who were in the upper tail of the dose distribution. For 1953, one such worker has the highest neutron dose of any worker and another has the next highest dose. So these were the people with the highest neutron exposure potential. There were, in fact, two levels of screening that bias the distribution of data in our spreadsheet high compared to the general plant population and the OTIB-0058 coworker data: (1) only those workers who were at the highest exposure potential were monitored, and (2) of the monitored workers, only those with both positive neutron and positive gamma doses could be used for calculation of an n/p ratio. Coworker data would not have the same distribution as this particular set.

**Arjun:** Were there workers at Plant C who are at significant risk of neutron exposure?

**Roger:** Yes, they did have the potential for neutron exposure. But there was a batch size change in 1957. Before that year, the batch size was 200 or 220 grams of plutonium; then in 1957, the batch size changed to 1,200 grams per batch. So you have a change of a factor of 5 or 6.

**Arjun:** So there is a whole group of workers for whom we do not have knowledge of n/p ratios, because the working conditions changed in 1957.

**Roger:** This is covered in Section 8.1 of OTIB-0058. The NDRP data contains actual measurements and notional doses.

**Arjun:** Wouldn't the increase in batch size lead to self-shielding, which could change the n/p ratio?

**Roger:** The change in batch size would be expected to have only minimal impact on n/p ratios.

**Ron:** Looking at the files, it looks like some of the workers were not assigned notional dose.

**Roger:** All workers monitored for photon radiations in Pu-related buildings prior to 1957 were assigned a notional dose by the NDRP, unless they were monitored for neutrons with the Los Alamos glass plates. The list of buildings is in the NDRP protocol.

**Arjun:** The coworker model is being applied to workers with a high risk of exposure, since workers at risk in Plant C were not even monitored until 1957 or 1958.

**Brant:** That NIOSH spreadsheet by design was for those who had neutron and gamma data. Anyone who was thought to be at risk of significant exposure was badged.

**Roger:** Rocky Flats used the Los Alamos glass plates, which were issued and read by the Los Alamos nuclear physics group. They were able to give us 20 glass plates, and the Rocky Flats Health Physics staff decided to whom they were going to issue the plates. They issued them to people who, in their judgment, were at the highest risk. After that, when Rocky Flats implemented its own neutron film-monitoring program, they continued that practice. So the monitored population continued to be workers at the highest risk of neutron exposures, until mid-1958. Therefore, the study set [in the NIOSH spreadsheet] is effectively at the 98$^{th}$ or 99$^{th}$ percentile, which you are now trying to compare to the 50$^{th}$ percentile. That comparison is not appropriate.

**Brant:** As a point of clarification, all Pu workers with positive photon measurements had notional measurements assigned for neutrons by NDRP, unless the worker was monitored for neutrons with glass plates or films in that exchange period.

**Brant:** I want to go back to the statement Arjun made regarding the lack of gamma monitoring in Building 71 prior to February 1957. That statement is in NDRP, but the next sentence indicates that wrist dosimeters were used; therefore, correct reference is lack of whole-body monitoring.

**Arjun:** Are you saying that Building 91 was at higher risk compared to Building 71?

**Roger:** The 20 people to whom neutron dosimeters were issued were judged to be at highest risk for neutron exposures. Prior to early 1957, they were the workers who were involved in final assembly and inspection of the Rocky Flats plutonium product [in Building 91]. There was a step in the final assembly in Building 91 that involved a neutron source. When the batch size of the plutonium feed material increased in 1957, then process workers [in Plant C, Building 71] were also at an elevated risk of neutron exposures.

**Ron:** From 1952–1956, there were only 20 glass plates. When Rocky Flats started, was it the same number?

**Roger:** The number of neutron dosimeters was not increased significantly until mid-1958. We should keep in mind that a couple of significant events occurred in Building 71 in 1957. There was a chemical explosion in June 1957 that caused extensive contamination and shut down operations in a room, and in September there was a major plenum fire that shut down routine process operations probably into 1958. So three things happened in 1957—batch change and two significant contamination events that shut down many of the operations for a period of time. Finally, in the summer of 1958, Rocky Flats started to do extensive neutron and gamma monitoring as the operations resumed in Building 71.

**Brant:** SC&A's next comment was the application of the n/p ratio of 1.2. Neutron-to-photon ratios for workers who were monitored in Building 91 were much higher than that and also the 1958. You have to keep in mind that the n/p ratio was high for Building 91. We used a methodology that was recommended there—using the sum of gamma and neutron measurements. SC&A is questioning whether the n/p ratio should be higher than 1.2?

**Ron:** If you look at Table 11.1 of NDRP, using 1.2 is on the lower end of the scale.

**Roger:** The ratio of 1.2 is for "Other Buildings" in Table 11.1 of the NDRP protocol and is a composite of all buildings, heavily dominated by Building 71.

**Ron:** A ratio of 1.2 seems low. When I went to Table 7-2 of OTIB-0058, it appeared that they did not use the missing photon dose. My concern was whether we had something to show that that was OK. That is why I wanted to do a comparison with measured dose. And the comparison seemed as if the coworker model was under-assigning dose.

**Brant:** What is the effect of the n/p ratio? Consider the way coworker dose is assigned. Picture a pie graph. We apportion the deep dose to gamma and neutron components. The thing is that if we increase the n/p ratio, we take a bigger slice to neutrons and less to photons. So if the neutrons go up, the gamma deep dose goes down. So the probability of causation will go down if a higher n/p ratio is used, assuming a 30 to 250 keV deep gamma dose spectrum.

**Ron:** That is true for composite dose. But for 1952 to 1958, there were very few measurements for neutrons, because most of the workers were not monitored for neutrons. So if you have a dose of record of 1 rem, it is a photon dose and you cannot apply that to a combined neutron and photon dose.

**Roger:** That is not correct. The NDRP data is now part of the claimant file. So the notional neutron doses are part of the record. It is my understanding that workers like that would not be affected by coworker data. The coworker data would not be applied to them.

**Ron:** If you have only photon dose, the n/p ratio should increase the overall dose, not just dividing the same pie.

**Roger:** Coworker doses in Tables 7-1 and 7-2 of OTIB-0058 do include NDRP notional neutron dose. Note that Section 6.0, first paragraph, p.8, OTIB-0058, Rev. 01, states that the dosimetry data in HIS-20 was used for the development of coworker data for Rocky Flats and that, "In addition, HIS-20 contains the results of the Neutron Dose Reconstruction Project (NDRP)…." A notional dose is included in the HIS-20 database for any worker with a positive photon (penetrating) dose measurement in a plutonium-related building unless there is a recorded neutron dose for that monitoring period. The HIS-20 database (and Tables 7-1 and 7-2 of OTIB-0058) also includes the difference between the original and NDRP neutron doses for neutron glass plates and films reread by the NDRP, as well as the NDRP-reconstructed penetrating photon doses for Building 71 plutonium workers, who were monitored only with wrist badges prior to 1958. Therefore, the penetrating dose totals are in HIS20 as well as in OTIB-0058.

**Arjun:** So HIS-20 was modified after NDRP was done?

**Roger:** Yes, the NDRP data and notional dose estimates were incorporated into HIS-20.

**Matt:** The HIS-20 penetrating dose was the input data for the OTIB-0058 process....which is shown in the support workbooks provided several months ago.

**Mark:** Ron's point is a proof-of-process question. It is about someone who had photon, but no neutron measurements. If they have photon measurements, are neutron doses calculated using an n/p ratio or coworker model? This is a question of how the dose reconstruction is being done.

**Roger:** All workers in Pu-related buildings who had measured gamma dose were automatically part of the NDRP database.

**Mark:** So anyone who had a positive photon dose, you would have calculated a notional neutron dose if they were in Pu buildings.

**Roger:** They would have either a monitored neutron dose or a notional neutron dose. We gathered up gamma worksheets and calculated a notional neutron dose for all workers in Pu-related buildings if the worker did not have a recorded neutron dose in the period of time when they had a recorded penetrating photon dose.

**Brant:** Arjun, you said plutonium foundry workers had no gamma dose monitoring. But they had wrist doses and we calculated the whole-body doses from that. That is in Section 11.2 of the NDRP report. The next item is about Am-241 and the impact on n/p ratios.

**Roger:** One of the changes was the ZPPR project. It used reactor grade Pu, which had a high Pu-241 and so a high Am-241 component. They were fabricating special fuel components for the ZPPR reactor starting perhaps in the mid-1960s, maybe 1966 or 1967. Starting in 1967 and going into 1968, there was a push to add gamma shielding and then neutron shielding to process lines.

**Brant:** Wasn't ZPPR confined to one building?

**Roger:** ZPPR was largely confined to Building 76/77, but Building 71 also was involved.

**Arjun:** It seems that workers with different potential for n/p ratios are being applied with a one-size-fits-all n/p ratio, since all gamma and all neutron doses are added up to get an average dose.

**Roger:** Yes, the ratios are at the level of building and calendar year. However, by the mid-1960s, the gaps in neutron monitoring for Pu workers were very small. And you had a composite method to assign the workers' actual monitored neutron doses for those years. So the use of n/p ratios was a minor component of neutron doses for those years. From the mid-1960s onward, the coworker dose would be applied mainly to visitors to the plutonium areas.

**Brant:** In response to the Am-241 issue raised in SC&A's points, Section 8.1 of OTIB-0058 provides extrapolation for the 1952 to 1958 period. The Am-241 content was low in 1959 and this is not expected to affect the n/p ratio. SC&A has already agreed that the Am-241 amounts were small in the 1950s. Is that all the issues?

**Joe:** It seems that we have covered the major points. We'll send you the draft notes for correction.

**Ron:** I would like to summarize the main points. According to NIOSH, the data in the 25 dose records reflect the high end of who would be exposed to neutrons, since the 20 glass track plates were given to the workers with the highest neutron exposure potential. Hence, the distribution of neutron dose in those records is not expected to represent the OTIB-0058 Table 7-2 doses, which are the results of all workers, not just the high-end workers.

**Brant:** That summarizes it correctly.

**Ron:** Is there any way in which individual data can be used to confirm OTIB-0058 neutron doses to see if there would be a match?

**Brant:** We have given you two databases in the past week: Paired neutron doses and the second [set, which] is the complete set. You should probably look at annual aggregated data in the first one.

**Roger:** The workers who have the paired data are the ones who were issued the plates and film, and those are the highest exposed workers. So that won't solve the problem of benchmarking the coworker estimates. This is an issue that an NDRP project wrestled with and we were not successful in finding any data that would validate the NDRP notional dose estimates with field measurements prior to 1959.

**Ron:** Are there area neutron measurements from area monitoring or calibration modeling?

**Brant:** You are not going to find neutron surveys. There are calibration surveys.

**Roger:** But we have not found that for the 1950s. The first study was for 1962.

**Ron:** Los Alamos was doing calibration, but there is no documentation that they went to Rocky Flats.

**Roger:** We searched very diligently for validation data. We did not find anything for the 1950s that would allow us to do our own benchmarking.

**Brant:** Did you do experiments that would be expected to bound conditions at Rocky Flats?

**Roger:** The process where they put Pu through the flouridator was the highest neutron source.

**Brant:** We don't have field surveys. But there is a laboratory study from the 1960s.

**Roger:** The Mann-Boss study was in 1962, and I did my studies in 1967 and 1968.

**Arjun:** Let me get this accurately for the notes. Here is what I understood you to say, Roger. You tried hard to find some field data on neutron exposure for the plutonium areas where workers were not monitored in the 1950s to validate your NDRP notional dose assignments. Despite these efforts, you were not able to find any. Right?

**Roger:** Yes, that is right. We discussed this topic in the formal interview that you conducted with me.

**Joe:** We will send you the draft notes soon.

End of call.

# ATTACHMENT 2: APRIL 12, 2007, CONFERENCE CALL MINUTES

**Conference call, April 12, 2007, on Rocky Flats Neutron Dose Issues**
**Final Minutes with Comments Incorporated**

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

**Participants:**

Working Group: Mark Griffon

NIOSH/ORAU: Brant Ulsh, Roger Falk, Jim Neton, Larry Elliott

SC&A: Joe Fitzgerald, Arjun Makhijani, Ron Buchanan, John Mauro, and for a short period, Bob Bistline

(1) **Number of workers in NDRP increases from ~800 in 1958 to ~2,000 in 1965. Is this due an increase of workers in Building 71, 76, 77, and 91? Or a change in who was considered at risk? Both? Since peak of work was in late 1950s and early 1960s, do we know how many were there in all then in these buildings?**

**Brant:** NDRP re-evaluated neutron doses for all workers in Pu buildings, so all workers in those buildings should be in the NDRP.

**Roger:** I do not know the total number of workers in any Pu building. We could find out the number of workers who were monitored from information in the NDRP database, but I don't know how to find the number of workers who were assigned to a building each year. I don't recall seeing that data. To clarify, a worker was included in the NDRP if they were monitored for neutrons or gamma radiation, listed in the dosimetry worksheets [in the plutonium buildings]. In effect, the gamma worksheet was the main driver for the worker to be included in the NDRP study.

**Ron:** The gamma worksheet—was it just for Pu-area workers or did it include those who went into Pu areas from other areas?

**Roger:** It was the roster for Pu buildings or Pu-related buildings, such as 122, 123, and 886 (included criticality laboratory and the home base for the nuclear safety engineers assigned to oversee operations in buildings with fissile materials). Also, maintenance workers were assigned to and were resident in the plutonium buildings in the 1950s and into the 1960s, but I don't have a clear year when they started to rotate people out of Building 334, which was the maintenance shop for the plant site. In the early years, the maintenance operations in plutonium buildings were very self-contained, and even the custodial workers—the janitors—were embedded in the plutonium building roster. The maintenance work in Building 334 was cold [non-radioactive] type of machine work. So the point is that the maintenance workers in the early years would be in the NDRP, when they were monitored for gamma or neutrons in the plutonium buildings.

**Arjun:** In the early years, there were a lot of workers who were not monitored for gamma.

**Roger:** I can't say that everyone in Pu buildings was monitored for gamma.

**Arjun:** So how do we establish that the NDRP was inclusive?

**Brant:** So was it just the odd person who was not monitored?

**Roger:** I can't go that far. The policy was that people with a potential for exposure over 10% of the annual limit were monitored. So secretaries may not have been monitored, for instance. One has to keep in mind what the practice was at that time. It was to monitor if the health physics staff thought they were at risk of 10% of the tolerance limit. I do not know who would have been left out [not monitored], such as secretaries or administrative staff that did not go into the process areas. But I do not know that level of detail [who was not monitored].

**Arjun:** From the 1969–1970 analysis, we have examples that people had more than 10% [in the pre-1969 period in non-Pu areas] who were thought not to be at risk, and so their badges were subsequently not read [in 1969]. So is the bottom line that we have to trust that the professional HP staff at the time were right most of the time or all of the time?

**Roger:** That is the case. I have said before that we have to trust the judgment of the professional staff at the time. That is the point.

(2) **Were there earlier NDRP reports other than the one we have of February 2005?**

**Roger:** No. There is the only final protocol.

**Arjun:** How about a trial protocol?

**Roger:** There were rough drafts. But there was no other report.

**Brant:** Was the Stanfield thesis a pilot study?[14]

**Roger:** It was not a pilot study. It was a thesis to explore the methodologies for n/p ratios. It was an extra project that Tom Borak (NDRP) thought would be helpful for n/p ratio for 1971.

**Arjun:** The Master's thesis also had a 1959–1966 component.

**Roger:** That was based on a pilot study we did in 1994; we let Stanfield use that data also. There was not a formal write up of that study, but we let Stanfield have the re-read film data.

**Arjun:** Is the Stanfield thesis a record of the pilot study?

[14] Stanfield, S. 1998. Sean Stanfield, *Uncertainty Analysis of Neutron Dose Estimates for Former Workers at the Rocky Flats Environmental Technology Site*, Masters' thesis, Colorado State University, Fort Collins, 1998.

**Roger:** It is not. I gave a verbal presentation to the DOE Rocky Flats field office and then we moved on.

**Arjun:** Were there minutes of this meeting?

**Roger:** I don't think there are minutes of this meeting.

**Joe:** Was the pilot study done on the heels of a push from Congress or GAO or someone? In that time frame?

**Roger:** I am not aware of that impetus [Congress or GAO]. The basic impetus was the epidemiological study for Rocky Flats that Dr. Ruttenber was doing with the Colorado Department of Health. That project, with my input, identified the early neutron data as the weakest part of the Rocky Flats dosimetry data; that is what drove the pilot study.

**Arjun:** The Congressional hearing was in 1994. We referred to it in our Site Profile review.

**Roger:** The pilot study started in 1993 and ended in the spring of 1994, but the first impetus came in 1993 with the Ruttenber epidemiologic project. That was 1993.

**Arjun:** So we have only two documents relating to the neutron dose reassessment; the NDRP report and the Master's thesis, since there is only one reference to a neutron-dose-related document in the NDRP report. The other two references in the NDRP report are a statistics textbook and a statistics software package. Are there any other reports relating to the neutron dose reassessment that we should look at?

**Roger:** The answer is no. You have what is available. The issue is that the protocol document of what we did in the project and the database gives you all the data. Those are the primary resources.

(3) **Besides the MS thesis, was there outside input or validation of the NDRP process and resulting dose assignment?**

**Brant:** The NDRP protocol, on page 2, lists the scientific advisory committee members.

**Arjun:** Did anyone on the outside QA the data or the results?

**Roger:** The advisory committee did not do that. Bob Bistline and Bruce Wallin (DOE) had that opportunity.

**Arjun:** Did they do so?

**Roger:** They were briefed. The project manager was Joe Aldrich (NDRP).

**Arjun:** Was he involved in the technical side of the project?

**Roger:** He is also technical, and he was involved in QA-ing the results.

**Arjun:** Is he accessible?

**Brant:** Joe Aldrich is part of the ORAU team. We can set up a call with him.

**Bob Bistline:** We were following the project and attended meetings and discussions and kept abreast of the project and looked over their shoulders, but we did not do any re-reading.

**Arjun:** Was Bruce Wallin [DOE] in the same capacity?

**Bob:** He and I were both with DOE and we were watching over what was going on.

**Arjun:** Were there summaries or minutes of the meetings?

**Bob:** I think there were minutes. There was a person keeping notes on that. Duane Hilmas (NDRP) was keeping notes. And Dana Hart (NDRP) was recording the proceedings of the NDRP Advisory meetings.

**Roger:** There were minutes of the Advisory Committee meetings. Those minutes were signed off by each member of the Advisory Committee. And they are archived in the ORAU/ORISE vault.

**Joe:** The question came up whether anyone did any QA/QC. Bob, do you know if anyone did that?

**Bob:** We were not doing major testing, but we were sample testing here and there of the data. Most of the checking was being done by Advisory Committee members.

**John:** Were the [NDRP film] readers counting tracks under a microscope and hence inferring dose?

**Roger:** Yes.

**John:** Were most workers not badged [monitored for neutrons] in the early years when glass plates were used?

**Roger:** Yes, that's right. The plates were given to us [and read] by the Los Alamos nuclear physics group, and they could only let us have 20 per exchange period. The Rocky Flats staff chose workers who they thought were at the highest risk of neutron exposure. I am not aware of a record of the decision process. We only know who was badged based on the worksheets.

**John:** You also have gamma exposures for the same workers?

**Roger:** I have not done a direct correlation, but I think that is right. There are 20 dosimeters per monitoring period, I think monthly. Twenty people were monitored per monitoring period, but they were not necessarily the same 20 people each period. There could be up to 12 change outs per year.

**Brant:** In the best case scenario, you would have 20 people with 12 records per year, but in practice that was mostly not the case. Those data have been provided.

**John:** So could we figure out a way to use the coworker model in a claimant-favorable way?

**Brant:** This is not about the coworker model in OTIB-0058, but about how individual neutron doses were assigned in the NDRP. [Arjun agrees.]

**Brant:** I assume for coworker data, you are asking about OTIB-0058. There were only nine claimants with employment at Rocky Flats before 1959 who did not have NDRP data, and they were all in non-Pu areas.

**Mark:** When you say that Pu-area workers were in NDRP, that is different than saying that NDRP people have monitoring. Just want to clarify that NDRP workers in many cases have 100% notional dose.

**Ron:** When there is no gamma dose, the NDRP does not assign a neutron or gamma dose. So during dose reconstruction, they assign OTIB-0058 doses for those periods when there was no gamma dose or neutron dose.

**Brant:** That is correct in theory. So far we have not identified any individual who was at significant risk of neutron exposure but was not included in the NDRP.

**John:** So is the conclusion that there was not a formal QA as a sampling?

**Roger:** There was an extensive in-house QA system and that is described in Section 9.4 of the protocol. There was a 10% plus re-read just to check. We also did extensive re-reads.

**Larry Elliott:** I was tangentially involved in the NDRP, and there was QA. How many levels of QA/QC do you want?

**Arjun:** I was asking about checks external to those involved in the project.

(4) **Who was the special expert against whose readings the measurements of the other personnel re-reading the neutron glass track and NTA film were validated?**

**Roger:** I was the one expert reader.

**Arjun:** You were the only one?

**Roger:** Yes.

**Arjun:** Did anyone verify your reading of the badges?

**Roger:** No.

**Arjun:** So it seems that there was no independent check of your work.

**Brant:** It wasn't just the reader being compared to Roger's reading of the films. There were a set of films exposed to known doses, and individual reader calibration factors were calculated.

**Roger:** Both of us [reader and Roger] read the same production films [to determine reader modification factors]. I was considered the gold standard. Arjun is largely correct. The readings of the individuals were ratioed against mine. I read more thoroughly. So the bias [in a re-reading of the badge] for each film reader was adjusted by checking against a thorough reading by myself. [Note: This process is discussed in Section 12.2 of the NDRP protocol.]

**John:** Were there blind batches given to you to read that were exposed to neutrons to check. Was that done – were you given blind calibration films as a check?

**Roger:** There were two sets of calibration films, but I was not blind to that. But I disciplined myself to be blind during reading of those films.

**John:** Was there a process by which your performance for reliably reading badges was checked?

**Roger:** My performance checked against pre-exposed calibration films that I had prepared in 1967 and 1968 that I had archived and saved. You also need to keep in mind that we have a consulting statistician, Phil Chapman, who independently analyzed the data of the films that we read. We took all of Chapman's analyses and used them as the final record. So that would be like a third party type of analysis. All of the attachments to the NRDP report are Phil Chapman's reports.

(5) **Would the n/p ratio be expected to vary by job in Building 71? For instance, would the $PuF_4$ n/p ratio be expected to be higher than in other areas processing the same grade and age of plutonium?**

**Roger:** The $PuF_4$ has a higher neutron exposure potential than other plutonium operations.

**Arjun:** So how do we get a bounding dose for those workers who had higher exposure potential within the building from a common n/p ratio?

**Roger:** When the project calculated the notional dose for the workers, we also calculated the standard error of the neutron dose, as well as the 95$^{th}$ percentile value for those workers. That information seems to cover a bounding dose.

**Arjun:** You used a normal rather than a lognormal distribution in estimating the 95$^{th}$ percentile. Can you explain the choice?

**Roger:** I am trying to remember the rationale. The central limit theorem states that, for a large number of measurements, the distribution of the sample mean approaches the normal distribution, regardless of the form of the population distribution. Workers rotated though a number of operations during the whole year. Workers were rotated through hot jobs [jobs with high radiation exposure potential], so that one worker was not exposed to the hottest job in the whole year.

**Brant:** Were the $PuF_4$ workers the ones who would have been monitored, assuming they were at highest risk?

**Roger:** They were certainly monitored for gamma in the early years. And when Building 71 workers were monitored for neutrons in the late 1950s, the workers involved in $PuF_4$ operations would have been monitored for neutrons.

**Arjun:** Since $PuF_4$ workers were not monitored from 1952 to 1958, there is no way to make a comparison of those workers with other workers in Building 71. Would that be right?

**Roger:** It is not really correct to call a worker a $PuF_4$ worker [in the 1950s]. One worker would follow a batch of plutonium through the entire process, including the fluorination operation. The worker started at the first task and then followed that batch through the entire process, so that only a fraction of the time would be spent on the task with the highest neutron exposure potential.

**Arjun:** Is that documented somewhere?

**Roger:** I got this information from [Name], but I am not aware that it is explicitly documented.

**Arjun:** Is there a date for when most doses were measured and not notional doses?

**Roger:** It varied by building and operations. Building 71 process operators were monitored extensively for neutrons starting in the summer of 1958 and the other operations in Building 71 were covered in 1963. The workers in plutonium metal working buildings (76 and 77) were well covered starting in about 1965.

**Ron:** The notional dose goes down in 1964 or 1965 relative to measured dose. At first, there were 20 badges to read. Then there was increasing production and there was the Mann-Boss study in 1963. Was the period 1958–1963 one in which the number of workers badged increased, then after the Mann Boss study the neutron dosimetry system was revamped and recalibrated?

**Roger:** First big recalibration and expansion of the neutron film-monitoring program started in 1958. In August 1958, they monitored all of the chemical operators in Building 71. Then in 1962 [published in 1963], there was the recalibration from the Mann-Boss study, along with a change in the film reading protocol. Initially, the amount of surface area of the film read was 1 $mm^2$. If the reading was more than a multiple of background, then they read 2 more $mm^2$. In

1962, the area that was read was increased to 10 $mm^2$. [For more information, see Section 3.2 of the NDRP protocol.]

**Mark:** In 1965, I get about 800 individuals with 100% notional dose out of about 2,000 total individuals. In the earlier years, more of the higher doses were notional. In 1965, I see a lower range of notional doses, and the higher data seem to be measured doses. I realize the badging was phased in, but it suggests that even in 1965, there was not a 100% monitoring for neutron exposed workers.

**Roger:** You have to remember it was phased in. The badging for higher-risk workers was increased first. After the neutron monitoring was expanded for a building or groups of workers, the gaps for notional doses became smaller and usually were embedded within neutron-monitored periods.

**Mark:** Was there some point at which the notional dose was minimal compared to measured dose?

**Ron:** 1969 still had 28% notional dose.

Some participants had to leave before all the questions were covered.

It was decided to schedule another call on Monday or Tuesday (April 16 or 17, 2007).

# ATTACHMENT 3: APRIL 17, 2007, CONFERENCE CALL MINUTES

**Notes of April 17, 2007, Conference Call on Rocky Flats Neutron Doses/Final**

Sent simultaneously to the participants for review on April 17, 2007. Review comments were received from Ron Buchanan, Brant Ulsh, and Roger Falk and incorporated.

Notes are not verbatim, but an attempt was made to make them as close to verbatim as possible in a technical, non-recorded call without a court reporter. Some points were written down in summary form.

**Participants:**

Advisory Board: Mark Griffon

NIOSH/ORAU: Brant Ulsh, Roger Falk, Jenni Hoff

SC&A: John Mauro, Arjun Makhijani, Joe Fitzgerald, Ron Buchanan

**Mark:** I want to give some context to the call. In the last call, we covered some general questions and the early time period. We still had some remaining questions on 1959 to 1971 or 1972 and that will be the main focus of today's call. But there are also a couple of questions in the general category.

(1) **We calculated the n/p ratios from paired data and could not match the NRDP results in some cases. Building 77 for 1964 I calc n/p= 2.99 and NDRP list n/p = 1.6. Was this because the 1963 value was used for 1964? We get values for 1959 and 1960 that are somewhat higher than yours for Building 91 (4.03 vs. 3.6 for 1959 and 8.21 vs. 6.8 for 1960). Are all the data on the O-drive? Also for Building 91 for 1961, we get an n/p value of 16.19 and NDRP lists it as 7.4. These SC&A calculations have not been QA-ed and we are asking you informally, since time is short. We will be checking these internally as well.**

**Ron:** I did double check the numbers last night, Arjun, but you may want to check them too.

**Roger:** I'm not sure what the issue is here. We used the data that Phil Chapman [the NDRP statistician consultant] gave us, based on his analysis, for the n/p ratios that are in Table 11.1 in the NDRP protocol. The n/p ratios are the sum of the neutron doses divided by the sum of the gamma doses from Phil's data set that he used for his statistical analysis. Dr. Chapman's data set may not have contained all of the final NDRP doses, but it did contain most of the data. I also do not know if he used some selection criteria to disqualify some of the data for his analysis. So I am not sure of the source of the discrepancies. I have not had a chance to review this information.

**Brant:** Can you give us the details?

**Ron:** I went through the O-drive and went to the AB Doc - Rocky Flats - NDRP - Copy of NDRP_BE_20070319 - *tblBetaGammaNeutron Matches* file for the year and building. I summed the neutron dose and the gamma dose, and then got the ratios. I matched a lot of the numbers by rounding up, but some I could not match. Building 91 seems to be problematic; the others match pretty closely. There were a lot of "ones" in the gamma dose for Building 91. Did they [the NDRP] cull out any of the numbers in the table that I used?

**Roger:** Ron, I really don't know all the details of the dataset that Phil [Chapman] used and there is the possibility that there was more data added after he did his analysis, although that would have been minimal. The "ones" are basically the result of the gamma dose being initially zero sometimes and was replaced by 1 millirem to calculate n/p ratios, because dividing by zero is not possible.

**Arjun:** Why are the zero gamma doses an interference if all gamma and all neutron are summed at first? The divide-by-zero issue would not arise in that case.

**Roger:** Dr. Chapman was exploring a lot of different approaches and taking the ratio of individual readings arose in that context.

**Arjun:** So the 1 millirem to replace the zeros is not the source of this discrepancy.

**Roger:** No, I don't think so.

**Ron:** I could not find anything else that stood out.

**Arjun:** Is the main possibility that there is more data in what Ron looked at than the NDRP had [when Dr. Chapman calculated the building ratios]?

**Roger:** That is a possibility, That is what I suspect, but I don't know for sure.

**Ron:** There was some data available that could be used for the n/p ratio. It appeared when there were less than 70 or 100 data points, they may have replaced the calculated n/p ratio by a limit of n/p = 10. Did they set it to 10 because it is an upper bound of what could be expected, or because there were not enough data points?

**Roger:** The ratio of 10 was set as a reasonable upper bound for what a credible ratio could be. It was based on my measurements with a bare plutonium fluoride source. It looked like the ratio was about 13 for an unshielded $PuF_4$ source. So the ratio of 10 was chosen as an arbitrary upper bound for the assigned n/p ratio.

**Brant:** I see a value of 10 for the n/p ratio for 1962, 1963, and 1964 for Building 91 [in Table 11.1 of the NDRP report].

**Ron:** If you use the data available, you get 13 [for 1963 and 1964] and 23 for 1 year [1962]. So that was the reason for my question.

(2) **The NDRP report states that Roger Falk's expertise was used in deciding which buildings to aggregate for estimating n/p ratios (Appendix IV, pages 4, 15, and 19). Was the Advisory Board involved technically in these decisions? How deeply? Would the minutes of the meetings in the ORAU vault reflect significant Advisory Board involvement, or was it mainly Roger Falk's judgment as indicated in the NDRP report?**

**Arjun:** Was there a written critique of or feedback about Roger Falk's expertise on these issues that the Advisory Board may have given?

**Roger:** The Advisory Committee did not delve into that kind of detail. Phil Chapman gave presentations of his studies (which are now appendices to the NDRP protocol) to the Advisory Committee, but they [the Advisory Committee] did not do a technical review and approval of the small details.

(3) **Is the "non-replaced original neutron dose" the part of the neutron dose that could not be re-read? What were the reasons for the non-reading and variation in it over the years?**

**Roger:** Yes, your understanding is correct. We did not re-read the film either because we could not find the film or we found the film but could not match it to a specific worker.

(4) **The NDRP dose replaces the re-read portion of the badges and the total reflects this re-read dose, the non-replaced dose, and the notional dose. What is the technical basis for adding the non-re-read portion, which is known to be in error and systematically biased downward, to the re-read portion?**

**Roger:** The rationale was that we could not make a judgment as to what the error [in the original neutron dose] was for the film we could not re-read. Therefore, we let the original reading stand unless we determined a neutron dose from a re-read film; then we could update that [original neutron dose]. It was not within the scope of what the project set out to do, because we did not have enough supplemental information to modify the [original neutron dose] value without a film that could be re-read.

**Arjun:** My review of the data indicates that generally re-read values were systematically greater than the originally read values. Is that right?

**Roger:** That is the case until 1967, but that is not the case from 1967 onward. That is why we did the project, because we knew that was the likely outcome [based on the pilot study].

(5) **Is the non-replaced fraction of doses high for 1957 and 1958 because the vast majority of badges were lost or not returned by the outside contractor?**

**Roger:** That is because we could not find archived films for that time period. We noted that we started to find archived film beginning in December 1958. We did have the LANL glass track plates.

**Arjun:** So 1957 and 1958 there were mostly not re-read?

**Roger:** Yes, Los Alamos glass-track plates went to the end of 1956 at least and may be up to January 1957.

(6) **According to Ruttenber 1993, full coverage of TLDs for neutron workers was not provided until 1973, though "some workers" had neutron TLDs starting in 1971 (p. 13). Is this right? If so, who was not covered in 1971 and 1972?**

**Roger:** All of the high-risk Pu workers were monitored with TLD neutron dosimeters in 1971. I don't recall any of the Pu workers in any of the Pu-related buildings not being monitored for neutrons with the TLDs by the end of 1971. So I am not sure where Dr. Ruttenber got his information.

**Brant:** It might be useful to distinguish beta gamma TLDs and neutron TLDs, so that might be the source of the confusion. Replacement of the beta-gamma film badges with beta-gamma TLDs was complete by the end of 1970.

**Ron:** Was there a period of time when neutron TLDs were being phased in that NTA film was used for some workers, or did they cut off NTA film at a certain point and just increase the coverage of TLDs as time went on?

**Roger:** That is a good question. We know that all the Pu hands-on workers had the TLD neutron system. I don't really recall neutron film being processed in 1971 and I haven't seen any dosimetry worksheets for 1971 for [NTA] film. I can't say definitely that none were used, but I don't recall any evidence of that.

**Brant:** When were they back and running after the 1969 Mother's Day plutonium fire?

**Roger:** The operations in Buildings 776 and 777 were transferred to Building 707, and that building was operational in May 1970.

**Brant:** So Pu work was significantly disrupted until May 1970.

**Roger:** Brant, we are talking about 1971 when the neutron TLD system was implemented.

**Arjun:** Were there areas other than Pu buildings where workers had neutron badges?

**Roger:** I think those people would have been changed to the TLD neutron system. Rocky Flats had nuclear safety staff and others who could be rotated to plutonium buildings. Nuclear safety was housed in 886, but they reviewed criticality safety limits in any building with fissile materials.

(7) **The NDRP report's conclusion about notional doses is as follows:**

> *Thus, a worker who had neutron reads available for 80% of the year and a gap for 20% of the year would receive a notional dose estimate for the gap period that was 80% derived from his/her neutron read average and 20% derived from his/her gamma value. Workers who had no neutron film in a year would receive a notional dose estimate for the year based entirely on his/her gamma value. The variance estimate for all notional doses was computed as if the entire notional dose had been obtained from the neutron-to-gamma ratios. The notional dose estimates should be considered somewhat speculative, and their variance estimates should be considered quite approximate. However, the actual precision of the estimates is thought to be generally better than the claimed precision, particularly for individuals for whom the notional dose estimate is derived primarily from the neutron average.* [ORISE 2005, pp. 26–27]

**Why did the NDRP give a single variance for the notional dose when n/p ratio derived portion is likely to have subcomponents in it?**

**Roger:** It is explained in Appendix IV Section 5 [ORISE 2005]. Dr. Chapman chose to estimate variance based only on the building ratios, because that method [the part estimated from n/p ratios] is the more variable part of the notional dose. Therefore, the variance of the notional dose was calculated as if all the variance of the notional dose estimate resulted from the more variable component (the n/p building ratio method) for all notional doses, even those heavily weighted by Method 1 (using the average neutron dose per day, based on NDRP re-read neutron film for that worker). That approach gave a larger variance value whenever a combination of the methods was used to estimate the notional dose, which we considered to be worker favorable, and which you [the NIOSH project] can use if you want to extrapolate the notional neutron dose to the upper bound.

**Arjun:** The second piece of the notional dose seems to have subcomponents to it.

**Roger:** This is the building n/p ratio; it was used to estimate 100% of the variability, because this is more claimant favorable. This would overstate the variance.

(8) **Do you agree with the conclusion of the statistician in Appendix 4 of the NDRP report that the notional doses are "somewhat speculative?" Are there parts of the 1952–1969 period where the notional doses would be less speculative than others?**

**Roger:** Yes, I agree that notional doses are basically estimates and they are our best shot at estimating the unmonitored neutron dose. They are more speculative the farther back we extrapolate. So the 1952–1958 period would be the more speculative part. As you got more and more workers monitored with NTA film in the 1960s, the method of using the average neutron dose as the estimator of the notional dose becomes more important [more heavily weighted in the notional dose estimate, discernable from the weighting factors in the notional dose equations in a worker's "Individual Timeline" NDRP report]. Then the notional dose becomes less and less speculative.

**Ron:** Figures 1.1 and 1.2 [in Appendix IV of the NDRP report] give the neutron dose and gamma dose. What are the years for that data?

**Roger:** Table 1.1 gives the first year, and in Table 1.2, the second column is year 2. So he was estimating based on year 2 the ratios which were used.

**Arjun:** I think Ron's question related to the figures, not the tables.

**Roger:** Maybe all years are in the figures or it is 1 year. I don't know. If I were to guess, I would guess it is for all the data points listed in Table 1.1, which are the annual records, which may have been plotted in Figure 1.1.

(9) **The Stanfield thesis indicates that there was more Am-241 in the Pu in the late 1950s (First part of the file, pdf page 19, thesis page 11) compared to earlier periods. Do you agree? (We understand that Am-241 extraction in significant quantity began in 1963.)**

**Roger:** My basic take on that is that the Stanfield thesis has a lot of errors in the history part that we did not have the opportunity to give him feedback on. Perhaps he is referring to ZPPR project in the 1960s—that is a misstatement by Stanfield.

**Arjun:** There were no device returns in the late 1950s?

**Roger:** [Name] has researched that topic in a different venue. I don't recall what his conclusion was.

**Arjun:** Is there a way to get that date [for the start of returns] from Bryce?

**Brant:** I will check with him and follow up on that.

(10) **The Stanfield thesis indicates that the Oak Ridge dosimeter had an over-response to the 60 keV Am-241 photon (p. 9 of the thesis, p. 17 of the pdf file). This indicates that the Am-241 component would be over-represented in the dose measurement with this dosimeter. Do you agree?**

**Roger:** I think that what he was referring to was the energy response of the beta-gamma film compared to the Cs [cesium] calibration. The sensitivity (optical density) per unit dose for the Am-241 60 keV gamma was about a factor of 7 or 8 greater than the sensitivity for the 662 keV gamma of Cs-137. However, the early dosimeters of the Oak Ridge design and the 60 keV data would have been derived from the cadmium-shielded portion of that film, and Cd is a very effective shield for 60 keV (or soft gamma) and for x-rays. So that issue would not be a significant factor in gamma dose for the early design. The open window was calibrated based on the L x-rays of the Pu. There may have been a small over-response, because of the calibration on the L x-rays, and Am-241 would be part of that. Then, in 1961, they modified the dosimeter holder and put a brass filter over part of the open window to get the third sector when the Am became more significant.

**John:** We are talking about gamma exposures now, but also about how n/p ratios were derived. Do I understand that you were getting information on the deep dose with the Cd shield? And you have some estimates of neutron dose from badges. So the gamma component was the portion beneath the Cd filter, which would give you the greatest n/p ratio.

**Roger:** No, that is not correct. In Section 11.2 of the protocol, we defined the algorithms for the photon dose. And for the gamma in the 1950s, it was the Cd sector dose plus half of the open window sector dose. When the brass filter was added to the dosimeter holder in 1961, the photon dose was equal to the Cd and brass sector doses plus 0.35 times the open window sector dose.

**John:** So both were used in the way described.

**Arjun:** What is the basis for the half of Cd rather than some other factor?

**Roger:** I don't know specifically what the basis was. It probably was a combination of the amount of L x-rays that would penetrate to 1 cm. There were three primary Pu x-rays—13 keV, 17 keV, and 20 keV—and they probably did a depth calculation. When you do that, you generally get about 0.35, and the 0.5 [used at that time] is a little more conservative.

**Arjun:** That would give you a bigger gamma dose and lower the n/p ratio.

**Roger:** But when you base the n/p ratio on this value and multiply by gamma dose for earlier years, that type of error cancels out. So any biases in the gamma values cancel out. That is why you want to use the same badge configuration for back-extrapolation so the gamma biases, if any, cancel out. That is the power of using the ratio.

**Arjun:** This does presume that there was essentially no Am-241 in 1959.

**Roger:** There could be some small variations, but that is not a major contributor to the variances.

(11) **If the notional dose was assigned to a worker monitored for neutrons and photons, would the result typically be expected to be about the same, less than, or greater than the measured dose?**

**Roger:** The comparison exercise was what Dr. Chapman did in Appendix 4. Since all methods have some variance, he was trying to determine the method that gave the least variance. I can't add much to what he did.

(12) **Were there any major neutron dosimetry changes made as a result of Roger Falk's efforts in the 1967–1968 time period and 1971 TLD introduction?**

**Roger:** That is on page 2 of the protocol, Section 2.0 of the NDRP protocol. Upgrades to the neutron-monitoring program in 1967 included [reading from page 2 of the NDRP protocol] "(1) implementation of quality assurance oversight, (2) implementation of a system to prioritize films to be evaluated microscopically, and (3) implementation of a program to assign "notional" neutron doses to personnel whose NTA films were not evaluated." Also, concurrently, I started to develop the method for the TLD neutron system.

**Arjun:** Do we have the original notional doses?

**Roger:** Those are embedded in the original doses of record that are noted on the NDRP reports.

**Ron:** So the original doses were mixtures of readings and notional dose. Is that right?

**Roger:** Yes. The original neutron dose was either from a film reading or an assigned neutron dose.

**Arjun:** So the column that says "original dose" in the data is not the badge reading?

**Roger:** 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:** 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 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:** 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.

**Ron:** So these were area surveys?

**Roger:** That is correct.

.
**Arjun:** The 1969 gamma badges were thrown away [not read]. How about neutron badges that were not read?

**Roger:** Starting in 1969, Rocky Flats started not to archive some of the neutron film.

**Arjun:** Does it date to the same March 1969 memo for not archiving [reading] gamma film?

**Roger:** That was a different situation. We and other AEC sites were starting to develop TLD systems. The old AEC rule was that you had to archive the primary dosimetry record. The AEC had defined the primary dosimetry record to be the film. When you got to the TLD era, they said, "Whoops, you can't archive the TLD as a record because that is a destructive reading." So they changed the policy as to what needed to be archived from old film to the dosimetry worksheet as the primary dosimetry record. Therefore, there was no longer a requirement to archive the film. That change happened sometime in 1969.

**John:** When the TLD readouts were started, did they archive the glow curves?

**Roger:** No.

**Arjun:** Did they throw away some of the NTA film starting in 1969?

**Roger:** Yes. The term I used was that it was "not archived."

**Brant:** Were they disposed of after they were read or at the end of the year?

**Roger:** I don't know that level of detail. Archiving of the films was generally done at the start of the following year.

**Brant:** But they weren't reading many of the badges?

**Roger:** They were reading all of the NTA film for workers highest at risk and not reading them for secondary and tertiary workers [with low gamma doses].

**Arjun:** Those [secondary and tertiary] workers were within the neutron buildings?

**Roger:** They were within the plutonium [or plutonium-related] buildings.

(13) **Previously we have discussed the fact that there do not appear to be any comparisons that can be made between measured neutron dose data and that assigned by the NDRP process and OTIB-0058 for 1952–1958 to establish benchmarks to validate these dose models. Please provide any information concerning the same type of comparisons for validation for the 1959–1963 and also the 1964–1969 time periods.**

**Roger:** The NDRP did studies where we compared the original doses and re-read doses. So that was the validation. [Upon further reflection, that really is not benchmarking or validation. However, there are also no dose models involved in the re-reading of the neutron films. Instead, the value added by the NDRP was the level of rigor, attention to detail, and QA in the re-reading of the neutron films and in the analysis of data.]

**Ron:** Were there any field measurements using neutron and gamma survey instruments prior to the surveys in 1967 and 1969? How about up to 1966?

**Roger:** The answer is yes. However, those field surveys were not archived. But they did perform regular workplace surveys both for neutrons and for gammas.

(14) **Can an estimate of the number of workers each year that would have been monitored for neutrons by today's standards be made for the period 1959–1969? This would allow comparison to the plot (see next page) on page 8 of the 2003 NDRP "Film Procedure Timeline" to help determine if most, or not many, of the workers potentially exposed to neutrons were monitored.**

**Ron:** This was answered last time [see notes of April 12, 2007 call].

**Arjun:** Sorry, I should have deleted this question from the list for this call.

(15) **Are there any measurements and/or analyses of the neutron exposure potential for the areas where the coworker model is being applied, so that a comparison can be made for those who were in the NDRP and those who were not? Specifically, are there any neutron-monitored data for the non-NDRP buildings in the 1952–1958 period, the 1959–1964 period, or the 1965–1970 period?**

**Arjun:** How do we validate the coworker model for non-NDRP buildings?

**Brant:** Are you talking about neutron exposure potential for uranium buildings?

**Roger:** I am not sure where this is going, and I am not sure that there is an answer for it.

**Arjun:** I am just trying to be clear about the neutron exposure for non-NDRP buildings.

**Brant:** We decided to delete, I think [it was] Table 7.3 [from OTIB-0058] in conversation with Ron. Ron?

**Ron:** For the workers in the NDRP, we have been discussing notional doses and so on and how to validate them. So now we shift to the coworker dose estimates and ask, if a non-NDRP worker had a chance to be routinely exposed to neutrons, then how do we assign the neutron dose to that worker and how do we validate that? The dose reconstructor uses Table 7-2 [in OTIB-0058]. So we are asking if someone gets assigned a certain value for neutron dose, can we point to some measurements in those buildings for those years and compare that to the assigned dose?

**Brant:** This speaks to philosophy of OTIB-0058. For a worker who was not monitored, we would not be routinely applying neutron dose, because there was no source for neutrons in those buildings. We see at least among our claimant population that workers who were at risk of neutron exposure are in the NDRP. We have not found a single case among claimants of workers at risk of significant neutron exposure who are not in the NDRP. So the coworker model is for a hypothetical contingency.

**Ron:** So are you saying that to date you have not used it so far.

**Brant:** Keep in mind the philosophy that workers with exposure potential of less than 10% of the annual limit were not necessarily monitored. So if a worker was in one of the NDRP buildings, but in administrative areas of that building, say Building 91, that may mean that worker was not monitored. That would be the kind of situation that we would apply the n/p ratio and come up with a neutron [coworker] dose that way. But if you are talking about a non-neutron building, say 881, we would not be assigning neutron dose. Outside of Pu areas, there really wasn't the potential for neutron exposures. There was no $UF_6$ at Rocky Flats, for instance, that would generate neutrons [from (alpha,n reactions)]. Rocky Flats had basically uranium metal.

**Ron:** Let me summarize. ORAUT-OTIB-0058 would be used for someone who was in Pu areas, but was not monitored.

**Brant:** That would be Table 7-2.

**Ron:** But someone outside of Pu areas would be assigned ambient dose.

**Brant:** No, we would assign gamma dose for uranium area work. If they did not visit production areas, they might be assigned ambient and this is the same as any other site. If they were routinely in production areas, 95$^{th}$ percentile would be assigned; if they were sometimes in production areas, like delivering letters, the 50$^{th}$ percentile might be assigned; otherwise ambient dose would be assigned. But you should check the TIB for the exact procedure. Speaking for NIOSH reviewers, we occasionally send a dose reconstruction back for such reasons.

(16) **The NDRP report states that its purpose was to make "the best reasonably achievable assessment of the neutron exposure" (ORISE 2005, p. 1) that workers received. Can this be described as a best-estimate dose in the sense that it is considered in the OCAS dose reconstruction program? If not, how would you characterize it?**

**Arjun:** It seems that the NDRP project's aim was to attempt to make a best estimate and a variance.

**Roger:** We tried to make a best estimate. Sometimes if there were choices, we made the choice that was favorable to the worker. The NDRP also calculated the variance for the annual re-read film doses, as well as for the notional doses, that can be used for establishing a 95 percentile or some other bounding neutron dose estimate, if there is a need to do that.

**Arjun:** If John and Joe want, I could send these notes to NIOSH and SC&A at the same time in order to expedite the availability of the notes.

**John:** Fine.

**Brant:** If you are going to attach the minutes to supplemental report, there may not be an urgency to get it done by Thursday.

**John:** We do what we can, but if we cannot do it by Thursday, that is okay, too.

**Arjun:** Roger, thanks so much for your expertise. It was very great help; this helped clear up many things.

**Roger:** You are welcome.

End of call.

# ATTACHMENT 4: APRIL 24, 2007, CONFERENCE CALL MINUTES

**SC&A Conference Call with NIOSH, April 24, 2007, on findings raised in draft SC&A report, *Supplemental Report on Neutron Doses at Rocky Flats, 1952 to 1958***

These minutes represent a substantive summary of the call by issue. Where statements are "bracketed" ([...]) in the text, this is to signify that this material was provided following the call as clarifying information by either NIOSH or SC&A, and that its inclusion does not necessarily represent acceptance by the other participants of its accuracy or validity.

**Present on the call:**

Advisory Board: Mark Griffon, Mike Gibson

NIOSH/ORAU: Brant Ulsh, Jim Neton, Roger Falk, Jenni Hoff, Matt McFee, Karin Jessen, Mutty Sharfi

SC&A: Joe Fitzgerald, Arjun Makhijani, Ron Buchanan

Arjun went over the main points of the report briefly to start off the call. The changes at Rocky Flats, which are important to the issue of the use of 1959 data as part of the 1952–1958 dose estimation, were discussed.

There was a discussion of the changes in the processes and the parts of the production operations that were conducted in various buildings in the 1952–1958 period and in 1959. This was followed by a discussion of each specific finding in the SC&A report of April 24.

## A. Building 71 Expansion and Issues related to Changes in Work in Various Buildings

SC&A noted that there was an expansion of Building 71 in the 1956–1957 period, the addition of an incinerator to Building 71 in 1958, and a change in the pit design in 1957. The site profile mentions an expansion in 1955, but there are no details.

Roger Falk explained the details of the changes as follows:

(1) Although a major expansion was authorized in 1955, the new buildings and other upgrades were not completed and functional until several years later. The reference in the site profile likely related to the funding and designs of the expansion. The expansion included several buildings, such as Building 83 (for the enriched uranium operations, operational in the summer of 1956), Building 86 (the nuclear safety and the criticality mass laboratory), and Building 76/77.

(2) Building 76/77 (one building structure) started to be constructed in the 1956 time frame. Operations were phased-in during 1957 and 1958.

(3) When Building 77 became operational, the assembly and inspection of Pu parts were transferred from Building 91 to Building 77. [The Historic American Engineering Record (HAER) for Building 991, page 3, states, "In 1957, production began on a new weapon design, requiring changes in the amount of machining and handling required, and the need for tighter controls. Because of the new design, final trigger assembly took place in the newly constructed Building 777." Note: The HAER reports for major building at Rocky Flats are posted at the website: http://192.149.55.183/HAER/base/Buildings/991.htm. This is the address for Building 991. For other buildings, substitute the three-digit building number for 991 in the above address.]

(4) Pu metal operations were transferred to Building 76 from Building 71 in the 1957–1958 timeframe. The 1957 fire accelerated that transfer, so that they could resume fabrication of Pu metal parts. [The HAER report for Building 776/777, page 1, states, "Beginning in 1958 and continuing through 1969, Building 776/77 was the main manufacturing facility for plutonium weapons components." The HAER report for Building 771, page 4, states, "Because of the damage to Building 771, and because construction of Building 776/777 was nearly complete, some of the plutonium operations started in Building 776/777 immediately following the fire. Much of the original production and fabrication equipment remained in Building 771 to provide supplemental plutonium production capabilities for the Plant. After 1957, Building 771 operations consisted primarily of aqueous plutonium recovery from scrap metal.]

(5) The major expansion of Building 71 was related to the increase in batch size. There was a new Chemistry Line that was established for the increased production. That Chemistry Line was in operation during 1959, and, therefore, it [the neutron and gamma exposures from that operation] would have driven the n/p ratios that were back-extrapolated [from 1959 to 1952–1958] for Building 71. Prior to the batch increase in 1957, the process line for the small batch size was largely a remote operation, and the neutron doses seemed to be much less significant than for the time when the batch size was increased in 1957 and when they started monitoring for neutron doses with NTA film.

## B. Exposure Conditions in Building 71

SC&A asked why the expansion had involved a change from remote operate to manual operation in a manner that would increase dose.

Roger Falk explained that in the early period [prior to the expansion], the remote operation lines occasionally got plugged with plutonium. The plugs had to be manually unclogged by the workers. [Which type of worker was not specified. Obstructions that could be easily dislodged by shaking the line or tube were likely fixed by the chemical operators.] So, the chemistry operation was redesigned to reduce the maintenance operations and the radiation exposures to those workers. Even though the batch size increased and the level of exposure during operations increased, the level of exposure during maintenance was reduced. It was part of the "lessons learned" from the early years.

SC&A pointed out that the early operations, therefore, involved manual maintenance, while the later ones were manual operations. So the manual maintenance in the early period would have led to higher doses.

Roger Falk stated that the larger batch size would have been more important than earlier maintenance practices in producing a higher neutron dose. It is expected that there were elevated gammas relative to the neutrons in the earlier period. It would be claimant favorable when you go from a remote operation and only do troubleshooting to a larger batch process, where one would expect a more favorable ratio [a possibly higher n/p ratio than the ratio for the earlier years] in 1959.

## C. Exposure Conditions in Building 91 and Building 91 n/p Ratios

SC&A noted that the general trend in Building 91 dose rates (average mrem/day experienced by workers) was downward (except for the rate going up from the start-up year of 1952 to 1953, as shown in Table 3 of the April 24, 2007, SC&A report). Specifically, the 1953 neutron dose rate was about 6 times the 1959 dose rate for Building 91. This indicates that the 1959 Building 91 neutron doses are not bounding, and their use in the back-extrapolation would not be indicated, unless a similar trend in gamma doses rendered the n/p ratio unchanged. SC&A has not estimated the gamma dose trend. Furthermore, SC&A noted that the n/p ratios in Building 91 on an annual average basis were on the order of 20, which was even greater than the bare $PuF_4$ ratio of 13 measured experimentally by Roger Falk. Roger explained that this was again because of the low gamma exposures and not from the neutron doses.

Mark Griffon stated that NIOSH has indicated that assembly operations were the primary concern for the health physicists in the early years. NIOSH now states that these were moved to Building 77. If these two things are true, how could there be a case for back-extrapolating 1959 Building 91 n/p ratios, since operations in that building had clearly undergone a significant change.

Roger Falk explained the situation as follows: There was a specialized operation involving assembly in Building 91. This included a neutron source as well as plutonium metal components. The specialized operation was transferred to Building 77 [circa 1958]. Pu metal was involved in final pit assembly. But there was an undefined "neutron source" (likely classified), not related to the Pu metal, that was of particular concern from the personnel monitoring standpoint. The concern of the Rocky Flats health physicists in the initial years was about the neutron source that was part of the assembly work in Building 91. They were concerned about routine exposures from that and from potential high neutron exposures that might result from the handling of that source. The n/p ratios increased in Building 91 after the transfer of the assembly to Building 77, because both gamma and neutron exposures were at the lower limit of detection, and the gamma background was being subtracted out, but neutron background was not. This would elevate the ratio, especially if the gammas are already at a low value. After 1956 or 1957, shipping and storing dominated the plutonium operations [these were operations with low risk of neutron exposures] in Building 91. That [low neutron doses without background subtracted, in the numerator of the n/p ratio, divided by gamma doses at or near the limit of detection, with background subtraction] would have skewed the data [to apparently high n/p ratios]. The n/p ratios for Building 91 [in the NDRP] are likely very claimant favorable. The NDRP had a choice between using the n/p ratios for Building 77, since final assembly of the plutonium trigger had been transferred to Building 77, or the n/p ratio for Building 91. The Building 91 ratio was selected for back-extrapolation because it was the higher ratio. Whenever they had a choice, they would choose the one that resulted in the higher neutron dose for the worker.

Mark Griffon noted that this explanation was not self-evident from previous NIOSH/ORAU documents. He asked for a clarification of the previous discussion of assembly operations. In those earlier discussions, Roger Falk had indicated that the n/p ratio for Building 91 was selected because it was higher than Building 77. But there was no mention of the fact that a new pit was involved in assembly during the later period. Doesn't that indicate that there were different processes and operations involving assembly in 1959 than in earlier periods? He stated that these changes lead to a lot of questions about the back-extrapolation.

**E. Effect of Changes in Job Types in Buildings Regarding n/p Ratios**

SC&A noted that there were a lot of operational changes that occurred at RFP from the initial years to the period after 1957–1958, including movement of specific operations from one building to another and a new pit configuration (to a hollow pit). SC&A asked whether the NDRP evaluated the effect of these changes on the comparability of the n/p ratios between 1959 and the earlier period. Furthermore, in prior calls, NIOSH had stated that the change in batch size in Building 71 would only lead to a "minimal" change in the n/p ratio. Now it seems that there are multiple changes of significance to consider.

Roger Falk's explanation: He reiterated that the effect of the change in batch size on the n/p ratio was minimal. The NDRP had not specifically investigated the effects of the changes in production within buildings. However, known changes did take place with respect to the transfer of Pu metal production workers. The highest neutron exposures stemming from alpha-n interactions occurred in the Pu chemistry operation [involving plutonium fluoride], which was still in Building 71. The Pu metal production operations typically had lower n/p ratios (neutrons were mainly from spontaneous fission) than n/p ratios for Pu chemistry operations. So with the transfer of Pu metal production workers from Building 71 to 76, claimant-favorable n/p ratios for Building 71, dominated by the doses from Pu chemistry operations, are claimant favorable for the Pu metal workers in Building 71 prior to 1959 in the back-extrapolation process.

SC&A noted that NIOSH's assertion all along has been that RFP operations were relatively stable in the 1950s [as for instance during the working group meeting of April 19, 2007]. However, it is increasingly clear that a number of significant changes occurred. There has been no demonstration in the NDRP or by NIOSH to date that the n/p ratios after these changes—that is the n/p ratios in 1959—can be back-extrapolated.

NIOSH's assertion was not that the processes were relatively stable, but rather that whatever changes that occurred would not significantly affect the n/p ratios in a way unfavorable to the claimant. NIOSH has provided technical justification on why n/p ratios would not be higher in the earlier years.

## F. Discussion of Specific Findings

**Finding 1:** The available data indicate that the limited number of workers who were monitored in Building 91 were not necessarily among the highest exposed workers. Data also indicate that Building 71 workers were not monitored during the 1952–1958 period (apart from some data in late 1958, which appears to be similar to that in 1959). Almost all of the monitoring data were for the period up to December 1958 for Building 71 has not been recovered or has not been matched to individual workers. Hence, for practical purposes, Building 71 can be considered to have no significant neutron monitoring data from 1952 to November 1958 (inclusive). As a result, available monitoring data for Building 91 for the 1952–1958 period cannot be used to develop bounding estimates of unmonitored workers at risk of neutron exposure.

NIOSH agreed that the workers receiving the highest doses were not necessarily the ones who were monitored. That was the original reason for the NDRP; to address workers who got significant neutron doses that were not reflected in their record. NIOSH agrees with SC&A on this issue, but is not sure why it is stated as a finding.

SC&A explained that the issue was there to document that there had been extensive discussion of the question about who was most exposed during 1952 to 1958, and whether they were monitored. It was also to ensure that if there were an approach applied other than n/p ratios, that the basic questions relating to who was monitored and back-extrapolation, itself, would be taken into account.

**Finding 2:** The fact that judgments made in the 1950s regarding the relative magnitude of the neutron doses for workers in Building 91 was in error has considerable implications for the Rocky Flats neutron dose reconstruction for the 1952 to 1958 period. Specifically, Building 91 doses from the 1952 to 1958 period cannot be used to develop a bounding dose estimate for workers at risk of neutron exposure in that period, even apart from the questions associated with back-extrapolation of 1959 data to the earlier period. Evidently, the same is also true of Building 91 doses in 1959.[15]

NIOSH stated that it could not agree that the judgment of the health physicists at the time was in error. The health physicists of the time did make an appropriate judgment by identifying workers at highest risk. They did a good job of controlling exposures and, therefore, actual exposures were higher in Building 71. So it would not be correct to say that they had not appropriately considered for monitoring those workers at highest risk.

Roger Falk agreed and stated that the health physicists were truly concerned about neutron risks associated with assemblies. Specifically, they were concerned about the workers involved in the final assembly being overexposed to the neutron source. That was the risk at that time, which they thought they really needed to control. That should not now be characterized as an error because at the time, the Building 71 workers were not exposed to the large batches of plutonium.

[15] NIOSH has not proposed to use Building 91 doses from 1959 for other buildings in the 1952–1958 period. This statement that this cannot be done is merely to make the conclusion of the analysis presented here explicit.

There was no potential there for a large, undetected acute neutron dose, which was the concern with handling neutron sources in Building 91.

SC&A pointed out that NIOSH had made that statement about the judgment of the health physicists of the time being in error, and asked whether NIOSH was now changing its conclusion about that.

NIOSH agrees that SC&A has accurately quoted our statements at the April 19 working group meeting. However, this is a fast-moving issue, and we may have been too quick to agree that the health physicists made an error. To clarify, it is important to distinguish between *potential* exposure and *actual* exposure. The health physicists at the time made badging decisions based on who they judged to have the highest exposure *potential*—that is why they chose workers in Building 91 over those in Building 71. They did a good job at managing the neutron exposure potentials in Building 91, so the actual received doses were lower. This should not be used to retrospectively impugn the judgment of the health physicists. Furthermore, you are comparing to neutron doses in Building 71, as estimated by the NDRP using a worker-favorable n/p ratio.

**Finding 3:** In view of these factors, the 1952–1958 data were regarded by the NDRP as an insufficient basis for assigning doses to workers who were not monitored in that period. SC&A concurs with this finding.

There was no discussion of this finding, since there was complete agreement.

**Finding 4:** There were several changes at Rocky Flats in the 1955–1958 period that could have materially affected either gamma doses or neutron doses and, hence, their ratio. These factors were not carefully investigated in the NDRP prior to the decision to use 1959 data to derive n/p ratios for back-extrapolation to the 1952–1958 period. Hence, the validity of the 1959 n/p ratios to the 1952 to 1958 period has not been established. Furthermore, any use of the 1959 data for back-extrapolation to the 1952–1958 period would require a detailed investigation of the extent to which the extensive changes that occurred at Rocky Flats changed radiological and working conditions with respect to resultant worker doses.

The discussion on this finding has been summarized above regarding the acknowledged changes that took place in the facilities. NIOSH's position is that the net result of the changes is that the 1959 n/p ratios are claimant favorable relative to the actual conditions of the earlier period. Changes in the facilities would not depress the n/p ratio causing us to underestimate the dose.

SC&A pointed out that neither the NDRP nor NIOSH has actually investigated the effects of the many significant changes in working conditions, job types, pit design, and operations in buildings on n/p ratios, so that the claim is an assertion without any technical demonstration.

NIOSH disagrees with this characterization. Both the NDRP and NIOSH have explicitly considered whether changes in (1) source term, (2) building configuration/shielding, or (3) the manner in which processing occurred (batch mode) would have significantly depressed the 1959 n/p ratios relative to what would be expected in the earlier years. We have concluded that the above-mentioned factors, if they had any appreciable affect on n/p ratios, would be in a claimant-favorable direction (higher ratio). The change in pit design would have minimal impact on Building 71 ratios, because those ratios were dominated by the plutonium chemistry operations. The NDRP protocol is the most relevant document, but you also have to consider the information discussed in the past few conference calls as supplementary information.

**Finding 5:** The data for Building 91 strongly indicate a lack of comparability between Building 91 neutron exposure in 1959 and earlier years, notably the 1952–1954 period. The factors that caused the lower exposures in the later years were not analyzed in the NDRP. On the face of it, a back-extrapolation of 1959 data for Building 91 appears to be unjustified. The lack of comparability of exposure conditions in Building 91 reinforces the above analysis for Building 71, which also indicated changing working conditions in the 1952–1958 period.

NIOSH stated that this finding does not address the issue of n/p ratios, but only addresses the question of neutron dose rates. We do not do back-extrapolation on neutron doses, but on the n/p ratios. SC&A pointed out that the detailed analysis does discuss that, and that it would edit the finding to reflect that.

**Finding 6:** The back-extrapolation using 1959 data to the 1952–1958 period cannot be validated with dose data or data on exposure conditions for the 1952–1958 period for Building 71. The significant changes in facilities that occurred during the period indicate the likelihood of changed exposure conditions. How these might have affected individual gamma and neutron doses, and the n/p ratio for Building 71 is unknown. This indicates that such back-extrapolation is scientifically inappropriate, at least for this building. The available data do not permit a definitive analysis.

There was a discussion of what the term “validation” might mean in the present context. SC&A mentioned field measurements of neutron radiation, for instance. It was agreed that data such as area neutron monitoring data from the 1952 to 1958 period did not exist to validate the notional dose estimates made by the NDRP. NIOSH questioned the usefulness of such data in view of the fact that workers followed a batch from beginning to end. NIOSH stated that field surveys would not provide accurate estimates of the n/p ratios and would be of little use. Field surveys are for a specific location. Badges followed workers and the workers followed the Pu batches from beginning to end. The workers did not stay in one location. It would be more relevant to look at the paired n/p doses.

**Finding 7:** The method of using 1959 data for 1952–1958 has not been validated. The data that exist do not support its use to estimate a bounding dose as envisioned in 42 CFR 83. The problem is more acute for 1957 and 1958, for which almost all the sparse original data appear to have been lost or could not be recovered. The back-extrapolation of 1959 n/p ratios to the 1952–1958 period is not well founded scientifically, and is stated by the NIOSH site expert to be “more speculative” than any other period of notional dose estimation.

NIOSH pointed out that 42 CFR 83 states that NIOSH may calculate a maximum credible dose for every type of cancer or a make a more accurate estimate if more information was available. The NDRP notional doses are claimant-favorable best estimates and, therefore, not maximum estimates. The NDRP does provide 95% upper bounds of notional doses that could be used.

However, the doses provided by the NDRP are more accurate than maximum estimates. It is NIOSH's position that the NDRP doses are meeting the requirements of 42 CFR 83.

**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.

Roger Falk agreed that he had himself calibrated those original badges in the 1960s—30 years prior to the NDRP. He stated that he did not "peek" at the original results before re-reading them as part of the NDRP.

Mark Griffon asked whether SC&A was indicating that this is a "less significant" issue, because it is not a "finding" but an "observation." SC&A stated that it was not asserting that Roger Falk made a mistake, but pointing out to the Board the highly unusual situation that the person against whom all reader biases had been corrected had not had an independent calibration of his readings. SC&A believed that this was an important issue that the Board should be aware of.

NIOSH pointed out that all of the NDRP film readers, including Roger Falk, were calibrated against the given neutron dose on the NTA films in the two calibration sets used by the NDRP.

### G. Correction Factor for Un-read Portion of the Original Dose Record

**Ron:** I would like to make clarifications concerning some discussions at the April 19, 2007, Advisory Board meeting in Cincinnati. This issue is applicable to the 1952–1958 time period we have been discussing, because it covers the time period 1951–1963. The 2.5 correction factor for neutrons below 800 keV and the 1.99 factor for n/p (or 'reading deficiencies' TBD-6 pages 49 and 50 are not clear on this terminology), are not automatically applied to the all neutron doses, or to the total neutron dose, as indicated on page 48 of TBD-6. Therefore, you do not end up multiplying the neutron dose by a factor of 5, i.e., 2.5 x 2 for all early neutron doses. According to OTIB-0050, page 7, the 2.5 factor for neutrons below the threshold is only applied for maximizing cases, and then only to the non-re-read original dose, not the total neutron dose, which is usually a small part of the total neutron dose. For best estimates, Table 6-21 of the new TBD will be used according to building number, with a correction factor ranging from 1.19 to 2.5. So a factor of 5 will not be used in all cases.

**Mutty:** According to Table 4-1 of OTIB-0027, the correction factor of 2.5 will be applied to the non-re-read neutron dose for all buildings—different building factors will not be used, as listed in Table 6-21 of the TBD. The TBDs and OTIBs are only part of the DR process, the DR will apply correction factors during the DR process as shown in the DR report.

Ron: If I understand you correctly, the factor of 2.5 will be applied for all buildings for 1951–1963 and the film bias factor of 1.99 will be applied for Building 771, and 1.13 for all other buildings. This will only be for the non-re-read portion of the neutron dose.

**Mutty:** Yes, that is correct.