

White Paper on NUMEC Issues and Feasibility of Coworker Model

Rev. 0

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Page 1 of 19

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Introduction:

The NIOSH Special Exposure Cohort (SEC) evaluation reports (SEC-00080 and SEC-00108) for the Nuclear Materials and Equipment Corporation (NUMEC) facilities in Apollo and Parks Twp. PA (hereafter referred to as NUMEC), concluded that it was not possible to plausibly bound internal and external doses at these facilities. The entire operational period for both NUMEC sites have been added to the SEC based on internal and external infeasibility (with some exceptions, which are elaborated below). An evaluation of the NUMEC Technical Basis Document (TBD) by Sanford Cohen & Associates, issued in April of 2013, resulted in 21 findings that were discussed during a meeting of the work group on Uranium Refining Atomic Weapons Employers of the Advisory Board on Radiation and Worker Health on August 3, 2015. At that meeting 10 of the 21 findings were closed, pending NIOSH incorporating the agreed upon changes into the revised site profile.

NIOSH has evaluated the remaining issues from the Work Group Discussion for NUMEC and has proposed the following updates to the issue resolution status. The revised NUMEC TBD (ORAUT-TKBS-0041, Rev. 03-B) has a tentative publication date of 8/12/2016 and is currently in draft status.

NIOSH does not expect any additional data capture for NUMEC to be feasible given the difficulties working with the contractor before. NIOSH made a large data capture effort in 2014, which involved the collection of over 14000 documents after many months of negotiation.

Status of Findings:

Finding 1: Clarification is needed regarding the start and end dates of Parks Township Site operations.

Proposed NIOSH resolution: Tables will be updated with new information and values possibly corrected.

August 2015 WG discussion: **Closed**, if change is included in TBD revision.

NIOSH update June 2016: Change included in draft ORAUT-TKBS-0041 Rev. 03-B.

Finding 2: The site profile should provide guidance about what level of uranium enrichment should be assumed for those urine bioassay results that are expressed in units of µg/L.

Proposed NIOSH resolution: NIOSH will add a section to TBD with guidance on enrichment assumption if no other information is available (assume highly enriched since it is claimant favorable and was used at Apollo).

August 2015 WG discussion: **Closed**, if guidance is included in TBD revision.

Finding 3: Some guidance is needed on how to perform dose reconstructions prior to 1959, and what approach to use for missed and unmonitored exposures.

Proposed NIOSH resolution: None. Pre-1959 dose reconstruction is infeasible per SEC.

August 2015 WG discussion: **Closed.**

Finding 4: Uranium inhalation recommendations for the Apollo Site need to consider the method discussed by Davis and Strom (2008) for dealing with uncertainties in DWE. This technique was evaluated and found to be appropriate in the site profile review for the Fernald Feed Materials Production Center (Fernald).

Proposed NIOSH resolution: Davis and Strom (2008) evaluated several HASL reports and concluded that the daily weighted exposures have a lognormal distribution with a geometric standard deviation of 5. HASL data is available for the Apollo site and has been used to evaluate exposure concentrations. As discussed in Finding 18, the air concentration used for the beginning of the residual period has been re-evaluated and is now based on General area (GA) monitoring rather than daily weighted average exposures (see response to Findings 5 and 18 below). The geometric standard deviation (GSD) for the revised air concentrations has been set to 5.0 based on Davis and Strom (2008).

August 2015 WG discussion: The discussion during the work group meeting moved from the question of using the HASL data in dose reconstructions to the more general issue of whether it was possible to develop co-worker models for uranium intakes. Based on the Apollo Evaluation Report, internal doses from uranium bioassay can be reconstructed when data are available for an individual claim. SC&A questioned if NIOSH has any claims with uranium bioassay where internal uranium dose was not assigned. SC&A would like to investigate more to find workers who were exposed to U and not had internal U assigned. NIOSH was tasked to review and evaluate if a coworker model is needed. **Issue 4 was closed;** however, NIOSH committed to assess the possibility of a coworker model. Dr. Neton pointed out that the SEC decision does not mean that every single feasibility and infeasibility was evaluated (meaning, just because the finding for the Apollo ER was that internal uranium dose reconstruction are feasible when data exist for a given claim does not necessarily mean that a coworker model can be developed for

this data). Any coworker model that is developed would have to hold up to the standards of the coworker implementation guide.

NIOSH update June 2016: During the initial discussion, there was some misunderstanding in NIOSH's part on the focus of this issue. The original issue addresses Section 5.4 of the TBD, which provides guidance to assign internal doses based on fixed BZ air data for uranium workers during 1959-1961. Upon further consideration of the guidance and the data, this section using HASL BZ data will now be removed from the TBD in accordance with the findings presented in the Apollo SEC evaluation report that internal doses cannot be reconstructed during that time period except when uranium bioassay are available. HASL BZ data were collected for specific projects and operators during a limited operating time and do not reflect the range of uranium activities carried out and NUMEC.

As for the coworker model discussion, it is not expected that the available data can be used to develop coworker models that would adhere to the guidelines expected from such a model. Please see detailed analysis below.

Finding 5: Inadequate information is given to replicate NIOSH's determination of median inhalation concentration of uranium. The NIOSH result could not be replicated, and it appears that relevant information has been omitted from the HASL studies reported in Appendix A to the site profile.

Proposed NIOSH resolution: No data from the HASL reports cited have been omitted, but the calculation approach has been revised since the previous TBD was issued and is now based on GA data.

August 2015 WG discussion: NIOSH should provide more guidance how the revised approach is to be used for partial dose reconstructions. This analysis was done to get to a starting point for levels to be used in the residual period. For the operational period, BZ samples are used if they are available. SC&A voices concerns that there were significantly higher intakes in the ceramics plant than other areas and whether those would be represented in the median intakes.

NIOSH update June 2016: See response to Finding 4.

Finding 6: The site profile would benefit from a discussion demonstrating that the Hanford fuel-grade mix, as opposed to the weapons-grade or commercial-grade plutonium, is limiting for the full range of plutonium mixes and ages that were used at NUMEC. In addition, given the complexity of this subject, a review of actual dose reconstructions would provide greater insight into how this matter is actually being addressed.

Proposed NIOSH resolution: Table will be updated with recently captured information on the fuel types used at NUMEC to represent more accurately the mixes that were handled.

August 2015 WG discussion: SC&A wants to review response in detail and provide comment on the response. SC&A was tasked with providing an additional response.

SC&A response after WG discussion: Other possible Pu mixes that may have been present at NUMEC should be investigated (such as Japanese fuels and fuels from the UK).

NIOSH update June 2016: This issue was not pursued further. Additional data capture is not considered to be a productive option for NUMEC. The currently available data can be used for a reasonable claimant-favorable assumption to assign partial internal dose. It would not be reasonable to speculate on additional Pu mixtures to complete partial dose reconstructions for non-presumptive cancers. Any reported Pu bioassay will be used at face value. No adjustments for other contaminants are available.

Finding 7: The MDAs for Am-241 lung counting are very low, and the counting method should be further explored in order to give them credibility.

Proposed NIOSH resolution: NIOSH will added some additional guidance to the draft TBD.

August 2015 WG discussion: NIOSH has addressed some of the MDA issues and added some more reasonable values, but SC&A's concerns remain. Dr. Neton agrees in that the MDA numbers for Pu look somewhat low, the Am MDA looks ok. The Pu MDA values are very much dependent on chest wall thickness. SC&A was tasked with providing additional assessment.

SC&A response after WG discussion: SC&A believes that the MDA value for in-vivo monitoring of Am-241 and Pu-239 are not reliable, that very limited data is available, and that the low reported values for MDAs for Am-241 in-vivo lung monitoring need to be further developed. The values for Pu-239 are not credible, due to the 17 keV X-rays being measured directly.

NIOSH update June 2016: NIOSH has discussed and evaluated the chest counting data that was supplied by Babcock and Wilcox. Many of the reported results have a reported MDA when a non-detectable amount is reported. The MDAs appear to be lower than what might be reported today, but it would be difficult to come up with an alternate value. Most measurements were done at the University of Pittsburg and the NUMEC in-vivo program was overseen by a person who was highly regarded in the field. The lower MDAs could be the result of the calibration phantoms used at the time. Until the advent of the Livermore realistic phantom in the late 1970's, the phantoms in use did not provide a sophisticated representation of human anatomy

and tissue equivalency. It was eventually discovered that the earlier phantoms tended to overestimate counting efficiency, especially for low-energy emitters like Pu and Am. Unfortunately, there does not seem a straightforward way to adjust the earlier values retroactively, to comport with what might be reported today.

There are too many unknown variables involved, including the exact design and configuration of the detectors used, the position of the detectors over the lungs (i.e., measurement geometry), and the chest wall thickness (CWT) for each subject counted. Even if the CWT is known for a person, the manner in which it was measured or calculated can lead to large differences in the value. Given all this, NIOSH intends to use the detection limits as reported for each original measurement. While there may be some negative bias associated with using these values, it seems to that this is preferable to making adjustments that would largely be based on conjecture. This approach would be consistent with performing partial dose reconstructions for non-presumptive cancers using “data that may be included in an individual’s file (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures)” to support a partial internal dose reconstruction for non-presumptive cancers and/or cases that have less than 250 working-days of employment.

Finding 8: The site profile would benefit from a more thorough discussion of the possible use of air sampling data to reconstruct internal plutonium exposures and to take into consideration the additional data provided by Crosby 1967 and NUMEC 1967.

Proposed NIOSH resolution: None. Internal dose reconstructions are partial and done only in cases where bioassay is available.

August 2015 WG discussion: **Closed.**

Finding 9: It does not seem appropriate to use ORAUT-OTIB-0054 (ORAUT 2007a) to reconstruct the internal exposures of workers at NUMEC who might have been exposed to mixed fission products. ORAUT-OTIB-0054 states that its guidance “does not apply to determination of intakes where radionuclides have been purposely extracted and concentrated as for heat generation sources, medical uses, or waste handling operations that caused significant alteration to the source term to which workers were exposed.” For example, see Table 5-1 of the site profile. Also, the fission product mix given in ORAUT-OTIB-0054 does not contain the same radionuclides as the fission product mixes given for the NUMEC Laundry in the 1975 effluent release report (SRDB #20081) and for in-vivo count results in SRDB #19970. The NUMEC mixes include Co-60, which the ORAUT-OTIB-0054 mix omits.

Proposed NIOSH resolution: The use of OTIB-0054 (ORAUT 2015) is appropriate when the source of activity is from reactors. As indicated in this finding, the NUMEC laundry processed materials from many sources in addition to the commercial reactor laundry. The site profile will be modified to remove guidance on use of OTIB-0054 for evaluation of dose from associated fission products and activation products. The guidance will indicate that doses are to be evaluated only for the radionuclides included in the bioassay results

August 2015 WG discussion: **Closed**, if new guidance is included in TBD revision.

NIOSH update June 2016: Change included in draft ORAUT-TKBS-0041 Rev. 03-B.

Finding 10: Internal dose reconstructions performed for NUMEC personnel might need to be revisited in light of changes to the Fernald site profile (ORAUT 2004) with respect to RU. Also, additional direction is needed with respect to which workers or operations should be assigned RU intakes.

Proposed NIOSH resolution: Some language will be added to the revised NUMEC TBD regarding assigning RU doses for NUMEC.

August 2015 WG discussion: Discussed whether any additional sources of information regarding the uranium composition were reviewed. **Closed** if NIOSH adds guidance on assigning RU doses to the TBD revision.

NIOSH update June 2016: Change included in draft ORAUT-TKBS-0041 Rev. 03-B.

Finding 11: NIOSH should explain whether the concerns expressed in the Pantex site profile (ORAUT 2007d) about the Helgeson chest count data might also apply to chest count data at NUMEC performed by Helgeson for NUMEC workers.

Proposed NIOSH resolution: The in vivo counting at NUMEC was performed by Helgeson only during 1968, 1971, and once in 1975. The Helgeson counts included primarily plutonium-239, with a few results for uranium and fission products. The majority of in-vivo counting was performed at the University of Pittsburg hospital. The issue with Pantex was that the counts for uranium were biased high and represented false positives (Brake 1989). The current Pantex internal dose TBD has eliminated all reference to Helgeson in-vivo measurements. Using the Helgeson results for uranium at NUMEC is favorable to the claimant, because any bias would be high. There was no issue identified related to Helgeson in-vivo counting for fission products, plutonium, or americium.

August 2015 WG discussion: SC&A wants to look into this issue more. SC&A will review the issue and provide findings to NIOSH.

SC&A response after WG discussion: SC&A remains concerned about the values used for MDA for in-vivo counts, as some are listed as 63 µg and some are listed as 80 µg for U-235. SC&A would like to see clarification and DR examples to ensure the correct value is used.

NIOSH update June 2016: NUMEC used the Helgeson mobile whole body counter for Pu and Am counts, and also some U-235. The MDA reported for U-235 in 1968 using the Helgeson unit is 80 µg. NUMEC mostly did whole body counts at the Low Level Radiation Monitoring Facility at the University of Pittsburg, which, on many count results, report a MDA value of 63 µg for U-235. A clarifying statement could be added to the TBD, but since generally the MDAs seem to be reported with the respective result, for a non-presumptive cancer, the MDA respective to the analysis would be used. As outlined for item 7, NIOSH has not located any information that would allow for a critical assessment and correction of reported MDA values that are perceived low by SC&A. The issue with Pantex was that the counts for uranium were biased high and represented false positives (Brake 1989). The current Pantex internal dose TBD has eliminated all reference to Helgeson in vivo measurements. Using the Helgeson results for uranium is not to the detriment to the claimant, since it would lead to a positive bias. No additional research is proposed at this point by NIOSH.

Finding 12: Table 6-2 and the associated text in Section 6.3.2 of the site profile should be reviewed and modified as needed to correct any oversights, inconsistencies, or errors.

Proposed ORAU resolution: The indium foil criticality dosimeters were not included in Table 6-2 because they were not used for routine workplace exposures. They were included only to determine dose from a criticality in the event that a criticality occurred. No criticality incidents were reported at the NUMEC facilities. The text was reviewed as suggested and the information in the text is consistent with information provided in Tables 6-2 and 6-3.

August 2015 WG discussion: SC&A insists there is still an error in the table. How are data from multi component badges handled? SC&A to elaborate further.

SC&A response after WG discussion: More information is needed regarding how the data from the neutron detection devices will be used to reconstruct neutron doses. For example, Table 6-2 describes the method for deriving the fast neutron dose that involved subtraction of the thermal dose, but it is not clear if this was determined from a cadmium-filtered film badge or not. The Landauer "Z1" dosimeter contains a neutron sensitive CR-39 component, but this is not

mentioned in the table or text. Both the text and table are unclear and inconsistent regarding the use of CR-39. Table 6.2 indicates that Z1 badges are used (for beta/gamma), but nowhere does it say that they contain a CR-39 neutron component. The text in section 6.3.2 mentions the use of NTA, then states that, after 1968, neutron monitoring was performed with TLDs. Table 6-2 does say that other types of neutron dosimeters (not mentioned in the body of the text) did contain CR-39 components. NIOSH needs to revisit this section and ensure that both the table and text agree with each other and with the dosimetry practices of the period

NIOSH update June 2016: The available guidance is suitable for assigning neutron doses for partial dose reconstruction of external neutron dose. NIOSH will clarify any outstanding questions from SC&A during the upcoming work group discussion.

Finding 13: Given our understanding that it is NIOSH's position that external exposures at the Parks Township Site can be reconstructed with sufficient accuracy, it appears that the description of the sources and circumstances responsible for external exposures need to be better developed, if possible.

Proposed NIOSH resolution: External dose can be evaluated only when dosimetry records exist. There was one dosimetry department for all NUMEC facilities that provided dosimetry for both the Parks Township and Apollo facilities. The limitations stated for the Apollo facilities also apply to the Parks Township facilities (see response to Finding 16).

August 2015 WG discussion: NIOSH to issue response on whether an external coworker model is feasible.

NIOSH update June 2016: It is not expected that the available data can be used to develop a coworker model that would adhere to the guidelines expected from such a model. Please see detailed analysis below.

Finding 14: The site profile should provide justification for why adjustment factors are not required for neutron exposures estimated using nuclear track emulsion Type A (NTA) film, considering that it appears that the neutron energy spectrum likely extended to well below 1 mega-electronvolt (MeV). For example, Table 6-8 of the site profile indicates that the energy range of neutron exposures extended from 0.1 to 2 MeV.

Proposed NIOSH resolution: A n:p approach was developed from available data.

August 2015 WG discussion: SC&A states that NIOSH response is thorough, but is not sure it makes technical sense. SC&A is to provide a response after additional review.

SC&A response after WG discussion: While the n/p methodology that NIOSH is proposing for NUMEC has been used at other AWE and DOE sites, the dose data used to derive the n/p values suggested by NIOSH for NUMEC are not comprehensive or robust. NIOSH may want to consider adopting a bounding n/p ratio that ensures that the neutron doses are not understated for circumstances where the available n/p data are limited.

NIOSH update June 2016: NIOSH has reviewed the suggested approach, and agrees that the data are limited; however, NIOSH is not aware of any additional data that may exist and that would allow for refining the currently proposed approach in any way. The proposed approach was included in draft ORAUT-TKBS-0041 Rev. 03-B.

Finding 15: The markedly different photon energies associated with the operations at NUMEC would indicate the possible need for adjustment factors for the results of film badge dosimeters, which are not provided in the site profile.

Proposed NIOSH resolution: Film badge dosimeters, while over responding to radiation recorded in the open window, may under respond to low energy photons (16 keV and 59 keV photons are a particular concern) (Wilson et al. 1990). Although the films and filters at NUMEC were different than the dosimeters discussed in the reference, a reasonable comparison between the film dosimeters is expected (AEC 1955). The site acknowledged this deficiency in a 1966 report (Caldwell and Judd 1966) and made corrections to the dosimetry to account for this under response. Prior to the report being issued (i.e. prior to 1966), to account for under response of film dosimetry to low energy photons, the result in the open window should be assigned as <30 keV photons for workers at plutonium facilities while the deep dose response is assigned in accordance with the worker location.

August 2015 WG discussion: Auger electrons are very low energy and would not penetrate skin; therefore, part of NIOSH response does not address issue. Also, do we assign these low energy betas for all alpha emitters at other sites? NIOSH wants to check this answer and get back, but WG decided that this is an SC&A action item for now – SC&A is to provide additional information on this finding.

SC&A response after WG: NIOSH concurred that the site profile needs to be revised to account for possible over- and/or under-responses of dosimeters under some circumstances. The decision to modify the site profile approach for situations where low-energy photons and betas

are present seems appropriate by assuming <30 keV photons for plutonium workers for open window results. However, NIOSH should endeavor to gather more information on the differing film badges and the protective coverings to enable a better assessment of situations where low-energy photons or betas were under-reported or missed entirely.

NIOSH update June 2016: The initially proposed guidance was added to the draft ORAUT-TKBS-0041 Rev. 03-B. Additional data capture is considered to be unproductive, but additional review in available NUMEC files continues.

Finding 16: NIOSH should consider developing a universal coworker model based on NUMEC claimant records, or specify a more consistent basis for assigning external doses beyond the medical x-rays associated with the site.

Proposed NIOSH resolution: A coworker model for non-presumptive claims is not expected to be feasible.

August 2015 WG discussion: NIOSH is tasked to do a formal review to see if a coworker model is feasible.

NIOSH update June 2016: It is not expected that the available data can be used to develop a coworker model that would adhere to the guidelines expected from such a model. Please see detailed analysis below.

Finding 17: The site profile should include guidance for deriving non-penetrating doses to skin and other organs from beta emitters associated with surface contamination during the residual period.

Proposed NIOSH resolution: Additional information was included in the draft of the revised TBD.

August 2015 WG discussion: **Closed.**

Finding 18: General air (GA) samples, as opposed to breathing zone (BZ) samples, should be used as the starting point for reconstruction of radionuclide intake rates during the residual period.

Proposed NIOSH resolution: The air concentration value that is favorable to claimants to use for the residual period is represented by the maximum median value of 222 dpm/m³. The maximum estimated GSD for all data sets is 6.95 for the HASL GA data. Therefore, the residual activity will

be based on a lognormal distribution with a median of 222 dpm/m³ and a GSD of 5.0. This represents a slight increase in median air concentration from the previous concentration of 210 dpm/m³ and GSD of 7.91.

August 2015 WG discussion: Some BZ samples are higher than some of the GA samples. Why is that? Possibly there are some process samples that were added to the GA sample set. The data need to be reviewed to make sure there are no inconsistencies.

NIOSH update June 2016: The data were reviewed and corrected if necessary and the revised approach was included in draft ORAUT-TKBS-0041 Rev. 03-B. The results from these measurements and the HASL reports indicate an air concentration value that is favorable to claimants to use for the residual period is represented by the maximum median value of 329 dpm/m³.

Finding 19: SC&A recommends that NIOSH use a resuspension factor of about 1E-5 per meter to derive the airborne dust loading for the beginning of the residual period, or perhaps simply assume that the average general air dust loading observed during the operational period is applicable to the beginning of the residual period.

Proposed NIOSH resolution: Resuspension factor for Apollo was changed, but not for Parks, because of cleanup activities.

August 2015 WG discussion: **Closed**, if the guidance is included in the TBD revision.

NIOSH update June 2016: The change was included in draft ORAUT-TKBS-0041 Rev. 03-B.

Finding 20: The site profile makes no reference to radionuclides other than uranium during the residual period at Apollo.

Proposed NIOSH resolution: Suggestion for adding thorium and progeny to approach.

August 2015 WG discussion: **Closed**, if the thorium guidance is added to the TBD revision.

NIOSH update June 2016: The change was included in draft ORAUT-TKBS-0041 Rev. 03-B.

Finding 21: There is conflicting guidance on how aged plutonium mixtures should be treated during the residual period at Parks Township.

Proposed ORAU resolution: add guidance to TBD

August 2015 WG discussion: **Closed**, if guidance was added to the TBD revision.

NIOSH update June 2016: The change was included in draft ORAUT-TKBS-0041 Rev. 03-B.

NIOSH position on coworker models for NUMEC to assign doses for partial dose reconstructions

During the work group meeting in August 2015, it was questioned how NIOSH assigns dose for non-presumptive claims for the NUMEC Apollo and Parks facilities when the worker in question was unmonitored. Specifically in question was the approach for internal uranium at Apollo and external dose assignment at the Parks facility. The Apollo SEC evaluation report specifies that internal uranium dose reconstruction is only feasible when uranium bioassay is available. The Parks SEC evaluation report states that internal dose reconstruction is not feasible. The Apollo Evaluation Report also specifies that external doses for non-presumptive claims can be reconstructed using available external dosimetry data. The Parks Evaluation Report states that the external dose reconstruction feasibility was not fully evaluated, because the report was prepared under § 83.14.

Additional research was requested of NIOSH to evaluate if the available uranium bioassay and external dosimetry data are sufficient for the development of a coworker model to support the dose reconstruction approach for non-presumptive claims of unmonitored workers. These are the findings:

A review of dose reconstruction approaches used after the SEC class implementation indicates that the guidance in the evaluation reports is followed. Those dose reconstructions are completed using available data such as uranium in urine, GA/BZ and external dosimetry for individual claims. When data is not available, doses are not reconstructed per the infeasibility decisions in the respective evaluation reports. As a result, for some claims only medical X-ray dose is assigned.

Both NUMEC SEC classes were driven by several issues affecting the feasibility to reconstruct internal doses:

- Internal monitoring data from 1957 through 1959 are not available.
- Adequate information on thorium operations is not available.
- Bioassay data from the company Controls for Environmental Pollution (CEP) is not suitable for use (years 1976 through 1993).

- No monitoring data, process descriptions or source term data exist for the fabrication of Ra-Be and Po-Be neutron sources at both facilities. In addition, no information is available on the fabrication of Co-60 and Ir-192 sources at the Parks facility.
- Potential elevated ambient radiation levels from stack releases at the Apollo plant are not well documented.
- Plutonium operations at the Apollo facility are not well documented. The NUMEC facility at Parks Township handled all plutonium processing and the available documentation does not indicate that major amounts of plutonium were handled at the Apollo plant. However, NUMEC Apollo was licensed to handle significant amounts of plutonium mostly in coated or encapsulated form. The laundry operations at the Apollo site had plutonium residues, resulting most likely from the handling of the work clothing from both NUMEC facilities. There is insufficient information to permit the construction of a source term model for plutonium at the NUMEC Apollo plant.
- No information is available on the operations with irradiated fuel in the hot cell at the Parks facility. Exposures from these activities are evident from incident reports and whole body counting reports that show uptakes; however, the available data is insufficient to calculate bounding doses.

Feasibility of internal coworker model for uranium:

Uranium was processed at both the Apollo and Parks Township site. Enrichment levels varied and included depleted uranium (DU), natural uranium (NU), low enriched uranium (LEU (3.5 %)) and highly enriched uranium (HEU (93 %)). No bioassay results are available before 1959. Data are available from late 1959 through 1988 and in 1999.

The uranium bioassay is not expected to fulfill the criteria currently used by NIOSH to evaluate coworker data sets. The available bioassay data sheets do not typically indicate work location and job title of the worker. Unless NOCTS claimant data was used to develop a model, it would not be possible to stratify the available data set or even separate the data out between the two NUMEC sites. The NOCTS claimant population is not large. As of June 2016, there are 239 claims for Apollo and 97 claims for Parks; 49 of those have co-employment for both sites, the majority of those workers having the same job title at both sites. It is not believed that the amount of data available in the NOCTS claim files is sufficient for the development of a coworker model as described in OTIB-0075. For the workers that had employment listed at both sites, it is generally difficult to place him/her at a specific site with the available information. The latter issue affects about 20 % of the Apollo claims and about 50 % of the Parks claims. The nature of the work at the NUMEC facilities

involved a number of different operations, so there is very little consistency in the exposure profile and a rather varied exposure potential, depending on the nature of the work.

Feasibility of External Coworker Model:

Many workers at the NUMEC facilities faced radioactive exposure potential; however, it has become quite clear from a review of the available files and claimant data that not everyone who worked in areas with potential exposure was monitored. An external coworker model, therefore, would be useful to assign doses to unmonitored workers. There are a number of occasions where significant dose rates in unrestricted areas were observed (AEC, 1967). An external dosimetry spreadsheet was developed in 2007, with about 28000 lines of data – see Table 1 for a summary of that data. There are several years missing in Table 2 and it is unclear without further research if this data is available. Based on the review of claimant records, some external data is available starting in 1957 at Apollo and 1959 at Parks. Not all workers were assigned radiation dosimeters and the site relied to some extent on work area monitoring for external dose limit enforcement (AEC, 1967). This is also evident from some of the claimant records, as there are a number of workers who have internal data but are lacking external data. For some years TLD data for certain job titles or work areas are available on handwritten log forms (such as ZPPR for 1968 and 1967) (NUMEC, 1968; NUMEC 1969), but for other years there are dosimetry reports without indication of work area or job title. There also seems to be at times a duality in external dose reporting for some workers, who wore in-house NUMEC badges but also had dosimetry records from the commercial vendor. Yet others who clearly worked in areas with an exposure potential (as evidenced by available internal monitoring data) were not monitored for external exposure. The main reasons for the infeasibility conclusion are the available gaps and the inability to separate out the data by site and work area/job title. In some cases, the external dosimetry reports from the contractor (such as Landauer) list the facility, but that is not always the case. It seems that this practice was taken up sometime in the 70s, but then stopped again. It is, therefore, not possible to separate out the data by site. There is also the factor that many workers who may have been routinely in radiation areas were not monitored by external dosimetry; therefore, the available data may not be representative of all exposure scenarios.

Table 1. Number of external dosimetry results per year

Year	Beta	Gamma	Neutron	Shallow	Deep	Ring	Wrist	Total # Individuals
1960						15		15
1964	29	1902	415		35	357		164

Year	Beta	Gamma	Neutron	Shallow	Deep	Ring	Wrist	Total # Individuals
1965	19	118			3	34	34	131
1967		39			25			41
1968	6	1200	22	4	921	22		245
1969	239	1693	224		184	197		570
1970	40	983	545		487			295
1971	9	248	566	515	1672	260		197
1972	1	1	1374	674	1128	299	287	332
1973	3	117	593	413	596	70	67	259
1974	1	1	824	815	880	2	1	207
1975		106	927	830	1503	101		356
1976			9		51	31		54
1977	1	1	90	59	94	390	22	95
1978	1	1	281	261	281	232	203	102
1979			1212	423	1211	1354	334	277
1980			505		505	679		128
1981			310	94	310	446	75	91
1982	14	9	285	67	319	326	16	86
1983	1		84	95	126	8	7	55
1984			168	303	303	31	30	110
1985	2	2	26	305	305	29	28	77
1986			94	97	97	1		24
1987			1	1	1	1		1
1988			35	221	222			38
1989			42	164	164			48
1990			24	172	172			25
1991			55	388	388			108
1992			27	92	92			23
1993			11	171	170			43
1994				158	192			93
1995				178	222			82
1996				697	746	13	13	191
1997				497	542			184
1998				596	606			159
1999				120	120			44

Year	Beta	Gamma	Neutron	Shallow	Deep	Ring	Wrist	Total # Individuals
2000				87	87			41
Grand Total	366	6421	8749	8497	14760	4898	1117	

Internal and external coworker model feasibility conclusion:

NIOSH has concluded that the available internal and external monitoring data available for the NUMEC Apollo and Parks facilities has several limitations and it is not expected that a coworker model for non-presumptive claims would fulfill the criteria that are currently expected of such a model.

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