M E M O

DATE: December 2, 2014
TO: Stu Hinnefeld
CC: Ted Katz, Fernald WG members, John Stiver, Bob Barton, John Mauro, Joyce Lipstein
FROM: U. Hans Behling
SUBJECT: Response to NIOSH's White Paper dated November 26, 2014

1.0 STATEMENT OF PURPOSE

On November 20, 21, and 28, 2014, SC&A received a series of emails along with two attachments from NIOSH that informed SC&A that a "White Paper" dated November 26, 2014, and a "supplement" dated November 28, 2014, had been prepared by NIOSH for the upcoming Fernald Work Group meeting on December 4, 2014, regarding radon emissions from the K-65 silos. One of the emails requested SC&A's response to the attachment, which in a **few sentences** "summarized" 55 pages representing the contents of two separate **White Papers** submitted by SC&A in November 2008 and in April 2010.

Presented below is SC&A's response to NIOSH's White Paper issued November 26, 2014, which chronicles previous discussions that date back to 2006 and addresses past and current concerns raised by NIOSH regarding SC&A's estimates of radon release rates from Silos 1 and 2 at the Fernald facility.

2.0 ESTIMATES OF RADON RELEASE RATES AND PREVIOUS WORK GROUP DISCUSSIONS

SC&A's two White Papers critically reviewed **modeled** radon release estimates cited in a 1995 report issued by the Radiation Assessment Corporation (RAC Report CDC-5, 1995). Our assessment of the RAC data/information, however, led to very different values of radon release rates that were based on documented **empirical measurements** and a single **assumption**: that the observed disequilibrium between Ra-226 and Pb-210 measured in 1991 and again in 1993 likely existed since the time of waste emplacement in the 1950s.

With regard to NIOSH's statement that SC&A's **assumed** disequilibrium at time of residue placement that ". . . neither **maximizes nor minimizes** the resulting estimates of radon emissions," we would like to respond that SC&A's assumed disequilibrium value most likely **underestimates** radon release rates derived by SC&A as discussed in Section 3.0 (and in greater detail in Attachment 1) of SC&A's 2008 White Paper. Here, data were presented that support much **lower** disequilibrium fractions (i.e., ~0.8 to 0.9 for Pb-210/Ra-226) than what SC&A assumed **at time of waste emplacement** and project radon releases higher than values derived by SC&A.

Additionally, there is a second reason that SC&A's radon release estimates are likely low/unconservative. Namely, SC&A's radon estimates are limited to all years **prior** to 1980, at which time silo repairs and dome covers were added that reduced radon releases, as shown by dramatic increases in dose rates on top of the silos. Thus, the disequilibrium measured in 1991 and again in 1993 would have benefitted from the reduced radon emission and the associated buildup of Pb-210 for years 1980 through 1991/1993.

In brief, SC&A's model consisted of a straight-forward, easily understood model that was based on first principles, which involved the following three sets of measurements and one assumption:

(1) Two independent sets of **empirical** measurements from wastes stored in Silos 1 and 2 in 1991 and 1993 (which were within the range of statistical uncertainty) concluded a disequilibrium of ~0.40 for the Pb-210/Ra-226 ratio.

(2) Multiple **empirical** dose rate measurements taken in 1964, 1972, and 1973 on top of Silos 1 and 2 **prior** to the sealing of the Silos, which yielded contact dose rate measurements that averaged about 70 mrem/hr.

(3) **After** sealing Silo openings in June 1979 and the installation of a Radon Treatment System (RTS) in 1987, empirical dose rate measurements for Silos 1 and 2 yielded the following average contact doses:

Baseline (No RTS operation) Average Dose Rate (1987)
- Silo 1: 193 mrem/hr
- Silo 2:   232 mrem/hr

After Operation of RTS Average Dose Rate (1987)
- Silo 1: 55 mrem/hr
- Silo 2: 68 mrem/hr

Note: It was stated that the RTS was operated for several hours until there was no further reduction in dose rate. It was further concluded that the RTS had removed 97% of radon and its short-lived daughters. Thus, it can be concluded that the residual dose rate(s) following RTS operation reflects primarily activity levels in the waste package with minimal contribution from the 3% residual radon/radon daughters in the Silo headspace.

(4) SC&A's Assumption for Deriving Radon Releases: that the empirically defined disequilibrium determined in 1991 and 1993 may have existed at time of waste emplacement in the 1950s. As explained above, SC&A considers the assumption as **unconservative** with the likelihood of having underestimated actual radon releases.

On the basis of these empirical measurements and the unconservative assumption of a disequilibrium fraction, SC&A derived radon release values of ~88,000 Ci/yr and ~23,000 Ci/yr, as described in Section 3.2 of the 2008 SC&A White paper enclosed herein as Exhibit #1.

SC&A's empirically based release model along with a substantial body of supportive data contained in SC&A's two White Papers has been presented/discussed by SC&A during Fernald Work Group meetings on several occasions since their issue. To date, however, no significant progress has been made that would lead to a final decision/resolution relating to radon releases.

In earlier discussions, NIOSH never questioned the credibility of the **RAC-reported** disequilibrium values of ~0.40 for the Pb-210/Ra-226 ratio, but refuted SC&A's radon release estimates, since it was NIOSH's opinion that the overwhelming fraction of radon production in the waste package was **released** to the silo headspace, where it decayed with only nominal releases to the environment.

This argument was neutralized by the empirical dose rate measurements taken before 1980 on top of the silos, which showed nearly identical values prior to 1980 to measurements taken after dome sealing and RTS operations in 1987 that removed 97% of radon in the headspace.

Thereafter, SC&A's estimates were dismissed for apparently frivolous/irrelevant reasons that included the fact that SC&A's estimates were neither reviewed by the National Academy of Sciences (as was the 1995 RAC Report) nor had the scientific pedigree of the RAC Report, which had been adopted/referenced by other "scientists," including authors of the "Pinney" Report. In response to NIOSH's position, the Fernald Work Group directed SC&A to review the National Academy of Sciences review of the 1995 RAC model. SC&A responded to these concerns in SC&A's second White Paper issued in April 2010 (see Exhibit #2: Excerpts from SC&A's White Paper Issued in April 2010).

Since 2011, the issue of radon releases at FEMP, along with other site profile issues, has remained largely unresolved by the Fernald Work Group in order to address and resolve many other issues that were considered relevant to the addition of a Special Exposure Cohort (SEC) class.

EXHIBIT #1: Radon Release Calculations from SC&A's 2008 White Paper

For estimating Rn-222 releases from Silos 1 and 2, the state of disequilibrium empirically observed in the 1990s will, therefore, be assumed to have existed at time of the emplacement of K-65 material.

RADON RELEASE CALCULATIONS

The following steps may be used to calculate annual Radon-222 releases from Silos 1 and 2:

(1) Determine amount of radon produced per year from 1 curie Ra-226.

(2) Determine specific activity of Ra-226:

$$SpA = \lambda N = \frac{(\ln 2)(N)}{t_{1/2}}$$

where N = Number of radioactive atoms per unit mass
= 6.0225×10^{23} atoms/atomic mass
= 2.6648×10^{21} atoms /g of Ra-226

$t_{1/2}$ = physical half-life of Ra-226
= 1602 years
= 8.4201×10^{8} min.

$$SpA_{Ra-226} = \frac{0.693(2.6648\,x\,10^{21})}{8.4291\,x\,10^{8}\text{ min}}$$

= 2.1932×10^{12} dpm/g of Ra-226
= 0.99669 Ci/gram of Ra-226

(3) Determine the number of Ra-226 atoms that decay in 1 curie per year that are transformed into Rn-222:

1 Ci $_{Ra-226}$ = 1.012 g of Ra-226
= $(6.0225 \times 10^{23}$ atoms/226 g)(1.012 g)
= 2.6928×10^{21} atoms of Ra-226

EXHIBIT #1 (Continued)

No. of Rn-222 atoms formed/yr from the decay of 1 Ci of Ra-226:

$$\text{Rn-222 atoms/yr} = A_o - A_{1\,yr}$$
$$= 1.16600 \times 10^{18} \text{ atoms of Rn-222}$$
$$= 4.298 \times 10^{-4} \text{ g of Rn-222}$$

(4) <u>Calculate the specific activity of Rn-222</u>:

$$SpA_{\text{Rn-222}} = 153{,}881 \text{ Ci/g}$$

Thus, the 4.298×10^{-4} g of Rn-222 generated per year from 1 Ci of Ra-226 correspond to the production of 66.15 Ci of Rn-222 per year.

(5) <u>Calculate annual Rn-222 production in Silo 1 and Silo 2 based on data presented in Table 5-16 of ORAUT-TKBS-0017-5</u>:

<u>Silo 1</u>:

$$\text{Total Ra-226 Activity} = (477 \text{ nCi/g})(5000 \text{ MT})$$
$$= (477 \text{ nCi/g})(5 \times 10^{9} \text{ g})$$
$$= 2385 \text{ Ci}$$

$$\text{Rn-222 per year} = 2385 \text{ Ci}_{\text{Ra-226}} \times 66.15 \text{ Ci/yr/Ci}_{\text{Ra-226}}$$

$$\boxed{\text{Rn-222}_{\text{Silo 1}} = 157{,}767 \text{ Ci/yr}}$$

<u>Silo 2</u>:

$$\text{Total Ra-226 Activity} = (263 \text{ nCi/g})(5 \times 10^{9} \text{ g})$$
$$= 1315 \text{ Ci}$$

$$\text{Rn-222 per year} = 1315 \text{ Ci}_{\text{Ra-226}} \times 66.15 \text{ Ci/yr/Ci}_{\text{Ra-226}}$$

$$\boxed{\text{Rn-222}_{\text{Silo 2}} = 86{,}987 \text{ Ci/yr}}$$

(6) <u>**Estimate annual release of Rn-222 into headspace of Silos 1 and 2**</u>

As stated in Section 3.1 above, the state of disequilibrium observed in 1993 between Ra-226 and Pb-210 is assumed to have existed unchanged from the beginning of K-65 material emplacement in silos. Under a steady-state of disequilibrium, it is assumed that the fraction of radon released from the waste package is proportional to the degree of disequilibrium.

EXHIBIT #1 (Continued)

$$Rn-222_{Silo1}(Ci/yr) = \left(157{,}767\,Ci/yr\right)\left(1-\frac{202\,nCi/g\,Pb-210}{477\,nCi/g\,Ra-226}\right)$$

$$= 157{,}767 \text{ Ci/yr } (1 - 0.4235)$$

$$= \mathbf{90{,}955 \text{ Ci/yr}}$$

$$Rn-222_{Silo2}(Ci/yr) = \left(86{,}987\,Ci/yr\right)\left(1-\frac{190\,nCi/g\,Pb-210}{263\,nCi/g\,Ra-226}\right)$$

$$= \mathbf{24{,}144 \text{ Ci/yr}}$$

(7) **<u>Estimate Rn annual release rates into environment for all years prior to 1980</u>:**

In Section 2.0 of this report, the transient use of the RTS was estimated to reduce the Rn-222 (and daughter products) to 3% of its equilibrium value in the silo headspace. Under RTS operation, the contact dose rate on top of the dome was essentially identical to the dose rate prior to the sealants applied to dome in 1979.

On the basis of this relationship, it may be concluded that prior to 1980, approximately 97% of radon entering the headspace was released to the environment:

Annual Environmental Releases prior to 1980:

Rn-222 (Silo 1) = (0.97)(90,955 Ci/yr)
= 88,226 Ci/yr

Rn-222 (Silo 2) = (0.97)(24,144 Ci/yr)
= 23,419 Ci/yr

EXHIBIT #2: Excerpts From SC&A's 2010 White Paper

1.0 RELEVANT BACKGROUND INFORMATION

On January 29, 2010, the Fernald Work Group met in Cincinnati, Ohio, to discuss/resolve six outstanding issues pertaining to the Fernald site. Among the unresolved issues was SC&A's contention that radon releases from the K-65 Silos may have been significantly underestimated by NIOSH, as stated in ORAUT-TKBS-0017-5 (ORAUT 2004):

> *As previously stated, the contents of the silos have not been disturbed during storage to any large degree. However, it has been calculated that during the* ***1953 to 1978 period 5,000 to 6,000 Ci/year of*** ^{222}***Rn were released from the silos (RAC 1995)****.* [Emphasis added.]

In a previous White Paper issued in November 2008 (SC&A 2008), SC&A conducted a critical review of the Radiological Assessment Corporation 1995 model (RAC 1995). Based largely on empirical measurements taken on top of the silos that ironically were included in Appendix J of the 1995 RAC Study, SC&A concluded that the **modeled** release estimates cited in the 1995 RAC Study were likely a factor of 10 to 20 too low.

In a memorandum to the Work Group Chairperson, dated October 6, 2009, NIOSH rejected SC&A's analysis and conclusions with the following statements:

> *NIOSH disagrees with the draft findings reported by SC&A. The* ***RAC model was supported by a National Academy of Sciences review; SC&A's was not****. NIOSH will rely upon the individual exposure estimates produced using the* ***Pinney/ Hornung model*** *which utilized radon exposure levels from the RAC study, plus an additional radon source term at Fernald.* . . . [Emphasis added.]

In response to NIOSH's position, the Work Group directed SC&A to review the National Academy of Sciences' (NAS) review of the 1995 RAC model (NAS 1994).[1] On January 26, 2010 (or three days before the Work Group meeting held on January 29, 2010 [SC&A 2010]), SC&A submitted its findings regarding the NAS review to the Work Group/NIOSH in the form of a memorandum. Our review of the NAS Report showed that there was little support for the RAC model.

[1] Note that the National Academy of Sciences performed their review on a 1993 draft of the 1995 RAC report.

EXHIBIT #2 (Continued)

2.0 DISCUSSION POINTS RAISED DURING THE FERNALD WORK GROUP MEETING HELD ON JANUARY 29, 2010

A review of the Work Group's transcript shows that the issue of radon emissions from the K-65 Silos was discussed on pages 266 through 294 (NIOSH 2010). For convenience, select statements contained in the transcript will be cited below for further discussion.

Regarding the "NAS Endorsement" of RAC (1995) Model: (pp. 278–279 of transcript)

> ***MR. ROLFES****: Okay. Looking at the National Academy of Sciences' review, it's got a -- I'm reading from the National Academy of Sciences' review of the RAC dose reconstruction for Fernald, and on page 17 of the PDF, it has a radon section, and I can read that if you'd like.*
>
> *DR. MAURO: Is that what you're reading now?*
>
> ***MEMBER ZIEMER****: I'm reading it right now, yes.* ***It certainly leaves the question open.***
>
> ***MR. ROLFES****: I'll go ahead and read that into the record. "The importance of the radon source term associated with the K-65 silos is difficult to establish primarily because the silos have been modified several times over the years. If the head space has been adequately sampled, the silos inventory could be modeled for release,* ***assuming no retardation by the cap which has been sealed to various degrees over the years as a worst case endpoint****.*
>
> *"It is reasonable to separate the calculations into daytime and nighttime dispersion because the dispersion figures would certainly differ. However, there is no justification given for the release terms of 140 curies per year continuous or 810 curies per year during the daytime only. It also might be a reasonable refinement to have transition periods in between."*
>
> *So I think that's really the part that is relevant, and* ***it basically calls into question what the release is, and so the RAC report doesn't really get us any further down the road on, you know, validating the radon releases****. . . .* [Emphasis added.]

From these statements, SC&A concludes that neither the Work Group nor NIOSH is of the opinion that the NAS concurred with the RAC (1995) model.

EXHIBIT #2 (Continued)

2.1 REGARDING THE USE OF THE "PINNEY STUDY" AS A MEANS FOR THE VALIDATION OF RADON RELEASES

The "Pinney Study" was referenced multiple times in the Fernald Work Group transcript and is a reference to a study that was published in 2008 entitled, *Estimation of Radon Exposure to Workers at the Fernald Feed Materials Production Center 1952–1988*, by R.W. Hornung, S.M. Pinney, J. Lodwick, G. Killough, D.E. Brewer, and J. Nasuta in the Journal of Exposure Science and Environmental Epidmiology, pages 1–12 (Hornung et al. 2008).

> From page 291 of the transcript:
>
> ***MR. MORRIS****: Okay. I'd like to also point you to a memo that Dr. Pinney wrote to* [[redacted]] *on September 13th, 2006, while* [[redacted]] *was preparing information for the SEC petition apparently, and she writes to* [[redacted]] *about using the data from the RAC report which was an off-site dosimetry model and extending it, extrapolating it back toward the source term to reconstruct the doses on the site. She got assurance from the model developer, Dr. Killough or Mr. Killough, that it could be extrapolated back on-site, and then took the initial action that she describes of validating that model based on some on-site information that was available. . . .* [Emphasis added.]
>
> From page 293 of the transcript:
>
> ***MR. ROLFES****: Right. That seems that the Pinney model has the validation of the RAC model essentially in it, and what we had previously said had been reviewed by the National Academy of Sciences, when the RAC model was reviewed by the NAS, we thought that it had spoken to the radon effluent, but it didn't very much, and now what we have here when we look back at the documentation we have,* ***we found that the Pinney model actually relies upon the RAC model, which has been validated by Susan Pinney's model as well****.* [Emphasis added.]

These statements lack clarity and appear contradictory, inasmuch as they suggest that Pinney "relied" upon the RAC model, but then states that it was "validated" by the "Susan Pinney Model."

EXHIBIT #2 (Continued)

From page 300 of the transcript:

> ***CHAIRMAN CLAWSON****: Well, you know, the bottom line comes down to* ***SC&A has not been able to see this****, and we've got to go back a little ways because this was held up to us as the holy grail for the radon and that everything was good with it, and now we've changed our whole course to that. So we're going to have to have SC&A review what NIOSH has put out there, the* ***Pinney report****, and so forth because, you know, we're changing whole directions.*
>
> ***MR. ROLFES****: That's a slightly different --* ***we've always said since our Evaluation Report that we were relying upon the Pinney data.*** *So I did want to point that out.* [Emphasis added.]

2.2 REVIEW COMMENTS AND RELEVANT CONCLUSIONS REGARDING THE "PINNEY REPORT"

At the request of the Fernald Work Group, SC&A reviewed the 2008 "Pinney Report" (Hornung et al. 2008) with regard to its use/validation of radon releases that were modeled by RAC. Based on our review, SC&A concludes the following:

(1) The Pinney Report simply accepted the source term releases of radon from the K-65 Silos, as described by the following two RAC reports issued in 1995 and 1998:

- RAC (1995): *The Fernald Dosimetry Reconstruction Project, Tasks 2 and 2 Radiologic Source Terms and Uncertainties.*
- RAC (1998): *The Fernald Dosimetry Reconstruction Project, Task 6 Radiation Doses and Risks to Residence from FMPC Operations from 1951–1988.*

(2) Using the modeled RAC (1995)/RAC (1998) radon release source terms, the "Pinney Report" investigators applied a modified Gaussian dispersion model originally intended for estimating exposure to residents living within a 10-km radius to estimate onsite radon exposures to Fernald workers, as explained in their report:

From page 2 of the 2008 "Pinney Report":

> *The radon dispersion model was developed by Radiological Assessments Corporation (RAC) under contract to the CDC as part of the overall dose reconstruction that also included uranium and thorium doses from air and water transport. The model had been applied to the estimation of radon exposures to residents living near the facility.* ***Details of the development of this model are given by Voilleque et al . (1995)*** **[RAC 1995]** ***and Killough et al. (1998)*** **[RAC 1998]** ***and are beyond the scope of this paper****. We have, however, included an abbreviated description of the* ***atmospheric dispersion model in***

EXHIBIT #2 (Continued)

> ***Appendix A***. *The model was studied to determine what revisions would be required to make it applicable to the estimation of radon exposures to Fernald workers who were considerably nearer to the K-65 silos.* ***The radon transport model involved emission rates from the silos, meteorological data, distance from the source, and decay rates of radon decay products***. *The output of the model was annual average exposure in either pCi/l or Bq/m^3 at any location specified by longitude and latitude coordinates. . . .* [Emphasis added.]

<u>From Appendix A of the 2008 Pinney Report</u>:

> *The K-65 source term model is an empirical representation of the annual release of radon from the K-65 silos from 1952 through 1988. It was calibrated to a variety of data, primarily (1) the concentration of radon in the silo headspace gas, measured in* ***1987****, (2) measurements of g-ray exposure on the external silo dome surfaces before and after they were sealed, and (3) a series of temperature and pressure readings in the silo headspace gas, taken in 1987. It is a stochastic model, with some parameters derived as probability distributions, which propagate into the annual release estimates.* ***Detailed information about the K-65 source term model and the ratio of decay products at the point of release is given in Appendix Q of Killough et al. (1998)*** **[RAC 1998]*****, with references to the earlier report of Voilleque et al. (1995)*** **[RAC 1995]** ***for some details.***
>
> *. . . The transport model used for the study described in this paper is adapted from the transport model of Killough and Schmidt (2000),* ***but it is coupled with the original K-65 source term developed for the CDC dose reconstruction study, as described in Appendix Q of Killough et al. (1998)*** **[RAC 1998]** ***and in Voilleque et al. (1995)*** **[RAC 1995]**. [Emphasis added.]

This last statement clearly states that the "Pinney Model" simply " . . . coupled the original K-65 source term . . .," as defined in RAC 1995 and RAC 1998, to the radon transport model employed by the "Pinney Model." Thus, contrary to NIOSH's opinion, the "Pinney Report" made no effort to validate the radon source terms defined in RAC 1995 and RAC 1998.

3.0 SC&A'S COMMENTS PERTAINING TO NIOSH'S WHITE PAPER DATED NOVEMBER 26, 2014

NIOSH's White Paper of November 26, 2014, states that **". . . NIOSH has not found a technical error in either SC&A's or RAC's approach, and cannot reconcile the widely disparate release values.**" [Emphasis added.] Presented below is a comparison between the two models that may explain why corresponding release estimates differ.

SC&A selected a simplistic approach that employed the credible measurements involving the radioactive disequilibrium between Pb-210 and Ra-226, and **measured** dose rates on the top of the silos prior to 1980 and after sealing of silos and operation of the RTS. In summary, SC&A's simplistic method is based on measured data with only one assumption for the initial state of disequilibrium that is likely to have underestimated radon release rates for years prior to 1980. (Note: SC&A did not attempt to estimate radon release rates for years post-1980.)

In contrast to SC&A's simplistic and empirically based method, the RAC model is a **complex** model that is based solely on (1) **passive diffusion kinetics** for the release of radon in the headspace, (2) their subsequent environmental release rates that are based on ambient temperature-driven diurnal expansions and increased pressures within the silos headspace, and (3) the resultant release of the "excess" volume (i.e., air containing radon) to the environment.

In addition to the RAC model's complexity and associated uncertainties that reflect the need to account for diurnal temperatures on a daily basis, the model also suffers from two serious deficiencies identified below.

3.1 RAC's Failure to Include the Impact of Wind and the Venturi Effect

In Section 4.0 of SC&A's White Paper dated November 2008, SC&A had concluded the following (SC&A 2008):

> *A serious deficiency of the RAC model is its failure to properly account for the **Venturi effect** that is likely to have dominated the release of Rn-222 from the silo headspace prior to June of 1979, when the silos were subjected to major sealing modifications. The Venturi effect would have the following impact: during periods of low to moderate winds, a steady flow of air over the curved smooth surface of the silo dome creates a partial vacuum (much like that over the leading edge of a forward-moving airplane wing that creates the necessary lift for flight).*

In essence, the wind-induced Venturi effect results in the reduction of atmospheric pressure over the external surface of the dome cap relative to the atmospheric pressure within the silo's headspace. Under sustained steady wind conditions, this pressure differential not only induces a pressure-driven release of air from the silo's headspace into the environment, but in time also results in a reduction of pressure within the headspace relative to the pressure within the waste material that is the radon source term. This secondary pressure differential between the headspace and silo waste material will also result in a pressure-driven migration of radon gas from the waste material into the dome's headspace.

Based on the fact that the cylindrical dome-capped silos represent a configuration that is optimally affected by wind-induced pressure differentials, it is puzzling why the RAC model excluded this important radon release mechanism, even though its **authors were fully aware** of its potential role and stated the following in their 1995 report:

<u>From pages J-31 and J-32 of Appendix J of RAC 1995</u>:

> *Since the silo can not hold any significant pressure, it is certainly plausible that the* ***cracks and other remaining penetrations*** *in the silo domes are large enough and numerous enough that additional ventilation of the silos occurs,* ***due to winds*** *across the domes. For the present work, it is assumed that the silo ventilation is the* ***sum*** *of the ventilation rate due to the* ***temperature effects*** *and a ventilation rate due to* ***wind*** *effects. That is,*

$$\lambda_{V,\,post} = \lambda_{V,\,\Delta T} + \lambda_{V,\,wind}$$

However, the authors subsequently elected to ignore the potential contribution of wind-induced ventilation, as given on page J-34 of Appendix J:

> *As discussed earlier, it is plausible that the cracks in the silo domes are numerous enough and large enough that the action of winds on the domes could create additional ventilation in the silos, represented by λ_V, wind.* ***However, no data have been found to substantiate an estimate of λ_V, wind****. . . . Since additional information has not been located to substantiate a value for λ_V, wind,* ***we now assume a value of zero****.* [Emphasis added.]

In summary, it is SC&A's firm belief that prior to 1979, the wind/Venturi effect was likely the dominant mechanism for the migration of radon into the headspace, ventilation of the headspace, and the release of radon to the environment. Support for high ventilation rates prior to June of 1979 and the role of the Venturi effect comes from the near-equal contact dose rate measurements taken on top of the dome **before 1979** and **after 1987** with the operation of the **Radon Treatment System**.

3.2 The Absence of Direct Radon Release Measurements as Well as Measurement of Parameters Used by RAC to Indirectly Estimate Radon Releases for Years Prior to 1980

In describing data limitations for estimates of radon releases for years prior to 1980, the authors of the 1995 RAC Report further acknowledged the following deficiencies and uncertainties regarding their estimates:

From Page 29 of the 1995 RAC Report:

> *For some other releases at the FMPC, extensive data sets of **direct** measurements of release quantities are available. However, for radon and radon decay product releases there are **no direct measurements of release quantities**. In addition, until the 1980s there were **few measurements of parameters that can be used indirectly to calculate radon releases** . . .*
>
> *The traditional model used to estimate radon releases from radium-226-bearing materials, such as uranium mill tailings, involves calculations of the quantity of radon formed in the material, and the subsequent **diffusion** of the radon through the material to the outside air. **For the K-65 materials, measurements have not been made of the diffusion coefficient and radon emanation fraction, which are two key parameters in this traditional calculation**. Literature values can be obtained for these parameters, but without site-specific values, the uncertainty ranges are **extremely large**.* [Emphasis added.]

From Pages J-71 and J-72 of Appendix J (RAC 1995):

> *. . . even with the large **associated uncertainties**, it is clear that the release rate of Rn-222 from the K-65 Silos was much greater in **1959–1979** period than in the **1980–1987** period . . .* [Emphasis added.]

For the post-1980 years, radon release estimates were still based on a ventilation rate that was modeled around daily temperature fluctuations (as previously described), but now at least included **measured concentrations** of radon in the headspace as a starting point, as described by RAC:

From Page J-27 of Appendix J (RAC 1995):

> *During the period from **1980 through 1987** the **major penetrations** through the silo domes, like the six-inch gooseneck pipe, had already been sealed. However, exchange of air between the silos and the atmosphere continued, through numerous cracks in the concrete of the domes. Radon releases for this time period are based on **measured concentrations of Rn-222 in silo air and on a silo ventilation rate calculated from the daily temperature changes in air.*** [Emphasis added.]

For years **post-1980**, however, RAC estimates are still likely too low, since these do not take into account enhanced ventilation rates that reflect the Venturi effect.

In an email that supplements NIOSH's 2014 White Paper, NIOSH addressed this RAC deficiency and calculated a 13.8% increase in the release rate for time periods after June 1979 to 1987 to account for the wind/Venturi effect.

As previously noted, radon release estimates by SC&A were derived from data that restricts radon release estimates to all years prior to 1980 only. In the absence of SC&A's attempt to estimate releases post-1980, SC&A concurs with the radon release estimate revised by NIOSH for time periods from June 1979 to 1987. For years prior to June 1979, however, SC&A remains committed to radon release estimates described in our original White Paper issued in 2008.

4.0 REFERENCES

42 CFR 82. *Methods for Radiation Dose Reconstruction Under the Energy Employees*

Occupational Illness Compensation Program Act of 2000; Final Rule, Federal

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