Review of Battelle-TIB-5000 Default Assumptions and Methods for AWE Sites

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Observation 1: TIB-5000 makes extensive use of an obsolete computer program, LOGNORM4

- LOGNORM4 was a freeware computer program:
  - Developed before the issuance of TIB-5000
  - No longer publicly available
  - A 16-bit computer code that cannot run on computers running Microsoft Windows 7 or later operating systems
- Options for NIOSH:
  - Make a Windows 10-compatible version of the program available to the public, *or*
  - Revise TIB-5000, substituting other calculational methods for LOGNORM4
- According to NIOSH: "This program is no longer used. Considering the ongoing CyberSecurity Modernization Initiative, developing a Windows 10 compatible version is not likely to occur."

Observation 2: There are more modern methods for treating censored data

- Censored data sets:
  - Contain some results that are reported only as "greater than" or "less than" some value
  - The only information retained is that a measurement was made and was part of a "high group" or a "low group"
- TIB-5000 prescribes a methodology for fitting lognormal distributions to data that contain "values [that] are reported as 'less-than' some number or as zero." This method has been called "regression on order statistics."
- A function, ros, that implements such more modern methods can be found in the R package NADA.

Example of data reported in groups: Airborne uranium concentration measurements

Exposure (mg/m^3)	1948	1949	1950	1951	1952
0–0.1	9	13	38	33	55
0.1–0.5	13	14	62	55	48
0.5–2.5	44	31	—	30	22
>2.5	34	61	32	8	—

Source: "Exposure to Soluble Uranium Compounds," reproduced from Eisenbud and Quigley (1956).

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Observation 3: Inconsistent number of observations listed for U > 2.5 mg/m^3 exposure group in 1949

- TIB-5000, section 2.1.4.1, states: "The first data point in 1949 represents 13 of the 119 total observations; the second, 14; the third, 31, and the final point, 64."
  - Sum of listed observations = 122
- TIB-5000, table 2.4, lists the number of observations corresponding to each of the four data points in 1949 as 13, 14, 31, and 61, respectively.
  - Sum of the numbers of observations = 119
  - 61 is most likely the correct number for the fourth data point

Description of mirror image method TIB-5000 proposed to characterize zero or negative results

- According to TIB-5000, the mirror image method is a way to characterize zero or negative results, as follows:
  - The analyst first deletes all data with values greater than zero (data with negative or zero values are unchanged).
  - For each negative or zero value, the analyst adds a new record equal to the absolute value of the negative or zero record.
  - The result is a symmetric distribution centered on zero, with the positive half being a mirror image of the negative half.
  - The analyst then computes the standard deviation of the new symmetric distribution and constructs a normal distribution with a mean of zero and the new standard deviation.

TIB-5000 introduced the preserved mean and variance method

- Characterize a normally-distributed measurement uncertainty and an underlying lognormally distributed measurand (true but unknown value of the specific quantity subject to measurement).
- "A more sophisticated alternative to the crude 'mirror image' technique" that is based on four assumptions:
  1. "The observed probability density function (pdf) is the result of combining a normally-distributed measurement uncertainty with a lognormally-distributed measurand."
  2. "The mean of the lognormal 'true state of nature' is equal to the mean of the observations."
  3. The mean of the uncertainty is zero. Therefore, the mean of the lognormal pdf is equal to the mean of the observations.
  4. The variance of the sum, $X + Y$, is equal to the sum of the variance of X and the variance of Y, provided X and Y are uncorrelated. If there are enough data to estimate the variance of the uncertainty of the measurement procedure, say by repeated measurements of blank samples, then there remains only one parameter to be estimated: the variance of the lognormal dose distribution.

Observation 4: Mirror image and preserved mean and variance methods not supported by theory

- These two methods are not supported by any technical background in statistical theory of which SC&A is aware.
- The examples given in TIB-5000 are just that: examples, not proofs.
- Conclusions are based on the specific data sets used in the analyses but are not necessarily applicable to other data sets.

TIB-5000 discussion of uncertainty in biokinetic models

- As reported by TIB-5000:

  The National Council on Radiation Protection and Measurements (NCRP) used an expert group of internal dosimetrists to create a subjective quantification of the reliability of ICRP Publication 30 biokinetic and dosimetric models . . . . While IMBA uses the newer ICRP Publication 66 respiratory tract model and newer biokinetic models, the results of these models may not be that much better than the ICRP 30 models for some radionuclides in cases where f_1 [fractional absorption in the gastrointestinal tract] is the dominant uncertainty.

Observation 5: The NCRP assessment of ICRP 30 models does not apply to ICRP 66

- TIB-5000 lacks a sound basis for speculating that the ICRP 66 respiratory tract and biokinetic models are not “that much better than the ICRP 30 models for some radionuclides in cases where f_1 is the dominant uncertainty,” and that the NCRP evaluation of the reliability of the ICRP 30 models is applicable to the ICRP 66 models.
- TIB-5000 cited an email communication from Bihl et al. to support the use of a lognormal distribution with GSD = 3 and claimed this “is reasonably consistent with the [NCRP] findings.” This email is not available; consequently, SC&A cannot determine if this document supports the use of a GSD of 3 for the uncertainty in internal dose.

Observation 6: GSD = 10 is excessive for a sitewide assessment of an individual worker

- TIB-5000 stated that "the current default assumption when no information is available on uncertainty in aerosol measurements is that they are lognormally-distributed with a *GSD* of 5 for a single process or activity, and 10 for an entire site, plant, or factory."
- The assumption regarding the GSD for a single process is based on an analysis of 108 sets of aerosol concentration data or worker exposures tabulated by Christofano and Harris (1960), who listed measured and calculated data for a number of processes at seven uranium refining plants.
- SC&A disagrees with the inclusion of data from single processes that would be responsible for episodic exposures of one or more workers and do not represent the chronic exposures used in dose reconstructions.

Determining a lognormal distribution from daily weighted average data

- Christofano and Harris (1960) listed 33 instances of daily weighted average or simply “weighted average” concentrations that represent the chronic exposures of workers from a given process.
- In each case, the range of concentrations was listed, along with the average.
- SC&A calculated σ = ln(GSD) by applying TIB-5000, Equation 10, reproduced here:

$$\sigma = \sqrt{2 \ln \bar{x} - \ln x_{min} - \ln x_{max}}$$

$\bar{x}$	=	arithmetic mean of *x*
x_{min}	=	minimum value of *x*
x_{max}	=	maximum value of *x*

- In four cases, the quantity under the square root sign was negative, indicating that the data did not fit a lognormal distribution.
- In 29 cases, 1.07 ≤ GSD ≤ 4.57. SC&A thus concurs that GSD = 5 is a plausible upper bound for the exposures of a single worker at a uranium refining plant.

SC&A's fit of a lognormal distribution to 136 average aerosol concentrations

- SC&A fitted a lognormal distribution to the average aerosol concentrations for the 136 processes tabulated by Christofano and Harris (1960).
- GSD = 9.05.
- The 136 data points represent a mixture of short-term measurements of individual processes and weighted averages of worker exposures at seven uranium refining plants.
- These individual processes are included in the weighted averages.
- Inclusion of both types of data is redundant and biases the analysis by exaggerating the effect of highly variable short-term exposures.

Radon air sample data for “BZ removing covers” at Lake Ontario Ordinance Works

Date	Time			Concentration
	Start	Stop	At minutes [a]	× 100 pCi/L
5/8	2:55p	2:56.5p	1.5	16.7
5/8	2:58p	3:02p	4.0	1.1
5/9	12:50p	—	<.5	2,370
5/9	12:51p	—	<.5	4.5
5/9	12:53p	—	<.5	450
5/9	12:55p	—	<.5	580

Source: Excerpted from Heatherton (1951, table II).
(a) The meaning of “At” is unclear, but the data in the column are equal to the sampling duration.

TIB-5000 approach to evaluating radon exposure of tower workers

- According to TIB-5000:

  The 6 individual results for "removing covers from drums" . . . are clearly not from the same population: 3 were in the range of 1.1 to 17 [× 100 pCi/L] and 3 were in the range 450 to 2,370 [× 100 pCi/L]. Separating the two data triplets, plausible *GSDs* were found for each . . . by simply finding the average and standard deviations of the natural logs of each result. Allocating 12 minutes exposure time to each of the two lognormal distributions derived for "removing covers from drums," . . . a mean TWA [time-weighted average] was computed from 10,000 Monte Carlo trials.

Observation 7: Dividing a 24-minute operation into two 12-minute operations is not claimant favorable

- SC&A does not agree with the TIB-5000 conclusion nor with its proposed solution.
  - The first two samples, with relatively low radon concentrations, were collected on May 8, 1951, in rapid succession.
  - The other four samples were collected the next day, also over a brief period. Three of them had high values—450–2,370 × 100 pCi/L—and one a much lower value—4.5 × 100 pCi/L.
  - Since the four samples were taken within the same brief time span, there is no basis for assigning them to two distinct populations.
- One simple approach to this problem is described on the next slide.

SC&A's alternate analysis of radon exposure of tower workers' removing covers at LOOW

- SC&A approach: Fit the six values to a lognormal distribution, weighted by each sample duration.
- Results:
  - Median = 5.65 × 100 pCi/L
  - GSD = 31
  - 95th percentile = 1,612 × 100 pCi/L
  - Square of the correlation coefficient r^2 = 0.944 (indicates a good fit to a lognormal distribution)
  - 95th percentile can be entered into IREP as a fixed value
- The preceding discussion presents an example of how the data for the drum cover removal can be used to assign radon exposures to workers performing this operation. Other solutions, using later methods than the one discussed here, are possible. However, SC&A believes that dividing this operation into two 12-minute periods is arbitrary and not claimant favorable.

Observation 8: Assessment of inadvertent ingestion for AWE site residual periods has been updated

- TIB-5000 stated that intakes by inadvertent ingestion for AWE sites are determined according to OCAS-TIB-009, rev. 0.
- That guidance is still used for assessing ingested intakes during the operational period at AWE sites.
- For residual periods, the procedure of calculating intakes from inadvertent ingestion was addressed by the SCPR during meetings on November 1, 2012, and February 5, 2013.
- It was agreed that NIOSH underestimated the ingestion rate during the residual periods at some sites by estimating it to be equal to 20% of the airborne activity from resuspension of the surficial contamination levels during the residual periods.
- SCPR concurred with the NIOSH proposal that the ingestion rate at the start of the residual period be set equal to that at the end of the operational period and then reduced by annual depletion factors recommended in ORAUT-OTIB-0070, rev. 01.

Observation 9: TIB-5000 refers to occupational medical dose guidance that has been revised

- Section 3.12, "Occupational Medical Doses," states, "The default assumptions in OTIB-0006 [rev. 03] will be used if no other information is available." The referenced document has been supplanted by ORAUT-OTIB-0006, rev. 05, which constitutes a total rewrite of the earlier versions of this document. In particular, revision 05 states:

> Because PFG [photofluorography] was primarily a mass screening technique most suitable to large populations, and therefore unlikely to have occurred on a mass scale at AWE sites, PFG should not be assumed to have occurred at AWE sites unless there is evidence to the contrary.

Observation 10: Protocol for assigning missed doses is inconsistent with current guidance

- TIB-5000 prescribed the procedures in OCAS-IG-001, rev. 1, and ORAUT-OTIB-0020, rev. 01, for assigning external doses to normally monitored workers whose doses were not reported or recorded for one or more time periods.
- Both documents have been revised since the release of TIB-5000, being replaced by OCAS-IG-001, rev. 3, and ORAUT-OTIB-0020, rev. 03, respectively.
- The procedures in the revised documents should be followed for assigning missed dose.
- Guidance to "substitute a value for each dosimeter reading . . . assign a triangular distribution with minimum = 0, mode = 0.5×*LOD*, and maximum = *LOD*" is no longer recommended.

Observation 11: Ingestion should be added to the pathways of environmental doses

- In Section 3.16, "Environmental Dose," TIB-5000 listed five components of environmental dose but did not discuss these pathways.
- The ingestion pathway was omitted altogether.

Equilibrium factors for radon isotopes

- If the concentrations of a radon isotope—Rn-220 (thoron) or Rn-222 (radon)—in ambient air are known, but the actual concentrations of its short-lived progeny are unknown, the working level (a unit of potential alpha-energy concentration (PAEC), used to assess the effect of exposure to radon isotopes) can, in principle, be estimated by assigning equilibrium factors.
  - An equilibrium factor is defined "as the ratio of the actual . . . PAEC . . . to the PAEC that would prevail if all the decay products in each series were in equilibrium with the parent radon or thoron, as the case may be" (United Nations, 2009).
- According to TIB-5000, lognormal distributions are assumed for equilibrium factors with mean values of 0.4 for radon and 0.02 for thoron.

A bounding, site-specific thoron equilibrium factor should be derived as needed from available data

- UNSCEAR 2006 report to the General Assembly (United Nations, 2009) states:

  > More caution should be exercised in assuming the average values of the equilibrium factor for dose assessment from inhalation of thoron decay products. An objection to the use of thoron gas measurements for dosimetric purposes is that thoron may not be well mixed in the indoor air because of its short half-life. . . . Only where a room fan is used would thoron be well mixed and a large variation of the thoron concentration in the room not be found. . . .
  >
  > Thus the use of an equilibrium factor for thoron should be limited to situations where large spatial variation is not found.

- More recently, Harley et al. (2010) derived an equilibrium factor "for both outdoor and indoor [thoron] environments (0.004±0.001 outdoors and 0.04±0.01 indoors)."

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Observation 12: TIB-5000 assumes a questionable equilibrium factor for thoron

- Representing an equilibrium factor for thoron by a lognormal distribution with mean = 0.02 is questionable.

TIB-5000 assumption about air sample distributions

- TIB-5000 assumed that, on average and in the absence of evidence to the contrary, an air sample distribution is unbiased.
- Thus, the uncertainty distribution due to lack of representativeness must be unbiased, that is, have an arithmetic mean of 1.

Observation 13: Questionable uncertainty of representativeness of lognormal distribution

- In the opinion of SC&A, even if the true underlying distribution of concentrations were lognormal, there is no real reason to assume that the distribution of the uncertainty of the representativeness parameter is also lognormal.

Questions?

References

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