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Internal Dose Overestimates for Facilities with Air Sampling Programs

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
03/18/2005	00	New technical information bulletin to provide information for internal dose overestimates for facilities with air sampling programs. Incorporates internal review comments. Incorporates changes requested by NIOSH, including Attachments B and C. Updates RU contaminant levels. Eliminates discussion about ORAUT-OTIB-0002 related to ORAUT-OTIB-0018. First approved issue. Initiated by Donald E. Bihl.
08/09/2005	01	Draft revision to 1) incorporate into Table 4-3 Nb-95 type S and Tc-99 type F beta choice and replace RU with U-234 alpha choice, 2) add Table 7-2 which provides excretion values for uranium and radiostrontium below which the default intakes was still valid, 3) add special air concentration values for LANL into Table 4-1.4) correct error in the ingestion intake formula #4. Text was added or modified in Sections 1.0 through 5.0, 7.0, and Attachment A. No entire Sections were deleted. No further changes occurred as a result of formal internal review. Incorporates NIOSH review comments. Approved issue of Revision 01. Training required: As determined by the Task Manager. Initiated by Elizabeth M. Brackett and Donald E. Bihl.
07/01/2022	02	Revised to incorporate current DOE derived air concentration values per 10 CFR Part 835, address Advisory Board on Radiation and Worker Health findings, and incorporate ORAUT-OTIB-0033. Recycled uranium contaminant ratios were replaced by the requirement to use site-specific values. Applicability and limitations sections were expanded to be more clear. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by John M. Byrne and authored by Elizabeth M. Brackett.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AMAD	activity median aerodynamic diameter
AWE	atomic weapons employer
BB	bronchial region
C.F.R.	*Code of Federal Regulations*
d	day
DOE	U.S. Department of Energy
dpm	disintegrations per minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ET1	extrathoracic region 1
ET2	extrathoracic region 2 (posterior nasal passage, larynx, pharynx, and mouth)
F	fast (absorption type)
hr	hour
ICRP	International Commission on Radiological Protection
LANL	Los Alamos National Laboratory
LN(ET)	extrathoracic lymph nodes
LN(TH)	thoracic lymph nodes
m	meter
M	moderate (absorption type)
mL	milliliter
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NU	natural uranium
ORAU	Oak Ridge Associated Universities
ORAUT	ORAU Team
ORNL	Oak Ridge National Laboratory
pCi	picocurie
RU	recycled uranium
S	slow (absorption type)
SEC	Special Exposure Cohort
SRDB Ref ID	Site Research Database Reference Identification (number)
SRS	Savannah River Site
SS	super slow (absorption type)
TIB	technical information bulletin
U.S.C.	*United States Code*

yr	year
µCi	microcurie
µg	microgram
µm	micrometer
§	section or sections

1.0 INTRODUCTION

Technical information bulletins (TIBs) are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s), such as changing scientific understanding of operations, processes, or procedures involving radioactive materials. TIBs may be used to assist NIOSH staff in the completion of individual dose reconstructions.

In this document the word "facility" is used to refer to an area, building, or group of buildings that served a specific purpose at a U.S. Department of Energy (DOE) or Atomic Weapons Employer (AWE) facility. It does not mean, nor should it be equated to, an "AWE facility" or a "DOE facility." The terms AWE and DOE facility are defined in 42 *United States Code* (U.S.C.) § 7384l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), respectively.

1.1 PURPOSE

The purpose of this TIB is to provide a simplifying overestimate method to facilitate timely processing of claims under the EEOICPA. Overestimates can be applied in accordance with guidance given in Internal Dose Reconstruction Implementation Guideline [NIOSH 2002], Roadmap to Reconstructing Dose [ORAUT 2020a], and Internal Dose Reconstruction [ORAUT 2018]. Restrictions on the application of such methods are also described in these documents.

2.0 BACKGROUND

Most DOE sites, including those of its predecessor agencies, had air sampling programs for particulate radioactive contamination and, with the exception of short-term unplanned situations, controlled air concentrations to limiting values established by the National Council on Radiation Protection and Measurements (NCRP) or DOE. The first official national guidelines on air concentrations were produced by the NCRP and published in 1953 in National Bureau of Standards (NBS) Handbook 52 [NBS 1953]. The NCRP revised its methodology and expanded the list of covered radionuclides in 1959, published as NBS Handbook 69 [NBS 1959]. Both of these documents were based on and consistent with similar guidance from International Commission on Radiological Protection (ICRP) Publication 2 [ICRP 1959]. After the publication of the NBS handbooks, DOE issued orders or regulations establishing air concentration limits applicable to its sites (for example, in *AEC Manual* Chapter 0524 [U.S. Atomic Energy Commission (AEC) 1968] and DOE Order 5480.11 [DOE 1988]). In December 1993, DOE issued 10 *Code of Federal Regulations* (C.F.R.) Part 835 to establish limits on air concentrations to be effective no later than January 1, 1996 [DOE 1993]. This rule was updated in 2010. 10 C.F.R. 835, 2010. Table 2-1 lists the history of workplace air concentration limits applicable at DOE sites for a number of important particulate radionuclides. This is not meant to be exhaustive, nor does it imply that all of these nuclides would be present at all sites to which this TIB is applicable.

Most sites performed total alpha and total beta counting on air samples using either a time delay or mathematical correction to account for radon progeny. Radionuclide identification was either not performed or was performed occasionally as a check on basic assumptions from knowledge of the facility source terms and processes. Trigger levels and prompt decisions for changing access to an area, usually by placing a "respiratory protection required" restriction for the area, were usually based on total alpha or total beta air concentrations. Because the radionuclide was not identified for every sample, the limit for the most restrictive, plausible radionuclide was often used to establish the trigger level. For facilities handling transuranic elements, the limiting air concentration for the alpha

Table 2-1. Limiting air concentrations for selected particulates from 1953 to present (µCi/mL).[a]

Alpha emitters

Radionuclide[b]	NBS 1953	NBS 1959	AEC Manual Chapter 0524[c]	DOE Order 5480.11[d]	10 C.F.R. Part 835 1993[e]	10 C.F.R. Part 835 2010[f]
Po-210	7E−11	2E−10	2E−10	3E−10	3E−10	2E−10
Th-230	Not listed	2E−12	2E−12	3E−12	3E−12	3E−12
Th-232	Not listed	2E−12[g]	3E−11[h]	5E−13	5E−13	3E−12
NU soluble	1.7E−11	7E−11	7E−11[h]	Not listed	Not listed	Not listed
NU insoluble	1.7E−11	6E−11	6E−11[h]	Not listed	Not listed	Not listed
U-234 soluble (D)	Not listed	6E−10	6E−10	5E−10	5E−10	5E−10
U-234 insoluble (Y)	Not listed	1E−10	1E−10	2E−11	2E−11	7E−11
U-238 soluble (D)	Not listed	7E−11	7E−11	6E−10	6E−10	5E−10
U-238 insoluble (Y)	Not listed	1E−10	1E−10	2E−11	2E−11	8E−11
Np-237	Not listed	4E−12	4E−12	2E−12	2E−12	8E−12
Pu-238	Not listed	2E−12	2E−12	3E−12	3E−12	6E−12
Pu-239	2E−12	2E−12	2E−12	2E−12	2E−12	5E−12
Am-241	3E−11	6E−12	6E−12	2E−12	2E−12	5E−12
Pu-242	Not listed	2E−12	2E−12	2E−12	2E−12	5E−12
Cm-244	Not listed	9E−12	9E−12	4E−12	4E−12	9E−12
Cf-252	Not listed	2E−11	6E−12	1E−11	1E−11	1E−11

Beta emitters

Radionuclide[b]	NBS 1953	NBS 1959	AEC Manual Chapter 0524[c]	DOE Order 5480.11[d]	10 C.F.R. Part 835 1993[e]	10 C.F.R. Part 835 2010[f]
Na-24	2E−8	2E−8	1E−7	2E−6	2E−6	4E−7
P-32	1E−7	7E−8	7E−8	2E−7	2E−7	1E−7
S-35	1E−6	3E−7	3E−7	9E−7	9E−7	5E−7
Sc-46	7E−8	2E−7	2E−8	1E−7	1E−7	1E−7
Cr-51	8E−6	1E−5	2E−6	8E−6	8E−6	1E−5
Mn-54	Not listed	4E−8	4E−8	3E−7	3E−7	4E−7
Co-58	Not listed	5E−8	5E−8	3E−7	3E−7	3E−7
Co-60	1E−6	9E−9	9E−9	1E−8	1E−8	3E−8
Fe-59	6E−7	5E−8	5E−9	1E−7	1E−7	1E−7
Ni-63	2E−8	4E−8	6E−8	7E−7	7E−7	1E−6
Zn-65	2E−6	6E−8	6E−8	1E−7	1E−7	2E−7
Sr-89	2E−8	3E−8	3E−8	6E−8	6E−8	1E−7
Sr-90	2E−10	3E−10	1E−9	2E−9	2E−9	7E−9
Y-91	4E−8	3E−8	3E−8	5E−8	5E−8	9E−8
Nb-95	4E−7	1E−7	1E−7	5E−7	5E−7	4E−7
Zr-95	Not listed	3E−8	3E−8	6E−8	6E−8	9E−8
Mo-99	2E−7	2E−7	2E−7	6E−7	6E−7	5E−7
Tc-99	Not listed	6E−8	6E−8	3E−7	3E−7	1E−7
Ru-103	Not listed	8E−8	8E−8	3E−7	3E−7	2E−7
Ru-106	3E−8	6E−9	8E−8	5E−9	5E−9	1E−8
Ag-110m	Not listed	2E−7	1E−8	4E−8	4E−8	7E−8
Sn-113	6E−7	5E−8	5E−8	2E−7	2E−7	2E−7
Sb-125	Not listed	3E−8	3E−8	2E−7	2E−7	1E−7
Cs-134	Not listed	1E−8	1E−8	4E−8	4E−8	5E−8
Cs-137	2E−7	1E−8	1E−8	7E−8	7E−8	8E−8
Ba-140	6E−8	4E−8	4E−8	6E−7	6E−7	3E−7
La-140	6E−8	1E−7	1E−7	5E−7	5E−7	3E−7

Radionuclide[b]	NBS 1953	NBS 1959	AEC Manual Chapter 0524[c]	DOE Order 5480.11[d]	10 C.F.R. Part 835 1993[e]	10 C.F.R. Part 835 2010[f]
Ce-141	Not listed	2E−7	2E−7	3E−7	2E−7	1E−7
Ce-144	7E−9	6E−9	6E−9	6E−9	6E−9	1E−8
Pm-147	2E−7	1E−7	6E−8	6E−8	6E−8	1E−7
Eu-152	Not listed	3E−7	2E−8	1E−8	1E−8	2E−8
Eu-154	6E−9	4E−9	7E−9	8E−9	8E−9	1E−8
Eu-155	Not listed	7E−8	7E−8	4E−8	4E−8	7E−8
Tb-160	Not listed	3E−8	3E−8	1E−7	1E−7	1E−7
Hf-181	Not listed	7E−9	4E−8	7E−8	7E−8	1E−7

a. NU = natural uranium.
b. Most limiting form (e.g., soluble, insoluble, inhalation class D, W, Y) is listed, with the exception of uranium, for which the soluble form was based on chemical toxicity.
c. Source: AEC [1968].
d. Source: DOE [1988] effective January 1989.
e. Source: DOE [1993].
f. Source: 10 C.F.R. 835, 2010.
g. Printed as 2E−12 µCi/mL, but a footnote stated that continued use of 3E−11 µCi/mL was recommended until further investigation.
h. Based on special definitions for the curie that added disintegrations from selected progeny.

measurements was based on plutonium; for facilities with potential exposure to fission or activation products, the limiting air concentration for beta measurements was based on ^{90}Sr; at uranium facilities, the limits for uranium were generally used.

The validity of the assumption that worker intakes, except for accidental intakes, were controlled so that intakes at limiting air concentrations for a chronic period are reasonable median values is discussed in Attachment A. Attachment A compares worker bioassay results to the urinary excretion that would be predicted from an intake at the rates assumed in this TIB.

3.0 APPLICABILITY, LIMITATIONS, AND ASSUMPTIONS

3.1 APPLICABILITY

This TIB applies to:

- Sites or facilities that sampled particulate air concentrations in areas of risk and controlled exposure to intakes according to the measured concentrations (or controlled air concentrations by limiting the inventory of radioactive material such that there was no risk of exceeding regulatory limits).

- Employment between 1953 and the present. If the limiting air concentrations for the site of exposure are documented for years before 1953, those concentrations are used with the methodology presented in Sections 4.0 and 6.0. Attachment B provides the justification for these values. These earlier years are listed as separate rows in Table 4-1.

- Claims for which it is likely that the covered employee had no significant intakes of particulate radioactive material. This is somewhat subjective but typically includes employees with no bioassay monitoring or with monitoring results that are less than the minimum detectable amount. Attachment C contains information to help with this determination.

- Intakes of particulate radioactive material only.

- All organs for unmonitored workers.

- All organs other than the respiratory tract for monitored workers. The respiratory tract includes extrathoracic regions 1 and 2 (ET1 and ET2), lungs, thoracic lymph nodes [LN(TH)], extrathoracic lymph nodes [LN(ET)], and bronchial region [ICRP 1994a].

3.2 LIMITATIONS

This TIB has the following limitations:

- It does not apply to Nevada Test Site outdoor exposures before 1963.

- It applies only to particulate radioactive material. These particulate intakes are in addition to any intakes of ^{3}H, radioiodines, ^{14}C, or radon/thoron and their progeny, as applicable.

- Because the thyroid is particularly sensitive to intakes of radioiodine, this TIB alone may not provide an overestimate to the thyroid (regardless of monitoring) if the worker had a potential for exposure to radioiodines. Any potential for exposure to iodine must be assessed and added to the TIB value when the thyroid is the organ of concern. This includes missed dose.

- Intakes of particulate material with a documented particle-size distribution other than 5-µm activity median aerodynamic diameter (AMAD) must be checked to ensure that the dose to the organ of concern from this TIB is greater.

- If site-specific limiting air concentrations were greater than those listed in Section 3.3, those concentrations must be used with the methodology presented in Sections 4.0 and 6.0. If the site-specific concentration was applicable to airborne contamination for a given radionuclide only and exposure was limited to that radionuclide, the dose reconstructor can apply the intake to that radionuclide only. For instance, Mound and Los Alamos National Laboratory (LANL) had special limits for exposure to ^{210}Po and LANL had special limits for general alpha and beta emitters through 1966.

- It does not apply to respiratory tract cancers where bioassay has been performed because missed dose from the insoluble forms of some of the more difficult-to-detect radionuclides can be larger than the values calculated here. This includes CLL because several respiratory tract organs are included in its assessment.

3.3 ASSUMPTIONS

This TIB applies the following assumptions:

- All significant intake exposure was covered by an air sampling program, or the radiation protection program had a valid method to ensure that air concentrations did not exceed limits. For example, airborne contamination might have been controlled by controlling the inventory of radioactive material in an area and/or the physical form of the material.

- Chronic intakes were for 40 hours per week, or 2,000 hours per year, of particulate radioactive material with a 5-µm-AMAD particle-size distribution. A graded approach to this assumption is applied based on exposure potential; this is discussed further in Section 6.0.

- The breathing rate was 9.6 m^3/workday [ICRP 1994a] or 1.2 m^3/hr averaged over an 8-hour day.

- For sites or facilities with an exposure to alpha-emitting radionuclides that was principally transuranic elements, chronic exposure was at 2×10^{-12} µCi/mL through 2009 and

5×10^{-12} µCi/mL beginning in 2010. These values are based on ^{239}Pu, which, as noted in Section 2.0, is the typical assumption when there is an unknown mixture of alpha emitters. This is also more favorable to the claimant than the application of the ^{232}Th limiting value because it will result in a larger assumed intake and therefore a larger dose.

- For sites or facilities with an exposure to beta-emitting radionuclides, chronic exposure was at 2×10^{-9} µCi/mL through 2009 and 7×10^{-9} µCi/mL beginning in 2010. These values are based on ^{90}Sr, which, as noted in Section 2.0, is the typical assumption when there is an unknown mixture of beta emitters. The largest value prior to 2009 was selected for application to that period because it will result in a larger assumed intake and therefore a larger dose. Another increase in the air concentration limits occurred in 2010, well after the initial implementation of this TIB, so the larger value is applied from 2010 forward.

- For sites or facilities with an exposure principally to uranium, chronic exposure was at 6×10^{-10} µCi/mL through 2009 and 5×10^{-10} µCi/mL beginning in 2010.

- Measured air sample concentrations were not always representative of the air concentration breathed. However, when applied to the long-term, 40-hour-per-week, chronic-intake assumption, it is assumed that the air sampling program was sufficient to prevent long-term intakes from exceeding the limiting air concentrations. See Section 7.0 for additional consideration of the possible nonrepresentativeness of air sampling.

4.0 INHALATION INTAKE

4.1 INTAKE QUANTITY

Table 4-1 lists the limiting air concentrations and the associated daily intake rates. There are some sites where alternative values were in place, as well as a handful of sites that had well-documented limits prior to 1953. The rationale for these values is documented in Attachment B. The inhalation intake is determined by:

$$\textit{Intake} = \textit{air conc.} \times \textit{breathing rate} \times \textit{exposure period} \quad (4\text{-}1)$$

From Equation 4-1, intakes in pCi/yr can be determined by:

$$\textit{Intake}\ (\text{pCi/yr}) = \textit{air conc.}\ (\mu\text{Ci/mL}) \times 1.2\ \text{m}^3/\text{hr} \times 2{,}000\ \text{hr/yr} \times 10^6\ \text{mL/m}^3 \times 10^6\ \text{pCi/}\mu\text{Ci} \quad (4\text{-}2)$$

or

$$\textit{Intake}\ (\text{pCi/yr}) = \textit{air conc.}\ (\mu\text{Ci/mL}) \times 2.4 \times 10^{15} \quad (4\text{-}3)$$

where the air concentration is obtained from Table 4-1 or from site-specific limiting air concentrations (in µCi/mL) when applicable. Selection of the air concentration values is described in Section 3.0.

Table 4-1. Default limiting air concentrations.[a]

Exposure type	Air concentration (µCi/mL)	Associated daily intake (pCi)
Alpha-emitting radionuclides except for uranium facilities, 1953–2009 (includes Hanford from 1949)	2E−12	1.31E+1
Alpha-emitting radionuclides except for uranium facilities, 2010 to present	5E−12	3.29E+1
Beta-emitting radionuclides except for uranium facilities, 1953–2009 (includes Hanford from 1949)	2E−9	1.31E+4

Exposure type	Air concentration (µCi/mL)	Associated daily intake (pCi)
Beta-emitting radionuclides except for uranium facilities, 2010 to present	7E−9	4.60E+4
Uranium including recycled uranium, 1953–2009 (includes Hanford from 1949 and LANL from 1951)	6E−10	3.94E+3
Uranium including recycled uranium, 2010–present	5E−10	3.29E+3
ORNL alpha-emitting radionuclides except for uranium facilities, 1944–1952	3E−11	1.97E+2
ORNL beta-emitting radionuclides, 1944–1952	1E−7	6.57E+5
Hanford alpha-emitting radionuclides except uranium facilities, 1946–1948	4E−11	2.63E+2
Hanford beta-emitting radionuclides, 1946–1948	1E−8	6.57E+4
LANL alpha-emitting radionuclides except uranium facilities or Po-210 facilities, 1948–1952	3.2E−11	2.10E+2
LANL alpha-emitting radionuclides except uranium facilities or Po-210 facilities, 1953–1963	4E−12	2.63E+1
LANL beta-emitting radionuclides, 1948–1952	1E−7	6.57E+5
LANL beta-emitting radionuclides, 1953–1969	3E−9	1.97E+4
LANL uranium facilities, 1948–1950	1.8E−10	1.18E+3
LANL Po-210 only,[b] 1948–1953 (exposure ended in 1953)	6.3E−10	4.14E+3
Mound Po-210 only,[c] 1952–1971 (exposure ended in 1971)	Not applicable	5.88E+3
Rocky Flats alpha-emitting radionuclides in Pu chemistry operations or default for the site, 1953–1994 (2E−12 µCi/mL was used in the metal operations)	4E−12	2.63E+1

a. ORNL = Oak Ridge National Laboratory.
b. LANL had special air concentration limits for Po-210. The doses associated with this intake will be larger than for general alpha-emitting radionuclides at 13.2 pCi/d for years of exposure but will be less for years after exposure ends. The dose reconstructor will have to run both cases and determine which option gives the largest probability of causation.
c. The Mound Po-210 intake rate is based on special urinalysis limits rather than an air concentration limit. The doses associated with this intake will be larger than for general alpha-emitting radionuclides at 13.2 pCi/d for years of exposure but will be less for years after exposure ends. The dose reconstructor will have to run both cases and determine which option gives the largest probability of causation.

From Equation 4-3, the intake per calendar day in pCi is:

$$\textit{Intake}\ (\text{pCi/cal. d}) = [\textit{air conc.}\ (\mu\text{Ci/mL}) \times 2.4 \times 10^{15}]/365.25\ \text{d} \quad (4\text{-}4)$$

or

$$\textit{Intake}\ (\text{pCi/cal. d}) = \textit{air conc.}\ (\mu\text{Ci/mL}) \times 6.6 \times 10^{12} \quad (4\text{-}5)$$

For most sites intakes will be assigned for alpha and beta intakes. Only the uranium intake should be assigned for facilities with exposure to only uranium (or natural thorium), with the exception of years when exposure was to recycled uranium. For recycled uranium, add the associated contaminant intakes as applicable to the site.

4.2 CHOICE OF RADIONUCLIDE

Because total alpha and total beta activity were measured on the air filters, the measurements represented all the particulate activity being breathed (as opposed to bioassay measurements that usually measure only certain radionuclides so that unmeasured radionuclides have to be accounted for in addition to the measured radionuclides). To be most accurate, the fractions of the total activity (alpha or beta) would have to be assigned to each radionuclide in the mixture in the air breathed. Those fractions were generally not determined on a regular basis and would have varied among sites, facilities, processes, or even specific work tasks.

Rather than estimating radionuclide fractions, this TIB overestimates the internal dose by assigning 100% of the intake to the single radionuclide that produces the largest dose per unit intake to the organ of concern. In addition, organ dose depends on the absorption type of the radionuclides. The radionuclide and absorption type combination that produces this "largest dose" can differ by organ, time of exposure, and time after end of exposure. Because the annual organ dose is the dose of interest, and the annual dose varies from year to year for a given radionuclide, the largest dose contributor could change over the years. For example, for a 10-year chronic intake of beta emitters, ^{134}Cs type F delivers the largest dose to the urinary bladder during years 1 through 10. However, if the date of diagnosis is sometime after the intake period, the assumption of a ^{106}Ru type F intake during the 10 years of exposure yields the largest dose for years 11 through 14, as does ^{90}Sr type F for all subsequent years. Rather than determining which radionuclide and absorption type combination produces the largest dose, an additional claimant-favorable assumption was made. Each year between the start of exposure and date of diagnosis is evaluated individually and the largest dose is assigned. For the previous example, it would be assumed that the intake was comprised of 100% type F ^{134}Cs when assigning years 1 through 10. For years 11 through 14, it would be assumed that the intake had been entirely made up of type F ^{106}Ru, and that it was ^{90}Sr for years 15 through 65.

Table 4-2 lists the inventory of radionuclides and absorption types from which the combination producing the largest dose can be obtained. This is the default list at present.

Table 4-2. Inventory of radionuclides and absorption types.[a]

Alpha choice

Radionuclide	Type
Am-241	M
Cf-252	M
Cm-244	M
Np-237	M
Po-210	F, M
Pu-238	M, S, nonmonotonic
Pu-239	M, S, SS

Radionuclide	Type
Pu-240	M, S
Pu-242	M, S
Ra-226	M
Th-228	M, S
Th-230	M, S
Th-232	M, S
U-234	F, M, S

Beta choice

Radionuclide	Type
Ag-110	M, S
Ba-140	F
Ce-141	M, S
Ce-144	M, S
Co-58	M, S
Co-60	M, S
Cr-51	F, M, S
Cs-134	F
Cs-137	F
Eu-152	M
Eu-154	M
Eu-155	M
Fe-59	F, M
Hf-181	F, M
La-140	F, M
Mn-54	F, M
Mo-99	F, S
Na-24	F

Radionuclide	Type
Nb-95	M, S
Ni-63	F, M
P-32	F, M
Pm-147	M, S
Ru-103	F, M, S
Ru-106	F, M, S
S-35	F, M
Sb-125	F, M
Sc-46	S
Sn-113	F, M
Sr-89	F
Sr-90	F
Tb-160	M
Tc-99	F, M
Y-91	M, S
Zn-65	S
Zr-95	F, M, S

Uranium choice

Radionuclide	Type
Th-232	M, S
U-234/RU	F, M, S

a. RU = recycled uranium (U-234 plus the contaminants applicable to the site). When site values are unknown, contaminant ratios from *Site Profiles for Atomic Weapons Employees that Worked Uranium Metals* [NIOSH 2011] should be applied.

NOTE 1: Actinium-227 is a progeny of ^{231}Pa in the ^{235}U decay chain. It was probably not present in significant quantities unless ^{231}Pa or ^{227}Ac was purposely concentrated; therefore, it was not included in the default list for the alpha choice. It should be added to the list if ^{231}Pa or ^{227}Ac was handled in a pure or concentrated form at the site in question.

NOTE 2: Thorium-232 is included in the uranium list because many uranium facilities also processed thorium at some time. Thorium-232 can be removed from the list if documentation clearly demonstrates that the facility did not handle thorium.

NOTE 3: For strontium, type S is applicable to the titanate form only and is unlikely to be present at most sites. Type S was not included in the default list for the beta choice. If it is established that a site had strontium titanate, type S strontium will have to be added to the list. Check the Site Profile for applicability. Adding type S strontium will significantly increase the dose for some organs.

NOTE 4: Nonmonotonic ^{238}Pu is addressed in DCAS-RPT-005, *Alternative Dissolution Models for Insoluble Pu-238* [NIOSH 2018]. Two models are described in the report. The appropriate model should be included for sites where pure ^{238}Pu was present.

5.0 INGESTION INTAKE

The possibility of ingestion intakes must be considered separately from inhalation intakes when intake is not based on bioassay measurements. OCAS-TIB-009, *Estimation of Ingestion Intakes*, provides the method for estimating ingestion intakes based on air concentrations [NIOSH 2004]:

$$\textit{Ingestion intake} = 0.021 \times \textit{inhalation intake} \qquad (5\text{-}1)$$

These intakes should be applied to the same years for which inhalation intakes occurred using the same radionuclide. Use the f_1 associated with the absorption type from Annex F in ICRP Publication 68 [ICRP 1994b].

6.0 APPLICATION

The primary application of this TIB is as an overestimating efficiency method applied to monitored workers with few to no positive bioassay results. This can greatly reduce the assessment time. While applicable to unmonitored workers, co-exposure intakes take precedence when available.

Because of the complexity of this approach, a tool is required for its application. Values from this TIB have been incorporated into the Web CAD application. Direction on its use can be found with the Web CAD user guidance documents.

As noted in the previous sections, there are three categories of radionuclides:

- Alpha-emitting.
- Beta-emitting.
- Uranium.

Multiple categories may be applicable to a site. Some large sites contained facilities that performed different functions. For example, the Hanford Site is a reactor site but also had fuel fabrication facilities. The fabrication facilities normally controlled air concentrations to uranium limits. Therefore, the uranium list should be applied to individuals working in those facilities.

Some sites operated with particular nuclides in campaigns. Once the campaign ended, the nuclide was no longer routinely handled. For example, the Fernald site produced thorium products during several campaigns but did not routinely handle it between these campaigns. Therefore, it is permissible to remove thorium from the list of possible radionuclides during times when the individual was not exposed to thorium. This can be done in other situations when there is clear evidence that the individual was not exposed to a particular radionuclide.

6.1 CONSIDERATIONS

Both the worker's exposure potential and employment period are considered when determining the intake rate to be applied.

6.1.1 Exposure Potential

The dose reconstructor must apply judgment when determining the appropriate category for the exposure potential for individual workers and take into account all information in the worker's file, (e.g., telephone interviews, work area). A worker's assigned category can change over time if the worker changed job titles or work locations.

- Intermittent: Individuals with jobs that could have involved work with unsealed sources on occasion but not routinely, or individuals who sometimes entered an area with a potential for airborne activity levels greater than the environmental background.
- Routine: Individuals with jobs that were likely to have routinely involved work with unsealed sources, or individuals who worked in areas likely to have airborne activity levels greater than the environmental background.

Attachment C and OTIB-0014, *Assignment of Environmental Internal Doses for Employees Not Exposed to Airborne Radionuclides in the Workplace*, provide guidance on making this determination [ORAUT 2004].

6.1.2 Employment Period

With the implementation of DOE Order 5480.11, *Radiation Protection For Occupational Workers*, in 1989 [DOE 1988] and the subsequent codification of requirements (10 CFR Part 835, Occupational Radiation Protection [DOE 1993]) a few years later, monitoring programs became more robust and personnel who had a modest exposure potential were likely to have been monitored. Respiratory protection was generally required for radiological areas that had levels greater than 10% of the derived air concentration on which this TIB is based.

6.2 INTAKE ASSIGNMENTS

6.2.1 Unmonitored Workers

Intakes for unmonitored workers are divided into multiple categories as described below. Table 6-1 summarizes this information. As noted above, co-exposure intakes take precedence when available.

Table 6-1. Unmonitored workers.

Exposure potential	Period	Application of dose
Intermittent	Before 1989	50% of Table 4-1 intake rates
Intermittent	1989 and later	5% of Table 4-1 intake rates
Routine	Before 1989	Table 4-1 intake rates
Routine	1989 and later	10% of Table 4-1 intake rates

6.2.1.1 Through 1988

Co-exposure intakes are the preferred assignment. If these are not available, this OTIB may be applied. For those workers who had a potential for routine exposure to airborne radioactivity, the Table 4-1 intake rates are applied. For those with an intermittent exposure potential, 50% of the Table 4-1 values are applied. This is based on occupancy factor, which is assumed to be uniformly distributed from 0 to 1, resulting in the application of a mean value of 0.5.

6.2.1.2 After 1988

As noted in Section 6.1.2, more stringent monitoring requirements were imposed in 1988. Based on this, 10% of the values described in Section 6.2.1 are applied beginning in 1989.

6.2.2 Monitored Workers

The full Table 4-1 intake rates may be applied to monitored workers when all of their results are less than the minimum detectable amount as an overestimate of the missed dose portion of the assessment. Any positive results or known incidents must be assessed separately and added to the doses resulting from the Table 4-1 intakes.

6.3 USE DURING SPECIAL EXPOSURE COHORT PERIODS

This TIB can be applied to any claim during a Special Exposure Cohort (SEC) period that meets the criteria, subject to the additional SEC limitations. In the case of an SEC class where there are identified infeasibilities that limit the nuclides that can be assessed, the intake rates in Table 4-1 are unaffected. The values are the gross airborne activities assumed to have been used for control during the operations. They can still be used to assign an upper bound to the nuclides that are not designated as infeasible. However, nuclides that have been designated as infeasible are to be removed from consideration. If an entire set of nuclides is deemed infeasible (e.g., alpha emitters or mixed fission products), then the corresponding category (alpha and beta, respectively) cannot be used because the infeasibility means it has been determined that an upper bound cannot be placed on the category.

6.4 SITES WITH URANIUM AND TRANSURANIC AREAS

At facilities where there are both uranium and transuranic areas, either the alpha or the uranium value is assigned because they are each based on gross alpha measurements and a worker would not be exposed to both at the maximum permissible concentration for 2,000 hours in a year. The beta category is in addition to this and not addressed in this section.

6.4.1 Monitored Workers

For those who worked in both transuranic and uranium areas, assign intakes based on the alpha values. If the worker has uranium bioassay, add uranium dose (missed or fitted as appropriate) to this value.

If monitored only for uranium and there is no evidence of work in nonuranium areas, apply uranium values or assess the uranium bioassay.

6.4.2 Unmonitored Workers

Co-exposure intakes are the preferred assignment. If these are not available, the Table 4-1 intakes may be applied. If the worker's employment was entirely in a uranium area, assign the uranium intake values. If employment was in multiple areas, use the alpha values.

7.0 UNCERTAINTIES

Assuming an intake at the limiting air concentration for every minute of employment is probably an overestimate. However, there are sources of uncertainty. For instance:

- The air sample results might not have been representative of the air breathed. If a worker was close to a localized source, the air concentration the worker breathed might have been higher than the air collected by a sampler several to tens of feet away. *Breathing Zone to General Area Air Concentration Ratios in Small Workrooms* [ORAUT 2021] discusses this issue in detail for certain conditions. Offsetting this problem somewhat is the likelihood that the worker breathed larger particles than the air sampler collected. The time spent near a localized source would have been less than full time.

- Enforcement of the limiting air concentrations at some facilities for some periods might have been lax.

- Workers may have worked overtime during some periods.

- Before widespread use of alarming continuous air monitors, exposure to air concentrations above limiting air concentrations for periods of days to a few weeks was possible. For instance, a filter exchanged weekly with delayed counting for radon decay could easily result in a 2-week lag between the change in air concentration and change in access control. Even with the use of continuous air monitors, radon progeny interference was a problem with alpha monitoring in many facilities so that immediate recognition of an air concentration slightly greater than the plutonium limit was difficult.

- For beta emitters, the counting efficiency for converting counts to total activity is dependent on the beta energy. If the beta energy of the radionuclide on the filter is less than the beta energy of the calibration source, the total activity would have been underestimated. This is offset somewhat by the generally lower dose per unit intake from the lower energy beta emitters. For alpha emitters, self-absorption of the alphas due to high dust loading might not have been compensated for.

- The volume of air sampled might not have been measured accurately; for instance, it was common to use flow rate meters and the average of the on/off flow rate to estimate the volume of air rather than using total air volume meters.

- Operational logistics might have temporarily compromised the air sampling in some areas, such as pump failures, leaking filters, filters destroyed by harsh chemicals, or filters obviously contaminated by a source other than the air.

These problems arguably could have enabled intakes exceeding the air concentration limits for some periods. While it is unlikely that a worker was exposed at the limiting air concentrations for 2,000 hours per year throughout their entire employment, because of the sensitivity to these uncertainties of the method used in this TIB to determine dose, the dose uncertainty distribution is lognormal with the geometric mean as determined by the equations in this document with a geometric standard deviation of 3.

Attachment A contains several comparisons with site data that demonstrate that this TIB provides overestimating intakes. Also, remember that exposure to tritium, radioiodines, radon/thoron, or ^{14}C has to be accounted for separately from these intake/dose estimations.

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ATTACHMENT A
VALIDATION OF THE BASIC ASSUMPTION

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LIST OF FIGURES

ATTACHMENT A
VALIDATION OF THE BASIC ASSUMPTION (continued)

In this TIB it is presumed that weapons sites with a radiological control program limited exposures to airborne radioactive contaminants to less than applicable limits. These limits varied with time and isotope of concern, and it is acknowledged that exposures to concentrations greater than these limits did occur. However, it is assumed that, when integrated over time, the average exposure to any individual was less than that which would occur from continuous exposure at the limit. The validity of this assumption is confirmed in this attachment by comparing the projected excretion rates from long-term intakes at the levels given in Table 4-1 to the geometric mean urine sample values determined from several co-exposure studies. Documentation for generation of the figures below can be found in ORAUT [2022].

A.1 URANIUM

Uranium urinalysis data from the Y-12 site were used to assess the validity of the assumption. The Y-12 site processed uranium extensively. The data consisted of hundreds of urine samples each month from 1952 through 1985 [ORAUT 2012]. Figure A-1 plots these median sample results as well as the uranium result predicted by this TIB for an inhalation of type M uranium.

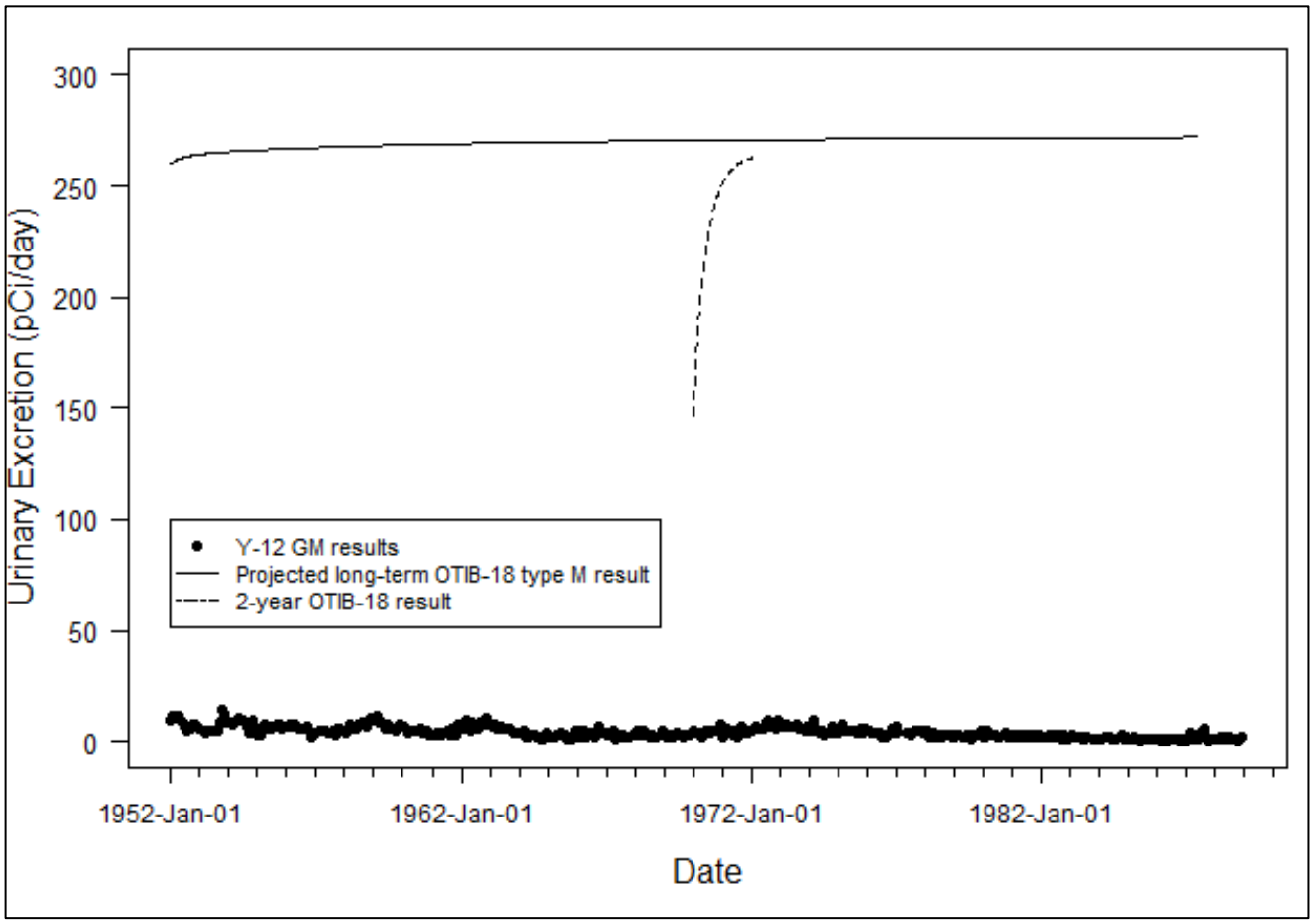

Figure A-1. Comparison of Y-12 co-exposure and predicted OTIB-0018 type M uranium in urine values.

The TIB result is considerably higher than the actual Y-12 median urine sample result. The predicted excretion from a short-term intake of 2 years beginning 1 month after the start of a chronic intake is

ATTACHMENT A
VALIDATION OF THE BASIC ASSUMPTION (continued)

also shown because it takes time for the intake activity to reach the bladder and subsequently be excreted. It can be seen from the figure that the urine activity rapidly reaches equilibrium and is approximately 10 times higher than the highest actual mean result. This verifies that for Y-12 uranium intakes, either the assumed intake is an overestimate or the lung absorption of the uranium is considerably slower than type M.

Figure A-2 shows the same information using an absorption type S assumption for the TIB values. This graph shows that for long-term exposure this TIB overestimates actual results even if absorption type S is assumed. The short-term exposure, on the other hand, indicates that it could take as long as 3 years to reach the level of the highest median urinalysis result. This implies that this TIB approach might not be an overestimate for type S exposures lasting less than 3 years. The more soluble types (F and M) will provide the largest doses to the systemic organs but type S is limiting for the respiratory tract. Therefore, this TIB is not applicable to the respiratory tract.

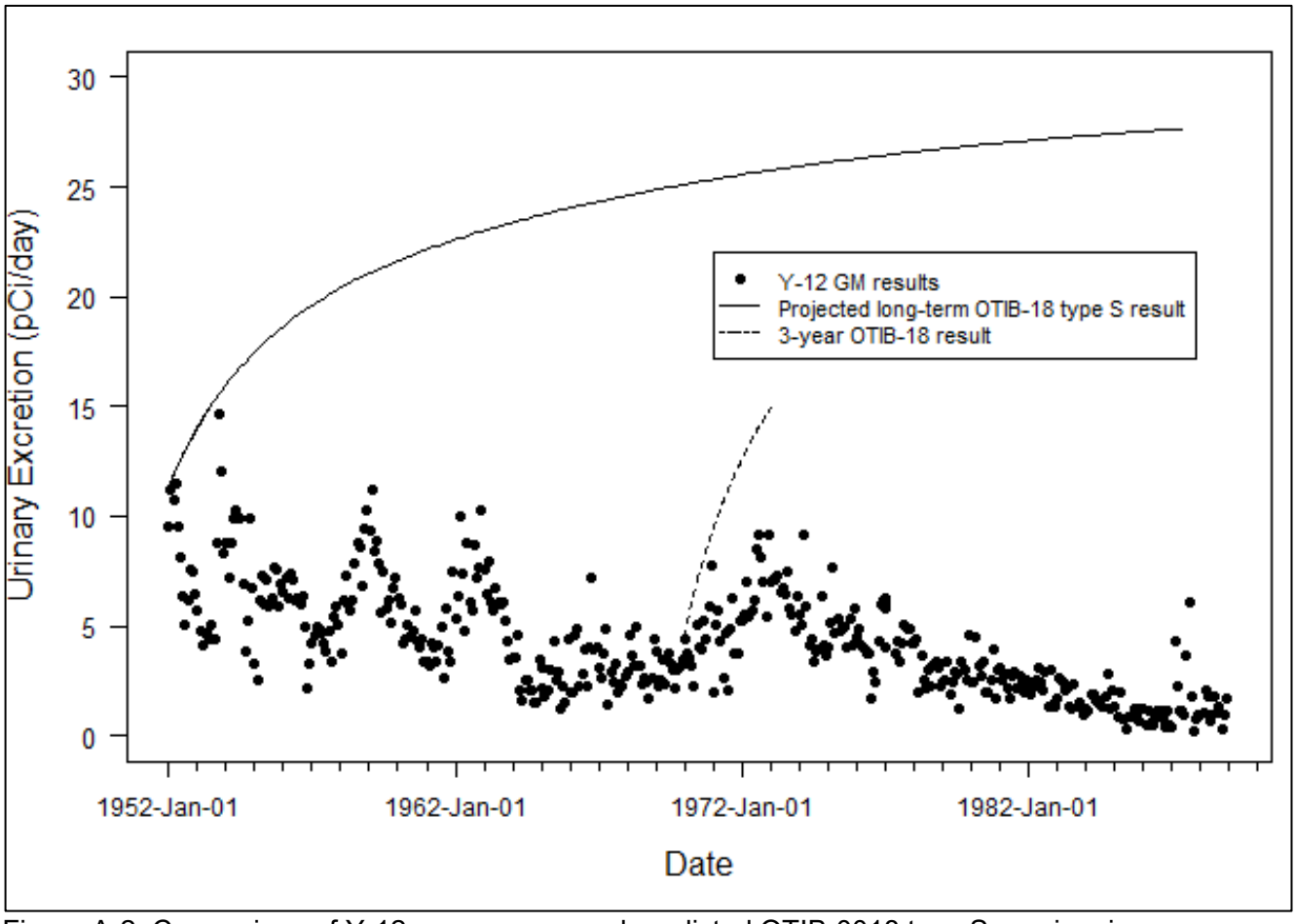

Figure A-2. Comparison of Y-12 co-exposure and predicted OTIB-0018 type S uranium in urine values.

A.2 PLUTONIUM

The Savannah River Site (SRS) worked extensively with plutonium. The geometric mean of the plutonium urine samples were evaluated from 1955 through 1990 [ORAUT 2020b].

ATTACHMENT A
VALIDATION OF THE BASIC ASSUMPTION (continued)

The expected excretion rates from a chronic intake of types M and S ^{239}Pu at the alpha-emitting radionuclides intake rate in Table 4-1 are plotted against the site co-exposure values in Figure A-3.The figure indicates that the TIB values would be likely to exceed the measured data soon after the start of a chronic type M inhalation. The type S inhalation, however, might not result in detectable urine samples.

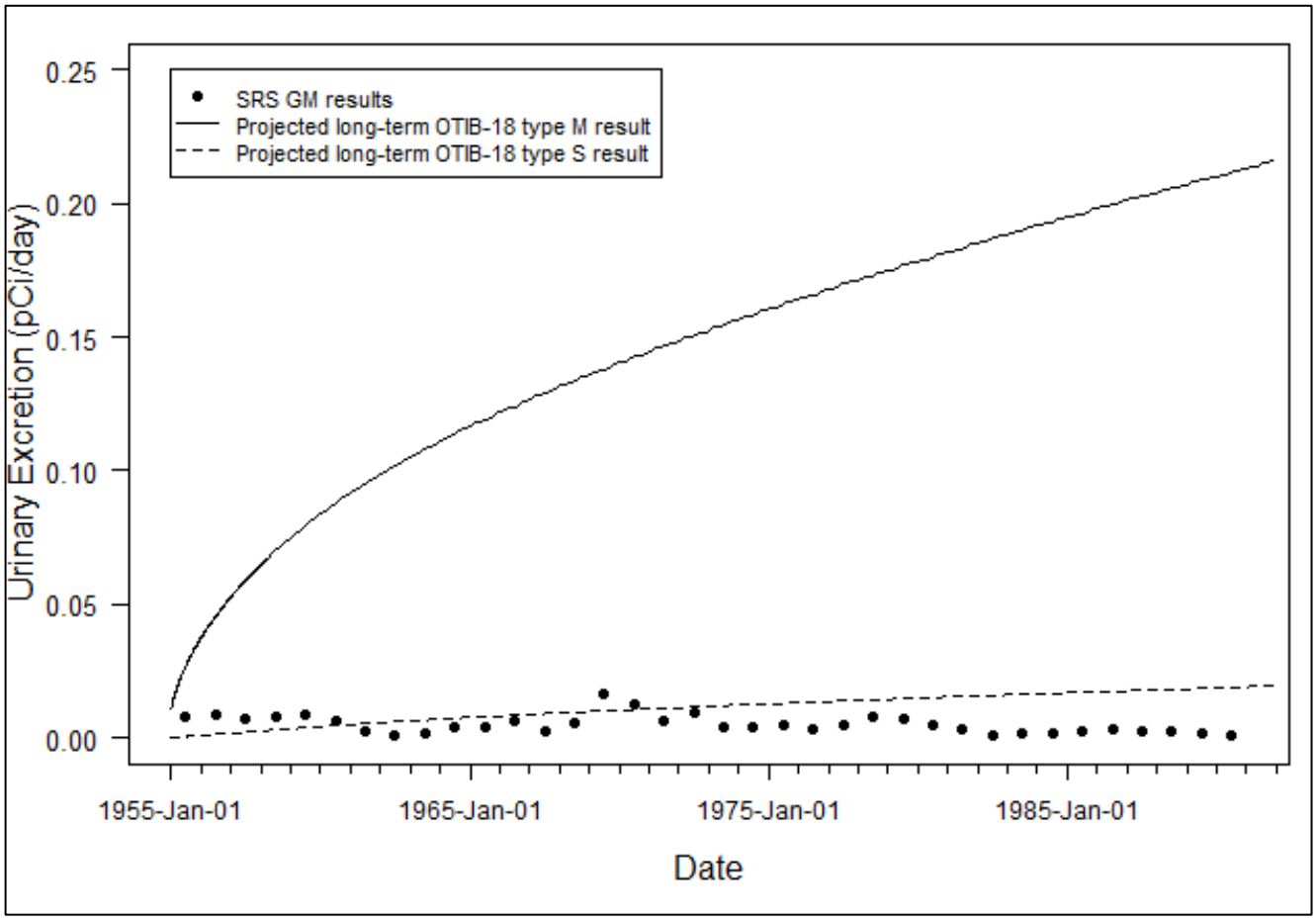

Figure A-3. Comparison of SRS co-exposure and predicted OTIB-0018 types M and S plutonium in urine values.

The Hanford site produced much of the plutonium used by the weapons program. It appears to be reasonable, therefore, to review Hanford site plutonium urine results against the assumptions in this TIB.

The TIB analysis evaluated plutonium urine samples from Hanford from 1949 through 1988 [ORAUT 2020c]. Figure A-4 shows the predicted excretion rates from this TIB for both a type S and a type M inhalation of ^{239}Pu. As with the SRS data, the graph indicates that the TIB values would be likely to exceed the measured data soon after the start of a chronic type M inhalation, but a type S inhalation might not result in a detectable urine sample.

ATTACHMENT A
VALIDATION OF THE BASIC ASSUMPTION (continued)

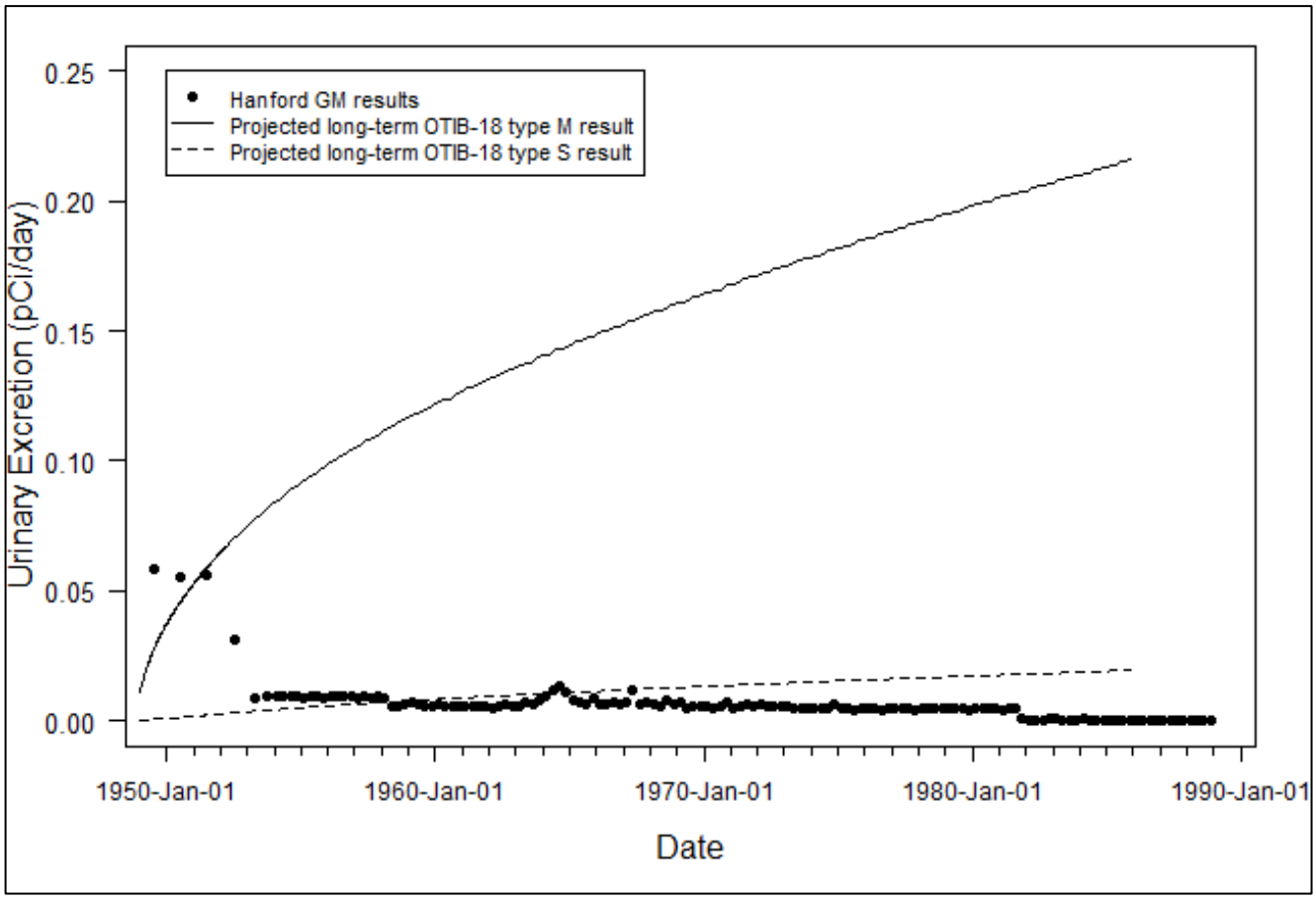

Figure A-4. Comparison of Hanford co-exposure and predicted OTIB-0018 types M and S plutonium in urine values.

A.3 FISSION PRODUCTS

The fission product that was primarily sampled in urine at Hanford was ^{90}Sr. Figure A-5 shows the urine result predicted from the values used in this TIB for a chronic inhalation of type F ^{90}Sr assuming an intake at the beta-emitting radionuclide rate. The figure shows that the TIB predictions greatly exceed the site co-exposure GMs.

ATTACHMENT A
VALIDATION OF THE BASIC ASSUMPTION (continued)

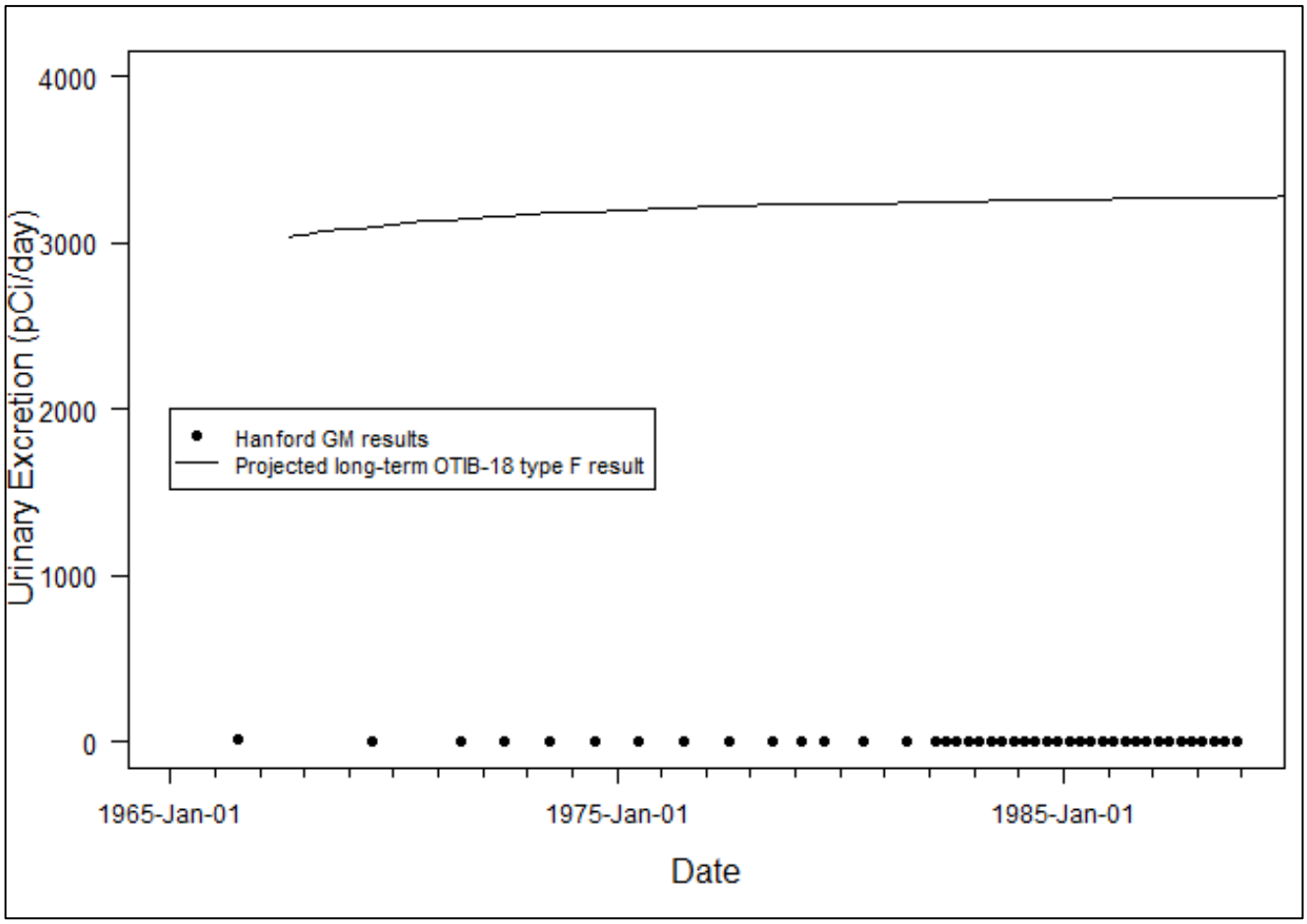

Figure A-5. Comparison of Hanford co-exposure and predicted OTIB-0018 type F ^{90}Sr in urine values.

A.4 CONCLUSION

The analysis discussed above indicates that the assumption made in this TIB is valid if the material to which an individual is exposed has type F or type M absorption characteristics. Because these are the limiting absorption types for systemic organs, it appears the assumption is valid for systemic organs.

Type S, however, is the limiting absorption type (when comparing the same intake values for different absorption types) for the respiratory tract. Due to the detection limits of urinalysis, it cannot be shown that the values of this TIB are an overestimate for the respiratory tract. Therefore, this TIB is not to be applied to cancers of the respiratory tract.

ATTACHMENT B
AIR CONCENTRATION OR OTHER LIMITS BEFORE 1953

Air concentration limits established for a site before 1953 can be used to extend the applicability of this TIB to those earlier years. This attachment provides the justification for the values in Table 4-1 that are prior to 1953.

Because Hanford Site tolerance levels were used to control intakes, they fit the criteria of air concentration limits. The alpha and beta particulate air concentration limits at Hanford from at least 1949 to 1952 were 1×10^{-12} µCi/mL for alpha in nonuranium facilities, 1×10^{-9} µCi/mL for beta, and 1.5×10^{-4} µg U/mL (which converts to 1.1×10^{-10} µCi/mL) for uranium facilities [Patterson 1949]. These concentrations are less than the concentrations listed in Table 4-1; thus, the use of Table 4-1 values is a plausible overestimate. Therefore, this TIB approach can be used unmodified for Hanford claims from 1949 to the present. Higher tolerance levels of 1×10^{-8} µCi/mL for beta emitters and 4×10^{-11} µCi/mL for plutonium were in place at least by October 1945 [Cantril 1945].

Oak Ridge National Laboratory (ORNL) used the concept of tolerance levels for air concentrations before 1953. By July 1944, ORNL had established an air concentration limit of 5×10^{-10} µg/mL (3×10^{-11} µCi/mL) for plutonium based on alpha counting [Parker 1944a]. A limit for beta emitters in air (based on tolerance in the thyroid for ^{131}I even though they might not have been collecting iodine properly on their filters) was established at least by 1944 at 1×10^{-7} µCi/mL [Parker 1944b].

LANL also established tolerance levels for air concentrations for specific buildings as early as 1948. The tolerance levels varied by building, apparently based on the predominant radionuclide used in the building. For beta emitters the limit was stated as 1×10^{-7} µCi/mL in one reference [LANL 1948]. The air concentration limit for alpha emitters other than uranium or ^{210}Po was 70 disintegrations per minute (dpm)/m^3 (3.2×10^{-11} µCi/mL) for 1948 through 1952 [LANL 1947, 1950, 1950–1952]. This was actually the highest limit, and many buildings had lower limits. For uranium buildings the highest air concentration was 400 dpm/m^3 (1.8×10^{-10} µCi/mL) reported in both late 1947 and 1950, so it was assumed to apply throughout the period 1948 to 1950 [LANL 1947, 1950]. For ^{210}Po, which was a source of exposure at LANL only for 1948 to 1953 [ORAUT 2013], the air concentration limit was the same throughout the period at 1,400 dpm/m^3 (6.3×10^{-10} µCi/mL) [LANL 1947, 1950, 1953–1954]. The concentration limits for alpha emitters and beta emitters changed in 1953. The highest air concentration limit for a plutonium facility was 9 dpm/m^3 (4×10^{-12} µCi/mL) [LANL 1953–1954], which continued to show in reports in 1961 [LANL 1961] and 1963 [LANL 1963]. Reports from 1964 [LANL 1964] show a drop to 4 dpm/m^3. The limiting air concentration for beta emitters found after 1953 (referred to as fission products for the earlier years and gross beta thereafter) was listed at 6,700 dpm/m^3 (3×10^{-9} µCi/mL) in annual reports from 1961 through 1969 [LANL 1961, 1962, 1963, 1964, 1965, 1966, 1969]. It was therefore assumed that this limit applied from 1953 to 1969. The limits for uranium in reports during and after 1951 [LANL 1950-1952, 1961, 1963, 1969] were less than the NCRP value in Table 4-2, so the NCRP value was assumed to apply. In other words no adjustment from the default value in Table 4-2 was needed.

The Rocky Flats site used two air concentration limits for plutonium operations throughout its operational period: 2×10^{-12} µCi/mL was used for plutonium metal operations and 4×10^{-12} µCi/mL was used for plutonium chemistry operations. These values were used through 1994 [ORAUT 2020b].

ATTACHMENT C
EXPOSURE POTENTIALS

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ATTACHMENT C
EXPOSURE POTENTIALS (continued)

C.1 JOB CATEGORIES

Likely Low Potential for Work with Unsealed Sources

Administrator	Draftsman	Program analyst
Assistant	Groundskeeper	Programmer
Business systems specialist	Instructor	Radio operator
Cafeteria worker	Manager	Recruiter
Checker	Medical technician	Scheduler
Clerk	Office supervisor	Secretary
Computer specialist	Planner	Telephone operator
Dispatcher	Quality assurance specialist	

Some Potential for Work with Unsealed Sources, Depending on Job Specifics

Biologist	Foreman	Patrolman
Boilermaker	Foundry worker	Photographer
Bricklayer	Heavy equipment operator	Scientist
Carpenter	Health physics analyst	Security guard
Construction worker	Instrument mechanic	Specialist
Driver	Insulator	Storekeeper
Electrician	Ironworker	Supervisor
Electronics technician	Janitor	Surveyor
Engineer	Laborer	Technician
Equipment operator	Mechanic	
Firefighter	Painter	

Likely High Potential for Work with Unsealed Sources

Analytical chemist	Material handler	Radiation monitor
Assembly worker	Metallurgist	Radiochemist
Chemical operator	Millwright	Reactor operator
Fabricator	Pipefitter	Steamfitter
Glovebox worker	Plumber	Ventilation and balance operator
Health physics technician	Processor	Waste handler
Machinist	Production worker	Welder

ATTACHMENT C
EXPOSURE POTENTIALS (continued)

C.2 EXAMPLE WORK LOCATIONS

High Potential for Airborne Activity (Alpha, Beta/Gamma, and/or Uranium)

- Uranium refining:
  - Natural, depleted, and enriched uranium reactor fuel and targets: Feed Materials Production Center and Weldon Spring Site.
  - Weapons parts and highly enriched reactor fuel: Oak Ridge National Laboratory.
  - Production of UF_6 feed: Oak Ridge, Paducah, and Portsmouth Gaseous Diffusion Plants.
- Fuel and target fabrication:
  - Highly enriched uranium: SRS 300 M Area; Hanford 300 Area.
- Chemical separations:
  - Weapons plutonium: Hanford 200 East and West Areas (PUREX [plutonium-uranium extraction], REDOX [reduction oxidation], T and B Plants, 231-Z Plant); SRS (F Canyon complex).
  - Uranium recycling: Hanford (UO_3 Plant, U Plant); SRS (H Canyon complex); Idaho National Laboratory (Idaho Chemical Processing Plant).
- Weapons component fabrication:
  - Plutonium: Rocky Flats Plant; Hanford 234-5 Plutonium Finishing Plant; Los Alamos National Laboratory (TA-21 and TA-55).
- Weapons component fabrication:
  - Plutonium recycling: Rocky Flats; Hanford 234-5 Plutonium Finishing Plant; Los Alamos National Laboratory (TA-55).
  - Highly enriched uranium; Y-12; Rocky Flats Plant.
- Isotope separation:
  - Uranium: Oak Ridge, Paducah, and Portsmouth Gaseous Diffusion Plants.
- Reactor operations:
  - Hanford (B, D, F, H, DR, C, KW, KE, and N Reactors); SRS (R, P, K, L, and C Reactors).

ATTACHMENT C
EXPOSURE POTENTIALS (continued)

- Weapons testing:
  - Nevada Test Site; Pacific Proving Ground; Tonopah Test Range.
- Weapons research and development:
  - Los Alamos National Laboratory; Lawrence Livermore National Laboratory; Sandia National Laboratories (New Mexico and California).
- Uranium ore sampling:
  - Feed Materials Production Center and Middlesex Sampling Plant.
- Other facilities with the potential for airborne uranium or plutonium.

Low Potential for Airborne Activity (Alpha, Beta/Gamma, and/or Uranium)

- Chemical separations:
  - Tritium: SRS.
- Weapons component fabrication:
  - Tritium including recovery and recycling: Mound Site, SRS (Tritium facilities).
  - ^{6}Li deuteride including recovery and recycling: Y-12 Plant.
- Weapons operations:
  - Assembly and dismantlement: Sandia National Laboratories (NM), Pantex Plant.
- Weapons operations:
  - Modifications and maintenance: Pantex Plant, Sandia National Laboratories (NM), Clarksville and Medina Modification Centers.
- Isotope separation:
  - Lithium: Y-12 Plant COLEX [column exchange] and ELEX [electrical exchange] Plants.
  - Heavy water: SRS Heavy Water Plant; Dana Heavy Water Plant.
- Fuel and target fabrication:
  - Enriched lithium: Y-12 Plant, SRS M Area.
- Administrative, support, and other nonradiological facilities.