ORAU Team **Dose Reconstruction Project for NIOSH** Internal Dose Overestimates for Facilities With Air Sampling Programs	Document Number: ORAUT-OTIB-0018 Effective Date: 03/18/2005 Revision No.: 00 Controlled Copy No.: _____ Page 1 of 27
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RECORD OF ISSUE/REVISIONS

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Draft	11/23/2004	00-A	New technical information bulletin to provide information for internal dose overestimates for facilities with air sampling programs. Initiated by Donald E. Bihl.
Draft	01/06/2005	00-B	Incorporates internal review comments. Initiated by Donald E. Bihl.
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03/18/2005	03/18/2005	00	First approved issue. Initiated by Donald E. Bihl.

1.0 PURPOSE

The purpose of this technical information bulletin (TIB) is to provide an alternative method to that discussed in Technical Information Bulletin 002, *Maximum Internal Dose Estimates for Certain DOE Complex Claims* (ORAU 2004), for estimating intakes and internal doses when overestimated doses are acceptable. The internal doses estimated using this TIB will be smaller than those obtained using ORAU (2004) under some situations but are still overestimates. See Section 7.0 for additional discussion about when to use this TIB rather than ORAU (2004).

2.0 BACKGROUND

ORAU (2004) provides default overestimated intakes based on the assumption "that an intake resulting in 10% of a MPBB [maximum permissible body burden] would not have likely occurred to an unmonitored worker or would have likely resulted in a readily noticeable bioassay result in a monitored worker, readily noticeable air sample, or other indicators of personnel contamination." ORAU (2004, Table 3.1.1-2) applies this assumption to each of a list of radionuclides to which workers at most U.S. Department of Energy (DOE)[1] sites might have been exposed. The list includes three beta/gamma-emitting radionuclides and nine alpha-emitting radionuclides for nonreactor sites and an additional 16 beta/gamma-emitting radionuclides for sites with reactors. However, the ORAU (2004) method resulted in unrealistically high intakes of long-lived, long-retained radionuclides when the exposure time was only a few years; that is, the air concentrations would have had to have been unrealistically high for a worker to have incurred unnoticed intakes resulting in 10% of the MPBB.

For efficiency in processing claims, another method was needed to estimate intakes that are

- Overestimates
- Derived from more realistic air concentrations

Most DOE sites 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 the International Commission on Radiological Protection (ICRP 1959). Subsequent to the publication of the NBS handbooks, DOE issued orders or regulations establishing air concentration limits applicable to its sites [for instance, in U.S. Atomic Energy Commission (AEC) Manual Chapter 0524 (AEC 1968) and DOE Order 5480.11 (DOE 1988)]. Since December 1993, 10 CFR Part 835 has established limits on air concentrations. Table 2-1 lists the history of workplace air concentration limits applicable at DOE sites for a number of important particulate radionuclides.

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

[1] In this document, reference to DOE includes its predecessor agencies.

Table 2-1. Limiting air concentrations for selected particulates from 1953 to present.

	Limiting air concentration (µCi/mL)				
Radionuclide[a]	**NBS 1953**	**NBS 1959**	**AEC Manual Chapter 0524[b]**	**DOE Order 5480.11[c]**	**10 CFR 835**
Alpha emitters					
Po-210	7E-11	2E-10	2E-10	3E-10	3E-10
Th-230	NL[d]	2E-12	2E-12	3E-12	3E-12
Th-232	NL	2E-12[e]	3E-11[f]	5E-13	5E-13
U natural sol	1.7E-11	7E-11	7E-11[f]	NL	NL
U natural insol	1.7E-11	6E-11	6E-11[f]	NL	NL
U-234 sol (D)	NL	6E-10	6E-10	5E-10	5E-10
U-234 insol (Y)	NL	1E-10	1E-10	2E-11	2E-11
U-238 sol (D)	NL	7E-11	7E-11	6E-10	6E-10
U-238 insol (Y)	NL	1E-10	1E-10	2E-11	2E-11
Np-237	NL	4E-12	4E-12	2E-12	2E-12
Pu-238	NL	2E-12	2E-12	3E-12	3E-12
Pu-239	2E-12	2E-12	2E-12	2E-12	2E-12
Am-241	3E-11	6E-12	6E-12	2E-12	2E-12
Cm-244	NL	9E-12	9E-12	4E-12	4E-12
Beta emitters					
Mn-54	NL	4E-8	4E-8	3E-7	3E-7
Co-58	NL	5E-8	5E-8	3E-7	3E-7
Co-60	1E-6	9E-9	9E-9	1E-8	1E-8
Fe-59	6E-7	5E-8	5E-9	1E-7	1E-7
Zn-65	2E-6	6E-8	6E-8	1E-7	1E-7
Sr-90	2E-10	3E-10	1E-9	2E-9	2E-9
Y-91	4E-8	3E-8	3E-8	5E-8	5E-8
Nb-95	4E-7	1E-7	1E-7	5E-7	5E-7
Zr-95	NL	3E-8	3E-8	6E-8	6E-8
Tc-99	NL	6E-8	6E-8	3E-7	3E-7
Ru-103	NL	8E-8	8E-8	3E-7	3E-7
Ru-106	3E-8	6E-9	8E-8	5E-9	5E-9
Cs-134	NL	1E-8	1E-8	4E-8	4E-8
Cs-137	2E-7	1E-8	1E-8	7E-8	7E-8
Ba-140	6E-8	4E-8	4E-8	6E-7	6E-7
La-140	6E-8	1E-7	1E-7	5E-7	5E-7
Ce-141	NL	2E-7	2E-7	3E-7	2E-7
Ce-144	7E-9	6E-9	6E-9	6E-9	6E-9
Pm-147	2E-7	1E-7	6E-8	6E-8	6E-8
Eu-152	NL	3E-7	2E-8	1E-8	1E-8
Eu-154	6E-9	4E-9	7E-9	8E-9	8E-9
Eu-155	NL	7E-8	7E-8	4E-8	4E-8

a. 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.
b. From 1968 version
c. From 1988 version (effective January 1989)
d. NL – not listed.
e. Printed as 2E-12 µCi/mL, but a footnote stated that continued use of 3E-11 µCi/mL was recommended until further investigation.
f. Based on special definitions for the curie that added disintegrations from selected progeny.

sample, the limit for the most restrictive, plausible radionuclide was often used to establish the trigger level. For facilities handling transuranics, the most restrictive air concentration for the alpha measurements was based on plutonium; for facilities with potential exposure to fission or activation

products, the most restrictive air concentration for beta measurements was based on ^{90}Sr; at uranium facilities, the limits for uranium were generally used.

3.0 APPLICABILITY, LIMITATIONS, AND ASSUMPTIONS

3.1 APPLICABILITY

This TIB applies to:

- Sites or facilities that rigorously sampled particulate air concentrations in areas of risk and controlled exposure to intakes according to the measured concentrations.
- Employment between 1953 and the present. (See first bullet in Section 3.2 for an exception.)
- Claims for which it is likely that the covered employee had no significant intakes of particulate radioactive material. (See Section 7.0 for a discussion on insignificant intakes in the context of this TIB.)
- Intakes of particulate radioactive material only.
- All organs except respiratory tract organs for monitored workers and the thyroid; however, it can apply to the thyroid for uranium facilities or plutonium-only facilities (i.e., where there is no chance of exposure to radioiodines).

3.2 LIMITATIONS

This TIB has the following limitations:

- It does not apply to employment prior to 1953; however, if the limiting air concentrations for the site of exposure are known for years prior to 1953, those concentrations can be used in the manner discussed in Sections 4.0 and 5.0. In addition, see Attachment A. It does not apply to Nevada Test Site outdoor exposures prior to 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.
- 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. If the site-specific concentration was applicable to 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 had special limits for exposure to ^{210}Po.
- It does not necessarily provide an overestimate to respiratory tract organs for monitored workers.

- It does not provide an overestimate to the thyroid (regardless of monitoring), unless the worker was employed only at a uranium facility or a plutonium-only facility (i.e., where there is no chance of exposure to radioiodines).

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 instance, 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.

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

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

- For sites or facilities with an exposure to beta-emitting radionuclides, chronic exposure was at 2×10^{-9} µCi/mL.

- For sites or facilities with an exposure principally to uranium, chronic exposure was at 6×10^{-10} µCi/mL.

- 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 6.0 for additional consideration of the possible nonrepresentativeness of air sampling.

4.0 INHALATION INTAKE

4.1 INTAKE QUANTITY

The inhalation intake is determined by

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

From Equation 1, intakes in Bq/yr can be determined by

$$\text{Intake (Bq/yr)} = (\text{air conc. µCi/mL})(1.2\ m^3/\text{hr})(2{,}000\ \text{hr/yr})(10^6\ \text{mL}/m^3)(3.7 \times 10^4\ \text{Bq/µCi})$$

or

$$\text{Intake (Bq/yr)} = (8.9 \times 10^{13})(\text{air conc. µCi/mL}) \quad (2)$$

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

Table 4-1. Default limiting air concentrations

Exposure type	Air concentration (µCi/mL)	Associated daily intake (pCi)
Alpha-emitting radionuclides except for uranium facilities (includes Hanford from 1949, see Attachment A)	2E-12	13.2
Beta-emitting radionuclides except for uranium facilities (includes Hanford from 1949, see Attachment A)	2E-9	1.32E4
Uranium including recycled uranium (includes Hanford from 1949, see Attachment A)	6E-10	3.96E3
ORNL alpha-emitting radionuclides except for uranium facilities, 1944-1952	3E-11	1.98E2
ORNL beta-emitting radionuclides, 1944-1952	1E-7	6.60E5
Hanford alpha-emitting radionuclides except uranium facilities, 1946-1949	4E-11	2.64E2
Hanford beta-emitting radionuclides, 1946-1949.	1E-8	6.60E4
Mound, 1952-71, Po-210 only[a]	NA	5.88E3

a. Mound had special urinalysis 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 total dose to the organ.

The intake per calendar day in pCi is

$$\text{Intake (pCi/cal. d)} = (\text{air conc. µCi/mL})(1.2\ m^3/\text{hr})(2{,}000\ \text{hr/yr})(10^6\ \text{mL}/m^3)(10^6\ \text{pCi/µCi})/365\ \text{cal. d/yr}$$

or

$$\text{Intake (pCi/cal. d)} = (6.6 \times 10^{12})(\text{air conc.}) \quad (3)$$

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 intakes as listed in Table 4-2.

Table 4-2. Intakes of contaminants in recycled uranium as fraction of uranium intake.

Radionuclide	Activity fraction of contaminant (e.g. pCi X/pCi U)
Pu-238	0.06
Np-237	0.005
Tc-99	0.4
Th-232	0.02
Ru-106	0.04

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 such 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 4-3 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 4-3. Inventory of radionuclides and absorption types.

Radionuclides/absorption types associated with the alpha choice

Am-241	M, S	Pu-240	M, S
Cf-252	M	Pu-242	M, S
Cm-244	M	Ra-226	M
Np-237	M	Th-228	M, S
Po-210	F, M	Th-230	M, S
Pu-238	M, S	Th-232	M, S
Pu-239	M, S	RU[a]	F, M, S

Radionuclides/absorption types associated with the beta choice

Ag-110	M, S	Fe-59	F, M	S-35	F, M
Ba-140	F	Hf-181	F, M	Sb-125	F, M
Ce-141	M, S	La-140	F, M	Sc-46	S
Ce-144	M, S	Mn-54	F, M	Sn-113	F, M
Co-58	M, S	Mo-99	F, S	Sr-89	F
Co-60	M, S	Na-24	F	Sr-90	F
Cr-51	F, M, S	Nb-95	M	Tb-160	M
Cs-134	F	Ni-63	F, M	Tc-99	M
Cs-137	F	P-32	F, M	Y-91	M, S
Eu-152	M	Pm-147	M, S	Zn-65	S
Eu-154	M	Ru-103	F, M, S	Zr-95	F,M,S
Eu-155	M	Ru-106	F, M, S		

Radionuclides/absorption types associated with the uranium choice

Th-232	M, S	RU	F, M, S

a. RU = U-234 plus the contaminants from Table 4-2 in the ratios provided in Table 4-2.

Notes: Ac-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.

Th-232 is included in the uranium list because many uranium facilities also processed thorium at some time. Th-232 can be removed from the list if it is known for sure that the facility did not handle thorium. Removal of ^{232}Th will reduce dose from 2 to 700 times depending on organ and length of exposure.

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.

5.0 INGESTION INTAKE

The possibility of ingestion intakes has to be considered separately from inhalation intakes when intake is not based on bioassay measurements. *Estimation of Ingestion Intakes* (OCAS 2004) provides the method for estimating ingestion intakes based on air concentrations:

$$\text{Ingestion intake} = 0.2\ (\text{inhalation intake}) \qquad (4)$$

These intakes would 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 DOSE DISTRIBUTION

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. 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.

- Prior to widespread use of alarming continuous air monitors (CAMs), 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 CAMs, radon progeny interference was a problem with alpha monitoring in many facilities such 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. 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.**

Remember that exposure to tritium, radioiodines, radon, or ^{14}C has to be accounted for separately from these intake/dose estimations.

7.0 WHEN TO USE THIS TIB

Dose reconstructors should use this TIB for workers who were not on a bioassay program or were monitored but had no indication of intakes in the bioassay data, except as discussed below and subject to the limitations in Section 3.0.

Some bioassay methods were capable of detecting small intakes, well below the intakes determined using this TIB. Whole-body counting for gamma emitters with high gamma abundance and energies greater than about 200 keV is a good example. Use of this TIB is still an overestimate even if there are bioassay indications of intakes (i.e., bioassay results exceeding the decision level, minimum detection level, or recording level, as appropriate), provided the results meet the conditions listed in Table 7-1. The values in Table 7-1 are actually a factor of 10 less than that which would equal the dose produced by the assumed intake to account for uncertainties in counting, the possibility of several radionuclides in a single count, undetected radionuclides, and the different impacts between inhaled or ingested material.

Urinalysis results from the intakes listed in this TIB can be predicted using the current ICRP models. If an individual has urinalysis results that are less than 0.1 times that predicted by the intakes of this TIB using the most favorable absorption type, the TIB intake can be considered an overestimate.

Table 7-1. Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi):
Cs-137	F	90	Adrenals	34
			Urinary bladder	30
			Brain	28
			Breast	27
			Gall bladder	58
			Heart wall	31
			Kidneys	31
			Liver	150
			Muscle	30
			Ovaries	32
			Pancreas	32
			Testes	29
			Thyroid	30
			Red bone marrow	115
			Bone surface	220
			Stomach	30
			SI	31
			ULI	52
			LLI	130
			Skin	26
			Spleen	31
			Thymus	30
			Uterus	32
			ET	69
			Lung	640
			Colon	87
			Esophagus	30
Cs-137	F	180	Adrenals	39
			Urinary bladder	34
			Brain	32
			Breast	30
			Gall bladder	66
			Heart wall	35
			Kidneys	35
			Liver	170
			Muscle	33
			Ovaries	36
			Pancreas	36
			Testes	33
			Thyroid	34
			Red bone marrow	130
			Bone surface	250
			Stomach	34
			SI	36
			ULI	58
			LLI	140
			Skin	29
			Spleen	35
			Thymus	34
			Uterus	36
			ET	78
			Lung	720
			Colon	98
			Esophagus	34

Table 7-1 (Continued). Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi):
Cs-137	F	365	Adrenals	24
			Urinary bladder	21
			Brain	19
			Breast	19
			Gall bladder	16
			Heart wall	22
			Kidneys	21
			Liver	106
			Muscle	21
			Ovaries	22
			Pancreas	22
			Testes	20
			Thyroid	21
			Red bone marrow	80
			Bone surface	150
			Stomach	21
			SI	22
			ULI	36
			LLI	89
			Skin	18
			Spleen	21
			Thymus	21
			Uterus	22
			ET	48
			Lung	440
			Colon	60
			Esophagus	21
Cs-137	F	730	Adrenals	2
			Urinary bladder	2
			Brain	2
			Breast	2
			Gall bladder	4
			Heart wall	2
			Kidneys	2
			Liver	10
			Muscle	2
			Ovaries	2
			Pancreas	2
			Testes	2
			Thyroid	2
			Red bone marrow	8
			Bone surface	15
			Stomach	2
			SI	2
			ULI	4
			LLI	9
			Skin	2
			Spleen	2
			Thymus	2
			Uterus	2
			ET	5
			Lung	43
			Colon	6
			Esophagus	2

Table 7-1 (Continued). Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi):
Co-60	M or S	90	Adrenals	10
			Urinary bladder	21
			Brain	25
			Breast	5
			Gall bladder	23
			Heart wall	4
			Kidneys	15
			Liver	36
			Muscle	13
			Ovaries	14
			Pancreas	11
			Testes	28
			Thyroid	15
			Red bone marrow	43
			Bone surface	108
			Stomach	11
			SI	13
			ULI	15
			LLI	25
			Skin	16
			Spleen	9
			Thymus	6
			Uterus	20
			ET	4
			Lung	11
			Colon	20
			Esophagus	6
Co-60	M or S	180	Adrenals	12
			Urinary bladder	27
			Brain	31
			Breast	8
			Gall bladder	30
			Heart wall	7
			Kidneys	19
			Liver	45
			Muscle	17
			Ovaries	18
			Pancreas	14
			Testes	35
			Thyroid	19
			Red bone marrow	51
			Bone surface	135
			Stomach	14
			SI	17
			ULI	18
			LLI	31
			Skin	29
			Spleen	14
			Thymus	9
			Uterus	25
			ET	6
			Lung	19
			Colon	25
			Esophagus	9

Table 7-1 (Continued). Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi)
Co-60	M or S	360	Adrenals	13
			Urinary bladder	28
			Brain	32
			Breast	9
			Gall bladder	30
			Heart wall	8
			Kidneys	19
			Liver	46
			Muscle	17
			Ovaries	18
			Pancreas	15
			Testes	36
			Thyroid	19
			Red bone marrow	60
			Bone surface	139
			Stomach	15
			SI	17
			ULI	19
			LLI	32
			Skin	21
			Spleen	14
			Thymus	10
			Uterus	26
			ET	5
			Lung	20
			Colon	26
			Esophagus	10
Co-60	M or S	730	Adrenals	6
			Urinary bladder	13
			Brain	14
			Breast	4
			Gall bladder	14
			Heart wall	4
			Kidneys	9
			Liver	21
			Muscle	8
			Ovaries	8
			Pancreas	7
			Testes	17
			Thyroid	570
			Red bone marrow	27
			Bone surface	63
			Stomach	7
			SI	8
			ULI	9
			LLI	15
			Skin	10
			Spleen	7
			Thymus	4
			Uterus	12
			ET	2
			Lung	9
			Colon	12
			Esophagus	4

Table 7-1 (Continued). Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi):
Mn-54	F or M	90	Adrenals	24
			Urinary bladder	49
			Brain	42
			Breast	23
			Gall bladder	35
			Heart wall	20
			Kidneys	29
			Liver	47
			Muscle	40
			Ovaries	31
			Pancreas	30
			Testes	65
			Thyroid	51
			Red bone marrow	70
			Bone surface	113
			Stomach	39
			SI	42
			ULI	43
			LLI	100
			Skin	47
			Spleen	39
			Thymus	26
			Uterus	43
			ET	15
			Lung	150
			Colon	71
			Esophagus	26
Mn-54	F or M	180	Adrenals	8
			Urinary bladder	17
			Brain	14
			Breast	16
			Gall bladder	12
			Heart wall	13
			Kidneys	10
			Liver	16
			Muscle	14
			Ovaries	11
			Pancreas	10
			Testes	22
			Thyroid	18
			Red bone marrow	24
			Bone surface	39
			Stomach	14
			SI	11
			ULI	15
			LLI	35
			Skin	16
			Spleen	16
			Thymus	17
			Uterus	15
			ET	6
			Lung	117
			Colon	24
			Esophagus	17

Table 7-1 (Continued). Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi):
Mn-54	F or M	365	Adrenals	0.5
			Urinary bladder	0.9
			Brain	0.8
			Breast	0.9
			Gall bladder	0.6
			Heart wall	0.7
			Kidneys	0.5
			Liver	0.9
			Muscle	0.7
			Ovaries	0.6
			Pancreas	0.6
			Testes	1.2
			Thyroid	1.0
			Red bone marrow	1.3
			Bone surface	2.1
			Stomach	0.7
			SI	0.6
			ULI	0.8
			LLI	1.9
			Skin	0.9
			Spleen	0.9
			Thymus	0.9
			Uterus	0.8
			ET	0.3
			Lung	14
			Colon	1.3
			Esophagus	0.9
Mn-54	F or M	730	Not applicable for all organs	
Nb-95	M or S	90	Adrenals	18
			Urinary bladder	34
			Brain	50
			Breast	13
			Gall bladder	35
			Heart wall	11
			Kidneys	16
			Liver	53
			Muscle	24
			Ovaries	14
			Pancreas	21
			Testes	65
			Thyroid	33
			Red bone marrow	57
			Bone surface	51
			Stomach	18
			SI	13
			ULI	11
			LLI	15
			Skin	34
			Spleen	22
			Thymus	14
			Uterus	27
			ET	3
			Lung	12
			Colon	13
			Esophagus	14

Table 7-1 (Continued). Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi):
Nb-95	M or S	180	Adrenals	4
			Urinary bladder	8
			Brain	12
			Breast	4
			Gall bladder	8
			Heart wall	3
			Kidneys	4
			Liver	13
			Muscle	6
			Ovaries	3
			Pancreas	5
			Testes	16
			Thyroid	8
			Red bone marrow	14
			Bone surface	12
			Stomach	4
			SI	3
			ULI	3
			LLI	4
			Skin	8
			Spleen	5
			Thymus	4
			Uterus	7
			ET	1
			Lung	3
			Colon	3
			Esophagus	4
Nb-95	M or S	365	Adrenals	0.1
			Urinary bladder	0.2
			Brain	0.3
			Breast	0.1
			Gall bladder	0.2
			Heart wall	0.1
			Kidneys	0.1
			Liver	0.3
			Muscle	0.2
			Ovaries	0.1
			Pancreas	0.1
			Testes	0.4
			Thyroid	0.2
			Red bone marrow	0.4
			Bone surface	0.3
			Stomach	0.1
			SI	0.1
			ULI	0.1
			LLI	0.1
			Skin	0.2
			Spleen	0.1
			Thymus	0.1
			Uterus	0.2
			ET	0.0
			Lung	0.1
			Colon	0.1
			Esophagus	0.1
Nb-95	M or S	730	Not applicable for all organs	

Table 7-1 (Continued). Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi):
Ce-141	M or S	90	Adrenals	130
			Urinary bladder	240
			Brain	270
			Breast	106
			Gall bladder	180
			Heart wall	79
			Kidneys	170
			Liver	29
			Muscle	180
			Ovaries	107
			Pancreas	140
			Testes	320
			Thyroid	240
			Red bone marrow	104
			Bone surface	20
			Stomach	37
			SI	18
			ULI	6
			LLI	6
			Skin	200
			Spleen	180
			Thymus	108
			Uterus	200
			ET	3
			Lung	4
			Colon	6
			Esophagus	108
Ce-141	M or S	180	Adrenals	36
			Urinary bladder	65
			Brain	74
			Breast	27
			Gall bladder	50
			Heart wall	20
			Kidneys	46
			Liver	8
			Muscle	48
			Ovaries	27
			Pancreas	39
			Testes	89
			Thyroid	67
			Red bone marrow	29
			Bone surface	6
			Stomach	9
			SI	5
			ULI	1.4
			LLI	1.5
			Skin	57
			Spleen	45
			Thymus	27
			Uterus	57
			ET	0.8
			Lung	0.9
			Colon	1.4
			Esophagus	27

Table 7-1 (Continued). Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi):
Ce-141	M or S	365	Adrenals	1.3
			Urinary bladder	2.4
			Brain	2.7
			Breast	0.9
			Gall bladder	1.8
			Heart wall	0.7
			Kidneys	1.7
			Liver	0.3
			Muscle	1.7
			Ovaries	0.9
			Pancreas	1.4
			Testes	3.3
			Thyroid	2.4
			Red bone marrow	1.1
			Bone surface	0.2
			Stomach	0.3
			SI	0.2
			ULI	<0.1
			LLI	<0.1
			Skin	2.1
			Spleen	1.5
			Thymus	0.9
			Uterus	2.0
			ET	<010
			Lung	<0.1
			Colon	<0.1
			Esophagus	0.9
Ce-144	M or S	90	Adrenals	56
			Urinary bladder	59
			Brain	46
			Breast	40
			Gall bladder	89
			Heart wall	52
			Kidneys	53
			Liver	3
			Muscle	49
			Ovaries	60
			Pancreas	56
			Testes	52
			Thyroid	54
			Red bone marrow	13
			Bone surface	15
			Stomach	30
			SI	15
			ULI	4
			LLI	4
			Skin	38
			Spleen	55
			Thymus	52
			Uterus	63
			ET	5
			Lung	3
			Colon	4
			Esophagus	52

Table 7-1 (Continued). Whole-body count (WBC) results below which this TIB method is still considered an overestimate.

Radionuclide	Absorption type	Time since last WBC (d)[a]	Organ of concern	WBC result must be less than (nCi):
Ce-144	M or S	180	Adrenals	86
			Urinary bladder	90
			Brain	69
			Breast	60
			Gall bladder	136
			Heart wall	79
			Kidneys	80
			Liver	5
			Muscle	75
			Ovaries	91
			Pancreas	86
			Testes	78
			Thyroid	82
			Red bone marrow	20
			Bone surface	22
			Stomach	46
			SI	20
			ULI	6
			LLI	5
			Skin	58
			Spleen	83
			Thymus	78
			Uterus	95
			ET	6
			Lung	4
			Colon	5
			Esophagus	78
Ce-144	M or S	365	Adrenals	103
			Urinary bladder	108
			Brain	84
			Breast	72
			Gall bladder	160
			Heart wall	96
			Kidneys	97
			Liver	6
			Muscle	90
			Ovaries	110
			Pancreas	103
			Testes	95
			Thyroid	99
			Red bone marrow	24
			Bone surface	27
			Stomach	53
			SI	22
			ULI	6
			LLI	6
			Skin	70
			Spleen	100
			Thymus	95
			Uterus	110
			ET	7
			Lung	4
			Colon	6
			Esophagus	95

a. ±15%. The choice of days is meant to represent general measurement frequencies, such as quarterly, semiannually, or annually. It is recognized that workers did not get whole-body counts at intervals that were exact to the day.

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Office of Compensation Analysis and Support, OCAS-TIB-009, *Technical Information Bulletin: Estimation of Ingestion Intakes, Rev 0*, April 13, 2004.

ORAU (Oak Ridge Associated Universities), 2004, *Technical Information Bulletin — Maximum Internal Dose Estimates for Certain DOE Complex Claims*, ORAUT-OTIB-0002, Rev. 1, Oak Ridge, Tennessee.

ATTACHMENT A
AIR CONCENTRATION LIMITS PRIOR TO 1953

Air concentration limits established for a site prior to 1953 can be used to extend the applicability of this TIB to those earlier years.

Because Hanford Site tolerance levels were used to control intakes, they fit the criteria of air concentration limit. The alpha and beta particular air concentration limit 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 prior to 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).

REFERENCES

Cantril, S. T., 1945, "Tolerance Limits," Letter to file, HW 4.159 or 7-2602, Hanford Works, Richland, Washington, October 18.

Parker, H. M., 1944a, "Product Concentration in the Air," Memo to I. Perlman, ORNL CF 44-7-78, Clinton Laboratories, Oak Ridge, Tennessee, July 1.

Parker, H. M., 1944b, *Review of Air Monitoring Procedures at Clinton Laboratories*, CH-2562, Clinton Laboratories, Oak Ridge, Tennessee.

Patterson, C. M., 1949, "General Operating Tolerances," Letter to Lauriston S. Taylor (National Bureau of Standards), HW-12710, Hanford Works, Richland, Washington, March 11.

ATTACHMENT B
VALIDATION OF THE BASIC ASSUMPTION IN THIS TIB

The basis for this TIB is that weapons sites with a radiological control program controlled exposures to airborne radioactive contaminates to less than an applicable limit. The limit varied with time and isotope of concern. This TIB acknowledges that exposures to concentrations greater than these limits did occur. However, the assumption is that, when integrated over time, the average exposure to any individual was less than that which would occur if someone were exposed to the limit continuously. The assumption is tested in the following analysis. Note that this analysis does not change the assumption but merely tests the validity of it.

B.1 URANIUM

Uranium urinalysis data from the Y-12 site was used to test 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. Because this TIB provides mean values that are to be used in a lognormal distribution, the median result was used in the comparison. Figure B-1 plots these median sample results as well as the uranium result predicted by this TIB for an inhalation of type M uranium.

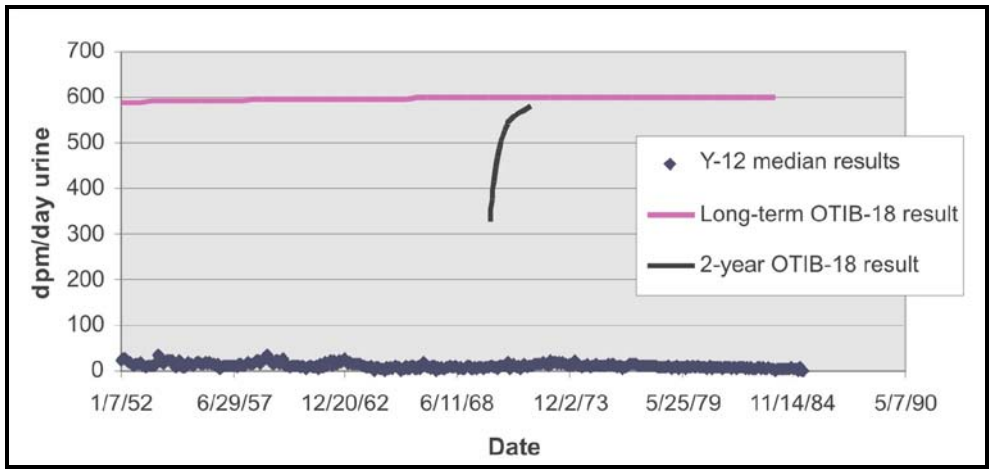

Figure B-1. Y-12 versus OTIB-18 uranium (type M).

The TIB result is considerably higher than the actual Y-12 median urine sample result. The 2-year result begins 1 month after the start of the chronic intake and is approximately 10 times higher than the highest actual median 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 B-2 shows the same information using an absorption type S assumption for the TIB values. This graph indicates that for a long-term exposure, it can be shown that 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 of duration that are less than 3 years.

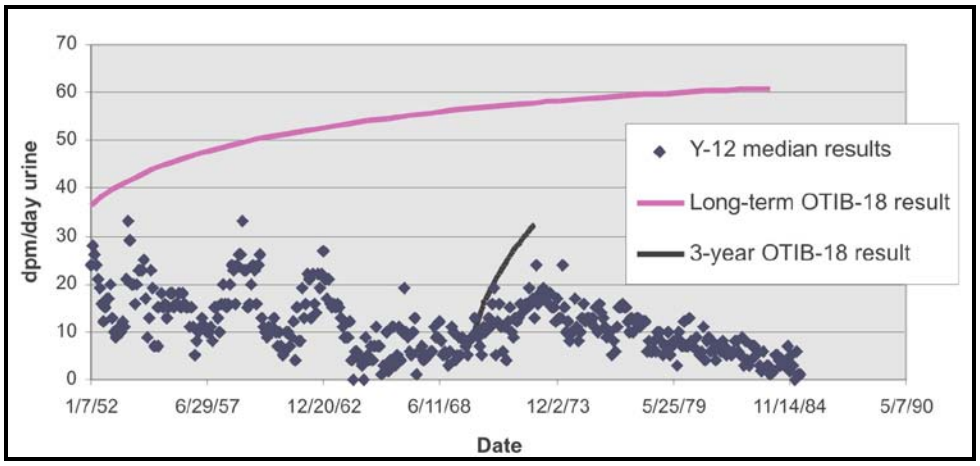

Figure B-2. Y-12 versus OTIB-18 uranium (type S).

B.2 PLUTONIUM

The Rocky Flats Plant worked extensively with plutonium. Plutonium urine samples from Rocky Flats were evaluated from 1953 through 1969. For every year, the median sample was recorded as zero. The lowest recorded positive value varied through the years from 0.02 dpm/day (0.009 pCi/day) to 0.09 dpm/day (0.04 pCi/day) with most years at 0.02 dpm/day. Figure B-3 shows the assumed intake in this TIB for both a type S and a type M inhalation. The figure also shows the 0.009-pCi/day and the 0.04-pCi/day values. 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.

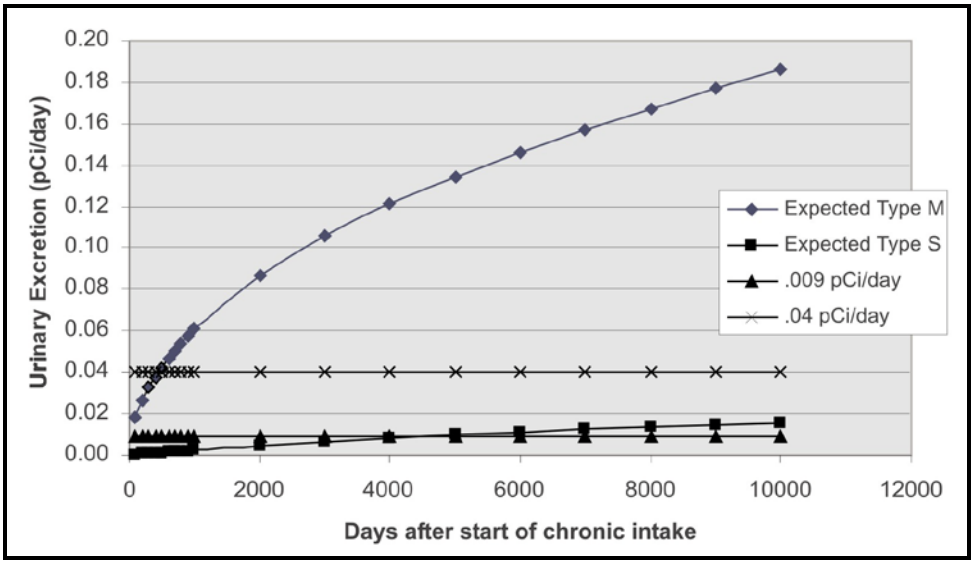

Figure B-3. Rocky Flats Pu expected urine versus actual results.

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 1953 through 1969. The median sample for each year varied. The median result was never more than 0.023 pCi/day and for

most years was less than that. Figure B-4 shows the assumed intake in this TIB for both a type S and a type M inhalation. The figure also shows the 0.023-pCi/day value. As with the Rocky Flats 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.

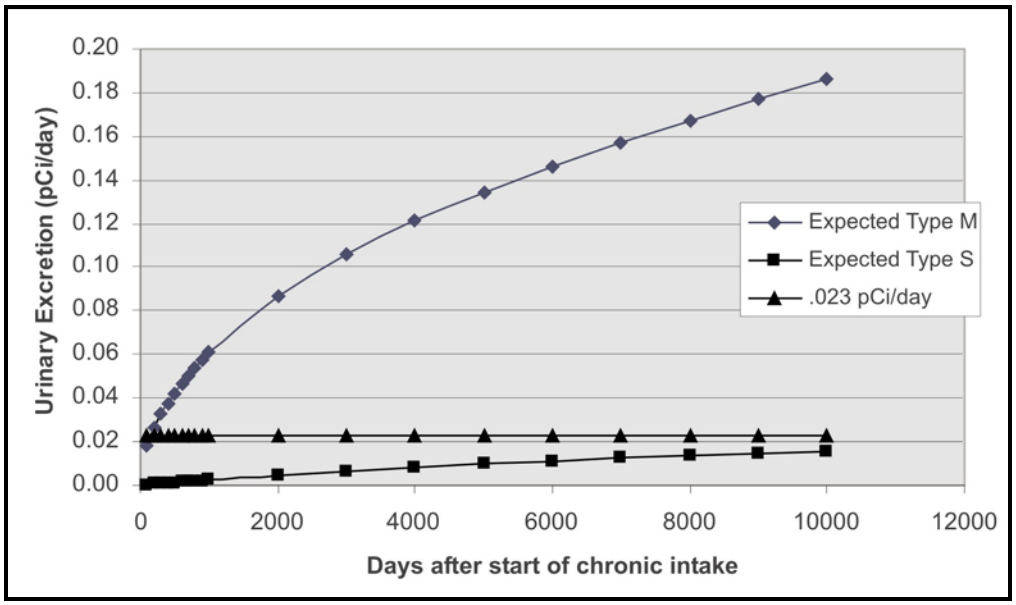

Figure B-4. Hanford Pu expected urine versus actual results.

B.3 FISSION PRODUCTS

The fission product that was primarily sampled in urine at Hanford was ^{90}Sr. In the 1960s, the recording limit at Hanford for ^{90}Sr urine samples appears to be 16.7 pCi/day. More than 95% of the samples in 1966, 1967, and 1968 were recorded as less than this limit. After that period, the recording limit decreased and enabled the evaluation of the median sample result.

Figure B-5 shows the median and 95th-percentile urine result predicted from the values used in this TIB for a chronic inhalation of type F ^{90}Sr. The 95th-percentile results were determined using the assumption in this TIB that the intakes are lognormally distributed with a geometric standard deviation of three. The figure also shows the recording limit of 16.7 pCi/day as well as the median sample results for 1970 through 1974.

Figure B-5 indicates that the results predicted from the 95th percentile of the intake in this TIB exceed the reporting limit from the 1960s. More than 95% of the values were reported as less than this value. In addition, it shows that when the reporting limit was reduced, the median result was less than the mean result predicted from the intake in this TIB.

B.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.

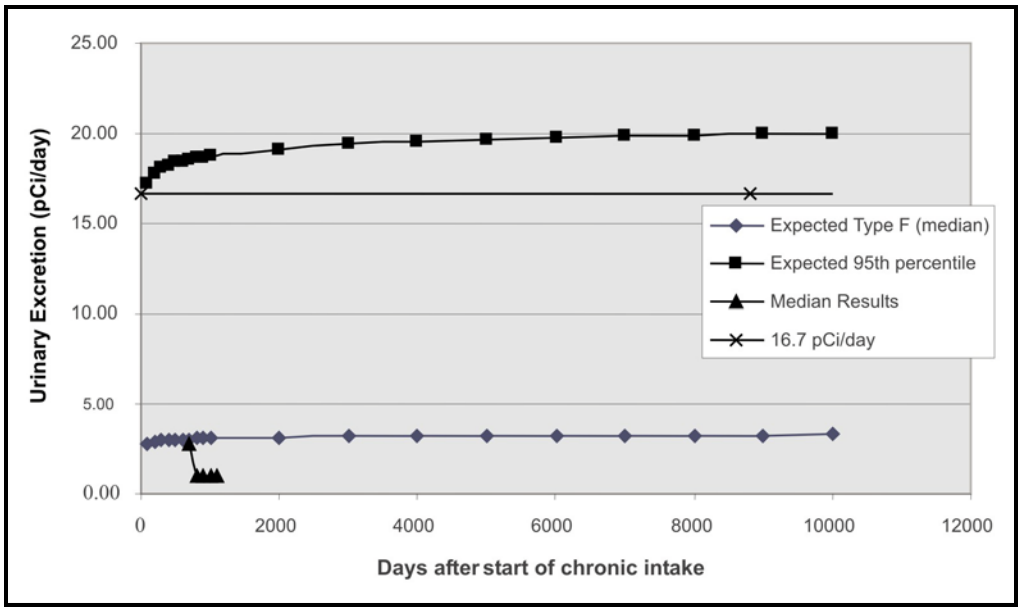

Figure B-5. Hanford Sr-90 expected urine versus actual results.

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. However, there are several important issues to point out.

1. While comparing the recording limit to the TIB mean cannot show the TIB to be an overestimate, continuous exposures at these levels would be reportable in many of the long-term workers. Levels below the reporting limit were seen in a large percent of the sampled population, much larger than 50%.

2. Long-term exposure to these levels requires that an employee would be working into the modern era. In more modern eras, chest counts, whole-body counts, and more sensitive urinalysis would indicate if the average worker were exposed to these levels for a long duration.

3. The data analyzed was obviously for monitored workers. The monitored population is probably the population that radiological control personnel believed to have the highest exposure potential.

Taken together, this implies that while it might not be possible to demonstrate that the average radiological worker was exposed to a lower concentration of type S material, it can be seen that it is very possible. Therefore this TIB should not be considered an overestimate for respiratory tract dose unless other information, such as chest counts or whole-body counts, is available for the individual.

However, the TIB assumes a continuous exposure every working minute of every day. For individuals who were only intermittently exposed, a considerably higher air concentration would have had to be routinely present to equal the same intake. Intakes considerably higher than those listed in this TIB would have been detectable in the urine results of those present more frequently in those areas. This TIB should, therefore, be considered an overestimate for intermittently exposed workers regardless of the organ of concern.

ATTACHMENT C
SITE APPLICABILITY

This TIB is applicable to all DOE sites with the limitations listed in the TIB and exceptions listed below. Table 4-3 contains three inventory lists of radionuclides. Dose reconstructors should use these lists as follows:

- The alpha list should apply alone to sites or facilities that primarily handled plutonium.
- The uranium list should be applied alone to sites or facilities that primarily handled uranium.
- The alpha plus the beta list should be applied to reactor sites, national laboratories, and any other sites.

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.

Exception
Until 1962, the Nevada Test Site performed atmospheric testing of nuclear weapons. These tests had the potential to create high airborne concentrations for relatively short periods. While it is possible that the continuous assumption made in this TIB will overestimate these intermittent exposures, further evaluation is necessary to verify this. Therefore, this TIB is not currently applicable to exposures at the Nevada Test Site prior to 1963.