ATTACHMENT D
OCCUPATIONAL INTERNAL DOSE FOR MONITORED WORKERS

TABLE OF CONTENTS

Section — Page

D.1 Codes Used in Bioassay and Internal Dose Records (Adapted from Carbaugh 2000) 3

D.2 Interpreting Mixtures 8
D.2.1 Separations Facilities 8

D.3 Tables for Chronic Intakes – Urinalyses 10
D.3.1 Based on Urinalyses 11
D.3.2 Based on Whole Body Counts 16

D.4 Tolerance Dose and Tolerance Values at Hanford

LIST OF TABLES

Table — Page

D-01 Sample type codes 3
D-02 Bioassay reason codes 3
D-03 Excreta sample kit codes 4
D-04 In vivo body location codes 5
D-05 Units codes 5
D-06 Excreta processing codes 5
D-07 Excreta laboratory codes 6
D-08 Excreta no-sample codes 6
D-09 In vivo invalid result codes 6
D-10 INTERTRAC mode-of-intake codes 7
D-11 INTERTRAC evaluation reason codes 7
D-12 INTERTRAC source-of-intake codes 7
D-13 INTERTRAC miscellaneous codes 7
D-14 Special whole body count resolution codes (RC) (used in 1983 only) 8
D.2.1-1 Relative activity abundance of fission/activation products in Hanford fuel at time of dissolution 9
D.3.1-1 ^{239}Pu chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period 11
3.1-2 ^{241}Am chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period 11
D.3.1-3 ^{238}U chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period 12
D.3.1-4 ^{90}Sr chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period 13
D.3.1-5 ^{144}Ce chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period 14
D.3.1-6 ^{141}Ce chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period 14

D.3.1-7 ^{147}Pm chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period 15

Table Page

D.3.1-8 ^{210}Po chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period 15
D.3.2-1 ^{137}Cs chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 16
D.3.2-2 ^{144}Ce chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 16
D.3.2-3 ^{141}Ce chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 17
D.3.2-4 ^{106}Ru chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 17
D.3.2-5 ^{60}Co chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 18
D.3.2-6 ^{51}Cr chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 18
D.3.2-7 ^{54}Mn chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 19
D.3.2-8 ^{59}Fe chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 19
D.3.2-9 ^{154}Eu chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 20
D.3.2-10 ^{95}Nb chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 20
D.3.2-11 ^{95}Zr chronic inhalation intake assessment based on unit MDA whole body count on last day of the period 21

D.1 Codes Used in Bioassay and Internal Dose Records (Adapted from Carbaugh 2000)

These codes apply to information contained in the Radiological Exposure (REX) database and include both present and historical uses. Different codes were implemented at different times according to the needs at the time; the early dates have few if any codes.

Table D-01. Sample type codes.

Code	Type of sample
B	Blood
F	Feces
S	Sputum
T	Tissue
U	Urine

Table D-02. Bioassay reason codes.

Code	Name	Description
BL	Baseline	Measurement is performed to establish a reference level against which subsequent measurements will be compared. Generally, this may be for new employees, or for established employees, prior to commencing work with radioactive materials, beginning a specific type of radiation zone work, or making an offsite trip where potential intakes could occur.
PR	Periodic	Measurement is performed at a regularly scheduled interval.
EA	End of Assignment	Measurement is performed following completion of specific work assignment, but not end of employment.
SP	Special	Measurement is performed as part of a specific investigation of potential internal dose. May include response to off-normal work conditions, or follow-up of abnormal periodic measurements.
CR	Contractor Request	Measurement requested by employer for reasons other than periodic, baseline, end of assignment, or special investigation.
RA	Reanalysis A	First reanalysis of sample by taking another aliquot and repeating the same radiochemical or chemical analysis.
RB	Reanalysis B	Second reanalysis of sample by taking another aliquot and repeating the same radiochemical or chemical analysis.
R1	Recount 1	First recount of original excreta sample or repeat in vivo exam.
R2	Recount 2	Second recount of original excreta sample or repeat in vivo exam.
QR	Quality and Research	Measurement performed as part of quality control, quality assurance, or research work.
TM or TS	Termination	Final bioassay at termination of employment.
12	Contract Work	In vivo measurement performed under contract to customers rather than for Hanford employees.
20	Source Count	In vivo source count made for system calibration or as a function check, usually using a known check source.
30	Background Count	In vivo system background measurement performed for system calibration or as a functional check.

Table D-03. Excreta sample kit codes.

Kit code*			
D/R	**P/U**	**Media**	**Sample description**
1	P	Urine	Approximate 24-hour urine collection. Collected at home over a 2-day period. Used for routine sampling and when a larger volume sample is desired. Designated sample date is the day after kit delivery to the employee.
2	Q	Urine	Approximate 12-hour urine collection for termination sampling only. Collected at home overnight. Designated sample date is the day after the date of kit delivery to the employee.
3	R	Urine	Total 24-hour urine collection. Collected at home and at work (if necessary) to collect all urine voided during a 24-hour period. Generally used for sampling immediately following an occurrence or for work restriction sampling. Designated sample date is the day after delivery or the date on which the sample collection began.
4	S	Urine	Single void (spot urine) collection. Collection in a single bottle, used for initial indications of an intake. Designated sample date is the date of voiding.
5	T	Feces	Collection of a single fecal voiding usually for investigation of a potential intake. Sample date is the day after kit delivery or the date on which the sample was actually voided.
6	U	Urine	Partial day or approximate 12-hour collection. Usually collected at home overnight. Used for collection following an occurrence or when a large volume urine sample is necessary, such as for tritium or uranium determination. Designated sample date is the date of delivery to the employee.
7	V	Urine	Approximate 12-hour collection Sunday-Monday sample (Friday delivery only). Generally used for workers chronically exposed to soluble uranium. Designated sample date is the Sunday in the sampling period.
8	W	Urine prior to 1986. Feces starting in 1986.	Associated with urine sampling in 1950s through 1970s; was used to mean undesignated or unknown. Starting in 1986: collection of a single fecal voiding used for a special program for plutonium oxide workers. Designated sample date for shift workers is the Tuesday of long shift change, and for day workers is the appropriate Sunday.
9	X	Urine	Kit designed for collection of urine outside the local service area. Transportation is handled by private carrier. Generally used for termination samples not collected locally.
A	Y	Urine	Simulated 48-hour urine collection. Collected at home over a 4-day period. Used for IPUL sampling. Designated sample date is two days after kit delivery to the employee.
B	Not Applicable	Urine	12-hour urine collection for termination sampling only. Collected at home overnight. Kit delivered in normal manner, but brought to a designated on-site location by worker for pick-up by Contractor. Designated sample date is the day after the date of kit delivery to the employee. Delivery Only, no home pick-up required.

*D/R = Delivery and Retrieval; P/U = Pick-Up only (the latter series of codes were not used prior to about 1990, but should have no impact on dose reconstruction).
Note: prior to about 1983 kit codes were called collection codes

Table D-04. In vivo body location codes.

Computer code	Body location
ABD	Abdomen
CHT	Chest result
CH1	Chest result
CH2	Chest result corrected by ultrasound measurement of chest wall thickness
HED	Head
HND	Hand
KNE	Knee
LG1	Lung result. (Chest result corrected for skeleton burden interference)
LG2	Lung result. (Chest result corrected for skeleton and liver burden interference)
LV1	Liver
LV2	Liver result corrected for skeleton burden interference
LV3	Liver result corrected for skeleton and lung burden interference
LYM	Lymph nodes
SKL	Skull (Head) – old code no longer used
SK1	Total activity in the skeleton based on a head count
SK2	Skeleton result based on something other than a head count
SPL	Special
THX	Thorax
THY	Thyroid
TRT	Throat – old code no longer used
WBC	Whole body
WND	Wound

Table D-05. Units codes.

Computer code	Description of units
1	dpm/sample
2	dpm/volume analyzed
3	µg/L until 07-01-82 µg/sample after 07-01-82
4	µg/gram until 07-01-82 µg/sample after 07-01-82
5	µCi/sample
6	µCi/L
7	nCi (nanocuries)
8	µCi (microcuries)

Table D-06. Excreta processing codes.[a]

Processing code	Description
R	Routine processing
P	Priority processing
X	Expedite processing (added about 1985)
E	Emergency processing

a. Used in conjunction with contract with commercial laboratory starting in 1965; used to designate turnaround time and MDAs, i.e., different processing codes had different MDAs.

Table D-07. Excreta laboratory codes.

Code	Analytical laboratory
IT	IT Analytical Services - Richland
LA	Los Alamos National Laboratory
OR	Oak Ridge National Laboratory
PL	PNNL Analytical Chemistry Laboratory
QN	Quanterra
RE	REECO (Reynolds Electric Company, Nevada Test Site)
ST	Severn Trent Laboratories-Richland
TA	TMA/Norcal, Richmond, California
WH	Westinghouse Hanford Company, 222-S Lab

Table D-08. Excreta no-sample codes.

No-sample code	Description
CN	Kit not out. Sample kit not out at time of scheduled pickup
CS	Cancelled sample/analysis
CT	Sample lost due to bioassay analysis contract termination
FA	Failed Analysis. A valid analytical result could not be obtained
IS	Insufficient sample. Sample provided by worker but volume insufficient to meet contractual requirements
LC	Lost container. Sample kit not retrieved
ND	Not delivered. Sample scheduled but kit never delivered
NS	No sample. Kit retrieved but no sample provided by worker

Table D-09. In vivo invalid result codes.

Code	Reason for no results
C	External contamination other than radon detected on the subject. Measurement invalid; no results obtained.
F	Failure of equipment or faulty setup of equipment. Measurement invalid; no results obtained.
I	Interference from localized activity in another part of the subject's body. Measurement invalid; no results obtained.
L	Location of internal or external activity was qualitatively determined by mapping, masking, or collimating. May include one or more measurement counts. These measurements are qualitative for identifying location of activity and do not yield quantifiable estimates of activity.
M	Medically administered radioactivity interfered with measurement. Measurement invalid; no results obtained.
P	Preliminary count, when followed by a more quantitative record count. Used to indicate measurement taken, but not a record count.
R	Radon interference from subject's clothing, hair, or skin. Measurement invalid; no results obtained.
S	The subject's actions interrupted completion of the count. Measurement invalid; no results obtained.
X	Measurement invalid; no results obtained. Other no-result codes do not apply. See comment field for a brief description.

Notes:
1. The comment field may have a brief explanation in addition to the codes listed above.

Table D-10. INTERTRAC mode-of-intake codes.

Code	Mode of intake
ABS	Absorption
ING	Ingestion
INH	Inhalation
NON	None (no intake)
UNK	Unknown
WND	Wound

Table D-11. INTERTRAC evaluation reason codes.

Code	Reason for evaluation
A	Annual chronic intake evaluation
C	Contractor requested evaluation
H	High routine bioassay evaluation
I	Incident evaluation
N	New hire measurement or previous employment record indicated exposure prior to Hanford employment
R	Reevaluation

Table D-12. INTERTRAC source-of-intake codes.

Code	Source of intake
DHE	Intake at DOE site while employed at Hanford
HAN	Intake at Hanford
NHE	Intake at non-DOE site while employed at Hanford
NOC	Nonoccupational intake
PTH	Intake occurred prior to Hanford employment

Table D-13. INTERTRAC miscellaneous codes.

Code type	Code	Description
Intake confirmed	Y	Yes
	N	No
Nature of intake	A	Acute
	C	Chronic
Recorded dose	Y	Yes
	N	No
	O	Undetermined - (old evaluation assessing body burden rather than dose, or an evaluation in process)
	Z	Recorded dose is zero mrem
Source known	Y	Yes
	N	No
Type of evaluation	P	Preliminary
	F	Final

Table D-14. Special whole body count resolution codes (RC) (used in 1983 only).

Code	Description
A	Investigation in progress
B	Recent intake < or = to 1% Maximum Permissible Annual Dose
C	Previous deposition
D	Under investigation with additional exams scheduled
E	Investigation completed, see radiation exposure records
F	Unresolved
G	Deposition from previous, non-Hanford employment
H	Exposure received offsite by Hanford employee
I	Activity derived from medical diagnostic or therapeutic procedure

D.2 Interpreting Mixtures

D.2.1 Separations Facilities

Fission products were greater sources of contamination at the separation facilities than activation products. Table D.2.1-1 shows the cooling times and relative activities (rounded to one significant figure) for fuel dissolved in the separation facilities by years though 1960 (i.e., prior to the advent of whole body counting.) Also shown are the radionuclides that would have been measured by the fission product urinalysis procedure. Activation products from the fuel cladding were considered in the calculations except none were ranked in the top 20 radionuclides. Of course, abundance in the fuel does not translate directly to probability of intake. Because of its volatility, ^{131}I was of concern in airborne effluents and offsite doses, but did not seem to be a concern in the workplace, with the exception of a few workers that worked routinely in the canyons (e.g., canyon crane operators). Even with short-cooled fuel in the 1940s, the radionuclides with short half-lives, when considered as contaminants in places where workers were exposed (e.g., sample gallery, operating gallery, exhaust filtration systems), would decay away or reach equilibrium, whereas long-lived radionuclides would continually increase in contamination levels. This probably explains why short-lived radionuclides abundant in the fuel were not commonly mentioned as sources of contamination, such as ^{123}Sn, ^{127}Te, ^{129}Te, ^{148m}Pr, ^{147}Nd.

Table D.2.1-1. Relative activity abundance of fission/activation products in Hanford fuel at time of dissolution.

Early years: low burnup, short cooled fuel							
1944-45		**1946, 51, 52, 53**		**1947**		**1948-50, 54, 55, 58**	
Cooling time: 40 days		**70 days**		**80 days**		**100 days**	
Radionuclide	**Relative activity**	**Radionuclide**	**Relative activity**	**Radionuclide**	**Relative activity**	**Radionuclide**	**Relative activity**
Nb-95	40000	Nb-95	30000	Nb-95	30000	Nb-95	30000
Zr-95	30000	Zr-95	20000	Zr-95	20000	Zr-95	20000
Y-91	30000	Y-91*	20000	Y-91*	10000	Y-91*	10000
Ce-141	20000	Ce-144*	10000	Ce-144*	10000	Ce-144*	10000
Ce-144	20000	Ce-141*	10000	Sr-89*	10000	Sr-89*	9000
Ru-103	20000	Sr-89*	10000	Ce-141*	9000	Ce-141*	6000
Sr-89	20000	Ru-103	9000	Ru-103	7000	Ru-103	5000
Pr-143	7000	Pr-143*	2000	Ru-106	2000	Ru-106	2000
La-140	7000	Ru-106	2000	Pm-147*	2000	Pm-147*	2000
Ba-140	6000	Pm-147*	2000	Pr-143*	900	Sr-90*	600
Ru-106	2000	La-140*	1000	La-140*	800	Cs-137	600
Pm-147	2000	Ba-140*	1000	Ba-140*	700	Pr-143*	300
Nd-147	2000	Sr-90*	600	Sr-90*	600	La-140*	300
I-131	800	Cs-137	600	Cs-137	600	Ba-140*	200
Sr-90	600	Nd-147*	200	Nd-147*	100	Te-127	100
Cs-137	600	Te-129	200	Te-129	100	Sb-125	100
Te-129	300	Te-127	100	Te-127	100	Te-129	80
Te-127	300	Sb-125	100	Sb-125	100	Sn-123	40
Sb-125	100	I-131	60	Sn-123	50	Nd-147*	40
Eu-156	80	Sn-123	50	I-131	30	Pm-148m	30

1957		**1956, 59, 60**	
Cooling: 120 days		**150 days**	
Radionuclide	**Relative activity**	**Radionuclide**	**Relative activity**
Nb-95	10000	Ce-144*	10000
Zr-95	10000	Nb-95	8000
Ce-144*	10000	Zr-95	7000
Y-91*	9000	Y-91*	6000
Sr-89*	6000	Sr-89*	4000
Ce-141*	4000	Ru-103	2000
Ru-103	4000	Pm-147*	2000
Pm-147*	2000	Ce-141*	2000
Ru-106	2000	Ru-106	2000
Sr-90*	600	Sr-90*	600
Cs-137	600	Cs-137	600
Pr-143*	100	Sb-125	90
Sb-125	100	Te-127	80
Te-127	90	Te-129	30
La-140*	90	Sn-123	30
Ba-140*	80	Cs-134	20
Te-129	60	Pr-123*	20
Sn-123	40	Te-125m	20
Cs-134	20	Eu-155*	20
Pm-148m*	20	La-140	20
Eu-155*	20	Ba-140	20

* Would have been detected by the fission product urinalysis after 1947.
All activity data obtained from ORIGEN 2 code generated for the Hanford Environmental Dose Reconstruction.
Cooling times from Heeb 1994.

For the purpose of determining default mixtures based on the fission product urinalysis, and to be claimant favorable, different mixtures were developed for different target organs. For simplicity and because the rank of radionuclides varied only a little between cooling times, the years were categorized into two groups. Relative abundances of radionuclides with half-lives longer than 1 year were doubled to account for buildup as contaminants in the workplace.

(Assume the following absorption types: Ce type M, Y type M, Sr type F, Nb type M, Zr type M, Ru type F, Pm type M.)

1944 -1955
Bone: Calculate the intake assuming the fission product activity is ^{141}Ce. Calculate the dose assuming that intake is ^{144}Ce. Then add (in multiples of the ^{141}Ce intake): 1.0 ^{91}Y, 0.5 ^{89}Sr, 1.5 ^{95}Nb, and 0.5 ^{103}Ru.

Liver: Calculate the intake assuming the fission product activity is ^{141}Ce. Calculate the dose assuming that the cerium intake is ^{144}Ce. Then add (in multiples of the ^{141}Ce intake: 1.5 ^{95}Nb, 1.0 ^{91}Y, and 0.5 ^{103}Ru.

GI: Calculate the intake assuming the fission product activity is ^{141}Ce. Add (in multiples of the ^{141}Ce intake): 1.5 ^{95}Nb, 1.0 ^{95}Zr, 1.0 ^{91}Y, and 0.5 ^{103}Ru.

Lung: Calculate the intake assuming the fission product activity is ^{141}Ce. Calculate the dose assuming that the cerium intake is ^{144}Ce. Add 1.5 ^{95}Nb, 1.0 ^{95}Zr, 1.0 ^{91}Y, 0.2 ^{147}Pm.

All other organs: Calculate the intake assuming the fission product activity is ^{141}Ce. Calculate the dose assuming that the cerium intake is ^{144}Ce. Add 1.5 ^{95}Nb, 1.0 ^{95}Zr, 1.0 ^{91}Y, 0.2 ^{147}Pm.

1956 -1960
Bone: Calculate the intake assuming the fission product activity is ^{144}Ce. Add (in multiples of the ^{144}Ce intake): 0.6 ^{91}Y, 0.4 ^{89}Sr, 0.8 ^{95}Nb, 0.1 ^{90}Sr, and 0.6 ^{106}Ru.

Liver: Calculate the intake assuming the fission product activity is ^{144}Ce. Add: 0.8 ^{95}Nb, 0.6 ^{91}Y, and 0.6 ^{106}Ru.

GI: Calculate the intake assuming the fission product activity is ^{144}Ce. Add: 0.8 ^{95}Nb, 0.7 ^{95}Zr, 0.6 ^{91}Y, and 0.6 ^{106}Ru.

Lung: Calculate the intake assuming the fission product activity is ^{144}Ce. Add 0.8 ^{95}Nb, 0.7 ^{95}Zr, 0.6 ^{91}Y, 0.4 ^{147}Pm.

All other organs: Calculate the intake assuming the fission product activity is ^{144}Ce. Add 0.8 ^{95}Nb, 0.7 ^{95}Zr, 0.6 ^{91}Y, 0.4 ^{147}Pm.

D.3 Tables for Chronic Intakes – Urinalyses

The tables in this section assume 5-µm AMAD particle size distribution and other default ICRP models and parameters.

D.3.1 Based on Urinalyses

Table D.3.1-1. ^{239}Pu chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period.

Absorption:		Type M			Type S		
Analytical MDA:		1dpm/d			1dpm/d		
Duration of intake		Daily intake rate	Cumulative intake		Daily intake rate	Cumulative intake	
(Years)	(Days)	(dpm/d)	(dpm)	(pCi)	(dpm/d)	(dpm)	(pCi)
1	365	367	1.34E+05	6.03E+04	15360	5.61E+06	2.53E+06
2	730	256	1.87E+05	8.42E+04	7780	5.68E+06	2.56E+06
3	1095	206	2.26E+05	1.02E+05	5180	5.67E+06	2.56E+06
4	1461	178	2.60E+05	1.17E+05	3900	5.70E+06	2.57E+06
5	1825	159	2.89E+05	1.30E+05	3150	5.75E+06	2.59E+06
6	2190	145	3.18E+05	1.43E+05	2670	5.85E+06	2.63E+06
7	2556	134	3.43E+05	1.54E+05	2330	5.96E+06	2.68E+06
8	2922	126	3.68E+05	1.66E+05	2110	6.17E+06	2.78E+06
9	3287	119	3.91E+05	1.76E+05	1890	6.21E+06	2.80E+06
10	3650	114	4.15E+05	1.87E+05	1740	6.35E+06	2.86E+06
12	4383	104.5	4.58E+05	2.06E+05	1510	6.62E+06	2.98E+06
14	5113	97.3	4.97E+05	2.24E+05	1340	6.85E+06	3.09E+06
15	5475	94.3	5.16E+05	2.33E+05	1280	7.01E+06	3.16E+06
16	5844	91.5	5.35E+05	2.41E+05	1220	7.13E+06	3.21E+06
18	6574	86.6	5.69E+05	2.56E+05	1120	7.36E+06	3.32E+06
20	7300	82.4	6.02E+05	2.71E+05	1040	7.60E+06	3.42E+06
25	9125	74.1	6.76E+05	3.05E+05	888	8.11E+06	3.65E+06
30	10950	67.8	7.43E+05	3.35E+05	784	8.59E+06	3.87E+06
35	12775	62.9	8.04E+05	3.62E+05	706	9.03E+06	4.07E+06
40	14600	58.9	8.61E+05	3.88E+05	647	9.35E+06	4.21E+06
45	16425	55.6	9.14E+05	4.12E+05	599	9.85E+06	4.43E+06
50	18250	52.8	9.64E+05	4.34E+05	561	1.02E+07	4.61E+06

Table D.3.1-2. ^{241}Am chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period.

Absorption:		Type M		
Analytical MDA:		1 dpm/d		
Duration of intake		Daily intake rate	Cumulative intake	
(Years)	(Days)	(dpm/d)	(dpm)	(pCi)
1	365	1.39E+02	5.07E+04	2.29E+04
2	730	1.09E+02	7.96E+04	3.58E+04
3	1095	9.40E+01	1.03E+05	4.64E+04
4	1461	8.44E+01	1.23E+05	5.55E+04
5	1826	7.77E+01	1.42E+05	6.39E+04
6	2190	7.27E+01	1.59E+05	7.17E+04
7	2556	6.88E+01	1.76E+05	7.92E+04
8	2922	6.56E+01	1.92E+05	8.63E+04
9	3287	6.30E+01	2.07E+05	9.33E+04
10	3652	6.08E+01	2.22E+05	1.00E+05
12	4383	5.71E+01	2.50E+05	1.13E+05
14	5113	5.43E+01	2.78E+05	1.25E+05
15	5475	5.31E+01	2.91E+05	1.31E+05
16	5844	5.20E+01	3.04E+05	1.37E+05
18	6574	5.00E+01	3.29E+05	1.48E+05
20	7305	4.83E+01	3.53E+05	1.59E+05
25	9131	4.50E+01	4.11E+05	1.85E+05
30	10958	4.25E+01	4.66E+05	2.10E+05
35	12784	4.05E+01	5.18E+05	2.33E+05
40	14610	3.89E+01	5.68E+05	2.56E+05
45	16436	3.75E+01	6.16E+05	2.78E+05
50	18263	3.63E+01	6.63E+05	2.99E+05

Table D.3.1-3. ^{238}U[a] chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period.[a]

Absorption:		Type F			Type M		
Analytical MDA:		1 dpm/d			1 dpm/d		
Duration of intake		Daily intake rate	Cumulative intake		Daily intake rate	Cumulative intake	
(Years)	(Days)	(dpm/d)	(dpm)	(pCi)	(dpm/d)	(dpm)	(pCi)
1	365	3.68E+00	1.34E+03	6.05E+02	1.59E+01	5.80E+03	2.61E+03
2	730	3.67E+00	2.68E+03	1.21E+03	1.51E+01	1.10E+04	4.97E+03
3	1095	3.66E+00	4.01E+03	1.81E+03	1.50E+01	1.64E+04	7.40E+03
4	1461	3.65E+00	5.33E+03	2.40E+03	1.49E+01	2.18E+04	9.81E+03
5	1826	3.64E+00	6.65E+03	2.99E+03	1.49E+01	2.72E+04	1.23E+04
6	2190	3.63E+00	7.95E+03	3.58E+03	1.48E+01	3.24E+04	1.46E+04
7	2556	3.62E+00	9.25E+03	4.17E+03	1.48E+01	3.78E+04	1.70E+04
8	2922	3.62E+00	1.06E+04	4.76E+03	1.48E+01	4.32E+04	1.95E+04
9	3287	3.61E+00	1.19E+04	5.35E+03	1.48E+01	4.86E+04	2.19E+04
10	3652	3.61E+00	1.32E+04	5.94E+03	1.48E+01	5.39E+04	2.43E+04
12	4383	3.60E+00	1.58E+04	7.11E+03	1.47E+01	6.44E+04	2.90E+04
14	5113	3.59E+00	1.84E+04	8.27E+03	1.47E+01	7.52E+04	3.39E+04
15	5475	3.59E+00	1.97E+04	8.85E+03	1.47E+01	8.05E+04	3.63E+04
16	5844	3.59E+00	2.10E+04	9.45E+03	1.47E+01	8.59E+04	3.87E+04
18	6574	3.58E+00	2.35E+04	1.06E+04	1.47E+01	9.63E+04	4.34E+04
20	7305	3.58E+00	2.62E+04	1.18E+04	1.46E+01	1.07E+05	4.80E+04
25	9131	3.57E+00	3.26E+04	1.47E+04	1.46E+01	1.33E+05	6.01E+04
30	10958	3.57E+00	3.91E+04	1.76E+04	1.46E+01	1.60E+05	7.21E+04
35	12784	3.56E+00	4.55E+04	2.05E+04	1.46E+01	1.87E+05	8.41E+04
40	14610	3.56E+00	5.20E+04	2.34E+04	1.46E+01	2.13E+05	9.58E+04
45	16436	3.56E+00	5.85E+04	2.64E+04	1.45E+01	2.38E+05	1.07E+05
50	18263	3.56E+00	6.50E+04	2.93E+04	1.45E+01	2.65E+05	1.19E+05

Absorption:		Type S		
Analytical MDA:		1 dpm/d		
Duration of intake		Daily intake rate	Cumulative intake	
(Years)	(Days)	(dpm/d)	(dpm)	(pCi)
1	365	432	1.58E+05	7.10E+04
2	730	319	2.33E+05	1.05E+05
3	1095	268	2.93E+05	1.32E+05
4	1461	240	3.51E+05	1.58E+05
5	1826	221	4.04E+05	1.82E+05
6	2190	208	4.56E+05	2.05E+05
7	2556	199	5.09E+05	2.29E+05
8	2922	192	5.61E+05	2.53E+05
9	3287	186	6.11E+05	2.75E+05
10	3652	181	6.61E+05	2.98E+05
12	4383	174	7.63E+05	3.44E+05
14	5113	168	8.59E+05	3.87E+05
15	5475	166	9.09E+05	4.09E+05
16	5844	164	9.58E+05	4.32E+05
18	6574	160	1.05E+06	4.74E+05
20	7305	157	1.15E+06	5.17E+05
25	9131	151	1.38E+06	6.21E+05
30	10958	147	1.61E+06	7.26E+05
35	12784	144	1.84E+06	8.29E+05
40	14610	142	2.07E+06	9.35E+05
45	16436	140	2.30E+06	1.04E+06
50	18263	139	2.54E+06	1.14E+06

a. Same results can be used for U-235, U-234, or gross uranium alpha results. Total intake of uranium isotopes will have to be adjusted depending on the enrichment of the uranium (e.g., depleted, natural, enriched) and the result from the analytical method (specific isotope, gross alpha, or total mass).

For depleted uranium results expressed in µg/L, the equivalence between µg/L and dpm/d of ^{238}U is close enough to substitute one for the other. Other handy conversions include (assuming daily excretion of 1.4 L):

One µg/L of depleted uranium = 1.2 dpm/d of total uranium activity
One µg/L of natural uranium is essentially equal to 1 dpm/day of ^{238}U
One µg/L of natural uranium = 2.2 dpm/d of total uranium activity
One µg/L of natural uranium = 1.1 dpm/d of ^{234}U.

Table D.3.1-3 includes absorption types F and M, for which the urinary excretion essentially reaches equilibrium instead of steadily increasing. For radionuclides and absorption types that reach equilibrium quickly, a series of less-than-MDA results would imply that actual excretion was not at or just below the MDA, otherwise nearly 50% of the sample results would exceed the MDA. In these situations, one-half of the MDA should be used. However, if the MDAs changed throughout the history of a worker's monitoring, the daily intake rate and cumulative intake will have to be calculated separately for each period of different MDAs, and the overall cumulative intake becomes the addition of the cumulative intakes for the various periods.

So for plutonium, americium, thorium, ^{154}Eu and type S uranium, the MDA of the last few samples is the most important. For most other radionuclides (i.e., the ones that reach equilibrium quickly), the chronic intake calculation must be adjusted for each MDA and for each period the MDA was in effect throughout the period of concern for the worker.

Tritium reaches equilibrium very rapidly (within 2 months) so a table is not needed. An intake rate of 6.09×10^6 dpm/d (2.74 µCi/d) will produce a daily urinary excretion of 1 µCi/L (ICRP 1997, table A.1.10).

Table D.3.1-4. ^{90}Sr chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period.

Absorption:		**Type F**		
Analytical MDA:		**1 dpm/d**		
Duration of intake		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	4.41	1.61E+03	7.25E-01
2	730	4.33	3.16E+03	1.42
3	1095	4.28	4.69E+03	2.11
4	1461	4.25	6.21E+03	2.80
5	1826	4.21	7.69E+03	3.46
6	2190	4.19	9.18E+03	4.13
7	2556	4.17	1.07E+04	4.80
8	2922	4.15	1.21E+04	5.46
9	3287	4.13	1.36E+04	6.12
10	3652	4.12	1.50E+04	6.78
12	4383	4.10	1.80E+04	8.09
14	5113	4.10	2.10E+04	9.44
16	5844	4.06	2.37E+04	1.07E+01
18	6574	4.05	2.66E+04	1.20E+01
20	7305	4.04	2.95E+04	1.33E+01
25	9131	4.03	3.68E+04	1.66E+01
30	10958	4.02	4.41E+04	1.98E+01
35	12784	4.01	5.13E+04	2.31E+01
40	14610	4.00	5.84E+04	2.63E+01
45	16436	4.00	6.57E+04	2.96E+01
50	18263	4.00	7.31E+04	3.29E+01

Table D.3.1-5. ^{144}Ce chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period[a].

Absorption		Type M			Type S		
Analytical MDA:		1 dpm/d			1 dpm/d		
Duration of intake		Daily intake rate	Cumulative intake		Daily intake rate	Cumulative intake	
(Years)	(Days)	(dpm/d)	(dpm)	(pCi)	(dpm/d)	(dpm)	(pCi)
1	365	4.64E+03	1.69E+06	7.63E+05	1.93E+05	7.04E+07	3.17E+07
2	730	3.09E+03	2.26E+06	1.02E+06	1.10E+05	8.03E+07	3.62E+07
3	1095	2.74E+03	3.00E+06	1.35E+06	8.96E+04	9.81E+07	4.42E+07
4	1461	2.62E+03	3.83E+06	1.72E+06	8.25E+04	1.21E+08	5.43E+07
5	1826	2.58E+03	4.71E+06	2.12E+06	7.97E+04	1.46E+08	6.56E+07
6	2190	2.57E+03	5.63E+06	2.54E+06	7.86E+04	1.72E+08	7.75E+07
7	2556	2.56E+03	6.54E+06	2.95E+06	7.82E+04	2.00E+08	9.00E+07
8	2922	2.56E+03	7.48E+06	3.37E+06	7.80E+04	2.28E+08	1.03E+08
9	3287	2.56E+03	8.41E+06	3.79E+06	7.79E+04	2.56E+08	1.15E+08
10	3652	2.56E+03	9.35E+06	4.21E+06	7.79E+04	2.84E+08	1.28E+08
12	4383	2.56E+03	1.12E+07	5.05E+06	7.79E+04	3.41E+08	1.54E+08
14	5113	2.56E+03	1.31E+07	5.90E+06	7.79E+04	3.98E+08	1.79E+08
16	5844	2.56E+03	1.50E+07	6.74E+06	7.79E+04	4.55E+08	2.05E+08
18	6574	2.56E+03	1.68E+07	7.58E+06	7.79E+04	5.12E+08	2.31E+08
20	7305	2.56E+03	1.87E+07	8.42E+06	7.79E+04	5.69E+08	2.56E+08
25	9131	2.56E+03	2.34E+07	1.05E+07	7.79E+04	7.11E+08	3.20E+08

a. For use with the fission product urinalysis procedure. See also ^{144}Ce for whole body counts.

Table D.3.1-6. ^{141}Ce chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period[a].

Absorption		Type M			Type S		
Analytical MDA:		1 dpm/d			1 dpm/d		
Duration of intake		Daily intake rate	Cumulative intake		Daily intake rate	Cumulative intake	
(Years)	(Days)	(dpm/d)	(dpm)	(pCi)	(dpm/d)	(dpm)	(pCi)
1	365	3.03E+04	1.11E+07	4.98E+06	1.55E+06	5.66E+08	2.55E+08
2	730	3.03E+04	2.21E+07	9.96E+06	1.55E+06	1.13E+09	5.10E+08
3	1095	3.03E+04	3.32E+07	1.49E+07	1.54E+06	1.69E+09	7.60E+08
4	1461	3.03E+04	4.43E+07	1.99E+07	1.54E+06	2.25E+09	1.01E+09
5	1826	3.03E+04	5.53E+07	2.49E+07	1.54E+06	2.81E+09	1.27E+09
6	2190	3.03E+04	6.64E+07	2.99E+07	1.54E+06	3.37E+09	1.52E+09
7	2556	3.03E+04	7.74E+07	3.49E+07	1.54E+06	3.94E+09	1.77E+09
8	2922	3.03E+04	8.85E+07	3.99E+07	1.54E+06	4.50E+09	2.03E+09
9	3287	3.03E+04	9.96E+07	4.49E+07	1.54E+06	5.06E+09	2.28E+09
10	3652	3.03E+04	1.11E+08	4.98E+07	1.54E+06	5.62E+09	2.53E+09
12	4383	3.03E+04	1.33E+08	5.98E+07	1.54E+06	6.75E+09	3.04E+09
14	5113	3.03E+04	1.55E+08	6.98E+07	1.54E+06	7.87E+09	3.55E+09
16	5844	3.03E+04	1.77E+08	7.98E+07	1.54E+06	9.00E+09	4.05E+09
18	6574	3.03E+04	1.99E+08	8.97E+07	1.54E+06	1.01E+10	4.56E+09
20	7305	3.03E+04	2.21E+08	9.97E+07	1.54E+06	1.12E+10	5.07E+09
25	9131	3.03E+04	2.77E+08	1.25E+08	1.54E+06	1.41E+10	6.33E+09

a. For use with the fission product urinalysis procedure. See also ^{141}Ce for whole body counts.

Table D.3.1-7. ^{147}Pm chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period.

Absorption		Type M			Type S		
Analytical MDA:		1 dpm/d			1 dpm/d		
Duration of intake		Daily intake rate	Cumulative intake		Daily intake rate	Cumulative intake	
(Years)	(Days)	(dpm/d)	(dpm)	(pCi)	(dpm/d)	(dpm)	(pCi)
1	365	2.43E+02	8.87E+04	4.00E+04	8.69E+03	3.17E+06	1.43E+06
2	730	1.84E+02	1.34E+05	6.05E+04	5.31E+03	3.88E+06	1.75E+06
3	1095	1.58E+02	1.73E+05	7.79E+04	4.03E+03	4.42E+06	1.99E+06
4	1461	1.44E+02	2.10E+05	9.48E+04	3.39E+03	4.95E+06	2.23E+06
5	1826	1.35E+02	2.47E+05	1.11E+05	3.02E+03	5.51E+06	2.48E+06
6	2190	1.30E+02	2.85E+05	1.28E+05	2.79E+03	6.11E+06	2.75E+06
7	2556	1.26E+02	3.22E+05	1.45E+05	2.64E+03	6.74E+06	3.03E+06
8	2922	1.23E+02	3.59E+05	1.62E+05	2.53E+03	7.40E+06	3.33E+06
9	3287	1.22E+02	4.01E+05	1.81E+05	2.46E+03	8.09E+06	3.64E+06
10	3652	1.20E+02	4.38E+05	1.97E+05	2.41E+03	8.80E+06	3.96E+06
12	4383	1.19E+02	5.22E+05	2.35E+05	2.35E+03	1.03E+07	4.63E+06
14	5113	1.18E+02	6.03E+05	2.72E+05	2.31E+03	1.18E+07	5.33E+06
16	5844	1.18E+02	6.90E+05	3.11E+05	2.30E+03	1.34E+07	6.05E+06
18	6574	1.18E+02	7.76E+05	3.49E+05	2.29E+03	1.50E+07	6.77E+06
20	7305	1.18E+02	8.62E+05	3.88E+05	2.28E+03	1.67E+07	7.51E+06
25	9131	1.18E+02	1.08E+06	4.85E+05	2.28E+03	2.08E+07	9.37E+06

Table D.3.1-8. ^{210}Po chronic inhalation intake assessment based on unit MDA urinalysis on last day of the period.

Absorption:		Type M		
Analytical MDA:		1 dpm/d		
Duration of intake		Daily intake rate	Cumulative intake	
(Years)	(Days)	(dpm/d)	(dpm)	(pCi)
1	365	4.67E+01	1.70E+04	7.67E+03
2	730	4.63E+01	3.38E+04	1.52E+04
3	1095	4.62E+01	5.06E+04	2.28E+04
4	1461	4.62E+01	6.76E+04	3.04E+04
5	1826	4.62E+01	8.44E+04	3.80E+04
6	2190	4.62E+01	1.01E+05	4.56E+04
7	2556	4.62E+01	1.18E+05	5.32E+04
8	2922	4.62E+01	1.35E+05	6.09E+04
9	3287	4.62E+01	1.52E+05	6.85E+04
10	3652	4.62E+01	1.69E+05	7.61E+04
12	4383	4.62E+01	2.03E+05	9.13E+04
14	5113	4.62E+01	2.36E+05	1.06E+05
16	5844	4.62E+01	2.70E+05	1.22E+05
18	6574	4.62E+01	3.04E+05	1.37E+05
20	7305	4.62E+01	3.38E+05	1.52E+05
25	9131	4.62E+01	4.22E+05	1.90E+05

D.3.2 Based on Whole Body Counts

Table D.3.2-1. ^{137}Cs chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption:		**Type F**		
Analytical MDA:		**1 nCi**		
Duration of intake		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	35.7	1.30E+04	5.87E+03
2	730	32.6	2.38E+04	1.07E+04
3	1095	32.3	3.54E+04	1.59E+04
4	1461	32.2	4.70E+04	2.12E+04
5	1826	32.2	5.88E+04	2.65E+04
6	2190	32.2	7.05E+04	3.18E+04
7	2556	32.2	8.23E+04	3.71E+04
8	2922	32.2	9.41E+04	4.24E+04
9	3287	32.2	1.06E+05	4.77E+04
10	3652	32.2	1.18E+05	5.30E+04
12	4383	32.2	1.41E+05	6.36E+04
14	5113	32.2	1.65E+05	7.42E+04
16	5844	32.2	1.88E+05	8.48E+04
18	6574	32.2	2.12E+05	9.54E+04
20	7305	32.2	2.35E+05	1.06E+05
25	9131	32.2	2.94E+05	1.32E+05
30	10958	32.2	3.53E+05	1.59E+05
35	12784	32.2	4.12E+05	1.85E+05
40	14610	32.2	4.70E+05	2.12E+05
45	16436	32.2	5.29E+05	2.38E+05
50	18263	32.2	5.88E+05	2.65E+05

Table D.3.2-2. ^{144}Ce chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption		**Type M**			**Type S**		
Analytical MDA:		**1 nCi**			**1 nCi**		
Duration of intake		**Daily intake rate**	**Cumulative intake**		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	1.32E+02	4.82E+04	2.17E+04	2.15E+02	7.85E+04	3.53E+04
2	730	9.88E+01	7.21E+04	3.25E+04	1.73E+02	1.26E+05	5.69E+04
3	1095	9.02E+01	9.88E+04	4.45E+04	1.63E+02	1.78E+05	8.04E+04
4	1461	8.73E+01	1.28E+05	5.75E+04	1.60E+02	2.34E+05	1.05E+05
5	1826	8.62E+01	1.57E+05	7.09E+04	1.59E+02	2.90E+05	1.31E+05
6	2190	8.58E+01	1.88E+05	8.46E+04	1.59E+02	3.48E+05	1.57E+05
7	2556	8.57E+01	2.23E+05	1.01E+05	1.59E+02	4.09E+05	1.84E+05
8	2922	8.56E+01	2.50E+05	1.13E+05	1.58E+02	4.62E+05	2.08E+05
9	3287	8.56E+01	2.81E+05	1.27E+05	1.58E+02	5.19E+05	2.34E+05
10	3652	8.56E+01	3.13E+05	1.41E+05	1.58E+02	5.77E+05	2.60E+05
12	4383	8.56E+01	3.75E+05	1.69E+05	1.58E+02	6.93E+05	3.12E+05
14	5113	8.56E+01	4.38E+05	1.97E+05	1.58E+02	8.08E+05	3.64E+05
16	5844	8.56E+01	5.00E+05	2.25E+05	1.58E+02	9.23E+05	4.16E+05
18	6574	8.56E+01	5.63E+05	2.53E+05	1.58E+02	1.04E+06	4.68E+05
20	7305	8.56E+01	6.25E+05	2.82E+05	1.58E+02	1.15E+06	5.20E+05
25	9131	8.56E+01	7.82E+05	3.52E+05	1.58E+02	1.44E+06	6.50E+05
30	10958	8.56E+01	9.38E+05	4.23E+05	1.58E+02	1.73E+06	7.80E+05

Table D.3.2-3. ^{141}Ce chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption		**Type M**			**Type S**		
Analytical MDA:		**1 nCi**			**1 nCi**		
Duration of intake		**Daily intake rate**	**Cumulative intake**		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	4.95E+02	1.81E+05	8.14E+04	6.54E+02	2.39E+05	1.08E+05
2	730	4.95E+02	3.61E+05	1.63E+05	6.54E+02	4.77E+05	2.15E+05
3	1095	4.95E+02	5.42E+05	2.44E+05	6.54E+02	7.16E+05	3.23E+05
4	1461	4.95E+02	7.23E+05	3.26E+05	6.54E+02	9.55E+05	4.30E+05
5	1826	4.95E+02	9.04E+05	4.07E+05	6.54E+02	1.19E+06	5.38E+05
6	2190	4.95E+02	1.08E+06	4.88E+05	6.54E+02	1.43E+06	6.45E+05
7	2556	4.95E+02	1.27E+06	5.70E+05	6.54E+02	1.67E+06	7.53E+05
8	2922	4.95E+02	1.45E+06	6.52E+05	6.54E+02	1.91E+06	8.61E+05
9	3287	4.95E+02	1.63E+06	7.33E+05	6.54E+02	2.15E+06	9.68E+05
10	3652	4.95E+02	1.81E+06	8.14E+05	6.54E+02	2.39E+06	1.08E+06
12	4383	4.95E+02	2.17E+06	9.77E+05	6.54E+02	2.87E+06	1.29E+06
14	5113	4.95E+02	2.53E+06	1.14E+06	6.54E+02	3.34E+06	1.51E+06
16	5844	4.95E+02	2.89E+06	1.30E+06	6.54E+02	3.82E+06	1.72E+06
18	6574	4.95E+02	3.25E+06	1.47E+06	6.54E+02	4.30E+06	1.94E+06
20	7305	4.95E+02	3.62E+06	1.63E+06	6.54E+02	4.78E+06	2.15E+06
25	9131	4.95E+02	4.52E+06	2.04E+06	6.54E+02	5.97E+06	2.69E+06
30	10958	4.95E+02	5.42E+06	2.44E+06	6.54E+02	7.17E+06	3.23E+06

Table D.3.2-4. ^{106}Ru chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption:		**Type F**			**Type S**		
Analytical MDA:		**1 nCi**			**1 nCi**		
Duration of intake		**Daily intake rate**	**Cumulative intake**		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	1.12E+02	4.09E+04	1.84E+04	1.81E+02	6.61E+04	2.98E+04
2	730	8.81E+01	6.43E+04	2.90E+04	1.41E+02	1.03E+05	4.64E+04
3	1095	8.13E+01	8.90E+04	4.01E+04	1.30E+02	1.42E+05	6.41E+04
4	1461	7.89E+01	1.15E+05	5.19E+04	1.26E+02	1.84E+05	8.29E+04
5	1826	7.81E+01	1.43E+05	6.42E+04	1.25E+02	2.28E+05	1.03E+05
6	2190	7.77E+01	1.70E+05	7.67E+04	1.24E+02	2.72E+05	1.22E+05
7	2556	7.76E+01	2.02E+05	9.08E+04	1.24E+02	3.22E+05	1.45E+05
8	2922	7.75E+01	2.26E+05	1.02E+05	1.24E+02	3.62E+05	1.63E+05
9	3287	7.75E+01	2.55E+05	1.15E+05	1.24E+02	4.08E+05	1.84E+05
10	3652	7.75E+01	2.83E+05	1.27E+05	1.24E+02	4.53E+05	2.04E+05
12	4383	7.75E+01	3.40E+05	1.53E+05	1.24E+02	5.43E+05	2.45E+05
14	5113	7.75E+01	3.96E+05	1.78E+05	1.24E+02	6.34E+05	2.86E+05
16	5844	7.75E+01	4.53E+05	2.04E+05	1.24E+02	7.25E+05	3.26E+05
18	6574	7.75E+01	5.09E+05	2.29E+05	1.24E+02	8.15E+05	3.67E+05
20	7305	7.75E+01	5.66E+05	2.55E+05	1.24E+02	9.06E+05	4.08E+05
25	9131	7.75E+01	7.08E+05	3.19E+05	1.24E+02	1.13E+06	5.10E+05
30	10958	7.75E+01	8.49E+05	3.83E+05	1.24E+02	1.36E+06	6.12E+05

Table D.3.2-5. ^{60}Co chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption:		**Type M**			**Type S**		
Analytical MDA:		**1 nCi[a]**			**1 nCi[a]**		
Duration of intake		**Daily intake rate**	**Cumulative intake**		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	2.10E+02	7.67E+04	3.45E+04	1.57E+02	5.73E+04	2.58E+04
2	730	1.69E+02	1.23E+05	5.56E+04	1.04E+02	7.59E+04	3.42E+04
3	1095	1.53E+02	1.68E+05	7.55E+04	8.48E+01	9.29E+04	4.18E+04
4	1461	1.45E+02	2.12E+05	9.54E+04	7.59E+01	1.11E+05	5.00E+04
5	1826	1.40E+02	2.56E+05	1.15E+05	7.08E+01	1.29E+05	5.82E+04
6	2190	1.37E+02	3.00E+05	1.35E+05	6.78E+01	1.48E+05	6.69E+04
7	2556	1.35E+02	3.71E+05	1.67E+05	6.58E+01	1.94E+05	8.74E+04
8	2922	1.34E+02	3.92E+05	1.76E+05	6.44E+01	1.88E+05	8.48E+04
9	3287	1.33E+02	4.37E+05	1.97E+05	6.34E+01	2.08E+05	9.39E+04
10	3652	1.33E+02	4.86E+05	2.19E+05	6.26E+01	2.29E+05	1.03E+05
12	4383	1.32E+02	5.79E+05	2.61E+05	6.17E+01	2.70E+05	1.22E+05
14	5113	1.32E+02	6.75E+05	3.04E+05	6.11E+01	3.12E+05	1.41E+05
16	5844	1.32E+02	7.71E+05	3.47E+05	6.07E+01	3.55E+05	1.60E+05
18	6574	1.32E+02	8.68E+05	3.91E+05	6.04E+01	3.97E+05	1.79E+05
20	7305	1.32E+02	9.64E+05	4.34E+05	6.03E+01	4.40E+05	1.98E+05
25	9131	1.32E+02	1.21E+06	5.43E+05	6.01E+01	5.49E+05	2.47E+05
30	10958	1.32E+02	1.45E+06	6.52E+05	6.00E+01	6.57E+05	2.96E+05
35	12784	1.32E+02	1.69E+06	7.60E+05	6.00E+01	7.67E+05	3.46E+05
40	14610	1.32E+02	1.93E+06	8.69E+05	5.99E+01	8.75E+05	3.94E+05
45	16436	1.32E+02	2.17E+06	9.77E+05	5.99E+01	9.85E+05	4.43E+05
50	18263	1.32E+02	2.41E+06	1.09E+06	5.99E+01	1.09E+06	4.93E+05

Table D.3.2-6. ^{51}Cr chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption:		**Type F**			**Type S**		
Analytical MDA:		**1 nCi[a]**			**1 nCi[a]**		
Duration of intake		**Daily intake rate**	**Cumulative intake**		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	4.80E+02	1.75E+05	7.89E+04	6.22E+02	2.27E+05	1.02E+05
2	730	4.80E+02	3.50E+05	1.58E+05	6.22E+02	4.54E+05	2.04E+05
3	1095	4.80E+02	5.25E+05	2.37E+05	6.22E+02	6.81E+05	3.07E+05
4	1461	4.80E+02	7.01E+05	3.16E+05	6.22E+02	9.08E+05	4.09E+05
5	1826	4.80E+02	8.76E+05	3.95E+05	6.22E+02	1.14E+06	5.11E+05
6	2190	4.80E+02	1.05E+06	4.73E+05	6.22E+02	1.36E+06	6.13E+05
7	2556	4.80E+02	1.23E+06	5.52E+05	6.22E+02	1.59E+06	7.16E+05
8	2922	4.80E+02	1.40E+06	6.31E+05	6.22E+02	1.82E+06	8.18E+05
9	3287	4.80E+02	1.58E+06	7.10E+05	6.22E+02	2.04E+06	9.21E+05
10	3652	4.80E+02	1.75E+06	7.89E+05	6.22E+02	2.27E+06	1.02E+06
12	4383	4.80E+02	2.10E+06	9.47E+05	6.22E+02	2.73E+06	1.23E+06
14	5113	4.80E+02	2.45E+06	1.10E+06	6.22E+02	3.18E+06	1.43E+06
16	5844	4.80E+02	2.80E+06	1.26E+06	6.22E+02	3.63E+06	1.64E+06
18	6574	4.80E+02	3.15E+06	1.42E+06	6.22E+02	4.09E+06	1.84E+06
20	7305	4.80E+02	3.50E+06	1.58E+06	6.22E+02	4.54E+06	2.05E+06

Table D.3.2-7. ^{54}Mn chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption:		**Type F**		
Analytical MDA:		**1 nCi**		
Duration of intake		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	1.81E+02	6.61E+04	2.98E+04
2	730	1.81E+02	1.32E+05	5.95E+04
3	1095	1.81E+02	1.98E+05	8.93E+04
4	1461	1.81E+02	2.64E+05	1.19E+05
5	1826	1.81E+02	3.31E+05	1.49E+05
6	2190	1.81E+02	3.96E+05	1.79E+05
7	2556	1.81E+02	4.63E+05	2.08E+05
8	2922	1.81E+02	5.29E+05	2.38E+05
9	3287	1.81E+02	5.95E+05	2.68E+05
10	3652	1.81E+02	6.61E+05	2.98E+05
12	4383	1.81E+02	7.93E+05	3.57E+05
14	5113	1.81E+02	9.25E+05	4.17E+05
16	5844	1.81E+02	1.06E+06	4.76E+05
18	6574	1.81E+02	1.19E+06	5.36E+05
20	7305	1.81E+02	1.32E+06	5.96E+05
25	9131	1.81E+02	1.65E+06	7.44E+05
30	10958	1.81E+02	1.98E+06	8.93E+05
35	12784	1.81E+02	2.31E+06	1.04E+06
40	14610	1.81E+02	2.64E+06	1.19E+06
45	16436	1.81E+02	2.97E+06	1.34E+06
50	18263	1.81E+02	3.31E+06	1.49E+06

Table D.3.2-8. ^{59}Fe chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption:		**Type F**		
Analytical MDA:		**1 nCi**		
Duration of intake		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	1.13E+02	4.12E+04	1.86E+04
2	730	1.13E+02	8.25E+04	3.72E+04
3	1095	1.13E+02	1.24E+05	5.57E+04
4	1461	1.13E+02	1.65E+05	7.44E+04
5	1826	1.13E+02	2.06E+05	9.29E+04
6	2190	1.13E+02	2.47E+05	1.11E+05
7	2556	1.13E+02	2.89E+05	1.30E+05
8	2922	1.13E+02	3.30E+05	1.49E+05
9	3287	1.13E+02	3.71E+05	1.67E+05
10	3652	1.13E+02	4.13E+05	1.86E+05
12	4383	1.13E+02	4.95E+05	2.23E+05
14	5113	1.13E+02	5.78E+05	2.60E+05
16	5844	1.13E+02	6.60E+05	2.97E+05
18	6574	1.13E+02	7.43E+05	3.35E+05
20	7305	1.13E+02	8.25E+05	3.72E+05
25	9131	1.13E+02	1.03E+06	4.65E+05
30	10958	1.13E+02	1.24E+06	5.58E+05
35	12784	1.13E+02	1.44E+06	6.51E+05
40	14610	1.13E+02	1.65E+06	7.44E+05
45	16436	1.13E+02	1.86E+06	8.37E+05
50	18263	1.13E+02	2.06E+06	9.30E+05

Table D.3.2-9. ^{154}Eu chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption :		**Type M**		
Analytical MDA:		**1 nCi**		
Duration of intake		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	1.10E+02	4.02E+04	1.81E+04
2	730	6.34E+01	4.63E+04	2.08E+04
3	1095	4.66E+01	5.10E+04	2.30E+04
4	1461	3.80E+01	5.55E+04	2.50E+04
5	1826	3.28E+01	5.99E+04	2.70E+04
6	2190	2.93E+01	6.42E+04	2.89E+04
7	2556	2.69E+01	9.71E+04	4.38E+04
8	2922	2.51E+01	7.33E+04	3.30E+04
9	3287	2.37E+01	7.79E+04	3.51E+04
10	3652	2.27E+01	8.29E+04	3.73E+04
12	4383	2.12E+01	9.29E+04	4.19E+04
14	5113	2.02E+01	1.03E+05	4.65E+04
16	5844	1.95E+01	1.14E+05	5.13E+04
18	6574	1.90E+01	1.25E+05	5.63E+04
20	7305	1.87E+01	1.37E+05	6.15E+04
25	9131	1.82E+01	1.66E+05	7.49E+04
30	10958	1.80E+01	1.97E+05	8.88E+04
35	12784	1.79E+01	2.29E+05	1.03E+05
40	14610	1.79E+01	2.62E+05	1.18E+05
45	16436	1.78E+01	2.93E+05	1.32E+05
50	18263	1.78E+01	3.25E+05	1.46E+05

Table D.3.2-10. ^{95}Nb chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption:		**Type M**			**Type S**		
Analytical MDA:		**1 nCi[a]**			**1 nCi[a]**		
Duration of intake		**Daily intake rate**	**Cumulative intake**		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	5.68E+02	2.07E+05	9.33E+04	6.11E+02	2.23E+05	1.00E+05
2	730	5.67E+02	4.14E+05	1.86E+05	6.11E+02	4.46E+05	2.01E+05
3	1095	5.67E+02	6.21E+05	2.80E+05	6.11E+02	6.69E+05	3.01E+05
4	1461	5.67E+02	8.28E+05	3.73E+05	6.11E+02	8.93E+05	4.02E+05
5	1826	5.67E+02	1.04E+06	4.66E+05	6.11E+02	1.12E+06	5.03E+05
6	2190	5.67E+02	1.24E+06	5.59E+05	6.11E+02	1.34E+06	6.03E+05
7	2556	5.67E+02	1.45E+06	6.53E+05	6.11E+02	1.56E+06	7.03E+05
8	2922	5.67E+02	1.66E+06	7.46E+05	6.11E+02	1.79E+06	8.04E+05
9	3287	5.67E+02	1.86E+06	8.40E+05	6.11E+02	2.01E+06	9.05E+05
10	3652	5.67E+02	2.07E+06	9.33E+05	6.11E+02	2.23E+06	1.01E+06
12	4383	5.67E+02	2.49E+06	1.12E+06	6.11E+02	2.68E+06	1.21E+06
14	5113	5.67E+02	2.90E+06	1.31E+06	6.11E+02	3.12E+06	1.41E+06
16	5844	5.67E+02	3.31E+06	1.49E+06	6.11E+02	3.57E+06	1.61E+06
18	6574	5.67E+02	3.73E+06	1.68E+06	6.11E+02	4.02E+06	1.81E+06
20	7305	5.67E+02	4.14E+06	1.87E+06	6.11E+02	4.46E+06	2.01E+06
25	9131	5.67E+02	5.18E+06	2.33E+06	6.11E+02	5.58E+06	2.51E+06
30	10958	5.67E+02	6.21E+06	2.80E+06	6.11E+02	6.70E+06	3.02E+06
35	12784	5.67E+02	7.25E+06	3.27E+06	6.11E+02	7.81E+06	3.52E+06
40	14610	5.67E+02	8.28E+06	3.73E+06	6.11E+02	8.93E+06	4.02E+06
45	16436	5.67E+02	9.32E+06	4.20E+06	6.11E+02	1.00E+07	4.52E+06
50	18263	5.67E+02	1.04E+07	4.66E+06	6.11E+02	1.12E+07	5.03E+06

a. Use most sensitive analysis for either ^{95}Nb or ^{95}Zr, then assume equal intake of the other

Table D.3.2-11. ^{95}Zr chronic inhalation intake assessment based on unit MDA whole body count on last day of the period.

Absorption:		**Type F**			**Type M**		
Analytical MDA:		**1 nCi[a]**			**1 nCi[a]**		
Duration of intake		**Daily intake rate**	**Cumulative intake**		**Daily intake rate**	**Cumulative intake**	
(Years)	**(Days)**	**(dpm/d)**	**(dpm)**	**(pCi)**	**(dpm/d)**	**(dpm)**	**(pCi)**
1	365	1.51E+02	5.51E+04	2.48E+04	3.84E+02	1.40E+05	6.31E+04
2	730	1.48E+02	1.08E+05	4.87E+04	3.81E+02	2.78E+05	1.25E+05
3	1095	1.48E+02	1.62E+05	7.30E+04	3.81E+02	4.17E+05	1.88E+05
4	1461	1.48E+02	2.16E+05	9.74E+04	3.81E+02	5.57E+05	2.51E+05
5	1826	1.48E+02	2.70E+05	1.22E+05	3.81E+02	6.96E+05	3.13E+05
6	2190	1.48E+02	3.24E+05	1.46E+05	3.81E+02	8.34E+05	3.76E+05
7	2556	1.48E+02	3.78E+05	1.70E+05	3.81E+02	9.74E+05	4.39E+05
8	2922	1.48E+02	4.32E+05	1.95E+05	3.81E+02	1.11E+06	5.01E+05
9	3287	1.48E+02	4.86E+05	2.19E+05	3.81E+02	1.25E+06	5.64E+05
10	3652	1.48E+02	5.40E+05	2.43E+05	3.81E+02	1.39E+06	6.27E+05
12	4383	1.48E+02	6.49E+05	2.92E+05	3.81E+02	1.67E+06	7.52E+05
14	5113	1.48E+02	7.57E+05	3.41E+05	3.81E+02	1.95E+06	8.78E+05
16	5844	1.48E+02	8.65E+05	3.90E+05	3.81E+02	2.23E+06	1.00E+06
18	6574	1.48E+02	9.73E+05	4.38E+05	3.81E+02	2.50E+06	1.13E+06
20	7305	1.48E+02	1.08E+06	4.87E+05	3.81E+02	2.78E+06	1.25E+06
25	9131	1.48E+02	1.35E+06	6.09E+05	3.81E+02	3.48E+06	1.57E+06
30	10958	1.48E+02	1.62E+06	7.31E+05	3.81E+02	4.17E+06	1.88E+06
35	12784	1.48E+02	1.89E+06	8.52E+05	3.81E+02	4.87E+06	2.19E+06
40	14610	1.48E+02	2.16E+06	9.74E+05	3.81E+02	5.57E+06	2.51E+06
45	16436	1.48E+02	2.43E+06	1.10E+06	3.81E+02	6.26E+06	2.82E+06
50	18263	1.48E+02	2.70E+06	1.22E+06	3.81E+02	6.96E+06	3.13E+06

a. Use most sensitive analysis for either ^{95}Zr or ^{95}Nb, then assume equal intake of the other

D.4 Tolerance Dose and Tolerance Values at Hanford

Various health physics textbooks and histories document the history of the tolerance dose. The brief description below was extracted from Jacob Shapiro's textbook (Shapiro 1981) and from *Radiation Protection Criteria and Standards: Their Basis and Use* (Parker 1960). Herbert M. Parker was the manager of the radiation protection activities at the start of Hanford and eventually became the manager of the Hanford Laboratories.

The tolerance dose was based on a rate of radiation exposure that produced no obvious harm. The basis for harm changed as understanding of health effects of radiation improved.

The first tolerance dose was established in 1934 by the International X-ray and Radium Protection Commission as 0.2 R/day. In 1936 the US Advisory Committee on X-ray and Radium Protection reduced the tolerance dose to 0.1 R/day. This value was used at the Manhattan Project Sites during World War II. For instance, Parker states that in 1945 the values accepted as a working basis for occupational exposure were:

- 100 mr/day for external X and gamma radiation
- 10-14 curies/cc for radon in air of working rooms
- 0.1 µg of radium as the maximum allowable amount deposited in the body.

In 1949 the NCRP recommended that the permissible dose by reduced to 0.3 rem/week. In 1953 the NCRP developed maximum permissible amounts of certain radionuclides in the body and maximum permissible concentrations in air and water, published as National Bureau of Standards Handbook 52 (NBS 1953). At that point tolerance values were replaced with the Maximum Permissible Body Burden and maximum permissible concentration.

Hanford's radiation protection standards were in accordance with these national and international standards. For instance the following are examples of the "tolerance limits for prolonged exposure" at Hanford in 1945 (Cantril, 1945):

External gamma and X radiation	0.1 r per day
External beta radiation	0.1 rep[(a)] per day
Fast neutron radiation	0.02 rep per day
Slow neutron radiation	0.025 rep per day
Internal alpha radiation	0.01 rep per day
Radium deposition in body	0.1 µg total accumulation
Radioactive iodine-131 in atmosphere	1.0×10^{-13} curie per cc
Mixed fission products in drinking water	1.2×10^{-9} curie per cc
Product(b) concentration in drinking water	10^{-5} µg per cc
Product concentration in atmosphere	5×10^{-10} µg per cc
Product deposition in body	0.5 µg total accumulation
Uranium dust in atmosphere	1.5×10^{-4} µg per cc

(a) rep (roentgen equivalent physical) was a unit of dose from particulate radiation invented by Herbert Parker. It was a precursor to the rad. It was defined as an absorbed dose of 83 erg per gram of tissue and was later changed to 93 erg/g.
(b) Product was a euphemism for plutonium.

By March 1949 the Hanford limits had changed to incorporate the 0.3 rem per week guidance from the NCRP. Examples are listed below (Patterson, 1949). The letter refers to these values as permissible tolerances.

External Radiation Limits
- Whole body – 0.3 rem per week or whatever the National Committee on Radiation Protection recommends
- Hands only – 1.0 rem per week or whatever the National Committee on Radiation Protection recommends

Internal Emitter Limits
- 0.3 rem per week to the significant organ or whatever the National Committee on Radiation Protection recommends

Drinking Water
- Uranium – 100 µg/liter - believe this is high
- Plutonium – 0.01 µg/liter – intend to revise to not more than 0.001 µg/liter
- Mixed fission products – 0.1 µc* /liter – to be changed when new figure provided by K.Z. Morgen's subcommittee

Air Contamination Limits
- Respiratory protection required
  - Uranium - >0.05 µg/liter
  - Plutonium - $>2 \times 10^{-8}$ µg/liter to be revised perhaps to 2×10^{-9} µg/liter
  - Mixed fission products - $>10^{-6}$ µc/liter
- Other air contamination limits

Tritium – gas 0.1 µc/liter, vapor 0.01 µc/liter
Carbon – 0.02 µc/liter
Argon – 1.6×10^{-3} µc/liter
Iodine – 1.5×10^{-6} µc/liter
Xenon – 0.01 µc/liter

*Assumed to mean microcuries.

The tolerance values for air and drinking water were based on the dose to the significant organ and state-of-the-air understanding of the biokinetics of the element in the body. An assumption of continuous inhalation or drinking of water was usually made, although in the example below a tolerance value based on a single inhalation was also established. A sample calculation was found (letter to file dated December 17, 1945) that provides the calculation of the tolerance value for "potentially long-continued exposure" to ^{131}I and a "one-shot tolerance value," the latter assuming a single 8-hr exposure (Parker 1945). For the chronic exposure, Parker assumed a thyroid radiation tolerance of 1 r/day, which resulted from an equilibrium thyroid burden of 1.95 µCi, which would result from a daily intake of 0.85 µCi. Parker assumed the volume of air breathed per 8-hr work day was 8×10^6 cc. For the acute intake, Parker referenced a "Project Handbook" that condoned a dose of 100 r; however, Parker stated that this was too close to the dose given patients in the treatment of hyperthyroidism, so he arbitrarily reduced the dose by a factor of 10. He then calculated an air concentration for a single 8-hr exposure to be 1.2×10^{-11} Ci /cc.