

SECTION 8.0

URANIUM

8.0 URANIUM

This section provides technical information on uranium sources, characteristics, biokinetics, and internal dosimetry for general application at Hanford. Also included are special sections that apply to exposures in specific facilities where uncontained uranium is routinely handled.

Bioassay monitoring and internal dosimetry for uranium at Hanford pose relatively unique problems, primarily because, except for highly enriched uranium, total containment is not provided. Thus, low-level chronic airborne contamination levels are assumed to exist in facilities in which uncontained uranium is routinely handled.

Additional difficulties with uranium dosimetry are caused by the relatively low sensitivity of direct (in vivo) measurement capabilities for depleted and low-enrichment uranium, and the presence of environmental uranium in urine as background interference.

8.1 SOURCES AND CHARACTERISTICS OF URANIUM

The sources, isotopic composition, transportability, particle size, environmental background, chemical toxicity, and biokinetic characteristics of uranium at Hanford are discussed in the following subsections.

8.1.1 Sources

Historically, at Hanford uranium has been used primarily as feed material in the plutonium production process. The uranium was received as slightly enriched metallic uranium in the form of large billets and extruded into fuel elements at the 300 Area Fuel Production Facility (FPF). After irradiation in production reactors, the elements are shipped to the PUREX facility for processing. The final operating plutonium production reactor (N Reactor) and its associated fuels production facility were shut down in 1987; however, the extraction of plutonium and uranium from the irradiated fuels will continue for several more years at the PUREX facility. The recovered uranium, as uranyl nitrate-hexahydrate, is shipped to the Uranium Oxide (UO₃) Plant in 200 West Area for conversion to uranium trioxide.

Uranium is also used in fuel elements for the FFTF reactor. The FFTF fuel consists of a mixture of plutonium and uranium oxide, with plutonium being the primary concern.

Depleted uranium metal is machined in shops in the 306-W Building in support of a long-term research and development program.

Uranium isotopes are stored and handled in several laboratories in the 200 and 300 Areas.

8.1.2 Isotopic Composition

Uranium handled at Hanford generally ranges from depleted to slightly enriched. Table 8.1 summarizes ^{235}U enrichment levels in several Hanford facilities. Table 8.2 gives radiological data for uranium isotopes.

Uranium that is used in the plutonium production process is recycled uranium and is subject to the ingrowth of impurities during the irradiation phase of the fuel cycle (Rich et al. 1988). These impurities are not

TABLE 8.1. Enrichments of Uranium at Hanford Facilities

Area	Facility	^{235}U Enrichment	
		Years	Days
100	N Reactor fuel	0.8 - 1.25%	^{235}U
200	PUREX, UO ₃ Plant	0.8%	^{235}U
300	306-W Building (PNL)	Depleted (0.3%)	^{235}U
	N Reactor FPF	0.95 - 1.25%	^{235}U

TABLE 8.2. Radiological Characteristics of Uranium Isotopes

Isotopes	Specific Activity, $\mu\text{Ci/g}$	Half-Life, yr	
		Years	Days
^{232}U	2.1E+7	72	2.63E+5
^{233}U	9.69E+3	1.59E+5	5.80E+7
^{234}U	6.25E+3	2.45E+5	8.94E+7
^{235}U	2.16	7.03E+8	2.57E+11
^{236}U	64.7	2.34E+7	8.54E+9
^{238}U	0.336	4.47E+9	1.63E+12

completely removed during the reprocessing and plutonium extraction phases of the production cycle and thus contribute to internal dose along with uranium. The impurities include ^{236}U , ^{239}Pu , ^{99}Tc , ^{237}Np , and other, shorter-lived, fission products.

Table 8.3 gives the isotopic composition of various types of uranium at Hanford. Recycled uranium is present in the FPF and in the UO3 Plant. Figure 8.1 shows how the specific activity of virgin (unirradiated) uranium

TABLE 8.3. Radiological Characteristics of Uranium Mixtures

Specific Activity, Mixture $\mu\text{Ci/g}$ (nCi/mg)		Atom Fractions			
		^{234}U	^{235}U	^{236}U	^{238}U
Natural	0.687	0.000054	0.0072	(a)	0.9927
Depleted	0.364	0.0000037	0.0025	(a)	0.9975
UO3-RU	0.90	0.000080	0.0083	0.00074	0.991
FPF-RU ^(b)	0.92	0.000084	0.011	0.00062	0.988

Mixture	Fraction of Total Uranium Activity of Mixture			
	^{234}U	^{235}U	^{236}U	^{238}U
Natural	0.492	0.023	(a)	0.486
Depleted	0.064	0.015	(a)	0.922
UO3-RU	0.56	0.020	0.053	0.37
FPF-RU	0.57	0.026	0.044	0.36

Mixture	Activity Per Microgram of Material, dpm/ μg of Mixture				
	^{234}U	^{235}U	^{236}U	^{238}U	U-Total
Natural	0.74	0.035	(a)	0.73	1.5
Depleted	0.05	0.012	(a)	0.74	0.8
UO3-RU	1.1	0.040	0.11	0.74	2.0
FPF-RU	1.2	0.053	0.09	0.74	2.0

(a) Negligible

(b) Average atom fraction based on range expected for facility.
Uranium-235 enrichment varies from 0.95% to 1.25%.

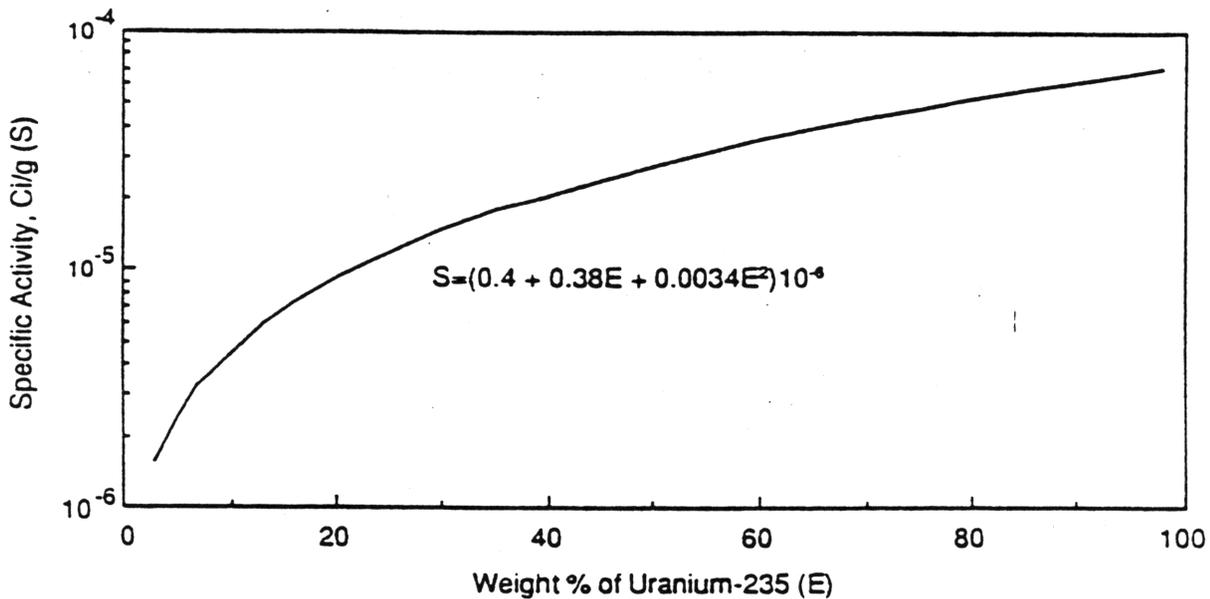


FIGURE 8.1. Specific Activity for Enriched Uranium (from WASH-1251 [Alexander 1974])

increases with ²³⁵U enrichment. Table 8.3 shows that the specific alpha activity of the recycled uranium exceeds that of virgin uranium for corresponding ²³⁵U weight percentages. This increase is due primarily to higher levels of ²³⁴U and ²³⁶U in the recycled uranium. The atom ratios used to calculate specific activity in Table 8.3 are based on operational data obtained from facility operating records and represent a reference recycled uranium mixture. Although the isotope ratios vary slightly between UO₃ Plant recycled uranium (UO₃-RU) and FPF recycled uranium (FPF-RU), the total specific activity for the two mixtures is the same at 2.0 dpm/μg uranium.

Other impurities in recycled uranium include plutonium, neptunium, technetium, and other fission products. Table 8.4 gives maximum allowed levels of these impurities in uranium handled at the UO₃ Plant. These levels can be considered to represent the maximum impurity levels for recycled uranium at Hanford. Actual operational experience shows that levels of impurities in recycled uranium at Hanford are substantially below the maximum allowed levels. Default reference levels for these impurities are also established in the table.

TABLE 8.4. Impurities in Recycled Uranium at Hanford

Constituent	Maximum ^(a) Allowed	Observed ^(b) Range	Reference Level ^(c)
Plutonium	10 ppbp U	<1-2 ppbp U	0.4 nCi Pu-alpha/g-U ^(d)
Neptunium	NE ^(e)	0.04-0.16 ppmp U	0.4 nCi ²³⁷ Np/g-U ^(f)
Thorium	750 ppmp U	8-10 ppmp U	5 pCi ²³² Th/g-U ^(g)
⁹⁹ Tc	NE ^(e)	3-4 ppmp U	0.2 μCi ⁹⁹ Tc/g-U ^(h)
^{103,106} Ru	<20 μCi/lb-U	<6 μCi/lb-U	40 nCi ¹⁰⁶ Ru/g-U ⁽ⁱ⁾
⁹⁵ ZrNb	<10 μCi/lb-U	<4 μCi/lb-U	20 nCi ⁹⁵ Zr/g-U ^(j)

(a) From UO3 Plant operating specifications, OSD-U-185-0001 (Thompson 1986).

(b) From analysis of uranium lots 88-1, 88-2, 88-3 that were processed in 1988.

(c) A reference level is chosen for determining bioassay monitoring needs and for use as an initial assumption in evaluating intakes. The use of the reference levels is expected to result in a slight overestimate of dose compared to levels actually observed in 1988.

(d) Based on 5 ppbp U and assuming plutonium is represented by aged 6% ²⁴⁰Pu grade material (per Section 9.0).

(e) NE = not established.

(f) Based on 0.5 ppmp U of ²³⁷Np.

(g) Based on 50 ppmp U of ²³²Th.

(h) Based on 10 ppmp U of ⁹⁹Tc.

(i) Based on 20 μCi/lb of ¹⁰⁶Ru.

(j) Based on 10 μCi/lb of ⁹⁵ZrNb.

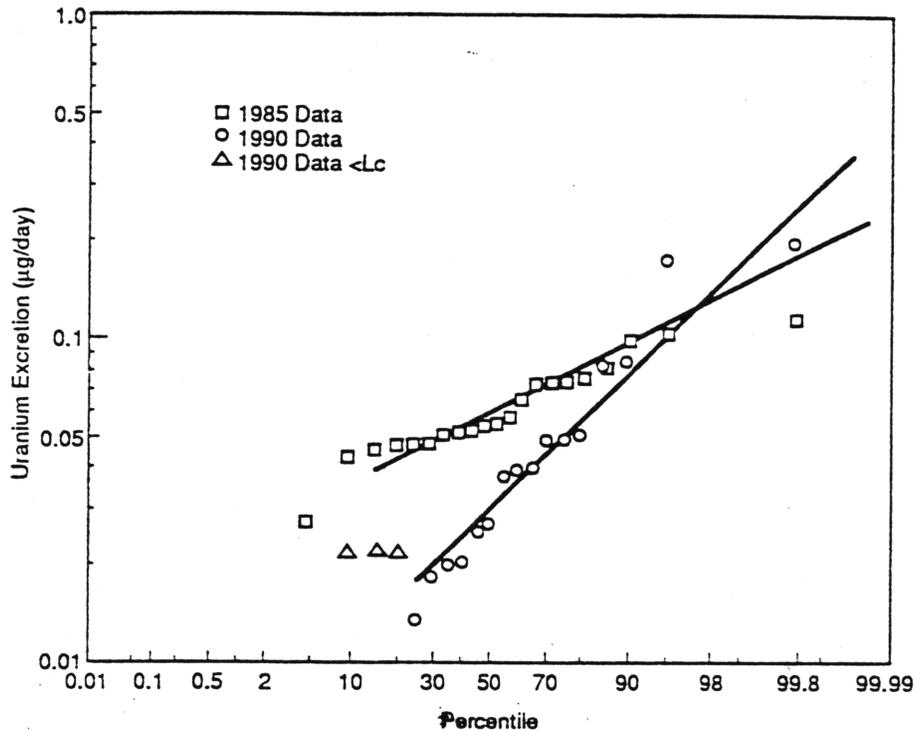
8.1.3 Environmental Background

The sensitivity of urine sampling as a uranium bioassay tool is limited by the presence of environmental levels of uranium, which is subject to some uncertainty in interpretation. In ICRP 30 (1979) the average daily ingestion intake of natural uranium in food and water is estimated to be 1.9 μg. Assuming that the GI tract absorption of uranium at environmental levels is about 1% (Wrenn 1985) at equilibrium, about 0.02 μg/day could be expected in the urine of occupationally unexposed workers. Two studies at Hanford, performed in 1985 and 1990, indicated that the concentrations of uranium in urine in the Hanford area are similar but slightly higher than the foregoing estimates

(Carbaugh, Sula, and McFadden 1990). The ICRP Reference Man Report (1974) lists urinary excretion from 0.05 to 0.5 $\mu\text{g}/\text{day}$ and fecal excretion from 1.4 to 1.8 $\mu\text{g}/\text{day}$, although the range reported in its cited literature is much greater.

Urine samples were collected in mid-1985 from 21 occupationally unexposed Hanford workers who resided in various locations around Hanford, including Yakima, Benton City, Kennewick, and Richland. Both municipal drinking water and individual well-water systems were represented by the sampling. The results ranged from below detectable levels (0.03 $\mu\text{g}/\text{day}$) to 0.12 $\mu\text{g}/\text{day}$. For seven of the individuals, three samples were collected over a 2-week period, and the daily excretion remained fairly constant for each individual over the period. Data for this group are shown as the 1985 curve in Figure 8.2. The median daily uranium output for the 1985 study group was 0.06 μg and 0.2 $\mu\text{g}/\text{day}$ was estimated to be the 99.9 percentile (one in a thousand samples collected from unexposed workers would be expected to exceed that value). Based on this study, samples containing less than 0.2 $\mu\text{g}/\text{day}$ of uranium were considered to be within the expected environmental range, and results above 0.2 $\mu\text{g}/\text{day}$ were considered to contain occupationally derived uranium. The net amount attributed to occupational sources was calculated as the total observed amount minus the average expected environmental level of 0.06 $\mu\text{g}/\text{day}$.

A second study of background uranium levels in urine commenced in 1990. Urine samples were collected from 20 nonoccupationally exposed workers in early 1990 with the intent of collecting quarterly samples from each worker throughout the year, as well as samples of their drinking water. The workers were selected to provide an indication of the possible correlation between drinking water sources and urinary excretion. Due to the cancellation of the analytical support services laboratory contract this study was terminated following collection of the first samples. However, the data are useful as a comparison with the 1985 data and, as can be seen in Figure 8.2, show some very interesting variations. The geometric mean of this sample group was 0.024 $\mu\text{g}/\text{day}$ with a 99.9 percentile of 2.8 $\mu\text{g}/\text{day}$. The 0.2- $\mu\text{g}/\text{day}$ value used as the 99.9 percentile for the 1985 data corresponds more closely to a 99



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FIGURE 8.2. Urinary Excretion of Uranium in Unexposed Hanford Workers

percentile for the 1990 data, implying that one in a hundred (rather than one in a thousand) samples from occupationally unexposed workers might exceed it.

At least two factors contribute to these apparent differences. First, the workers sampled were a substantially different subset than the first group; whereas the 1985 subjects were primarily from two large municipal water systems, the 1990 subjects were carefully selected to provide an indication of possible impact from water consumption in numerous outlying communities around Hanford. Second, a significant change in the analytical process occurred during the time that elapsed between the two sets of samples - namely, the practice of subtracting reagent blanks from sample results was initiated. Interpretation of the 1990 data is still considered preliminary.

Fecal excretion of uranium from ingestion of nonoccupational sources of uranium in the Hanford environs has not been studied in a manner similar to

that of urine excretion. Lacking Hanford-specific information, it is assumed that the ICRP Reference Man values of 1.4 to 1.8 $\mu\text{g}/\text{day}$ are reasonable.

8.2 BIOKINETIC BEHAVIOR OF URANIUM

The inhalation class, particle size, distribution, retention, excretion and chemical toxicity of uranium are included here in the discussion of its biokinetic behavior.

8.2.1 Inhalation Class

Table 8.5 provides transportability classifications for uranium compounds as recommended in ICRP 30. Unless special dissolution analysis is performed, these assigned classifications are used. Special dissolution studies have been performed for uranium handled in the UO₃ Plant, the FPF, and the 306-W Building. (See Section 8.7.)

8.2.2 Particle Size

Unless determined by specific measurements, it is assumed that the AMAD for uranium particulates is 1 μm . Particle sizing has been performed in several facilities using a cascade impactor and, where available, the results of the measurements are provided in Section 8.7.2.

8.2.3 Distribution, Retention, and Excretion

For the design of monitoring programs and for the assessment of dose equivalents when there is insufficient bioassay measurement data to develop

TABLE 8.5. Inhalation Classes and f_1 Values for Some Uranium Compounds^(a)

<u>Class</u>	<u>Compounds</u>	<u>f_1</u>
D	UF ₆ , UO ₂ F ₂ , UO ₂ (NO ₃) ₂	0.05
W	UO ₃ , UF ₄ , UCl ₄	0.05
Y	UO ₂ , U ₃ O ₈	0.002

(a) Dissolution studies of uranium at Hanford have resulted in some modification to the values shown in this table. Hanford specific values are given in Section 8.7.

individual-specific characteristics, the distribution, retention, and excretion of uranium are assumed to follow the biokinetic model described in ICRP 30. This model assigns the transportability classes shown in Table 8.5. For material entering the systemic circulation, fractions 0.2 and 0.023 are assumed to go to mineral bone and be retained there with half-lives of 20 and 5000 days, respectively; fractions 0.12 and 0.00052 are assumed to go to the kidneys and to be retained with half-lives of 6 and 1500 days, respectively; and fractions 0.12 and 0.00052 are assumed to go to all other tissues of the body and be retained with half-lives of 6 and 1500 days, respectively. Uranium is assumed to be uniformly distributed among these other tissues. Fraction 0.54 of the uranium entering the systemic circulation is assumed to go directly to excretion. Long-lived uranium isotopes entering the bone are assumed to be distributed uniformly throughout the bone volume.

Selected lung retention, urinary, and fecal excretion functions for acute and chronic inhalations are tabulated in Tables 8.6, 8.7, and 8.8. These factors were calculated using the computer code GENMOD (Johnson and Carver 1981; see Appendix A).

8.2.4 Chemical Toxicity

Because of the comparatively high mass-to-activity ratio at low enrichments (<10% ^{235}U), consideration is given to the potential toxicological effects of an intake in addition to the radiological effects. For readily transportable uranium of low enrichment, concerns about chemical toxicity predominate; and for slowly transportable uranium, concerns about the radiation dose received by the lung following inhalation predominate.

The following subsections provide additional guidance for evaluating bioassay data to determine the potential toxicological effects of chronic and acute exposure.

Chronic Exposure

A chronic kidney burden of 3 $\mu\text{g/g}$ of kidney has historically been the basis for development of action levels for bioassay monitoring of workers who are chronically exposed to uranium (Hursh and Spoor 1973). Recent studies with the most highly transportable and toxic form of uranium, UO_2F_2 , indicate

TABLE 8.6. Lung Retention Factors Following Inhalation of Uranium^(a,b,c)

Days Post Intake	Acute Inhalation			Chronic Inhalation		
	Class D Lung	Class W Lung	Class Y Lung	Class D Lung	Class W Lung	Class Y Lung
0	3.3E-1	3.3E-1	3.3E-1	0.0E-0	0.0E-0	0.0E-0
1	1.4E-1	2.2E-1	2.2E-1	2.7E-1	2.7E-1	2.6E-1
2	4.3E-2	1.8E-1	1.8E-1	3.6E-1	4.7E-1	4.5E-1
5	1.1E-3	1.5E-1	1.5E-1	3.9E-1	9.4E-1	9.4E-1
7	8.1E-5	1.4E-1	1.5E-1	3.9E-1	1.2E+0	1.2E+0
14	0.0E+0	1.3E-1	1.5E-1	3.9E-1	2.2E+0	2.3E+0
30	0.0E+0	1.0E-1	1.4E-1	3.9E-1	4.0E+0	4.6E+0
60	0.0E+0	7.0E-2	1.4E-1	3.9E-1	6.5E+0	8.9E+0
90	0.0E+0	4.8E-2	1.4E-1	3.9E-1	8.3E+0	1.3E+1
180	0.0E+0	1.5E-2	1.3E-1	3.9E-1	1.1E+1	2.5E+1
365	0.0E+0	1.4E-3	1.0E-1	3.9E-1	1.2E+1	4.6E+1
730	0.0E+0	1.1E-5	7.3E-2	3.9E-1	1.2E+1	7.8E+1
1825	0.0E+0	1.3E-9	2.9E-2	3.9E-1	1.2E+1	1.3E+2
3650	0.0E+0	0.0E+0	9.6E-3	3.9E-1	1.2E+1	1.6E+2
7300	0.0E+0	0.0E+0	4.2E-3	3.9E-1	1.2E+1	1.8E+2
18,250	0.0E+0	0.0E+0	3.8E-3	3.9E-1	1.2E+1	2.2E+2

- (a) Factors are expressed as a fraction (or multiple) of acute intake or chronic daily intake rate and apply to 1- μ m-AMAD particles.
 (b) Factors are applicable to natural uranium, recycled uranium, depleted uranium, ^{234}U , ^{235}U , ^{238}U , or any combination thereof.
 (c) Lung includes pulmonary lymph nodes.

that steady-state kidney concentrations of 3 $\mu\text{g/g}$ in dogs were sufficient to produce indications of uranium poisoning (Morrow et al. 1982). Although UO_2F_2 is not handled at Hanford, it is prudent for bioassay monitoring purposes to assume a renal toxicity threshold of less than 3 $\mu\text{g/g}$ of kidney. Based on recent studies by a number of investigators, current consensus is that the "no effect" threshold for uranium in kidney is 1.1 $\mu\text{g/g}$ (Rich et al. 1988). As an additional conservative measure, this technical basis uses 0.4 $\mu\text{g/g}$ (one-third of the 1.1- $\mu\text{g/g}$ value, rounded to one significant figure) for routine bioassay monitoring as described in Sections 8.5.2, 8.7.1, and Table 8.20.

TABLE 8.7. Urinary Excretion Factors Following Inhalation of Uranium^(a,b)

Days Post Intake	Acute Inhalation			Chronic Inhalation		
	Class D Urinary	Class W Urinary	Class Y Urinary	Class D Urinary	Class W Urinary	Class Y Urinary
0	0.0E+0	0.0E+0	0.0E+0	0.0E-0	0.0E-0	0.0E-0
1	1.0E-1	1.6E-2	8.0E-4	1.9E-1	4.2E-2	2.2E-3
2	4.1E-2	5.5E-3	2.7E-4	2.6E-1	5.1E-2	2.7E-3
5	1.2E-2	2.5E-3	1.2E-4	3.2E-1	6.1E-2	3.2E-3
7	9.4E-3	2.1E-3	1.0E-4	3.4E-1	6.6E-2	3.4E-3
14	5.1E-3	1.4E-3	6.3E-5	3.8E-1	7.7E-2	4.0E-3
30	1.7E-3	7.2E-4	3.2E-5	4.3E-1	9.3E-2	4.7E-3
60	4.5E-4	4.1E-4	2.2E-5	4.6E-1	1.1E-1	5.4E-3
90	1.5E-4	2.7E-4	1.9E-5	4.7E-1	1.2E-1	6.0E-3
180	8.5E-6	9.4E-5	1.8E-5	4.7E-1	1.3E-1	7.7E-3
365	1.7E-6	1.1E-5	1.8E-5	4.7E-1	1.4E-1	1.1E-2
730	1.6E-6	5.8E-7	1.7E-5	4.7E-1	1.4E-1	1.7E-2
1825	1.3E-6	3.9E-7	1.1E-5	4.7E-1	1.4E-1	3.3E-2
3650	9.7E-7	2.9E-7	3.8E-6	4.8E-1	1.4E-1	4.5E-2
7300	5.7E-7	1.7E-7	3.7E-7	4.8E-1	1.4E-1	5.0E-2
18,250	1.2E-7	3.7E-8	1.7E-8	4.8E-1	1.5E-1	5.1E-2

- (a) Factors are expressed as a fraction (or multiple) of acute intake or chronic daily intake rate and apply to 1- μ m-AMAD particles.
- (b) Factors are applicable to natural uranium, recycled uranium, depleted uranium, ^{234}U , ^{235}U , ^{238}U , or any combination thereof.

Acute Exposure

Guidance for a maximum single acute intake of uranium has been provided in ICRP 6 (1964), based on work by Eve (1964). Eve's analysis was derived from the assumption that a daily intake of 2.5 mg of uranium could be tolerated without harm. Of more relevance for acute intakes are the results of human injection studies that have shown that an uptake of 0.07 mg of hexavalent uranium per kilogram of body weight produced transient injury and 0.1 mgU/kg produced catalasuria and proteinuria (Hursh and Spoor 1973). More recent studies of the highly soluble uranyl fluoride (UO_2F_2) showed that

TABLE 8.8. Fecal Excretion Factors Following Inhalation of Uranium^(a,b)

Days Post Intake	Acute Inhalation			Chronic Inhalation		
	Class D Fecal	Class W Fecal	Class Y Fecal	Class D Fecal	Class W Fecal	Class Y Fecal
0	0.0E+0	0.0E+0	0.0E+0	0.0E-0	0.0E-0	0.0E-0
1	6.8E-2	1.0E-1	1.3E-1	4.1E-2	3.9E-2	5.0E-2
2	4.2E-2	1.3E-1	1.6E-1	9.8E-2	1.6E-1	2.1E-1
5	2.7E-3	2.2E-2	2.4E-2	1.4E-1	3.6E-1	4.4E-1
7	3.7E-4	6.0E-3	5.5E-3	1.5E-1	3.9E-1	4.7E-1
14	0.0E+0	1.2E-3	1.7E-4	1.5E-1	4.0E-1	4.8E-1
30	0.0E+0	8.9E-4	1.3E-4	1.5E-1	4.2E-1	4.8E-1
60	0.0E+0	5.9E-4	1.3E-4	1.5E-1	4.4E-1	4.8E-1
90	0.0E+0	3.9E-4	1.2E-4	1.5E-1	4.6E-1	4.9E-1
180	0.0E+0	1.1E-4	1.1E-4	1.5E-1	4.8E-1	5.0E-1
365	0.0E+0	8.6E-6	8.4E-5	1.5E-1	4.8E-1	5.2E-1
730	0.0E+0	5.6E-8	5.0E-5	1.5E-1	4.8E-1	5.4E-1
1825	0.0E+0	0.0E+0	1.1E-5	1.5E-1	4.8E-1	5.7E-1
3650	0.0E+0	0.0E+0	1.4E-6	1.5E-1	4.8E-1	5.7E-1
7300	0.0E+0	0.0E+0	4.5E-0 0.0E+0	1.5E-1	4.8E-1	5.7E-1
18,250	0.0E+0	0.0E+0	0.0E+0	1.5E-1	4.8E-1	5.7E-1

- (a) Factors are expressed as a fraction (or multiple) of acute intake or chronic daily intake rate and apply to 1- μ m-AMAD particles.
- (b) Factors are applicable to natural uranium, recycled uranium, depleted uranium, ²³⁴U, ²³⁵U, ²³⁸U, or any combination thereof.

intravenous doses of 0.01 mgU/kg of body weight for dogs and 0.1 mgU/kg of body weight for rats were nephrotoxic, and that the threshold for injury in man was thought to be about 0.07 mgU/kg of body weight (Morrow et al. 1982). The renal toxicity of uranium varies with the compound form, with toxicity increasing with chemical solubility (Morrow et al. 1982).

Uranium compounds encountered during production operations at Hanford range from the highly soluble uranyl nitrate, UO₂(NO₃)₂, to somewhat less soluble uranium trioxide, UO₃, to relatively insoluble uranium oxides, UO₂ and U₃O₈. The highly reactive uranium hexafluoride, UF₆, and uranyl fluoride,

UO₂F₂, are not handled at Hanford. For the purpose of establishing action levels for bioassay monitoring, a renal toxicity threshold of 0.1 mg acute uptake to blood per kilogram of body weight or a 7-mg acute uptake for Reference Man is established. This corresponds to an acute inhalation of 15 mg of Class D uranium.

1991 Update on Chemical Toxicity

Since the foregoing discussion on chemical toxicity of uranium was written in 1989, additional publications have appeared on the subject, raising some question as to the appropriate assumption for a "no effects threshold level" of uranium intake, uptake, or kidney burden. In an extensive review article, Leggett (1989) noted that results and conclusions of studies have varied widely and that "apparent discrepancies may be due largely to differences in 1) perceptions and/or definitions of toxicity, 2) sensitivity of the measurements of kidney damage or dysfunction, 3) patterns of exposure (for example, acute versus chronic), and 4) sensitivity to renal U in different species." Leggett concluded that "it may be prudent to lower this long-standing guidance level [of 3 μ gU/g] by roughly an order of magnitude until more is known about subtle physiological effects of small quantities of U in the kidneys." Similar sentiment was expressed by SuLu and Zhao (1990) in recommending a maximum safe uranium burden in the kidney of 0.26 μ g/g, based on a 10-fold safety factor below mild kidney impairment observed in one human case at 2.6 μ gU/g. McGuire (1990) concluded that an intake of soluble uranium of 10 mg or less is unlikely to have any detectable (even transient) effects, and that a 40 mg intake (possibly as high as 100 mg) is likely to be below the level of any permanent effects. These levels are all within a factor of 2 to 3 of those proposed in the first release of this document (Sula, Carbaugh, and Bihl 1989).

Considering that Leggett noted that the early researchers cited ranges of "much less than 5 μ g/g, probably 2 to 3 μ g/g" rather than absolute values, the question of a 1.1 μ g/g versus a 0.3 μ g/g "no effects" threshold relates more to a matter of an assumed factor for conservativeness rather than actual linkage to identifiable effects.

8.3 INTERNAL DOSIMETRY FOR URANIUM

Specific effective energy (SEE) factors for uranium isotopes are provided in Table 8.9, and weighted SEE factors for reference uranium isotope mixtures are shown in Table 8.10. From the tables it is seen that doses are essentially the same on a "per nanocurie" basis for natural uranium, recycled uranium, and ^{236}U . Thus, for a rough "rule of thumb," dose from intakes of recycled or natural uranium can be evaluated on a per alpha activity basis using dosimetry factors for ^{236}U . Table 8.11 gives first-year and 50-year committed doses from an acute inhalation intake of 1 nCi of "natural" uranium without any other radio-nuclide impurities. These dose factors can also be used directly for evaluating intakes of recycled uranium if consideration is also given to the presence of impurity radionuclides as discussed below.

TABLE 8.9. Specific Effective Energy Factors for Uranium Isotopes^(a)

	<u>MeV/q-transformation (source=target)</u>		
	<u>Lung</u>	<u>Bone Surfaces</u>	<u>Kidney</u>
^{234}U	0.097	0.014	0.31
^{235}U	0.089	0.013	0.29
^{236}U	0.092	0.013	0.30
^{238}U	0.085	0.012	0.28

(a) From ICRP 30 (1979).

TABLE 8.10. Weighted Specific Effective Energy Factors for Hanford Uranium Mixtures

<u>Uranium Mixture</u>	<u>MeV/q-Transformation</u>		
	<u>Lung</u>	<u>Bone Surfaces</u>	<u>Kidney</u>
Natural	0.091	0.013	0.30
Depleted	0.085	0.012	0.28
UO ₃ -RU	0.092	0.013	0.30
FPF-RU	0.092	0.013	0.30

TABLE 8.11. First-Year and 50-Year Committed Dose Equivalents Following Inhalation of 1 nCi^(a) of Natural Uranium

	Dose, rem		
	Inhalation Class, 1- μ m AMAD		
	D	W	Y
Lung			
First-year	9.5×10^{-4}	5.3×10^{-2}	2.1×10^{-1}
50-year	9.8×10^{-4}	5.3×10^{-2}	1.00
Bone surface			
First-year	3.2×10^{-3}	9.2×10^{-4}	6.2×10^{-5}
50-year	3.7×10^{-2}	1.1×10^{-2}	3.8×10^{-3}
Bone marrow			
First-year	2.0×10^{-4}	5.7×10^{-5}	3.9×10^{-6}
50-year	2.3×10^{-3}	6.8×10^{-4}	2.3×10^{-4}
Kidney			
First-year	8.5×10^{-3}	2.5×10^{-3}	1.9×10^{-4}
50-year	1.5×10^{-2}	4.5×10^{-3}	1.6×10^{-3}
Effective dose equivalent			
First-year	8.3×10^{-4}	6.7×10^{-3}	2.5×10^{-2}
50-year	2.8×10^{-3}	7.4×10^{-3}	1.2×10^{-1}

(a) Alpha activity. The above values were calculated for natural uranium. Doses from intakes of other isotopic mixtures will be similar on a "per nanocurie" alpha-activity basis.

Impurity radionuclides present in recycled uranium must be considered in dose assessments. Table 8.12 summarizes the contributions to the 50-year committed effective dose equivalent from the presence of reference levels of impurities in recycled uranium. From the table, it is seen that impurities do not significantly affect doses from class Y recycled uranium intakes, but do contribute sufficiently to doses of class D and class W intakes to warrant their consideration. Table 8.13 shows the factors that can be used to modify the doses from recycled uranium mixtures present in the UO₃ Plant and the N Reactor FPF.

TABLE 8.12. Committed Effective Dose Equivalent from Inhalation of Recycled Uranium, ^(a) Reference Mixture

<u>Constituent</u>	<u>Committed Effective Dose Equivalent Per Gram Uranium Inhaled (rem/g-uranium)</u>		
	<u>Class D</u>	<u>Class W</u>	<u>Class-Y</u>
Recycled Uranium	2.5	6.6	110
Pu-alpha ^(b)	0.2 ^(c)	0.2	0.14
²³⁷ Np	0.2 ^(c)	0.2	0.2 ^(d)
²³² Th	0.008	0.008	0.006
⁹⁹ Tc	0.0002	0.002	0.002 ^(d)
¹⁰⁶ Ru	0.003	0.004	0.018
⁹⁵ Zr	<u>0.0004</u>	<u>0.0003</u>	<u>0.0004</u>
Total	2.9	7.0	110
Ratio of total to U only dose	1.16	1.06	1.00

(a) Assuming 1- μ m-AMAD particulate.

(b) Assuming aged 6% grade plutonium (see Section 9.0).

(c) Class D inhalation characteristics are generally considered to not exist for this nuclide, thus class W behavior is assumed.

(d) Class Y inhalation characteristics are generally considered to not exist for this nuclide, thus class W behavior is assumed.

Contributions to total dose from non-uranium impurity radionuclides may be estimated by multiplying the annual and committed dose from uranium isotopes by the ratio of the total 50-year committed effective dose equivalent to the committed dose from uranium activity alone, as given in Table 8.12 or Table 8.13. This represents an adequate assessment of the total dose for cases involving annual effective dose equivalents on the order of 100 mrem/yr or less. If annual effective doses significantly exceed 100 mrem/yr, then consideration should be given to evaluating the annual dose for impurity radionuclides separately and adding to the dose from uranium isotopes. If intakes are sufficiently high that depositions of impurity radionuclides may be observable via bioassay measurements, then such measurements should be performed.

TABLE 8.13. Dose Factors from Reference Levels of Non-Uranium Impurities in Recycled Uranium

<u>Material</u>	<u>Inhalation Class</u>	<u>Total to Uranium Only Dose Factor</u>
UO ₃ -RU	80% D, 20% W	1.14
FPF-RU (333 Bldg)	30% D, 70% Y	1.04
FPF-RU (303-M Bldg)	10% D, 90% Y	1.02

Tables 8.14 and 8.15 give intake effective dose equivalent factors for acute or chronic intakes of uranium isotopes and reference mixtures, including the contribution from reference levels of impurities.

8.4 BIOASSAY FOR URANIUM

Bioassay monitoring procedures for uranium include excreta analysis and in vivo measurements. Urinalysis is an indicator of systemically deposited uranium; fecal analysis provides an indication of the amount of uranium that is being cleared from the lung; and in vivo counting provides a direct measurement of the quantity of uranium in the lung. The following subsections discuss urine sampling, fecal excretion, in vivo measurement, the routine bioassay monitoring program, and bioassay measurements following a potential acute intake.

8.4.1 Urine Sampling

The interpretation of urinalysis measurements is highly dependent on knowledge of the time and duration of the intake and on assumptions regarding the biokinetic transport and excretion of systemically absorbed uranium. Standard biokinetic models provide estimated uranium excretion rates in terms of daily output (i.e., micrograms per day). The influence of diurnal variations in urination frequency and volume may be lessened if a full 24-hour collection is obtained rather than a single grab sample.

According to ICRP 30, studies of the metabolism of uranium in man show that a significant amount of uranium entering the circulatory system (54%) is not deposited in body tissue but instead passes directly to excretion. The

TABLE 8.14. Acute Intake Dose Conversion Factors for 1- μ m-AMAD Particles

	Activity Intake DCF, rem/nCiU/day		Mass Intake DCF, rem/mqU/day	
	First-Year	50-Year	First-Year	50-Year
<u>Class D</u>				
238 _U	8.0E-4	2.7E-3	2.7E-4	9.0E-4
236 _U	8.6E-4	2.9E-3	5.5E-2	1.9E-1
235 _U	8.4E-4	2.8E-3	1.8E-3	6.1E-3
234 _U	9.0E-4	3.1E-3	5.6E+0	1.9E+1
U-Nat	8.3E-4	2.8E-3	5.7E-4	1.9E-3
U-Dep	7.8E-4	2.6E-3	2.8E-4	9.1E-4
U-Rec	1.0E-3	3.2E-3	9.1E-4	2.9E-3
<u>Class W</u>				
238 _U	6.4E-3	7.1E-3	2.2E-3	2.4E-3
236 _U	7.0E-3	7.6E-3	4.5E-1	4.9E-1
235 _U	6.8E-3	7.4E-3	1.5E-2	1.6E-2
234 _U	7.3E-3	8.0E-3	4.6E+1	5.0E+1
U-Nat	6.7E-3	7.4E-3	4.6E-3	5.1E-3
U-Dep	6.4E-3	7.2E-3	2.3E-3	2.6E-3
U-Rec	7.4E-3	7.8E-3	6.7E-3	7.0E-3
<u>Class Y</u>				
238 _U	2.4E-2	1.2E-1	8.1E-3	4.0E-2 4.9E-2
236 _U	2.6E-2	1.3E-1	1.7E+0	8.2E+0
235 _U	2.5E-2	1.2E-1	5.5E-2	2.7E-1
234 _U	2.8E-2	1.3E-1	1.7E+2	8.4E+2
U-Nat	2.5E-2	1.2E-1	1.7E-2	9.2E-2
U-Dep	2.3E-2	1.1E-1	8.3E-3	4.0E-2
U-Rec	2.6E-2	1.2E-1	2.3E-2	1.1E-1
<u>Facility Specific Data</u>				
221-U Bldg ^(a)				
U03-RU	2.3E-3	4.3E-3	2.1E-3	3.9E-3
333 Bldg ^(b)				
FPF-RU	1.8E-2	8.7E-2	1.6E-2	7.8E-2
303-M Bldg ^(c)				
FPF-RU	2.3E-2	1.1E-1	2.1E-2	9.9E-2
306-W Bldg ^(d)				
306W-DU	1.9E-2	8.9E-2	6.7E-3	3.2E-2

(a) U03-RU (221-U Building) is 80% class D and 20% class W (see Section 8.7).

(b) FPF-RU (333 Building) is 30% class D and 70% class Y (see Section 8.7).

(c) FPF-RU (303-M Building) is 10% class D and 90% class Y (see Section 8.7).

(d) 306W-DU (306-W Building) is 20% class D and 80% class Y (see Section 8.7).

TABLE 8.15. Chronic (365 days/year) Intake Dose Conversion Factors for 1- μ m-AMAD Particles

	Activity Intake DCF, rem per nCiU/d		Mass Intake DCF, rem per mgU/d	
	First-Year	50-Year	First-Year	50-Year
<u>Class D</u>				
238U	2.6E-1	9.6E-1	8.7E-2	3.5E-1
236U	2.7E-1	1.0E+0	1.7E+1	6.8E+1
235U	2.7E-1	1.0E+0	5.8E-1	2.3E+0
234U	2.9E-1	1.1E+0	1.8E+3	7.2E+3
U-Nat	2.7E-1	1.0E+0	1.8E-1	7.2E-1
U-Dep	2.5E-1	9.1E-0	8.3E-2	3.3E-1
U-Rec	2.7E-1	1.0E+0	2.4E-1	9.4E-1
<u>Class W</u>				
238U	1.9E+0	2.4E+0	6.4E-1	7.8E-1
236U	2.0E+0	2.5E+0	1.3E+2	1.6E+2
235U	2.0E+0	2.5E+0	4.3E+0	5.2E+0
234U	2.1E+0	2.6E+0	1.3E+4	1.6E+4
U-Nat	2.0E+0	2.5E+0	1.4E+0	1.7E+0
U-Dep	1.9E+0	2.4E+0	7.2E-1	8.7E-1
U-Rec	2.3E+0	2.9E+0	2.1E+0	2.6E+0
<u>Class Y</u>				
238U	4.7E+0	4.2E+1	1.6E+0	1.4E+1
236U	5.1E+0	4.6E+1	3.3E+2	3.0E+3
235U	5.0E+0	4.5E+1	1.1E+1	9.7E+1
234U	5.4E+0	4.8E+1	3.4E+4	3.0E+5
U-Nat	4.9E+0	4.4E+1	3.4E+0	3.0E+1
U-Dep	4.6E+0	4.1E+1	1.7E+0	1.5E+1
U-Rec	5.0E+0	4.5E+1	4.6E+0	4.1E+1
<u>Facility Specific Data</u>				
221-U Bldg ^(a)				
U03-RU	7.4E-1	1.4E+0	6.7E-1	1.3E+0
333 Bldg ^(b)				
FPF-RU	3.7E+0	3.2E+1	3.4E+0	2.9E+1
303-M Bldg ^(c)				
FPF-RU	4.6E+0	4.0E+1	4.3E+0	3.7E+1
306-W Bldg ^(d)				
306W-DU	3.7E+0	1.3E+1	1.4E+0	1.2E+1

(a) U03-RU (221-U Building) is 80% class D and 20% class W (see Section 8.7).

(b) FPF-RU (333 Building) is 30% class D and 70% class Y (see Section 8.7).

(c) FPF-RU (303-M Building) is 10% class D and 90% class Y (see Section 8.7).

(d) 306W-DU (306-W Building) is 20% class D and 80% class Y (see Section 8.7).

excretion of this unabsorbed fraction can result in highly variable urinary levels under conditions of ongoing repeated or chronic exposure as depicted in Figure 8.3. Table 8.1 (Section 8.2.3) shows urine excretion factors for selected days following acute or chronic intake of 1- μ m-AMAD particles.

Because of the possible large time variability in uranium excretion rates due to this unabsorbed fraction, quantitative interpretation of bio-assay data is best accomplished by either collecting all of the unabsorbed fraction (i.e., that voided during the first several days after exposure) or by collecting samples after the unabsorbed fraction has been eliminated. For routine sampling of potentially chronically exposed workers, it is desirable to collect the urine sample several days after any possible exposure. For the initial evaluation of potentially significant uptakes of uranium, a single void sample within 3 to 4 hours of the exposure is appropriate.

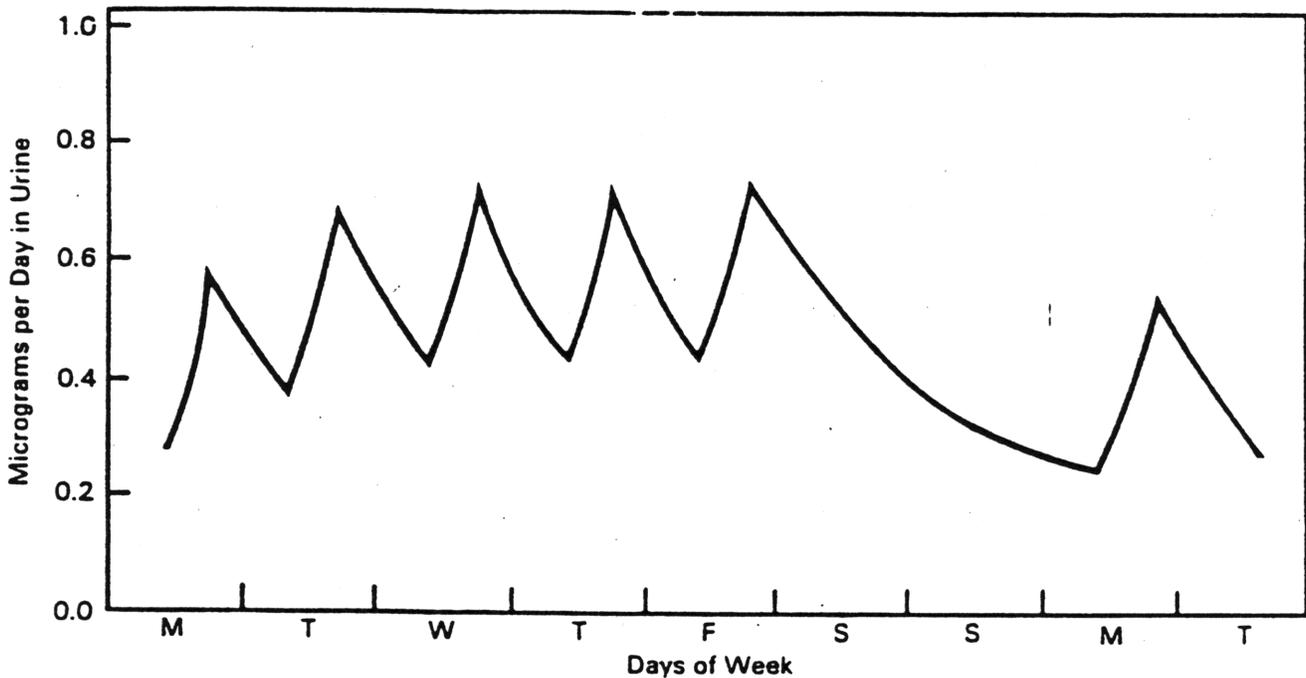


FIGURE 8.3. Daily Variability in Instantaneous Urinary Excretion from Chronic Inhalation of 1 mg/workday of Class D Uranium (Curve shown is for 52nd week of exposure.)

For the reasons stated above, the optimum urine sample for a routine uranium bioassay sampling program is a 24-hour total urine collection following several days' absence from any source of intake. Because this is not always practicable to implement on a large scale, simulated 24-hour or simulated 12-hour samples are commonly used. The simulated 12-hour sample consists of urine voided between one-half hour of retiring to bed in the evening and one-half hour after rising. The 24-hour simulated sample consists of two 12-hour simulated samples collected on consecutive days. For the initial evaluation of bioassay measurement results, the result in terms of $\mu\text{g}/\text{sample}$ may be normalized to a single day's excretion using reference volumes of 1400 mL/day for males and 1000 mL/day for females.

The sensitivity of urine sampling is limited by the presence of environmental levels of uranium. As discussed previously, it is estimated that environmental levels in urine locally average $0.06 \mu\text{g}/\text{day}$ and range from $<0.03 \mu\text{g}/\text{day}$ to $0.2 \mu\text{g}/\text{day}$. The net occupationally derived uranium in urine can be approximated by subtracting $0.06 \mu\text{g}/\text{day}$ from the observed total daily excretion.

Figure 8.4 shows expected excretion rates following an acute inhalation of natural uranium resulting in a first-year effective dose equivalent of 100 mrem. Samples containing less than $0.2 \mu\text{g}/\text{day}$ of uranium are generally considered to be within the expected environmental range. As such, any result above $0.2 \mu\text{g}/\text{day}$ is considered to contain occupationally derived uranium and the net amount attributed to occupational sources is generally calculated as the total observed amount minus the average expected environmental level of $0.06 \mu\text{g}/\text{day}$. Thus, $0.14 \mu\text{g}/\text{day}$ becomes the de facto minimum detectable occupational urine excretion rate. From Figure 8.4, it can be seen that this means that acute inhalation intakes of class W material at the 100-mrem first-year effective dose equivalent level could be detected via urinalysis measurements for a year after intake. Class D intakes at this level could be detectable for about 10 months, and class Y intakes could be detectable for only about 2 months.

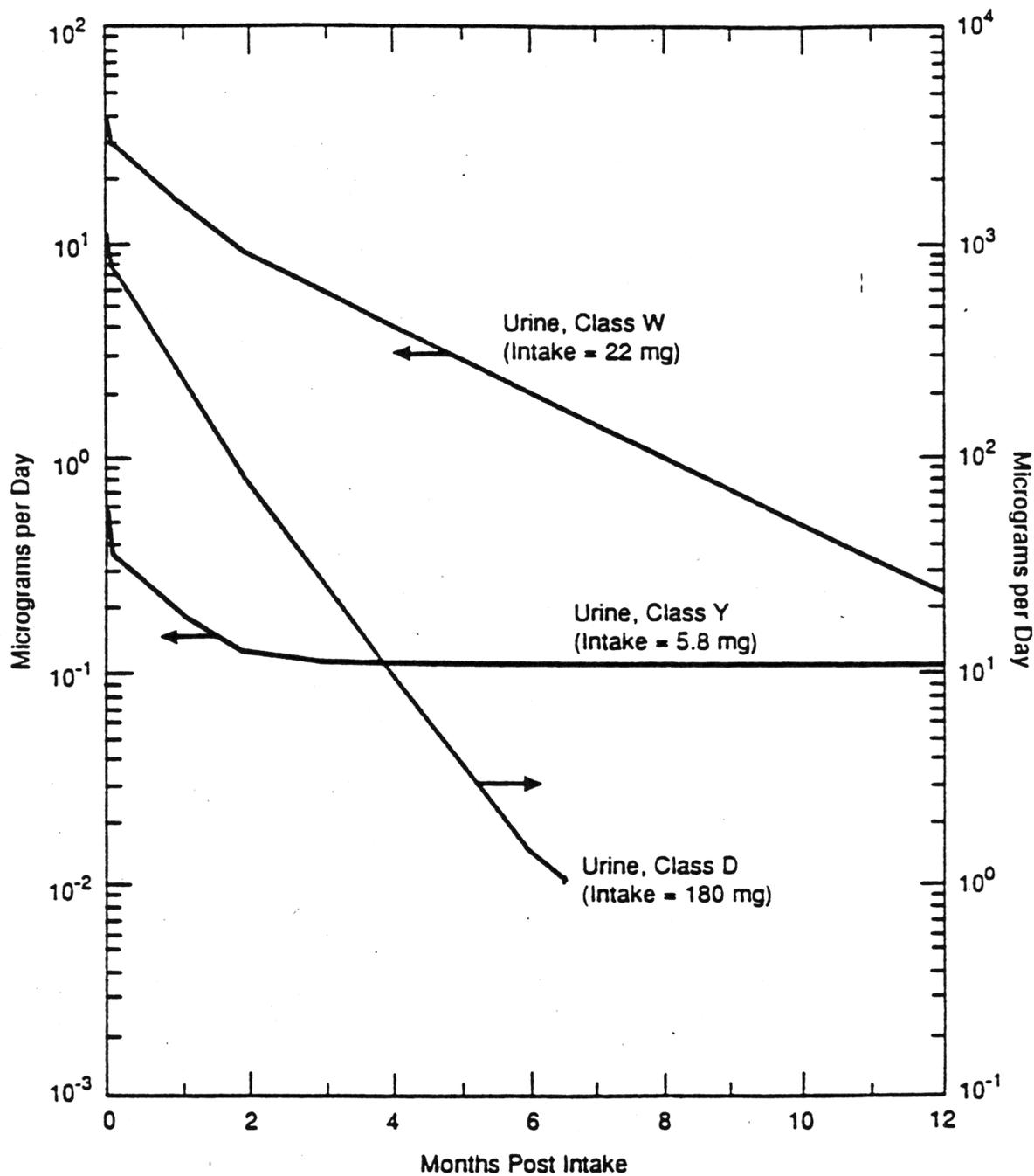


FIGURE 8.4. Net Long-Term Urinary Excretion Following an Acute Inhalation of Natural Uranium Resulting in a First-Year Effective Dose Equivalent of 100 mrem (curves exclude excretion of environmental uranium)

Of special importance in the evaluation of bioassay measurement capability is the potential for chronic intakes. Any chronic exposure subsequent to an acute intake could significantly affect the interpretation of the urinalysis measurement. In facilities where uncontained uranium is handled, urinalysis as a means for monitoring for acute intakes is acceptable, but quantitative assessment of intake or dose equivalent based on the results of routine urine samples is subject to large uncertainties. Assessment of intakes of poorly transportable uranium using urinalysis should be cautiously performed and should consider available in vivo measurement results and other information regarding the exposure.

8.4.2 Fecal Excretion Measurements

Through the application of the TGLD model (ICRP 1979; see Appendix D), estimates can be made of the expected daily fecal excretion of uranium following an inhalation intake. Clearance of uranium via feces can be divided into two components: that which represents rapid clearance from the respiratory tract and that which represents longer-term clearance from the pulmonary region and systemic circulation. For evaluation of an inhalation of slowly transportable uranium, the measurement of the quantity of uranium excreted via feces during the first few days following the intake can provide a basis for estimating the significance of the intake, when levels are below that detectable using in vivo techniques. Table 8.16 gives the ratio of intake and initial, long-term pulmonary deposition to the rapidly clearing component of the intake for three particle sizes of class Y material. The table also provides the estimated ratio between this component and the first-year effective dose equivalent. Table 8.8 (Section 8.2.3) provides fecal excretion factors for selected days post intake following an acute or chronic intake of 1- μ m-AMAD particles.

Because the quantity of uranium ingested daily through food is about 2 μ g, it is generally not practicable to use fecal sampling as a routine bioassay monitoring technique. However, it can be used effectively following incidents or for monitoring of potential intakes of enriched uranium.

TABLE 8.16. Comparison of Rapid Clearance^(a) via the Gastrointestinal Tract with Intake, Initial Long-Term Pulmonary Deposition, and First-Year Effective Dose Equivalent for Class Y Uranium

	Quantity per Nanocurie Cleared Rapidly via the GI Tract		
	<u>0.30 μm</u>	<u>1.0 μm</u>	<u>3.0 μm</u>
Intake/ Rapid Clearance	3.0 nCi	2.1 nCi	1.4 nCi
Pulmonary Deposition/ Rapid Clearance	0.76 nCi	0.31 nCi	0.11 nCi
First-Year EDE ^(b) / Rapid Clearance	130 mrem	53 mrem	18 mrem
50-Year Committed EDE/ Rapid Clearance	620 mrem	250 mrem	87 mrem

(a) Rapid clearance means complete clearance from all short-lived compartments in the respiratory tract.

(b) EDE = effective dose equivalent.

8.4.3 In Vivo Measurements

Uranium is detectable in the lung using in vivo techniques. Detection is achieved by measuring photon emissions from ^{235}U and ^{234}Th . Thorium-234 is a decay product of ^{238}U in secular equilibrium. Techniques for in vivo measurements are discussed by Palmer et al. (1990).

Table 8.17 gives the MDAs of ^{235}U and ^{238}U by some typical in vivo chest counts using an array of six germanium detectors. These MDAs are derived from the three-sigma MDA data by Palmer et al. (1990) and adjusted to the ANSI N13.30 (1989) definition of MDA (4.65-sigma). Table 8.18 shows the capability of chest counting in terms of detectable dose.

Figures 8.5 and 8.6 show the expected activity of natural and depleted uranium in the lung following an acute intake resulting in a 100-mrem annual effective dose equivalent. Figure 8.5 illustrates that in vivo counting would not be able to detect activity in the lung resulting from an acute intake of class Y uranium of 100-mrem first-year effective dose equivalent, even for a 4000-second count. Figure 8.6 shows that detection of an intake of class W

TABLE 8.17. Sensitivity of an In Vivo Chest Examination for Uranium

Count Time, sec	^{235}U , nCi	^{238}U (^{234}Th), (a) nCi
1000	0.17	2.6 (7.6 mg ^{238}U)
2000	0.12	1.8 (5.4 mg ^{238}U)
4000	0.085	1.3 (3.8 mg ^{238}U)

(a) Assuming secular equilibrium with ^{238}U .

TABLE 8.18. Sensitivity of an In Vivo Chest Count in Terms of First-Year and 50-Year Committed Effective Dose Equivalent Following Acute Inhalation of 1- μm -AMAD, Class Y Uranium^(a)

Days Post Intake	Effective Dose Equivalent, rem					
	U-Nat	First-Year		50-Year Committed		
		U-Dep	U-Rec ^(b)	U-Nat	U-Dep	U-Rec ^(b)
7	0.57	0.28	0.76	2.7	1.3	3.6
30	0.57	0.28	0.76	2.7	1.3	3.6
60	0.61	0.30	0.81	2.9	1.4	3.9
90	0.61	0.30	0.81	2.9	1.4	3.9
180	0.66	0.33	0.88	3.2	1.6	4.3
365	0.85	0.42	1.1	4.1	2.0	5.5
730	1.1	0.55	1.5	5.3	2.7	7.1
1825	2.8	1.4	3.7	13.0	6.7	17.0
Constant burden	0.66	0.33	0.88	3.2	1.6	4.3

(a) 2000-second count. Based on detection of ^{234}Th decay product of ^{238}U . The in vivo detection capability using ^{235}U will be similar for natural and recycled uranium, but much poorer for depleted uranium.

(b) Recycled uranium, specific activity of 2.0 dpm/ μg .

uranium at the 100-mrem first-year dose equivalent level is possible only for depleted uranium--and then only if the measurement was performed within a week or so of the intake. Because of the relatively rapid removal of readily transportable (class D) forms of uranium from the lung, in vivo measurements do not provide a useful bioassay technique for these materials.

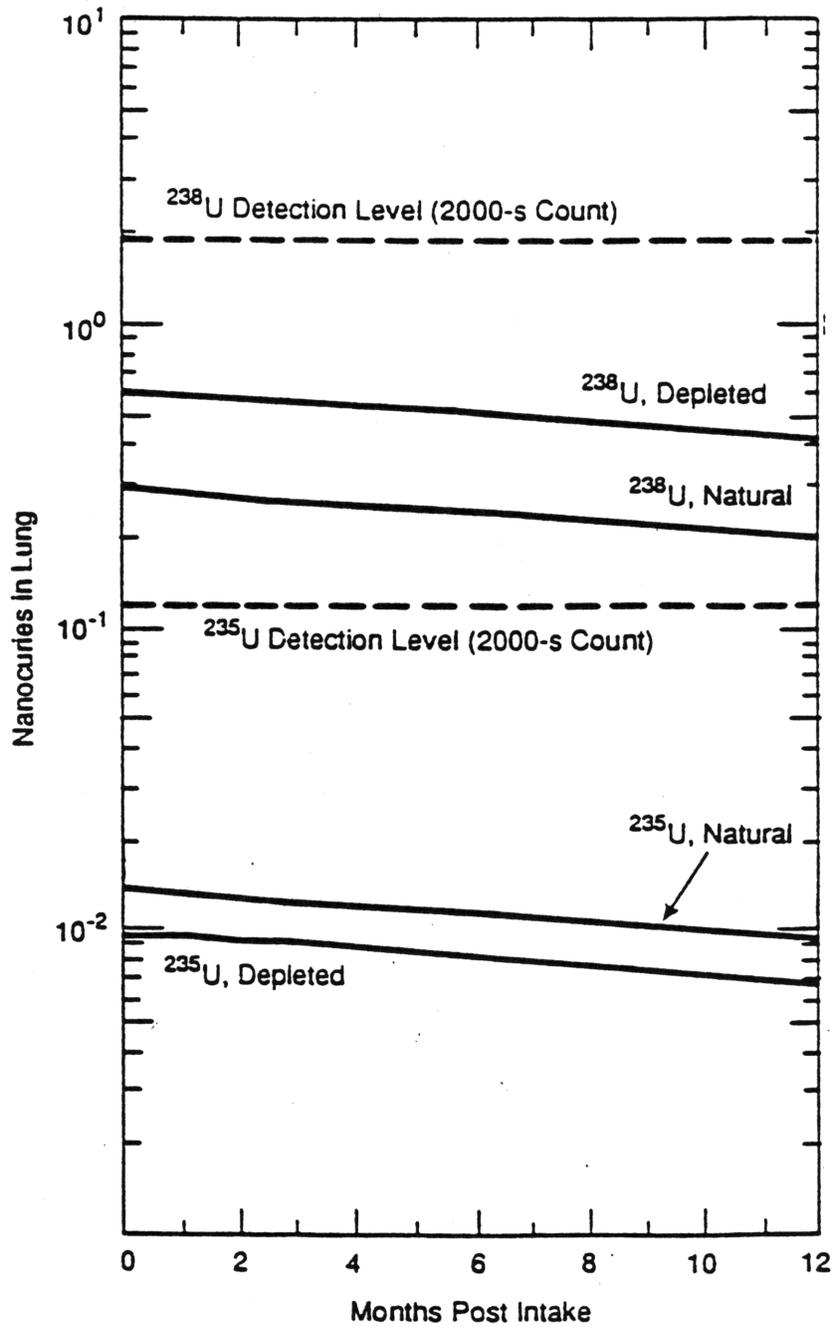


FIGURE 8.5. Predicted Long-Term Retained Quantities in the Lung Following an Acute Inhalation of Class Y Uranium Resulting in a First-Year Effective Dose Equivalent of 100 mrem

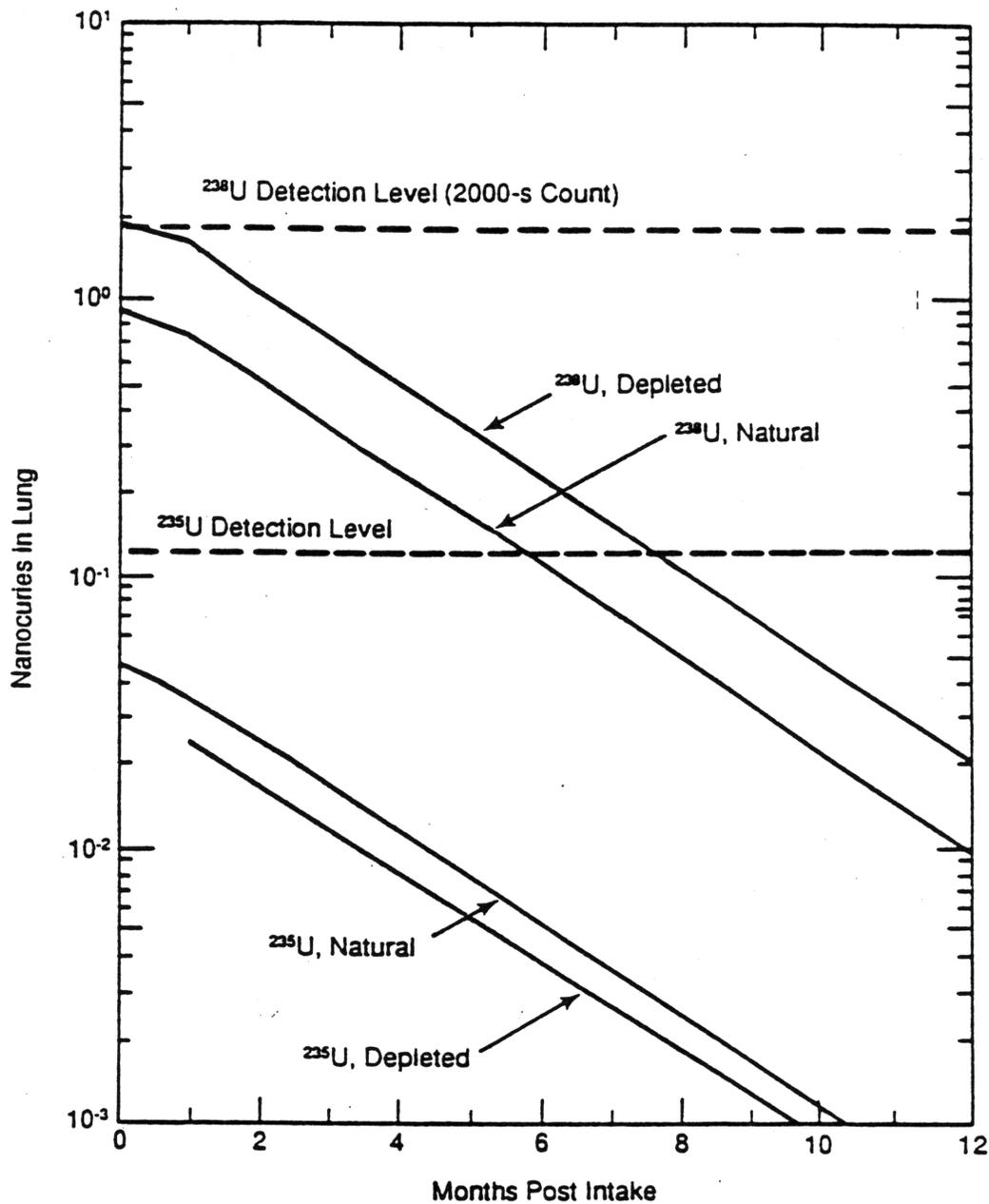


FIGURE 8.6. Predicted Long-Term Retained Quantities in the Lung Following an Acute Inhalation of Class W Uranium Resulting in a First-Year Effective Dose Equivalent of 100 mrem

In vivo measurements of ^{235}U and ^{234}Th are used as indicators of natural and recycled uranium based on the isotopic compositions shown in Table 8.3. These compositions and the MDAs of Table 8.17 show that ^{234}Th is a more sensitive indicator of natural uranium than ^{235}U and a comparably sensitive

indicator of recycled uranium. These two results, obtained from a single in vivo chest measurement, can be used as independent verification of the presence of uranium, or alternatively as a method of identifying potential false-positive detections. For example, the relative isotopic activity abundance of ^{238}U to ^{235}U for a mixture can be multiplied by the detected amount of ^{235}U . This result (the ^{238}U implied by the ^{235}U measurement) can then be compared with the ^{234}Th (assumed to be in equilibrium with the ^{238}U) to determine if the measurements reasonably agree.

8.4.4 Routine Bioassay Monitoring Program

The preceding section discusses the capabilities and limitations of bioassay for uranium in terms of limits of detection and interpretation of results. In particular, it is evident that current routine bioassay measurement programs are generally not sensitive enough for desired prospective monitoring for poorly transported forms of uranium. As such, it is generally necessary to rely on workplace monitoring to detect potential internal exposures. Follow-up urine and fecal sampling, initiated promptly upon indication of a potential internal exposure, can detect intakes resulting in a first-year effective dose equivalent of 100 mrem. Routine bioassay monitoring should thus be considered to supplement the facility monitoring program and provide backup verification that significant (relative to the occupational exposure standards) internal exposures are not occurring.

Table 8.19 summarizes routine bioassay monitoring capabilities based on radiological considerations for several monitoring frequencies when it can be assumed that exposures will be acute and infrequent. The doses shown are for natural uranium; however, capabilities for both depleted and recycled uranium can be easily obtained as described in the footnotes to the table. Table 8.19 gives routine monitoring capabilities for readily transportable uranium based on consideration of chemical toxicity. The values in Table 8.20 are independent of specific activity or impurity radionuclide levels.

In vivo measurements are the preferred routine bioassay monitoring method for poorly transportable (class Y) forms of uranium, because they measure the lung deposition directly and because urine samples are easily biased by low level intakes of relatively soluble uranium. However, due to the

TABLE 8.19. Routine Bioassay Monitoring Capabilities for a Single Acute Inhalation of Natural Uranium^(a)

Inhalation Class	Type of Measurement	Frequency	Detectable Effective Dose Equivalent	
			First-Year	50-Yr Committed
Y	In vivo ^(b)	Annual	850 mrem	4100 mrem
		Semiannual	660 mrem	3200 mrem
		Quarterly	610 mrem	2900 mrem
	Urinalysis ^(c)	Monthly	570 mrem	2700 mrem
		Annual	125 mrem	600 mrem
		Semiannual	125 mrem	600 mrem
		Quarterly	125 mrem	600 mrem
		Monthly	70 mrem	340 mrem
		Biweekly	40 mrem	190 mrem
W	In vivo ^(b)	Quarterly	670 mrem	740 mrem
		Monthly	360 mrem	400 mrem
	Urinalysis ^(c)	Annual	69 mrem	76 mrem
		Semiannual	7 mrem	8 mrem
		Quarterly	2 mrem	2 mrem
		Monthly	<1 mrem	<1 mrem
D	In vivo Urinalysis ^(d)	Not Recommended		
		Quarterly	4 mrem	14 mrem
		Bimonthly	1 mrem	3 mrem
		Monthly	<1 mrem	1 mrem
		Biweekly	<1 mrem	<1 mrem
		Weekly	<1 mrem	<1 mrem

(a) This is a summary table for natural uranium. Bioassay capabilities for depleted and recycled uranium can be easily derived from the information in this table as follows:

- for depleted uranium, multiply the doses in the table by 0.5.
- for recycled uranium, multiply the doses in the table by:
 - 1.5 for class D
 - 1.4 for class W
 - 1.3 for class Y

These factors account for impurity radionuclides in recycled uranium as well as for specific activity differences in natural, depleted, and recycled uranium.

(b) 2000-second chest count.

(c) Sample is a simulated 24-hour excretion. Threshold of detection is 0.14 $\mu\text{g}/\text{day}$, based on the assumption that daily excretion greater than 0.2 μg can be attributed primarily to occupationally derived sources and that 0.06 μg is the average daily environmental uranium in urine.

(d) Sample is a simulated 12-hour excretion. The minimum detectable activity is 1 $\mu\text{g}/\text{day}$.

TABLE 8.20. Routine Urinalysis Monitoring Capabilities for a Single Acute Intake of Class D Uranium in Percent of the Threshold for Acute Toxicity (TAT)^(a,b)

<u>Sample Frequency</u>	<u>Percent TAT</u>
Quarterly	50
Bimonthly	17
Monthly	4
Biweekly	1
Weekly	<1

(a) Based on a minimum detectable daily excretion of 1 μ gU/d.

(b) TAT is a acute uptake to blood of 7 mgU.

limited ability to detect uranium in vivo, urinalysis is useful as a supplementary method and is recommended when in vivo measurements are unable to detect exposures at the 100-mrem/yr level.

The interpretation of routine urinalysis measurements is highly dependent on the nature of the intake, i.e., low-level chronic exposure conditions significantly affect the interpretation of bioassay measurements. Chronic exposure to uranium occurs in the UO3 Plant, FPF, and the 306-W Building, and therefore it is difficult to use urine sampling as the standard routine bioassay monitoring technique for acute intakes in these facilities. Instead, bioassay programs for these facilities are developed based on the assumption of chronic exposure and are described in Section 8.7. In other cases, it can be generally assumed that chronic exposures do not occur; i.e., that intakes are acute.

8.4.5 Bioassay Measurements Following a Potential Acute Intake

Bioassay monitoring should be initiated promptly upon indication that a potential acute intake has occurred. The primary consideration in determining the appropriate measurements is the mode of intake and the clearance rate of the material from the initial deposition site. For readily transportable materials, urine sampling to determine kidney burden is required. For slowly

transportable material, in vivo measurements and collection of early fecal excretion are necessary. For unknown forms or mixtures with a range of transportabilities, both urine and fecal samples are recommended in addition to lung counts.

For potential intakes of readily transportable forms of uranium, a urine sample should be collected and analyzed within 12 hours of the intake. If preliminary information indicates that a significant intake was likely, the contractor should be advised to contact HEHF Occupational Medicine promptly for medical support. (See also Section 8.6.)

8.5 ASSESSMENT OF INTERNAL DOSE

Internal dose assessment can be performed for acute or chronic intakes using the methods described in Section 8.5.1. The kidney burden and potential chemical toxicity associated with uranium intakes are discussed in Section 8.5.2.

8.5.1 Assessment of Dose Equivalent

Assessment of internal dose equivalents from intakes of uranium is preferably based on evaluation of bioassay measurements. The choice of bioassay measurement depends on consideration of the transportability of the inhaled material and the nature of the exposure. Generally, urinalysis measurements are most indicative of systemically deposited uranium, and in vivo measurements provide a measure of lung burden. The potential for mixed chronic and acute intakes complicates the interpretation of available data and must be carefully considered during the evaluation process.

Experience has shown that actual uranium exposures usually involve varying mixtures of inhalation classes and particle sizes that are not adequately represented by a single classification. If there is no basis for establishing the inhalation class and particle size characteristics of the intake, then it is prudent to assume a class Y material with a particle AMAD of 1 μm for evaluation of dose equivalent. Evaluations of potential for renal damage, based on urinalysis, are relatively insensitive to transportability and particle variations. If either the threshold for toxicity or an annual effective

dose equivalent of 100 mrem is exceeded, simplifying assumptions should be reviewed for their appropriateness and additional bioassay and other measurements should be performed, as necessary, to improve the quality of the assessment.

Special care should be taken to account for the isotopic composition of the uranium. For example, the dose equivalent for an intake of recycled uranium, such as is present at the N Reactor FPF, will exceed the dose equivalent from an equal mass of natural uranium by about 33% because of the higher specific alpha activity. Impurity radionuclides present in the recycled uranium can also increase the magnitude of the internal dose received, particularly for soluble forms of uranium. Section 8.7 provides facility-specific uranium dosimetry data for the UO3 Plant, the N Reactor FPF, and the 306-W Building.

Tables and graphs provided in this section have been constructed using the ICRP 30 model for uranium biokinetics and thus can be used to convert bioassay measurement results to intake and first-year or committed effective dose equivalent. Although the tables and figures are sufficient for evaluating lower-level intakes and those that are relatively straightforward, additional computing capability may be necessary for more complex evaluations, particularly when bioassay data indicate that distribution and retention patterns deviate from the standard model. In this case, evaluations are performed using the computer code GENMOD (see Appendix A). GENMOD parameters are set up according to the ICRP 30 biokinetic model for uranium; however, the code provides the capability to change model parameters based on bioassay measurement results. Deviations from the standard ICRP model are documented in the assessment.

Dose assessments include annual and committed effective dose equivalents, as well as dose equivalents to specific organs of concern based on the criteria discussed in the Hanford Internal Dosimetry Program Manual.^(a) (See

(a) Pacific Northwest Laboratory. 1989. Hanford Internal Dosimetry Program Manual. PNL-MA-552, Richland, Washington.

also Appendix B.) Dose factors for organs receiving the greatest dose equivalent following intake are provided in Table 8.11.

The following subsections provide additional guidance for assessment of internal dose equivalents for acute and chronic exposures.

Acute Exposure

Acute exposures are best assessed through the performance of bioassay measurements beginning shortly after the intake. It is important that any additional exposure to uranium, even low-level chronic intakes, be avoided during the period of bioassay monitoring following an acute intake. Interpretation of excreta data is highly susceptible to errors introduced by subsequent intakes and thus, if the possibility of continued exposure cannot be ruled out, all excreta sample data collected following an acute intake must be considered to be potentially biased.

Acute intakes of readily transportable forms of uranium are best evaluated through collection and analysis of follow-up urine samples. Samples collected after the unabsorbed fraction is eliminated from the body provide the best estimate of systemically deposited material. Table 8.7 (Section 8.2.3) lists urine excretion fractions for selected times following an acute intake.

In vivo measurements of lung activity provide the most direct basis for the assessment of internal dose equivalent for moderately or poorly transportable forms of uranium. Multiple measurements of internal activity provide a measure of the pulmonary retention for the specific exposure case; however, the initial assessment of intake, based on a single in vivo measurement can be made using Figure 8.4 or 8.5, for class Y or class W uranium, respectively, or the retention factors of Table 8.6 (Section 8.2.3).

Although intakes of poorly transportable uranium are preferably assessed using direct (in vivo) bioassay measurements, most acute intakes of such material will be below the sensitivity of in vivo measurement techniques. The collection and analysis of fecal samples within the first week provides an alternative indicator of activity deposited in the respiratory tract. It is difficult to obtain all fecal matter representing the rapidly clearing component from the lung to the GI tract, and normalizing available fecal sample

data to account for partial collection may be required. Sample collections over 24-hour intervals should be normalized, as appropriate, to a total daily expected excretion of 135 g for males and 110 g for females if the mass is less than 60 g, unless it is known that the samples account for the total 24-hour excretion or there is a basis for otherwise determining total 24-hour excretion. Samples for three to five 24-hour intervals following the intake are advised to avoid the uncertainties associated with single samples. Normalization to the total expected excretion during the period of rapid clearance is necessary, unless it is known that all early clearance has been intercepted. Table 8.21, which shows the daily expected excretion immediately following an inhalation of a 1- μm -AMAD class Y particulate, provides a basis for accounting for the fact that only a part of the early clearance is collected by the follow-up sampling program. Dividing the early clearance phase into 24-hour intervals and attributing normalized daily excretions to the intervals, as appropriate, enable an estimate of the total early clearance via the GI tract to be made. A 1- μm -AMAD particle size should be assumed if no other information is available. Additional information on the collection and evaluation of fecal samples is provided in Appendix E, and Table 8.8 (Section 8.2.3) provides fecal excretion fractions for longer times post intake.

Chronic Exposure

Urinalysis is the preferred bioassay measurement technique for monitoring chronic exposures to readily transportable forms of uranium where the

TABLE 8.21. Fraction of Intake Excreted via Feces Following an Acute Inhalation of Class Y 1- μm -AMAD Uranium (Lessard et al. 1987)

<u>Days Post Intake</u>	<u>Fraction of Intake Excreted During Interval</u>	<u>Accumulated Fecal Excretion</u>
1 (0 - 24 h)	0.052	0.052
2 (24 - 48 h)	0.16	0.21
3 (48 - 72 h)	0.13	0.34
4 (72 - 96 h)	0.074	0.42
5 (96 - 120 h)	0.036	0.45
6 (120 - 144 h)	0.017	0.47

primary contribution to the effective dose equivalent is from deposition in the bone. For predominantly moderately or poorly transportable forms of uranium, the lung is the primary contributor to effective dose equivalent and in vivo chest measurements are the most direct indicator of internal dose. Because of the relatively poor sensitivity of in vivo techniques for low-enrichment uranium, the results of periodic urinalysis measurements may provide a means for estimating the magnitude of dose equivalent from chronic exposures below the sensitivity of the in vivo measurements.

Although chronic exposures are known to occur in several facilities at Hanford (UO3 Plant, N Reactor FPF, and 306-W Machine Shop), exposure levels in the facilities have historically been minimal. Simplified schemes for assessing dose equivalents from low-level chronic exposures have been developed. The simplified dose assessment procedure is based on the establishment of default assumptions regarding the exposure scenario and the interpretation of bioassay data. These assumptions are expected to result in overestimates of internal dose; however, as long as the annual effective dose equivalent is estimated below 100 mrem/yr, use of the simplified scheme is justified. If estimated doses exceed 100 mrem/yr, then review of all exposures occurring during the year and the default assumptions used in evaluating these exposures should be performed, and collection of additional bioassay and other data regarding the exposures should be considered.

Chronic exposures to moderately or poorly transportable forms of uranium will result in accumulations of uranium activity in the lung. Use of in vivo chest activity measurements provides a direct means for assessing the magnitude of the chronic exposure and the resulting dose equivalents. Urinalysis and air monitoring data can be used to help characterize the nature of the exposures. The computer code GENMOD is used to estimate intakes yielding the observed bioassay measurement results and to calculate resulting dose equivalents. Distribution and retention parameters in GENMOD may be modified to better reflect bioassay measurement results.

In cases where urinalysis data indicate chronic exposures, but in vivo measurements do not detect internal activity, the urinalysis data can be used to provide an estimate of intake; however, the uncertainty associated with

such estimates is quite high and should be modified as necessary to be consistent with in vivo measurement results. Dose equivalents from chronic exposures to uranium, based on urinalysis, can be computed using the procedure described below by assuming the following:

- Intake is by intermittent inhalation throughout the year. (If a dominating acute intake occurs, it should be assessed separately.)
- The magnitude of the intake can be approximated by the geometric mean (μg) of the daily excretion (or normalized daily excretion) rate [$M_u(t)$] based on analysis of urine samples (n) collected during the period of exposure.

$$\mu\text{g} = \text{Antilog} \left[\frac{\sum \log M_u(t)}{n} \right] \quad (8.1)$$

- Chronic exposure has continued at the current rate for at least 5 years.

Calculation of the effective dose equivalent proceeds as follows:

1. Urine samples collected during the exposure period of interest are corrected for natural background levels (see Section 8.1.3) and normalized to daily excretion rates (see Section 8.4.1) and the geometric mean is calculated.
2. The daily intake rate is estimated by applying the excretion-to-intake conversion factor from Table 8.22, according to the facility involved. This factor assumes that the exposure has been under way at the current level for the past 5 years. (This assumption is necessary because of the gradual buildup of uranium in the bone of chronically exposed individuals, and results in a slightly underestimated dose equivalent for actual chronic exposures of duration less than 5 years and a slightly overestimated dose for exposures longer than 5 years.)
3. The daily intake rate in mass units is converted to an annual intake in activity units using the data in Table 8.3, and the activities are apportioned into component inhalation classes, as appropriate considering the facility and material involved or use Table 8.14.

TABLE 8.22. Ratio of Daily Excretion to Daily Inhalation at 5 Years After the Onset of Chronic Exposure

<u>Solubility Class</u>	<u>Sample During Exposure</u>	<u>Sample After Early Clearance^(a)</u>
Class D	0.47	0.22
Class W	0.14	0.065
Class Y	0.033	0.015
UO3 Plant (80%-D, 20%-W)	0.40	0.19
333 Bldg (70%-Y, 30%-D)	0.20	0.12
303-M Bldg (90%-Y, 10%-D)	0.089	0.064
306-W Bldg (80%-Y, 20%-D)	0.12	0.060

(a) After 2 days of no exposure.

4. The committed effective dose equivalent is calculated by application of the intake dose equivalent factors for natural uranium in Table 8.11 to each inhalation component. If recycled uranium is involved, the doses should be modified to account for the presence of impurity radionuclides using the factors provided in Tables 8.12 or 8.13. The contributions from the various components are then summed.
5. If the effective dose equivalent in any year is projected to exceed 100 mrem, then the assumptions and model should be reviewed for adequacy, and additional bioassay and other data should be collected as needed to better define the exposure.

Use of the above procedure will yield a committed effective dose equivalent of 100 mrem for an average net daily excretion of 14 μg (assuming 365 days of intake and 2 days of no exposure) of UO3 Plant uranium. The procedure will yield a committed effective dose equivalent of 100 mrem (assuming 365 days of intake and 2 days of no exposure) for a net daily excretion rate of 0.48 μg of N Reactor FPF (333 Building) uranium.

8.5.2 Kidney Burden and Potential Chemical Toxicity Associated with Intakes

Kidney burdens can be assessed from urinalysis data using the following information. Table 8.23 shows the expected urinary excretion rates following an acute inhalation resulting in the uptake of 7 mg of uranium from rapidly clearing compartments of the respiratory tract, regardless of inhalation class. As previously discussed in Section 8.2.4, a 7-mg uptake of readily transportable uranium is below that considered harmful.

The average daily urinary excretion for continuous intake is related to the kidney burden as shown in Figure 8.7. This ratio varies with time, but is independent of inhalation class and particle size. For continuous exposures lasting longer than about 5 years, the ratio of the kidney burden to the average daily excretion is about 2. Thus, assuming a kidney burden of 340 μg (i.e., 1.1 $\mu\text{g/g}$; the assumed threshold level at which a chronic kidney burden may result in renal damage), the average daily excretion would be about $340/2 = 170 \mu\text{g/day}$. If exposure was halted for 2 days (such as during a

TABLE 8.23. Urinary Excretion of Uranium Following an Acute Inhalation Resulting in the Uptake of 7 mg of Uranium^(a)

<u>Days Post Intake</u>	<u>Excretion^(b)</u>	
	<u>$\mu\text{g/day}$</u>	<u>$\mu\text{g/L}$</u>
2	580	410
5	170	120
7	130	93
14	70	50
30	24	17
90	6.0	4.5
180	0.1	0.9

(a) Excluding environmental background levels in urine.

(b) Assuming a daily excretion volume of 1.4 L (ICRP 1974).

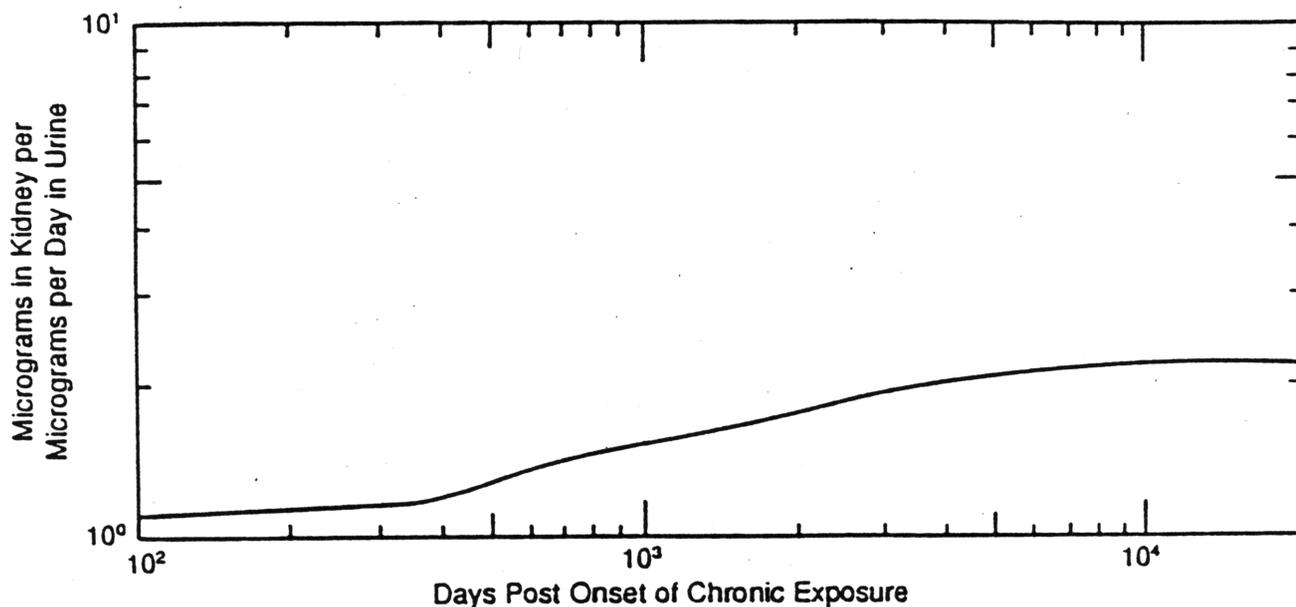


FIGURE 8.7. Ratio of Uranium in Kidneys to Daily Excretion in Urine for Chronic Exposure to Class D Uranium

weekend), the daily excretion would drop to about 85 $\mu\text{g}/\text{day}$. For class D uranium, the 340 μg kidney burden would result from prolonged intakes of about 320 $\mu\text{g}/\text{day}$.

If preliminary information indicates that an intake at the nephrotoxicity threshold was possible, investigation of the potential intake should be performed. If evidence suggests that a significant intake was likely, follow-up samples should be promptly collected and analyzed, and HEHF Occupational Medicine should be notified. Because acute damage of the kidneys is the primary consideration, kidney function tests provide the most direct and useful means of assessing the impact of the exposure. Sensitive tests for kidney damage include beta-2-microglobulin and catalase relative to creatinine (Fisher 1985). Albuminuria is also an indicator of kidney damage. Leggett (1989) and Fisher et al. (1990) have identified a number of other potentially useful tests. The decision to perform such tests is made by HEHF Occupational Medicine.

8.6 MANAGEMENT OF INTERNAL CONTAMINATION CASES

Acute intakes of uranium pose both radiological and nephrotoxicity concerns. Renal damage results in failure of the proximal tubules to reabsorb constituents filtered from the blood. Laboratory abnormalities include proteinuria, glucosuria, and increased urine output. Clinical symptoms of severe uranium poisoning may include nausea, vomiting, abdominal cramps, and diarrhea.

Urine samples should be collected within 3 to 4 hours following any potentially significant uranium uptake. As a general rule, biological indicators of kidney damage should be checked if urine concentrations exceed 2 mg/L. Clinical indicators of kidney damage include albuminuria, glucose, catalase, and beta-2 microglobulin. Urine concentrations on the order of 20 mg/L indicate serious exposure with potential life-threatening consequences and are cause for immediate medical attention (Rich et al. 1988).

Antidotal therapy for uranium poisoning includes oral administration of sodium bicarbonate. The bicarbonate promotes formation of the uranyl-bicarbonate complex, which is more rapidly excreted in urine (Fisher 1985). Ethylene diamine tetraacetic acid (EDTA) and DTPA have been used in experimental animals to increase the excretion of uranium; however, chelation therapy appears to have no beneficial effect more than 4 hours after exposure (NCRP 1980).

8.7 BIOASSAY MONITORING AND INTERNAL DOSIMETRY FOR SPECIFIC FACILITIES

Uncontained uranium is routinely handled in three Hanford facilities: the UO3 Plant in the 200 West Area, the N Reactor FPF in the 300 Area (currently in cold standby condition), and the 306-W Building Machine Shop in the 300 Area. Although exposures to uranium in these facilities are low under normal operating conditions, the interpretation of routine bioassay measurements for workers at these facilities is complex due to the potentially chronic nature of intakes. For this reason, bioassay monitoring and internal dosimetry for these facilities have been specially evaluated. The internal dosimetry for workers at each of the three facilities is discussed in the following subsections.

8.7.1 Internal Dosimetry for Workers at the Uranium Oxide Plant

This section provides the basis for bioassay monitoring of workers at the UO3 Plant in the 200 West Area, but is equally applicable to any situation in which workers are potentially exposed to readily transportable forms of uranium for which chemical toxicity is the primary consideration (i.e., less than 10% ^{235}U enrichment). The facility-specific uranium characteristics inhalation exposure conditions and bioassay monitoring program are discussed.

Characteristics of Material

The UO3 Plant receives uranium as uranyl nitrate hexahydrate from the PUREX Plant and converts this to uranium trioxide for shipment offsite. Uranium trioxide, a yellow powder, is the predominant form of uranium available for intake in the UO3 Plant. The material is slightly enriched (0.8% ^{235}U) recycled uranium with a specific activity of about 2 dpm/ μg . The material also contains impurities, principally plutonium and ^{237}Np , as described in Table 8.4. A solubility test using simulated lung fluid, performed on a smear sample from the UO3 Plant in 1984, showed the material to be approximately 80% class D and 20% class W. This is consistent with a similarly performed evaluation of uranium trioxide solubility (Morrow, Gibb, and Beiter 1972).

Inhalation of Uranium

Chemical toxicity of uranium in the UO3 Plant is the primary health consideration for internal exposure. Because complete containment of the uranium is not provided, low-level chronic exposure conditions are assumed to exist; however, acute intakes can also occur in the facility. In the case of a chronic intake, a daily inhalation of 7.9 $\mu\text{g}/\text{day}$ would result in an annual effective dose equivalent of 100 mrem after 10 years. In the case of an acute inhalation intake, the first-year and 50-year effective dose equivalents are 2.1 mrem/mg (2.3 mrem/nCi) and 3.9 mrem/mg (4.2 mrem/nCi), respectively. These dose factors assume recycled uranium as specified in Tables 8.3 and 8.4.

Bioassay Monitoring

Urine sampling is the preferred method for the routine assessment of uptakes of readily transportable uranium. However, in identified exposure situations where renal damage is possible, tests for kidney function are the most direct and meaningful way to evaluate the significance of an intake. Medical assistance should therefore be requested in cases where a significant uptake may have occurred.

To minimize the contribution of the unabsorbed fraction of uranium that is excreted immediately following an intake, it is recommended that urine samples be collected following 2 days of no exposure. Samples should thus be simulated 12-hour collections beginning at the end of a weekend.

For a bioassay monitoring program that does not rely on facility air monitoring to assess and document exposure conditions, the urine sampling program should consider potential acute intakes as well as the underlying chronic exposure expected to occur routinely at the facility. It is recommended that follow-up investigation of potential exposures be initiated if bioassay results indicate that an intake at 33% of the toxicity threshold levels established in Section 8.2.4 potentially occurred. Table 8.24 gives recommended follow-up levels for various sampling frequencies.

Assessments based on bioassay measurement results are discussed in Section 8.5.1. Table 8.25 lists the expected urinary excretion rates following inhalation intakes of UO₃ Plant uranium. Based on the chemical toxicity discussion in Sections 8.2.4 and 8.5.2, chemical toxicity would not be an issue at levels three times those indicated in Table 8.24 for acute inhalation or over 50 times those shown for chronic inhalation.

Assessments of radiological dose equivalent (any associated nephrotoxicity) should be based on an assumed chronic exposure unless evidence suggests that the bioassay result should be attributed to a single acute or short duration exposure. A review of facility air monitoring data and contamination survey data, discussions with workers, as well as additional bioassay measurements from involved workers can help in the determination of the exposure scenario.

TABLE 8.24. Recommended Follow-Up Levels for Chronic and Acute Intakes, $\mu\text{g}/\text{day}$ ^(a)

<u>Frequency</u>	<u>Follow-Up Level^(b) (33% Threshold)</u>
Weekly ^(d)	28
Biweekly	23
Monthly	8
Bimonthly	2
Quarterly	0.7

-
- (a) Sample collected following a 2-day absence from any potential uranium exposure.
- (b) Follow-up level: Internal Dosimetry will review available information to determine the potential intake scenario and will consider follow-up samples. A work restriction or limitation will be considered until appropriate follow-up measurements are made and evaluated. If it appears that a significant intake was likely, then a recommendation for the contractor to notify HEHF Occupational Medicine will be made.
- (c) Chronic exposure is limiting. For all other frequencies, an acute exposure is limiting.

8.7.2 Bioassay Monitoring and Internal Dosimetry for Workers at the 300 Area Fuel Production Facility

The N Reactor FPF in the 300 Area fabricated fuel elements for the Hanford N Reactor. The operations performed in the FPF included extrusion, cutting, grinding, and welding of fuel elements. Airborne uranium generated during these operations resulted in intermittent or chronic exposures to workers in the immediate vicinity. The primary FPF facility is the 333 Building, where all steps in the fuel element production process were performed, and where FPF workers were normally located. The 303-M Building houses "burn

TABLE 8.25. Predicted Uranium Excretion via Urine Following an Inhalation of UO₃ Plant Recycled Uranium^(a)

Days Post Intake ^(c)	Micrograms of Uranium in Urine Per Day ^(b)			
	Acute Inhalation		Chronic Inhalation	
	Intake = 4.8 mg (H _{E,1} = 10 mrem)	Intake = 2.6 mg (H _{E,50} ^C = 10 mrem)	Intake Rate = 7.9 µg/day (H _{E,10} = 10 mrem/yr) ^(d)	
			Direct + Systemic ^(e)	Systemic Only ^(f)
2	160	91	1.7	0.13
5	48	26	2.1	0.38
7	38	21	2.3	0.52
14	21	11	2.5	0.85
30	7.2	3.9	2.9	1.2
60	2.1	1.2	3.1	1.4
90	0.85	0.47	3.2	1.4
180	0.12	0.065	3.2	1.4
365	0.017	0.009	3.3	1.4
730	0.007	0.003	3.3	1.4

- (a) Assumes uranium trioxide, 80% class D, 20% class W; recycled uranium includes impurities at concentrations shown in Table 8.4.
- (b) Excludes environmental background levels in urine.
- (c) Days post acute intake or post onset of chronic intake.
- (d) Annual effective dose equivalent rate = 10 mrem/yr after 10 years of continuous intake.
- (e) Includes all excretion pathways.
- (f) Excludes uranium excreted directly from blood; representative of levels that would be expected several days after cessation of chronic exposure.

boxes" where metal uranium scrap fines from the production facility were oxidized prior to shipment offsite. The 303-M Building was only used intermittently and is generally not occupied by workers. Bioassay monitoring programs are thus based on uranium that is characteristic of the 333 Building. However, data are also provided for uranium that is characteristic of the 303-M Building.

The facility-specific uranium characteristics, dose equivalent from intakes, and bioassay monitoring program are discussed in the following subsections.

Characteristics of Material

Uranium in the FPF is recycled and is composed of the isotopic mixtures shown in Table 8.3. The specific alpha activity for recycled uranium (FPF-RU) is 2.0 dpm/ μ g (0.92 μ Ci/g), or about 1.33 times the specific alpha activity of natural uranium.

Aerosols generated during the machining and oxidizing of metallic uranium are composed of various oxides of uranium including UO_2 and U_3O_8 , as well as other forms. The degree to which various oxides are created depends on the heat generated by the pyrophoric combustion of uranium fines--with high temperatures resulting in the generation of more insoluble particulates. Insoluble oxides of uranium tend to be retained in the lung and are poorly absorbed by the circulatory system; however, the degree of retention depends on the particular oxide compound. Estimates of the retention characteristics of uranium particulates in the lung were made by studying the in vitro dissolution, in simulated lung fluid, of the uranium-bearing particulates from room air samples collected in the 303-M and 333 Buildings. The study found that the uranium should be considered to be a mixture of readily transportable and slowly transportable material represented by the ICRP's TGLD inhalation classifications (ICRP 1979) as given in Table 8.26.

The particle size distribution of airborne uranium particulates at locations in the 303-M and 333 Buildings was measured using a nine-stage cascade impactor air sampler. The samples were collected during normal operations. A sampler was located near the room air sampler between the two sets of "burn boxes" in the 303-M Building and near the De Sanno saw in the 333 Building. The results of the measurements indicated that in both cases the majority of the particulates was deposited on the first stage of the impactor representing

TABLE 8.26. In Vitro Solubility Classification of Uranium in the N Reactor Fuel Production Facility

<u>Building</u>	<u>Class D</u>	<u>Class Y</u>
303-M	10%	90%
333	29%	71%

particles with an AMAD of greater than 8.35 μm . The distribution of particle sizes was not lognormal. Therefore, the regional deposition in the respiratory tract was estimated by applying deposition fractions for monodisperse aerosols to the mass of uranium collected on each stage of the cascade impactor air sampler, based on information provided in International Atomic Energy Agency (IAEA) Technical Report 142 (1973). Table 8.27 summarizes the resulting deposition fractions calculated for the airborne particulates in the 303-M and 333 Buildings. The distribution in the respiratory tract must be considered when evaluating excretion bioassay data, but the dose per unit intake is the same as for a 1- μm -AMAD particulate.

Dose Equivalent from Intakes

Table 8.14 shows the first-year and 50-year committed effective dose equivalent from an acute inhalation of 1 mg of 303-M and 333 Building uranium. The doses were calculated based on retention functions given in ICRP 30 and assuming a pulmonary deposition of 25% of the intake (see Table 8.27). The lung accounts for essentially all of the effective dose equivalent received following inhalation exposures to these materials. Activity-to-dose conversion was performed using the SEE values in ICRP 30, weighted for the relative activities of the various isotopes in the mixture.

From Table 8.14, it can be calculated that an acute intake of about 1 mg of 303-M Building uranium or about 1.3 mg of 333 Building uranium could result in a 50-year committed effective dose equivalent of 100 mrem.

Table 8.28 shows, for different exposure periods, the daily intake rate of uranium that would cause a sufficient quantity of buildup in the lung to

TABLE 8.27. Expected Deposition Fractions for Airborne Uranium Particulates in the 303-M and 333 Buildings

<u>Region</u>	<u>Deposition Fraction</u>	
	<u>303-M</u>	<u>333</u>
Nasal-pharyngeal	0.67	0.53
Tracheal-bronchial	0.08	0.08
Pulmonary	0.25	0.25

TABLE 8.28. Daily Intake Rate of Uranium Yielding an Annual Effective Dose Equivalent Rate of 100 mrem/yr^(a) by the End of the Intake Period

Exposure Period, yr	Milligrams of Uranium Per Day	
	303-M (10% D, 90% Y)	333 (30% D, 70% Y)
1	0.012	0.016
2	0.0074	0.0093
5	0.0043	0.0055
10	0.0037	0.0047
20	0.0032	0.0041
50 ^(a)	0.0027	0.0035

(a) Lung dose equivalent rate = 830 mrem/yr.

(b) Intakes at this rate for one year will result in a 50-year committed effective dose equivalent of 100 mrem.

result in a 100-mrem/yr effective dose equivalent. For example, a daily intake of 0.0035 mg of 333 Building uranium would result in a gradual buildup of lung activity sufficient to produce a 100-mrem/yr effective dose equivalent rate after 50 years of exposure. Conversely, this intake rate, if maintained for 1 year, would result in a 50-year committed effective dose equivalent of 100 mrem.

Using the ICRP 30 model and assuming the particle-size distribution and inhalation classifications observed in samples collected in the 333 Building (30% class D, 70% class Y), the assumed renal toxicity threshold for an acute uptake is calculated to be reached following an acute inhalation of about 30 mg. Similarly, a chronic intake of about 0.2 mg/day of 333 Building uranium would eventually (after about 50 years) result in a retained quantity in the kidney at the assumed renal toxicity threshold.

Bioassay Monitoring

Bioassay monitoring for slowly transportable materials, for which the lung is the critical organ, is most directly and accurately performed through in vivo measurements; however, the sensitivity of in vivo measurements is somewhat limited as discussed below.

In view of the limitations of in vivo measurements as a routine monitoring technique, urine sampling is also performed. Urine samples provide a measure of the systemically deposited uranium, and, using biokinetic models, this enables an indirect estimate of intake to be made. However, the interpretation of urine sample data is highly dependent on the nature of the intake; that is, whether acute, intermittent, or chronic.

In Vivo Measurements. Table 8.17 gives estimated in vivo measurement capabilities for the slightly enriched, class Y uranium, representative of the type of material in the FPF facilities. Based on these detection limits, the sensitivity of a 2000-second chest count is about 22% of the annual effective dose equivalent standard of 5 rem at 1 year after an acute exposure, and about 18% of the standard for a constant lung burden. Extending the counting time to 4000 seconds increases the sensitivity for the two cases to about 15% and 12%, respectively.

An annual chest count is recommended for workers potentially exposed to poorly transportable forms of uranium. Any indication of uranium in the body via in vivo monitoring warrants follow-up investigation including additional in vivo measurements and urine samples. Positive in vivo measurements should be confirmed as soon as practical, and additional measurements should be performed as long as the uranium remains detectable.

Urinalysis. Figures 8.8 and 8.9 and Tables 8.29 and 8.30 show the urinary excretion following acute and chronic exposures to FPF recycled uranium. The predicted excretion values are based on an assumed acute intake that would result in a first-year effective dose equivalent of 100 mrem (a lung dose of 830 mrem) and an assumed chronic inhalation rate that would result in an effective dose equivalent rate of 100 mrem/yr after 10 years of continuous intake. The values do not include environmental uranium in the urine. The derived intake rates are 0.0037 mg/day for 303-M Building uranium and 0.0047 mg/day for 333 Building uranium. For 50 years of chronic exposure, the intake rates to produce a 100-mrem/yr effective dose equivalent after the 50 years are 0.0027 mg/day for the 303-M Building and 0.0035 mg/day for the 333 Building, and the expected excretion rates would thus be about 75% of those shown in Figures 8.8 and 8.9.

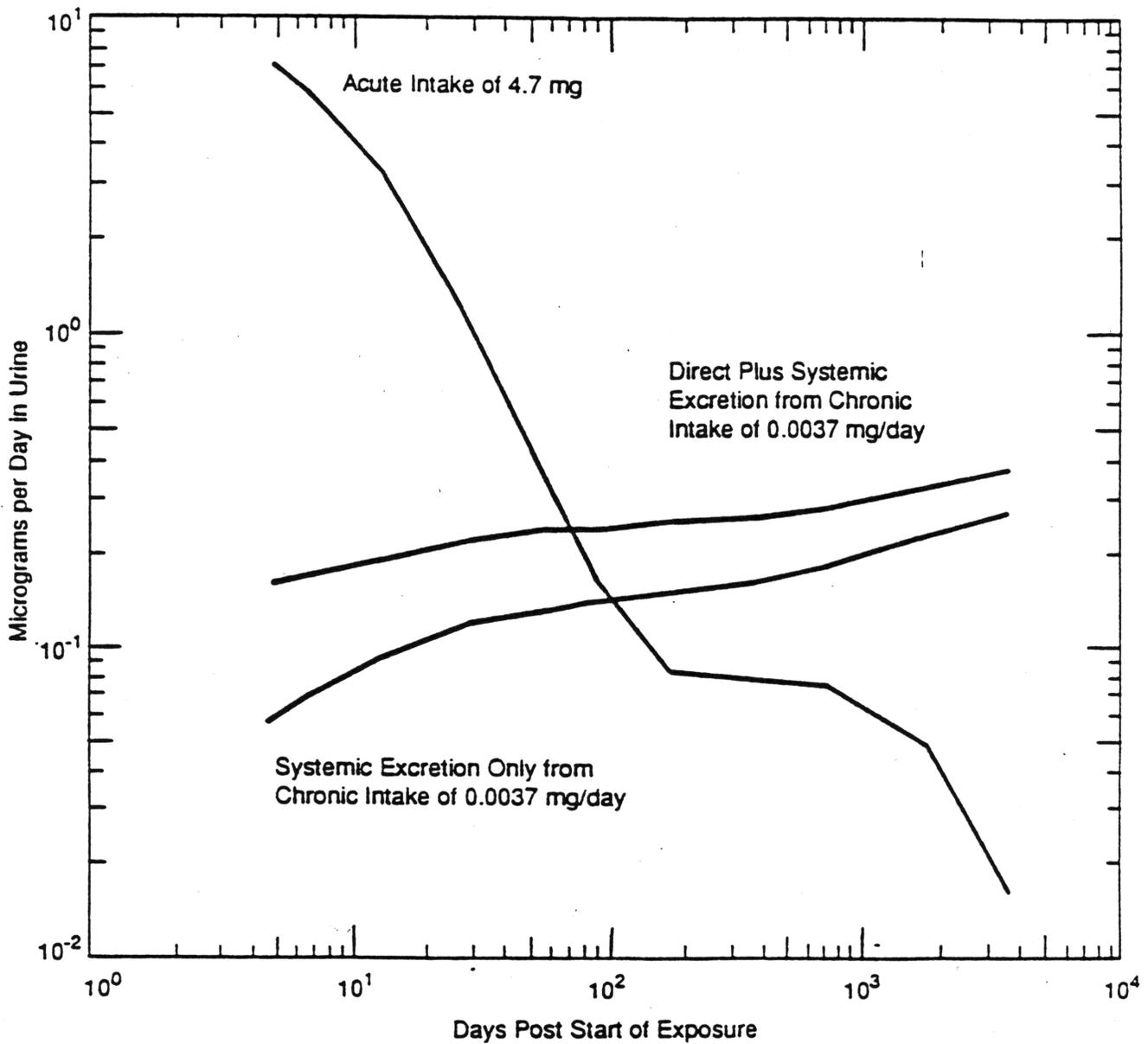


FIGURE 8.8. Predicted Urinary Excretion Following an Inhalation of 303-M Building Uranium Resulting in a First-Year Effective Dose Equivalent of 100 mrem (Curves exclude excretion of environmental uranium)

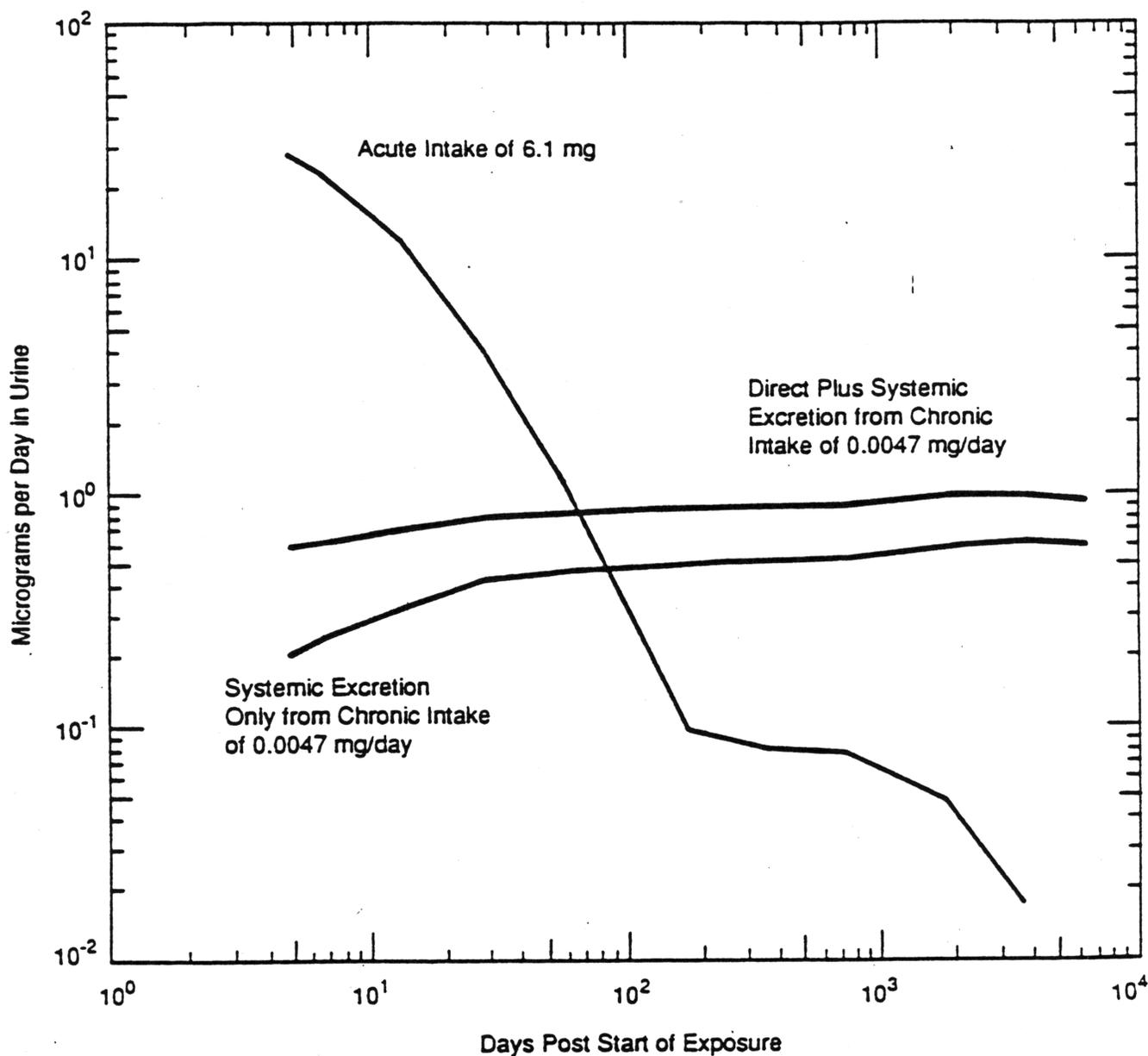


FIGURE 8.9. Predicted Urinary Excretion Following an Inhalation of 333 Building Uranium Resulting in a First-Year Effective Dose Equivalent of 100 mrem (Curves exclude excretion of environmental uranium)

TABLE 8.29. Predicted Uranium Excretion via Urine Following an Inhalation of 303-M Building Uranium^(a)

Days Post Intake ^(c)	Micrograms of Uranium Per Day Via Urine ^(b)		
	Acute Inhalation Intake = 4.7 mg [H _{E,1} = 100 mrem]	Chronic Inhalation	
		Intake Rate = 0.0037 mg/day [H _{E,10} = 100 mrem/yr] ^(d)	
		Direct + Systemic ^(e)	Systemic Only ^(f)
5	7.1	0.16	0.058
7	5.7	0.17	0.069
14	3.1	0.19	0.094
30	1.1	0.22	0.12
60	0.34	0.24	0.13
90	0.17	0.24	0.14
180	0.082	0.25	0.15
365	0.079	0.26	0.16
730	0.074	0.28	0.18
1825	0.047	0.33	0.23
3650	0.016	0.37	0.27

- (a) Assumes 90% class Y, 10% class D; recycled uranium with impurity radionuclides as shown in Table 8.4.
- (b) Excludes environmental background levels in urine.
- (c) Days post acute intake or post onset of chronic intake.
- (d) Annual effective dose equivalent rate = 100 mrem/yr after 10 years of continuous intake.
- (e) Includes all excretion pathways.
- (f) Excludes uranium excreted directly from blood; representative of levels that would be expected several days after cessation of chronic exposure.

Two levels have been developed for interpretation of urine samples from FPF workers. A screening level is defined as the excretion rate that exceeds that expected due only to environmental sources. This level is 0.2 $\mu\text{g}/\text{day}$ as discussed in Section 8.1.3. Workers exceeding the screening level should be maintained on a quarterly urinalysis frequency and their dose should be assessed annually.

The second level is the net occupational excretion rate expected following chronic exposures in excess of the 100-mrem/yr effective dose equivalent.

TABLE 8.30. Predicted Uranium Excretion via Urine Following an Inhalation of 333-M Building Uranium^(a)

Days Post Intake ^(c)	Micrograms of Uranium Per Day Via Urine ^(b)		
	Acute Inhalation Intake = 6.1 mg [H _{E,1} = 100 mrem]	Chronic Inhalation	
		Intake Rate = 0.0047 mg/day [H _{E,10} = 100 mrem/yr] ^(d)	
		Direct + Systemic ^(e)	Systemic Only ^(f)
5	28	0.58	0.20
7	22	0.62	0.24
14	12	0.70	0.32
30	4.0	0.79	0.42
60	1.1	0.83	0.46
90	0.44	0.85	0.48
180	0.097	0.87	0.50
365	0.082	0.88	0.51
730	0.077	0.90	0.52
1825	0.049	0.97	0.59
3650	0.018	1.0	0.63

- (a) Assumes 70% class Y, 30% class D; recycled uranium with impurity radionuclides as shown in Table 8.4.
- (b) Excludes environmental background levels in urine.
- (c) Days post acute intake or post onset of chronic intake.
- (d) Annual effective dose equivalent rate = 100 mrem/yr after 10 years of continuous intake.
- (e) Includes all excretion pathways.
- (f) Excludes uranium excreted directly from blood; representative of levels that would be expected several days after cessation of chronic exposure.

This level is calculated to be 0.63 $\mu\text{g/day}$ for 333-Building uranium, assuming that the exposure has been occurring for 10 years. If this level is exceeded, then an investigation into the nature of the exposure is warranted. Additional follow-up bioassay measurements should be performed to confirm the nature and magnitude of the intake and the resulting dose equivalent should be assessed. In addition, it should be noted that an annual average excretion rate of 0.42 $\mu\text{g/day}$ (net after 2 days of no exposure) will result in a committed effective dose equivalent of 100 mrem.

8.7.3 Internal Dosimetry for Workers at the 306-W Building

The 306-W Building houses a machine shop where depleted uranium-titanium rods are handled. Machining operations conducted in the shop include cutting, milling, grinding, and lathing. Possible internal uranium exposure conditions exist in the shop due to the generation of airborne particulates during the machining operations.

Characteristics of Material

Depleted uranium in the 306-W Building Machine Shop is represented by the isotopic mixture shown in Table 8.3. Depleted uranium contains approximately one-half of the specific activity ($0.36 \mu\text{Ci/g}$) of natural uranium. The isotope ^{238}U accounts for about 92% of the activity in a given quantity of depleted uranium.

Aerosols generated during machining of the metallic uranium-titanium rods are composed of various oxides including UO_2 , U_3O_8 , and other forms. The degree to which various oxides are created is related to the heat generated by the combustion of uranium fines--with high temperatures tending to result in the generation of more insoluble particulates. Inhaled insoluble oxides of uranium tend to be retained in the lung and poorly absorbed by the circulatory system; however, the degree of retention depends on the particular oxide compound. An estimate of the retention characteristics of uranium particulates in the lung was made by observing the in vitro dissolution of the uranium-bearing particulates from air samples collected in the shop in simulated lung fluid. The study found that the uranium in the shop should be considered to be a mixture of readily and slowly transportable material represented by the ICRP 30 inhalation classifications as 20% class D and 80% class Y.

Dose Equivalent from Intakes

Table 8.31 shows the first-year and 50-year committed doses to the lung, bone surfaces, kidneys, and the effective dose equivalent following the acute inhalation of 1 mg of 306-W depleted uranium. The doses were calculated using retention functions given in ICRP 30 for a $1\text{-}\mu\text{m-AMAD}$ particle size. Activity-to-dose conversion was performed using SEE values in ICRP 30, weighted for relative activities of the various uranium isotopes.

TABLE 8.31. First-Year and 50-Year Committed Dose Following an Acute Inhalation of 1 mg of 306-W Depleted Uranium

<u>Organ</u>	<u>Dose Equivalent, mrem</u>	
	<u>First-Year Dose</u>	<u>50-Year Dose</u>
Lung	57	270
Bone Surfaces	0.017	1.0
Kidney	0.052	0.43
Effective	6.9	33

Based on the data in Table 8.31, it can be calculated that an acute inhalation intake of about 3 mg of 306-W uranium would be expected to result in a 50-year committed effective dose equivalent of 100 mrem.

Table 8.32 shows the daily intake rate of 306-W depleted uranium that would result in a sufficient buildup in the lung to cause a 100-mrem/yr dose rate for different intake periods. For example, a daily intake of 0.0083 mg of 306-W uranium would result in the gradual buildup in lung activity sufficient to produce a 100-mrem/yr dose rate by the end of 50 years. Conversely,

TABLE 8.32. Daily Intake Rate of Depleted Uranium Yielding an Effective Dose Equivalent^(a) of 100 mrem/yr by the End of the Exposure Period

<u>Exposure Period,</u> <u>yr</u>	<u>Intake Rate, mg/day</u> <u>306-W Mixture</u>
1	0.039
2	0.023
5	0.014
10	0.011
20	0.0098
50 ^(b)	0.0083

(a) Lung dose = 830 mrem.

(b) Intakes at this rate for 1 year will result in a 50-year committed effective dose equivalent of 100 mrem.

this intake rate, if maintained for 1 year, would result in a 50-year committed effective dose equivalent of 100 mrem.

Bioassay Monitoring

Intakes by 306-W workers are considered to be chronic unless otherwise indicated by workplace monitoring. Bioassay monitoring for slowly transportable materials for which the lung is the critical organ is most directly and accurately performed using in vivo measurements; however, the sensitivity of in vivo measurements is somewhat limited as discussed below.

In view of the limitations of in vivo measurements as a routine monitoring technique, urine sampling is also performed. Urine samples provide a measure of the systemically deposited uranium, and, using biokinetic models, this enables an indirect estimate of intake to be made. However, the interpretation of urine sample data is highly dependent on the nature of the intake; that is, whether it is acute, intermittent, or chronic.

In Vivo Measurements. Table 8.18 gives practical routine in vivo measurement capabilities for depleted uranium based upon the in vivo measurement detection levels in Table 8.17. At these levels, an annual chest count (2000-seconds) is capable of detecting an internal exposure to class Y depleted uranium of about 8% of the annual effective dose equivalent standard of 5 rem for an acute exposure, and about 7% of the standard for a constant burden. Increasing the length of the count to 4000 seconds will increase the sensitivity of the count to about 6% of the standard.

An annual chest count is recommended for workers who are potentially exposed to poorly transportable forms of uranium. Any indication of uranium in the body via in vivo monitoring warrants follow-up investigation including additional in vivo measurements and urine samples. Positive in vivo measurements should be confirmed as soon as practical, and additional measurements should be performed at least quarterly as long as the uranium remains detectable.

Urine Sampling. Figure 8.10 and Table 8.33 show the urinary excretion following acute and chronic exposures to 306-W depleted uranium. The predicted excretion values are based on an assumed acute intake that would result

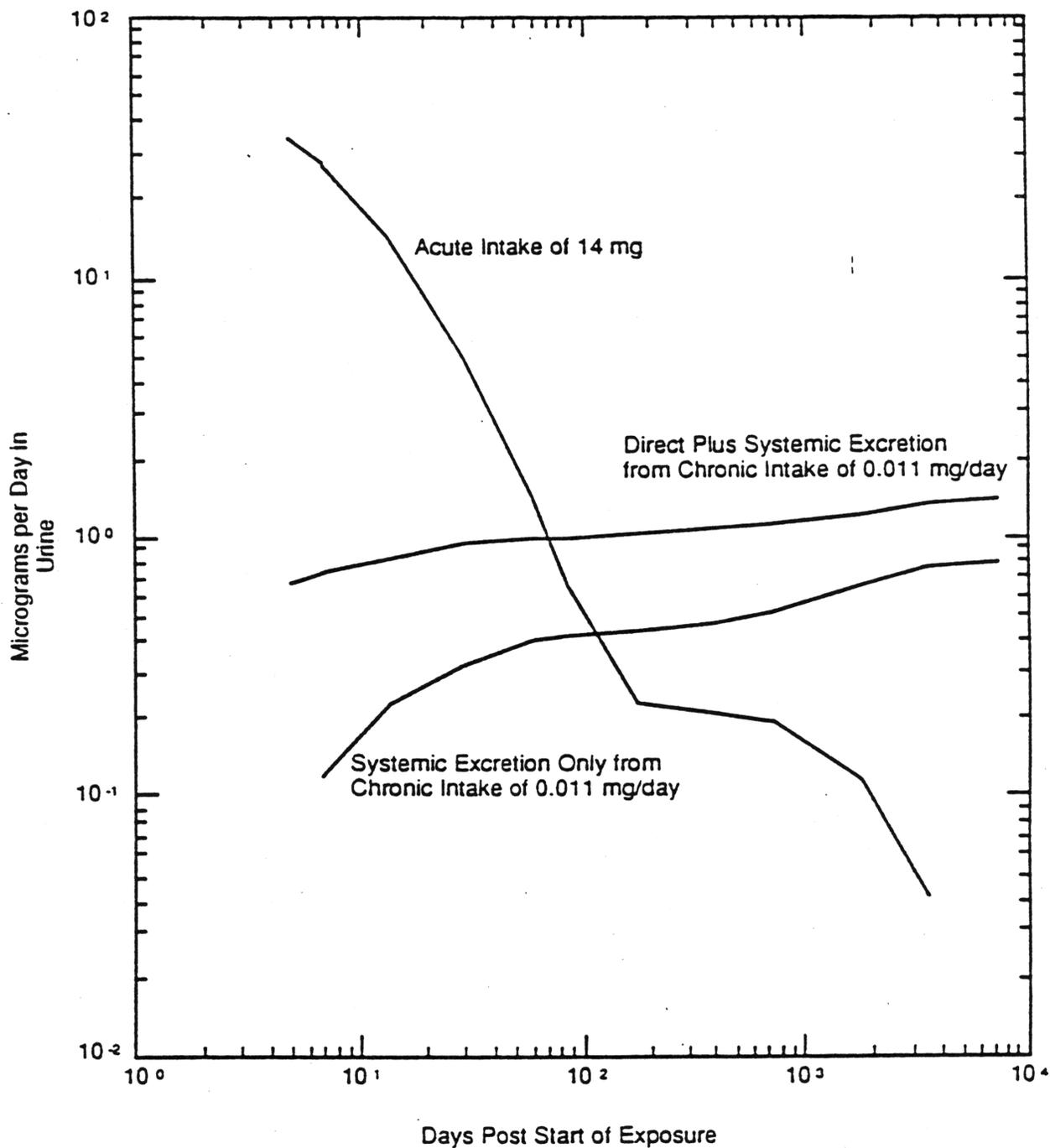


FIGURE 8.10. Predicted urinary Excretion Following an Inhalation of 306-W Building Uranium Resulting in a First-Year Effective Dose Equivalent of 100 mrem (curves exclude excretion of environmental uranium)

TABLE 8.33. Predicted Uranium Excretion Via Urine Following an Inhalation of 306-W Building Uranium^(a)

Days Post Intake ^(c)	Micrograms of Uranium Per Day Via Urine ^(b)		
	Acute Inhalation Intake = 6.1 mg [H _{E,1} = 100 mrem]	Chronic Inhalation	
		Intake Rate = 0.011 mg/day [H _{E,10} = 100 mrem/yr] ^(d)	
		Direct + Systemic ^(e)	Systemic Only ^(f)
5	34	0.68	----
7	27	0.73	0.12
14	15	0.83	0.23
30	5.0	0.94	0.33
60	1.5	1.0	0.40
90	0.64	1.0	0.42
180	0.23	1.0	0.44
365	0.21	1.1	0.47
730	0.19	1.2	0.52
1825	0.11	1.3	0.66
3650	0.04	1.4	0.76

- (a) Assumes 80% class Y, 20% class D; depleted uranium.
 (b) Excludes environmental background levels in urine.
 (c) Days post acute intake or post onset of chronic intake.
 (d) Annual effective dose equivalent rate = 100 mrem/yr after 10 years of continuous intake.
 (e) Includes all excretion pathways.
 (f) Excludes uranium excreted directly from blood; representative of levels that would be expected several days after cessation of chronic exposure.

in a first-year effective dose equivalent of 100 mrem (a lung dose of 830 mrem) and an assumed chronic inhalation rate that would result in an effective dose equivalent rate of 100 mrem/yr after 10 years of continuous intake. The values do not include environmental uranium in the urine. The derived intakes are 14 mg (acute) and 0.011 mg/day (chronic).

Two levels have been developed for interpretation of urine samples from 306-W Machine Shop workers. A screening level is defined as the excretion rate that exceeds that expected due only to environmental sources. This level

is 0.2 $\mu\text{g}/\text{day}$. Workers exceeding the screening level should be maintained on a quarterly urinalysis frequency and their doses should be assessed annually.

The second level is the net occupational excretion rate expected following chronic exposures in excess of a 100-mrem/yr effective dose equivalent. This level is calculated to be 0.8 $\mu\text{g}/\text{day}$ for 306-W Building depleted uranium, assuming that the exposure has been occurring for 10 years. If this level is exceeded, then an investigation into the nature of the exposure is warranted. Additional follow-up bioassay measurements should be performed to confirm the nature and magnitude of the intake, and the resulting dose equivalent should be assessed and documented via an internal dose evaluation report. In addition, it should be noted that an annual average daily net excretion of 0.52 $\mu\text{g}/\text{day}$ (assuming 2 days of no intake) will result in a committed effective dose equivalent of 100 mrem.