

## **5. DESIGN AND CONDUCT OF A BIOASSAY PROGRAM**

### **5.1 Derived Investigation Levels**

To demonstrate how intake retention functions can be used for the design and conduct of a bioassay program, derived investigation levels have been calculated for 24-hour incremental urine samples. The levels were determined by multiplying values of the incremental urine intake-retention function by an investigation level based upon 5% ALI, or an investigation level based upon the ICRP Publication 26 recommendation of  $0.3 \times f \times \text{ALI}$ , where  $f$  is the fraction of the year to which the monitoring applies. Values for an inhalation intake of Class W, 1 micrometer AMAD aerosols of  $^{70.8}$  day Co-58 are summarized in Table 5.1.1. The value for the ALI is  $4 \times 10^7 \text{ Bq}$  ( $1.1 \times 10^3 \text{ uCi}$ ), which is the stochastic value given in ICRP Publication 30 based upon consideration of limiting the risk from stochastic effects to that corresponding to a whole-body committed effective dose equivalent of 0.05 Sv (5 rem). Thus, the 5% ALI-based derived investigation level corresponds to a committed effective dose equivalent of 2.5 mSv (250 mrem) to the whole body of Reference Man. Monitoring is assumed to take place every  $t$  days post intake; thus, the fraction  $f$  of the year is calculated here by dividing the time  $t$  in days by 365 days. The daily frequencies of monitoring associated with small values of

t would not be realistic. However, an investigation is normally triggered by a single measurement and it is most appropriate to base the derived investigation level on the fraction of three-tenths of the limit corresponding to the fraction of the year to which the monitoring of an individual refers. Numerical values are shown for the purpose of comparing these two definitions of an investigation level. Because the ICRP Publication 26 investigation level depends on the frequency of monitoring, the ICRP Publication 26 based values first decrease to about 5 days but then increase over a small time period before decreasing again. It is noted that NRC has not yet recommended these methods of determining derived investigation levels.

**Table 5.1.1 Derived Investigation Levels for Urine Samples and Time Post Intake of Class W, 1 Micrometer AMAD Aerosols of 70.8 Day Co-58**

TIME POST INTAKE	INTAKE IN 24-HOUR URINE SAMPLE	DERIVED INVESTIGATION LEVELS			
		FOR 5% of ALI Bq	(nCi)	FOR 0.3xfxALI Bq	(nCi)
1	2.56E-02	5.12E04	(1.38E03)	8.41E02	(2.27E01)
2	1.08E-02	2.16E04	(5.84E02)	7.11E02	(1.92E01)
5	2.16E-03	4.31E03	(1.17E02)	3.55E02	(9.60E00)
7	1.56E-03	3.13E03	(8.47E01)	3.60E02	(9.74E00)
10	1.15E-03	2.31E03	(6.24E01)	3.79E02	(1.03E01)
20	5.47E-04	1.10E03	(2.96E01)	3.60E02	(9.72E00)
100	7.23E-05	1.45E02	(3.91E00)	2.38E02	(6.42E00)

## 5.2 Frequency of Monitoring

The minimum frequency of monitoring can be determined from the derived investigation levels shown in Table 5.1.1. To demonstrate this application, suppose that an analytical procedure has a minimum detectable activity of 111 Bq (3 nCi). From values that are summarized in Table 5.1.1 for a constant investigation level of 0.05 ALI, the minimum frequency of monitoring is approximately every 100 days since the derived investigation level approaches the minimum detection limit. Obviously, other factors such as the potential for exposure and the exposure history should be considered in the establishment of the bioassay monitoring frequency. If air monitoring data and the exposure history of workers show little potential and infrequent and insignificant exposures, the frequency of monitoring can be relaxed. The potentially highest exposed workers can be randomly selected for bioassays as a quality control procedure, and operational monitoring can be used to demonstrate the adequacy of the internal radiation protection programs.

In considering other factors, the exposure history is important since continuous or multiple exposures to nuclides with long half-lives and long retentions limit the usefulness of single intake IRFs for the derivation of investigation levels. Continuous intake IRF values and corresponding derived investigation levels could then be used. However, for most radiation workers in nuclear medicine, in nuclear power plants, and in the national laboratories, inhalation and ingestion of radioactive materials are not planned to occur; rather, acute intake following an unplanned exposure is encountered. Thus, single intake IRFs are useful for the derivation of investigation levels.

Intake retention functions can be used to determine those routine bioassay procedures that have sufficient sensitivity and accuracy for the internal radiation protection program. Consider, for example, the appropriateness of lung counting for Pu-239 as a routine bioassay procedure. The draft ANSI 13.30 standard, "Draft Performance Criteria for Radiobioassay," specifies the acceptable minimum detectable activity as 190 Bq (5 nCi) L X-rays per nuclear transformation for lung counting of transuranics (ANSI86). This value is acceptable since it represents the current state of the art. For the reported L X-ray yield of Pu-239 of 4.2% (ICRP83), this corresponds to an acceptable minimum detectable activity of 4.4 kBq (120 nCi). Based upon approximately 0.15 of an intake of Class W and Class Y compounds expected to be present in the lungs at 7 days, this corresponds to a minimum detectable intake of 2.9 E+04 Bq (790 nCi). The Class W and Class Y ALIs for Pu-239 are respectively 200 Bq (5.4 nCi) and 500 Bq (14 nCi). Thus, the minimum detectable intake corresponds to 150 ALI for Class W and 56 ALI for Class Y compounds of Pu-239 and committed doses to bone surfaces of 73 Sv (7,300 rem) and 28 Sv (2,800 rem) respectively. Although lung counting may be useful for very large accidental exposures to Pu-239, it should not be relied upon as the primary routine bioassay procedure. Other internal dose assessment procedures, such as fecal monitoring, attocurie-level urine monitoring (Mo86), or the use of personal breathing zone air samplers (Sk85) should be used for assuring adequate protection from exposures involving Pu-239.

Urinary monitoring for Pu-239 may be a good choice if sufficient sensitivity is available. Recent advances in radiochemical separation of Pu in urine, in the presence of uranium, have resulted in a technique which has a minimum detectable activity (MDA) of 90 attocuries per liter for a one day urine sample (see ANSI86 for the MDA equations for bioassay). The new system relies on a fluence of neutrons and the fissioning of Pu. However, even with attocurie sensitivity for Pu-239 for urine, the estimate of intake relies on associating the activity in urine with 1.0E-04 to 1.0E-07 of the activity inhaled or ingested. Thus, several urinary measurements are needed in order to reduce the order-of-magnitude uncertainty associated with variation in Pu excretion due to diet. On the other hand, recent work by Jones on a urinary excretion function for Pu shows realistic estimates of uptake are obtained from sets of urinary measurements when judged against autopsy data (Jo85). Better agreement of the estimate of uptake from urinary results with autopsy results will occur if new values for retention of Pu in bone and liver are adopted by ICRP (ICRP85). Thus, urinary monitoring of Pu-239 is very appropriate, provided sufficient sensitivity is available. Because the annual limit of intake is based on the radiotoxic effects to bone, urinary monitoring may be more appropriate than feces monitoring, which may be associated mainly with the lung and gastro-intestinal deposit of Pu-239.

### 5.3 Table of Derived Investigation Levels

To demonstrate how intake retention fractions can be used for the design and conduct of a bioassay program, derived investigation levels (DILs) have been calculated for some in-vivo or in-vitro compartments of interest. The levels were determined based upon the ICRP Publication 26 recommendation of  $0.3 \times f \times ALI$ , where  $f$  is the fraction of the year to which the routine monitoring applies, and ALI is the annual limit on intake from ICRP Publication 30. Values for inhalation and ingestion intake of tritiated water, Co-60, I-131, Cs-137, Sr-90, U-238, Pu-239 and Am-241 are summarized in Table 5.3.1.

**Table 5.3.1 Derived Investigation Levels for An Acute Intake**

Time Post Intake, days	IRF In Compartment			DIL In Compartment, Bq		
	Lungs	Total Body	24-Hour Urine	Lungs	Total Body	24-Hour Urine
<b>Tritiated Water, Ingestion or Inhalation, ALI = 2.55 E+09 Bq</b>						
1.0	9.32E-01	3.92E-02		1.95E+06	8.22E+04	
5.0	7.05E-01	2.96E-02		7.39E+06	3.10E+05	
10.0	4.97E-01	2.09E-02		1.04E+07	4.38E+05	
30.0	1.22E-01	5.14E-03		7.67E+06	3.23E+05	
100.0	9.12E-04	3.83E-05		1.91E+05	8.03E+03	
200.0	8.32E-07	3.49E-08		3.49E+02	1.46E+01	
365.0	-	-		-	-	
<b>Co-60, Ingestion, ALI = 2.02E+07 Bq</b>						
1.0	7.06E-01	1.25E-02		1.17E+04	2.08E+02	
5.0	3.54E-02	8.48E-04		2.94E+03	7.04E+01	
10.0	1.43E-02	4.52E-04		2.37E+03	7.50E+01	
30.0	8.80E-03	7.21E-05		4.38E+03	3.59E+01	
100.0	5.95E-03	1.51E-05		9.88E+03	2.51E+01	
200.0	4.38E-03	6.14E-06		1.45E+04	2.04E+01	
365.0	3.28E-03	2.57E-06		1.99E+04	1.56E+01	
<b>Co-60, Class W Inhalation, ALI = 5.43E+06 Bq</b>						
1.0	2.11E-01	5.66E-01	2.59E-02	9.42E+02	2.53E+03	1.16E+02
5.0	1.44E-01	2.06E-01	2.26E-03	3.21E+03	4.60E+03	5.04E+01
10.0	1.32E-01	1.63E-01	1.27E-03	5.89E+03	7.27E+03	5.67E+01
30.0	1.01E-01	1.23E-01	4.48E-04	1.35E+04	1.65E+04	6.00E+01
100.0	4.03E-02	5.77E-02	1.85E-04	1.80E+04	2.58E+04	8.26E+01
200.0	1.07E-02	2.44E-02	6.86E-05	9.55E+03	2.18E+04	6.12E+01
365.0	1.47E-03	1.16E-02	1.77E-05	2.39E+03	1.89E+04	2.88E+01
<b>Co-60, Class Y Inhalation, ALI = 8.47E+05 Bq</b>						
1.0	2.13E-01	5.83E-01	4.64E-03	1.48E+02	4.06E+02	3.23E+00
5.0	1.52E-01	1.90E-01	8.17E-04	5.29E+02	6.61E+02	2.84E+00
10.0	1.48E-01	1.57E-01	3.33E-04	1.03E+03	1.09E+03	2.32E+00
30.0	1.43E-01	1.49E-01	6.43E-05	2.99E+03	3.11E+03	1.34E+00
100.0	1.30E-01	1.34E-01	2.60E-05	9.05E+03	9.33E+03	1.81E+00
200.0	1.13E-01	1.17E-01	1.99E-05	1.57E+04	1.63E+04	2.77E+00
365.0	9.08E-02	9.37E-02	1.64E-05	2.31E+04	2.38E+04	4.17E+00

**Table 5.3.1 continued**

Time Post Intake, days	IRF In Compartment			DIL In Compartment, Bq		
	Lungs	Total Body	24-Hour Urine	Lungs	Total Body	24-Hour Urine
<b>Sr-90, Ingestion, ALI = 1.00E+06 Bq</b>						
1.0	7.15E-01	5.85E-02			5.88E+02	4.81E+01
5.0	1.58E-01	1.30E-02			6.49E+02	5.34E+01
10.0	9.90E-02	5.60E-03			8.14E+02	4.60E+01
30.0	6.04E-02	3.41E-04			1.49E+03	8.41E+00
100.0	5.11E-02	7.15E-05			4.20E+03	5.88E+00
200.0	4.44E-02	4.21E-05			7.30E+03	6.92E+00
365.0	3.80E-02	2.37E-05			1.14E+04	7.11E+00
<b>Sr-90, Class D Inhalation, ALI = 7.00E+05 Bq</b>						
1.0	7.97E-02	5.05E-01	8.57E-02	4.59E+01	2.91E+02	4.93E+01
5.0	5.80E-04	2.67E-01	2.45E-02	1.67E+00	7.68E+02	7.05E+01
10.0	8.96E-07	1.78E-01	1.04E-02	5.16E-03	1.02E+03	5.98E+01
30.0	0.00	1.06E-01	6.21E-04	0.00	1.83E+03	1.07E+01
100.0		8.99E-02	1.26E-04		5.17E+03	7.25E+00
200.0		7.81E-02	7.42E-05		8.99E+03	8.54E+00
365.0		6.68E-02	4.18E-05		1.40E+04	8.78E+00
<b>Sr-90, Class Y Inhalation, ALI = 1.00E+05 Bq</b>						
1.0	2.13E-01	5.86E-01	1.34E-03	1.75E+01	4.81E+01	1.10E-01
5.0	1.53E-01	1.85E-01	4.22E-04	6.29E+01	7.60E+01	1.73E-01
10.0	1.48E-01	1.52E-01	1.87E-04	1.22E+02	1.25E+02	1.54E-01
30.0	1.45E-01	1.47E-01	2.32E-05	3.58E+02	3.62E+02	5.72E-02
100.0	1.34E-01	1.36E-01	1.55E-05	1.10E+03	1.12E+03	1.28E-01
200.0	1.20E-01	1.22E-01	1.50E-05	1.97E+03	2.01E+03	2.47E-01
365.0	1.00E-01	1.03E-01	1.47E-05	3.00E+03	3.09E+03	4.41E-01
<b>I-131, Class D Inhalation, ALI = 1.85E+06 Bq</b>						
1.0	1.33E-01	2.74E-01	3.04E-01	2.02E+02	4.17E+02	4.62E+02
5.0	1.20E-01	1.25E-01	1.31E-03	9.12E+02	9.50E+02	9.96E+00
10.0	7.51E-02	8.00E-02	1.88E-04	1.14E+03	1.22E+03	2.86E+00
30.0	1.16E-02	1.32E-02	6.25E-05	5.29E+02	6.02E+02	2.85E+00
100.0	1.80E-05	2.11E-05	1.24E-07	2.74E+00	3.21E+00	1.89E-02
200.0	-	-	-	-	-	-
365.0	-	-	-	-	-	-

**Table 5.3.1 continued**

Time Post Intake, days	IRF In Compartment			DIL In Compartment, Bq		
	Lungs	Total Body	24-Hour Urine	Lungs	Total Body	24-Hour Urine
<b>I-131, Ingestion, ALI = 1.33E+06 Bq</b>						
1.0	2.54E-01	3.21E-01	6.43E-01	2.78E+02	3.51E+02	7.03E+02
5.0	1.88E-01	1.94E-01	1.49E-03	1.03E+03	1.06E+03	8.14E+00
10.0	1.17E-01	1.25E-01	8.76E-04	1.28E+03	1.37E+03	9.58E+00
30.0	1.82E-02	2.06E-02	1.16E-04	5.97E+02	6.76E+02	3.80E+00
100.0	2.82E-05	3.29E-05	1.66E-07	3.08E+00	3.60E+00	1.81E-02
200.0	-	-	-	-	-	-
365.0	-	-	-	-	-	-
<b>Cs-137, Ingestion, ALI = 3.57E+06 Bq</b>						
1.0	9.66E-01	2.70E-02	2.83E+03	7.92E+01		
5.0	8.90E-01	1.03E-02	1.31E+04	1.51E+02		
10.0	8.48E-01	5.32E-03	2.49E+04	1.56E+02		
30.0	7.44E-01	3.76E-03	6.55E+04	3.31E+02		
100.0	4.76E-01	2.41E-03	1.40E+05	7.07E+02		
200.0	2.52E-01	1.27E-03	1.48E+05	7.45E+02		
365.0	9.24E-02	4.68E-04	9.90E+04	5.01E+02		
<b>Cs-137, Class D Inhalation, ALI = 5.60E+06 Bq</b>						
1.0	7.97E-02	6.22E-01	1.35E-02	3.67E+02	2.86E+03	6.21E+01
5.0	5.80E-04	5.72E-01	7.16E-03	1.33E+01	1.32E+04	1.65E+02
10.0	8.96E-07	5.43E-01	3.51E-03	4.12E-02	2.50E+04	1.61E+02
30.0	0.00E+00	4.76E-01	2.41E-03	0.00E+00	6.57E+04	3.33E+02
100.0	-	3.05E-01	1.54E-03	-	1.40E+05	7.09E+02
200.0	-	1.61E-01	8.16E-04	-	1.48E+05	7.51E+02
365.0	-	5.93E-02	3.00E-04	-	9.96E+04	5.04E+02
<b>U-238, Class D Inhalation, ALI = 5.01E+04 Bq</b>						
1.0	7.97E-02	4.10E-01	1.87E-01	3.28E+00	1.69E+01	7.70E+00
5.0	5.81E-04	1.68E-01	1.31E-02	1.20E-01	3.46E+01	2.70E+00
10.0	8.96E-07	1.21E-01	7.26E-03	3.69E-04	4.98E+01	2.99E+00
30.0	0.00E+00	5.06E-02	1.71E-03	0.00E+00	6.25E+01	2.11E+00
100.0	-	1.47E-02	1.11E-04	-	6.05E+01	4.57E-01
200.0	-	1.15E-02	5.15E-06	-	9.47E+01	4.24E-02
365.0	-	1.11E-02	1.72E-06	-	1.67E+02	2.59E-02

**Table 5.3.1 continued**

Time Post Intake, days	IRF In Compartment			DIL In Compartment, Bq		
	Lungs	Total Body	24-Hour Urine	Lungs	Total Body	24-Hour Urine
<b>U-238, Class W Inhalation, ALI = 2.52E+04 Bq</b>						
1.0	2.11E-01	5.57E-01	4.13E-02	4.37E+00	1.15E+01	8.55E-01
5.0	1.45E-01	2.03E-01	2.69E-03	1.50E+01	2.10E+01	2.79E-01
10.0	1.32E-01	1.59E-01	1.75E-03	2.73E+01	3.29E+01	3.62E-01
30.0	1.02E-01	1.17E-01	7.28E-04	6.34E+01	7.27E+01	4.52E-01
100.0	4.18E-02	4.81E-02	2.43E-04	8.66E+01	9.96E+01	5.03E-01
200.0	1.15E-02	1.57E-02	7.49E-05	4.76E+01	6.50E+01	3.10E-01
365.0	1.66E-03	5.14E-03	1.29E-05	1.25E+01	3.89E+01	9.75E-02
<b>U-238, Class Y Inhalation, ALI = 1.51E+03 Bq</b>						
1.0	2.13E-01	5.85E-01	2.23E-03	2.64E-01	7.26E-01	2.77E-03
5.0	1.53E-01	1.83E-01	1.31E-04	9.49E-01	1.14E+00	8.13E-04
10.0	1.48E-01	1.50E-01	8.42E-05	1.84E+00	1.86E+00	1.04E-03
30.0	1.45E-01	1.46E-01	3.27E-05	5.40E+00	5.43E+00	1.22E-03
100.0	1.35E-01	1.35E-01	1.87E-05	1.68E+01	1.68E+01	2.32E-03
200.0	1.22E-01	1.22E-01	1.81E-05	3.02E+01	3.03E+01	4.49E-03
365.0	1.03E-01	1.04E-01	1.82E-05	4.67E+01	4.71E+01	8.26E-03
<b>U-238, Ingestion, ALI = 7.33E+06 Bq</b>						
1.0		7.01E-01	2.76E-01		4.22E+03	1.66E+03
5.0		3.37E-02	2.89E-02		1.02E+03	8.71E+02
10.0		1.23E-02	2.00E-04		7.41E+02	1.20E+01
30.0		5.14E-03	0.00		9.29E+02	0.00
100.0		1.50E-03	-		9.04E+02	-
200.0		1.18E-03	-		1.42E+03	-
365.0		1.14E-03	-		2.51E+03	-
<b>Pu-239, Class W Inhalation, ALI = 2.03E+02 Bq</b>						
1.0	2.11E-01	5.96E-01	2.83E-04	3.52E-02	9.94E-02	4.72E-05
5.0	1.45E-01	2.45E-01	5.39E-05	1.21E-01	2.04E-01	4.50E-05
10.0	1.32E-01	2.09E-01	2.54E-05	2.20E-01	3.49E-01	4.24E-05
30.0	1.02E-01	1.86E-01	1.76E-05	5.11E-01	9.31E-01	8.81E-05
100.0	4.18E-02	1.42E-01	1.12E-05	6.97E-01	2.37E+00	1.87E-04
200.0	1.15E-02	1.21E-01	7.89E-06	3.84E-01	4.04E+00	2.63E-04
365.0	1.66E-03	1.14E-01	4.96E-06	1.01E-01	6.94E+00	3.02E-04

**Table 5.3.1 continued**

Time Post Intake, days	IRF In Compartment			DIL In Compartment, Bq		
	Lungs	Total Body	24-Hour Urine	Lungs	Total Body	24-Hour Urine
<b>Pu-239, Class Y Inhalation, ALI = 5.26E+02 Bq</b>						
1.0	2.13E-01	5.87E-01	1.55E-05	9.21E-02	2.54E-01	6.70E-06
5.0	1.53E-01	1.85E-01	2.87E-06	3.31E-01	4.00E-01	6.20E-06
10.0	1.48E-01	1.53E-01	1.29E-06	6.40E-01	6.61E-01	5.58E-06
30.0	1.45E-01	1.49E-01	8.81E-07	1.88E+00	1.93E+00	1.14E-05
100.0	1.35E-01	1.41E-01	6.99E-07	5.84E+00	6.10E+00	3.02E-05
200.0	1.22E-01	1.29E-01	7.73E-07	1.05E+01	1.12E+01	6.68E-05
365.0	1.03E-01	1.14E-01	8.03E-07	1.63E+01	1.80E+01	1.27E-04
<b>Pu-239, Ingestion, ALI = 2.43E+05 Bq</b>						
1.0		2.82E-01	3.31E-07		5.63E+01	6.61E-05
5.0		3.14E-02	7.42E-08		3.14E+01	7.41E-05
10.0		2.20E-04	2.84E-08		4.39E-01	5.67E-05
30.0		0.00E+00	1.57E-08		0.00E+00	9.41E-05
100.0		-	-		-	-
200.0		-	-		-	-
365.0		-	-		-	-
<b>Am-243, Ingestion, ALI = 5.00E+04 Bq</b>						
1.0		7.14E-01	2.86E-01		2.93E+01	1.18E+01
5.0		1.87E-02	3.06E-02		3.84E+00	6.29E+00
10.0		5.74E-04	2.13E-04		2.36E-01	8.75E-02
30.0		4.50E-04	0.00E+00		5.54E-01	0.00E+00
100.0		4.49E-04	-		1.85E+00	-
200.0		4.47E-04	-		3.67E+00	-
365.0		4.45E-04	-		6.68E+00	-
<b>Am-243, Class W Inhalation, ALI = 2.00E+02 Bq</b>						
1.0	2.11E-01	5.90E-01	4.21E-02	3.47E-02	9.70E-02	6.92E-03
5.0	1.45E-01	2.39E-01	3.41E-02	1.19E-01	1.96E-01	2.80E-02
10.0	1.32E-01	2.03E-01	2.07E-03	2.17E-01	3.34E-01	3.40E-03
30.0	1.02E-01	1.80E-01	9.44E-04	5.03E-01	8.88E-01	4.66E-03
100.0	4.18E-02	1.36E-01	3.58E-04	6.87E-01	2.24E+00	5.88E-03
200.0	1.15E-02	1.15E-01	8.94E-05	3.78E-01	3.78E+00	2.94E-03
365.0	1.66E-03	1.09E-01	1.15E-05	9.96E-02	6.54E+00	6.90E-04