5.0 BIOASSAY MONITORING

This chapter recommends bioassay programs for some typical applications. In addition, it discusses who should be included in a routine bioassay monitoring program, what measurements should be performed, and at what frequency.

This chapter provides recommendations and methods to implement the requirements of 10 CFR 835 and the appropriate recommendations of the Implementation Guide. The DOE Standard Internal Dosimetry (1999) recommends particular criteria for participation in periodic, baseline, termination (or end-of-assignment), and special bioassay monitoring. Elaboration on the technical basis of some of these criteria is provided in the following subsections.

5.1 RECOMMENDED BIOASSAY PROGRAMS FOR TYPICAL APPLICATIONS

A summary of recommended combinations of measurements for various nuclides and situations is given in Table 5.1 for single nuclides and for some typical Hanford radionuclide combinations. This tabulation is provided as a convenience for use in a wide range of Hanford facilities, and the recommendations should meet the objectives of Section 2.3. The following sections of this chapter provide guidance and methods for designing task or facility-specific bioassay programs which may be desired as alternatives to those of Table 5.1. Optimum programs can be designed by Internal Dosimetry based on characterized sources and potential intake patterns.

5.2 MINIMUM DETECTABLE DOSE FOR BIOASSAY INTERVALS

Selected minimum detectable doses associated with various nuclides, bioassay techniques, and intervals are shown in the exhibits at the end of this chapter. For acute intakes, the analyses assume that an intake occurs on the day following a bioassay measurement and that the bioassay measurement has fallen below the MDA by the next scheduled measurement. For chronic intakes, a uniform daily intake pattern is assumed to exist for the monitoring interval. Dosimetry methods and factors are those described in the internal manual, *Methods and Models of the Hanford Internal Dosimetry Program (PNNL-MA-860)*, unless otherwise noted.

TABLE 5.1. Recommended Bioassay Programs for Typical Applications

Application	Program Description
High-energy gamma emitters (e.g., ^{137}Cs, ^{60}Co, ^{154}Eu)	Annual whole body count. If activity is detected on a stand-up count, a coaxial germanium count is performed.
^{90}Sr and ^{137}Cs mixtures (^{137}Cs as an indicator for the mixture)	Annual whole body count if the Sr:Cs ratio does not exceed 20:1. Supplement with biennial ^{90}Sr urinalysis at ratios above 20:1. Use of coaxial germanium whole body counter changes ratio to 40:1.
^{137}Cs and Pu-alpha mixtures (^{137}Cs as an indicator for the mixture)	Annual whole body count supplemented by Pu urinalysis based on mixture composition.
Cs:Pu > 100:1	Annual whole body count.
Cs:Pu between 10:1 and 100:1	Annual whole body count, preferably using coaxial germanium system. Periodic program may not detect 100-mrem CEDE.
Cs:Pu < 10:1	Consider as a Pu bioassay program supplemented with an annual whole body count. (Annual Pu urinalysis, annual or biennial chest count, and annual whole body count.) Periodic program cannot detect 100-mrem CEDE.
Pu mixtures containing ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and possibly ingrown ^{241}Am. Application to either class W or unknown class.	Annual Pu urinalysis (IPU code) for all Pu workers. Supplement with annual chest counts for high risk workers. No periodic program is adequate to detect 100-mrem CEDE.
Pu mixtures consisting of high-fired Pu oxides	Annual Pu urinalysis (IPU analysis code) and annual chest counts. The low-level Pu urinalysis (IPUL code) may be appropriate.
Readily transportable (Class D) uranium, chronic exposure	Biweekly or monthly urine samples obtained after a 2-day absence from workplace (kit code 7). Elemental (U) or isotopic (IU) analysis, as appropriate for mixture.
Readily transportable (Class D) uranium, infrequent or acute exposure	Quarterly monitoring or end-of-assignment for short duration work. Elemental (U) or isotopic (IU) analysis, as appropriate for mixture.
Relatively non-transportable uranium (mixtures of uranium metal or oxides involving predominantly inhalation class W or Y forms)	Annual urine sample and chest count is adequate for acute exposure scenarios. For chronic exposure use a combination of quarterly urine samples and annual or semi-annual chest counts. No periodic program is adequate to detect 100-mrem CEDE for Class Y uranium.

Application	Program Description
Tritium (tritium oxide, tritiated water)	Monthly urine samples for potential chronic or multiple acute exposure, with frequency changed to biweekly if annual tritium dose will likely exceed 100-mrem. End-of-assignment sample appropriate for infrequent or short-term (<1-month) exposure periods.
^{90}Sr (pure, i.e., without ^{137}Cs)	Annual urinalysis. Biennial urinalysis is capable of meeting the 100-mrem bioassay goal but may allow intakes to go undetected for up to two years.
^{90}Sr and Pu-alpha mixtures (^{90}Sr as an indicator for the mixture)	Annual ^{90}Sr urinalysis supplemented by Pu urinalysis based on mixture composition.
Sr:Pu> 600:1	Annual ^{90}Sr urinalysis
Sr:Pu between 100:1 and 600:1	Annual ^{90}Sr urinalysis and consider plutonium urinalysis Routine program may not be able to detect 100 mrem CEDE.
Sr:Pu < 100:1	Annual ^{90}Sr urinalysis and plutonium urinalysis . Consider annual chest count. Routine program cannot detect 100 mrem CEDE.
^{131}I	Monthly whole body count or bimonthly thyroid counts.
^{129}I, ^{125}I	Annual thyroid counts
Np	The chief contributor to dose, even in high-purity Np situations, will most likely be trace quantities of Pu which can be monitored by Pu bioassay. Np bioassay may not be required. Verify the specific situation with the IDP staff.
Thorium (^{232}Th, ^{228}Th, Th-natural)	Use DAC-hours for routine dose assessment. Reliance must be placed on workplace indicators as initiators for special bioassay. Reasonable periodic bioassay is not adequate for demonstrating compliance with dose limits. Consult with IDP staff on specific situations.
Short half-life radionuclides (e.g., ^{90}Y, ^{24}Na	Bioassay programs may not be feasible, thus reliance must be placed on workplace indicators and air sampling (DAC-hours) for exposure or intake assessment. Consult IDP staff on specific applications.

5.3 CONDITIONS FOR MONITORING WORKERS

Personnel are required by 10 CFR 835 to participate in an internal dosimetry program, including routine bioassay, if they are likely to receive intakes in a year resulting in a CEDE of 100-mrem. In addition, minors and declared pregnant workers are required to participate in such programs if they are likely to receive over 50-mrem CEDE from intakes.

Monitoring programs are required by 10 CFR 835.402.(d) to be adequately sensitive to demonstrate compliance with the total dose equivalent limits of 10 CFR 835.202 [i.e., 5 rem total effective dose equivalent (TEDE) and 50 rem total organ dose equivalent (TODE), defined as the sum of deep dose equivalent for external exposures and committed dose equivalent from all intakes in a year]. The DOE Internal Dosimetry Program Guide (DOE 1999a) suggests that bioassay programs should be capable of verifying doses in excess of 100-mrem CEDE. Because the TEDE and TODE includes external dose, as well as the CEDE, the principle design goal for dose assessment at Hanford is to be able to identify and confirm an intake resulting in a 100-mrem CEDE. For some circumstances (e.g., plutonium and class Y forms of uranium), this goal can be achieved only through special (nonroutine) bioassay monitoring that is promptly initiated by workplace indicators. Other factors must be considered in bioassay program design, and these are addressed in the objectives listed in Section 2.3.1.

Periodic Bioassay

The IDP recommends workers to participate in periodic bioassay monitoring if one or more of the following conditions applies:

- Work requires use of a respiratory protection device for radiological protection. (Bioassay program participation provides verification that respiratory protection was adequate.)
- Work in a High Contamination Area that involves contact with or disturbance of contamination.
- Work with unencapsulated radioactive material at or exceeding the values listed in Table 5.2.[(a)] If such work is limited to observing, supervising from a distance, or entering the room without contacting the material, then bioassay is not required unless workplace monitoring indicates that a loss of material control occurred.
- Work with contaminated soil at or exceeding the values listed in Table 5.3[(a)]
- Exposure to low-level airborne activity (below posting requirements) such that the total exposure for a year would exceed 40 DAC-hours.

End-of-assignment monitoring can be used in lieu of periodic monitoring if the work period is shorter than the periodic interval.

(a) These tables provide conservative guidance for meeting the 100-mrem criterion. Improved guidance can be determined in specific cases using case-specific source information and the methods provided in this chapter.

Additional consideration for periodic bioassay programs should be given to the following:

- Knowledge of or prior experience with the work performed or the facility involved.
- Workers who are subjected to a wide range of potential internal exposure conditions.

Baseline and Termination Bioassay

The IDP also identifies the following specific circumstances under which baseline and termination bioassay monitoring are recommended:

- Baseline bioassay monitoring of personnel likely to receive intakes resulting in a CEDE greater than 100 mrem shall be conducted before they begin work that may expose them to occupational intakes. (The Hanford Radiological Control Forum has noted that "monitoring" does not necessarily mean "measuring" but may include review of the worker's exposure history.)
- Termination or end-of-assignment bioassay monitoring is required for any worker who participated in or qualified for participation in bioassay monitoring, unless it is documented in the worker's radiation exposure file that the worker was not potentially exposed to unencapsulated material in the workplace.
- if the worker has had previous intakes which might affect interpretation of current bioassay measurements.
- regardless of prior exposure, if there is potential for occupational intakes of material that may be present in bioassay measurements from naturally-occurring or nonoccupational radioactive sources (e.g., uranium in urine).

Special Bioassay

Special bioassay is recommended by the IDP under any of the following conditions, unless it was caused by radon progeny (also see Table 7.1):

- Facial contamination that indicates a potential for intake.
- Nasal contamination is present.
- Air monitoring indicates the potential for intakes resulting in a CEDE exceeding 100 mrem.
- An unplanned intake is suspected for any other reason.
- Periodic or ending work results indicate an unexpected intake resulting in a CEDE of 100 mrem or more.

Special bioassay is also recommended by the IDP if skin contamination can result in an intake. The levels of skin contamination requiring special bioassay are listed in Chapter 7 (see Table 7.1).

General Recommendation Based on Committed Dose

The IDP recommends placing workers on a routine bioassay monitoring program if the CEDE from a single intake or multiple intakes in a single calendar year may exceed 100 mrem for all radionuclides.

For bioassay program planning purposes, a 100-mrem CEDE may be considered to correspond to chronic exposure for 1 year to 2% of a DAC, an acute or chronic intake equal to 2% of an ALI, and a time-integrated exposure to airborne contamination of 40 DAC-hours. Technically, this is not completely accurate, because if the DAC or ALI is based on the

nonstochastic limit for a particular organ or tissue, the corresponding CEDE will be less than 100 mrem. Thus, the use of established DAC and ALI values is an acceptable practical and conservative approach.

The DAC, ALI, and DAC-hour concepts, as well as the nature of the work and the exposures, may be used to determine who should be included in a bioassay-monitoring program. The following subsections provide guidance for applying these concepts and conditions to bioassay monitoring.

TABLE 5.2. Amount of Radioactive Material Requiring Bioassay Monitoring[a]

Type of Material[b]	Activity Requiring Bioassay (µCi) [c]		
	Bench Top	Fume Hood	Glovebox
Pu, ^{241}Am-, Pu mixtures with Am	0.1	1.0	10
Uranium, very soluble, class D[d]	300 mg	3,000 mg	30,000 mg
Uranium, moderate to insoluble, class W or Y	1	10	100
Mixed fission/activation products (based on class D ^{90}Sr)	400	4,000	40,000
Strontium-90, insoluble, class Y	80	800	8,000
Radioiodines, half-life > 1 day < 1 yr	8,000	80,000	800,000
Iodine-129	2,000	20,000	200,000
Tritium (HTO and HT) (nucleotide precursors)	10,000	100,000	1,000,000

(a) Involves actual work with or contact with the material. Not intended to include occasional observation, unrelated work in the same room, or other activities involving much less risk of contamination.
(b) For other types of radioactive material, other contaminants, or unique situations, consult with Internal Dosimetry for guidance.
(c) Calculated using the method described in Section 5.3.2, assuming inhalation of 1 µm AMAD aerosol and the ALI of Federal Guidance Report No. 11 (EPA 1988)
(d) Based on 15mg intake of 1-µm AMAD particles.

TABLE 5.3. Bioassay Monitoring Criteria for Work Involving Exposure to Contaminated Soil[a]

Nuclide, Form[b]	Soil Contamination (pCi/g)[c] Acute[d]	Chronic[e]
Uranium - Total[f]		
class D or W	40,000	1,000
class Y	3,000	70
Pu-α class W	400	20
Th-232 class W	60	2
Th-228 class W	600	20
Sr-90 class D	1,000,000	40,000
Cs-137 class D	20,000,000	400,000
Co-60 class Y	2,000,000	50,000
Tritium in groundwater[g]	5,000 µCi/L	1,000 µCi/L

(a) Criteria are established for two potential scenarios. "Acute" implies normally not exposed to contamination but potential exists for a single, heavy exposure. "Chronic" implies frequent exposure to less dusty conditions. Bioassay would be required if either scenario applied to a worker.
(b) For other nuclides or chemical forms, consult with Internal Dosimetry for guidance.
(c) Units apply to uniform concentrations representative of the soil being disturbed, and not to small, spotty contamination.
(d) Assumes a 360-mg inhalation intake of 1-µm AMAD soil dust in a single exposure.
(e) Assumes a 48-mg/day inhalation intake rate of 1-µm AMAD soil dust particles for 250 working days/year.
(f) U-natural, ^{234}U, ^{235}U, or ^{238}U in any combination. Based on recycled uranium common at Hanford. Same numbers apply for uranium in units of ppm or µg/g soil.
(g) Assumes consumption of one cup (acute) or one cup per day of groundwater at the indicated contamination.

5.3.1 Derived Air Concentration

Long-Term Chronic Exposures

A worker should be placed on a routine bioassay program if chronic exposure to airborne radioactivity could exceed an average of 2% of the DAC. For exposures to multiple nuclides, the contribution from each significant nuclide should be considered. The DACs referred to in this manual are those contained in Appendix A of 10 CFR 835.

Short-Term Chronic Exposures

Workers exposed to short-term chronic exposures should participate in a routine bioassay monitoring program for each radionuclide to which they are exposed when the average air concentration exceeds that determined by the following formula:

$$\text{Air Concentration Implying Bioassay Monitoring} = \frac{0.02 * \text{DAC}}{f_w} \qquad (5.1)$$

where DAC is the derived air concentration listed in 10 CFR 835, and f_w is the occupancy factor determined by

$$f_w = \frac{\text{number of hours per year in airborne area}}{\text{200 working hours per year}} \qquad (5.2)$$

5.3.2 Annual Limit on Intake

The ALI is a useful concept for bioassay planning when acute intakes are considered or exposure may be limited to readily identified quantities or sources. A routine bioassay program should be considered if an acute or chronic intake of activity corresponding to 2% of the ALI might be possible. Although ALIs are not listed in 10 CFR 835, they can be derived by multiplying the 10 CFR 835 DAC (units of µCi/ml) by 2.4E+9 (giving the ALI in units of microcuries) or by using the values in the U.S. EPA Federal Guidance Report No. 11 (EPA 1988). Even if not chronically exposed to airborne radioactivity, certain workers risk incurring an intake because of an unplanned breakdown of a protection barrier. Potential conditions may be identified by the amount of material handled in a process, the physical form of the material, and the type of containment, or by the determination that the workers frequently need respiratory protection.

One approach to the consideration of source magnitude and containment is to use potential intake factors related to material form and containment. The potential intake factors in Table 5.4 should be considered as general guidance only. Actual facility experience should be used whenever possible.

For example, a worker should be included in a routine bioassay monitoring program if the activity of an unencapsulated radionuclide that is frequently handled, processed, or worked with in any way equals or exceeds the activity calculated by the following formula:

$$\text{Activity of Material Indicating Bioassay Monitoring Required} = \frac{0.02 * \text{ALI}}{\text{potential intake fraction}} \qquad (5.3)$$

where ALI is the annual limit on intake. Potential intake fractions are listed in Table 5.4 as a function of the type of containment and physical form. The information in that table should be considered as general guidance only; actual facility experience should be used whenever possible. Equation 5.3 and Table 5.4 were used to prepare Table 5.2 that shows the amount of radioactive material requiring bioassay monitoring.

If a worker is exposed to more than one radionuclide, the result of Equation (5.3) should be weighted, based on the number of significant nuclides.

TABLE 5.4. Potential Intake Fractions[(a)] as a Function of Containment Type and Physical Form

Form	Containment		
	Glovebox	Open-Faced Hood	Open Area
Tritium[(b)]	1.6E-4	1.6E-3	1.6E-2
Powders	1E-5	1E-4	1E-3
Volatile liquids, elevated temperatures, iodines	1E-6	1E-5	1E-4
Normal liquids	1E-7	1E-6	1E-5
Grinding, sawing, polishing, etc., on solids	1E-8	1E-7	1E-6

(a) Extrapolated from data and discussion in Watson and Fisher (1987; pp. 15-19) and from Brodsky (1980). The purpose of these potential intake fractions is to determine the need for participation in a bioassay program. The fractions should not be used to estimate actual expected releases under average conditions.
(b) Data from NRC Regulatory Guide 8.32 (1988).

5.3.3 DAC-hours

DAC-hours are an indication of potential intake. Worker exposure (in terms of DAC-hours) should be expressed after appropriate correction for respiratory protection. The dose to an individual can be determined based on airborne radioactivity data according to the direction of items a through g below, but these actions are not necessary if routine bioassay monitoring can detect exposures less than 40 DAC-hours, and a policy of performing special bioassays is implemented for potential intakes resulting from unplanned incidents. For conversion to dose, DAC-hours should be first converted to a potential intake. The following actions are recommended for purposes of dosimetry:

a) A DAC-hours tracking log should be initiated for single intakes in excess of 1 DAC-hour. Single intakes below 1 DAC-hour are considered insignificant and do not require tracking.
b) Acute exposures > 40 DAC-hours should be investigated by special bioassay with a subsequent evaluation issued by the Hanford Internal Dosimetry Program.

c) Acute exposures between 10 and 40 DAC-hours should be considered for special bioassay and undergo an internal dose evaluation based on the data most appropriate for the individual, factoring in considerations for sensitivity and representativeness. (Note: for ^{239}Pu using the Hanford models, 1 DAC-hour will correspond to approximately 1.1 mrem CEDE for 5-µm particles. Thus, the implied dose of 10 – 40 DAC-hours is nominally 10 to 40 mrem.)

d) Acute exposures below 10 DAC-hours need not be confirmed by bioassay for dose evaluation. At such low levels, the determination of whether bioassay or DAC-hours is most representative is highly subjective and the decision should be made by the contractor in consultation with Internal Dosimetry, based on the circumstances of each case. Bioassay is useful to provide a possible upper bound on the individual's intake and dose, although actual assessment of that upper bound is not required. However, doses may be assigned directly from DAC-hours exposure, without bioassay, if it is concluded that the DAC-hours exposure is a reasonable estimate of the worker's intake.

e) For multiple small acute exposures or chronic low-level exposures, where the cumulative exposure does not exceed 40 DAC-hours in a calendar year, doses may be assigned directly from DAC-hours estimates.

f) Cumulative DAC-hours exposures > 10 DAC-hours in a calendar year should undergo dose assessment and be included in the worker's exposure history.

g) Cumulative DAC-hours exposures ≤10 DAC-hours in a calendar year may be dispositioned at the contractor's discretion. They may be permanently recorded in the worker's files, but individual dose assessment and recording is not required. It is highly unlikely that CEDEs in excess of 10 mrem (Pu) would go unreported. The upper bound of a CEDE for ^{90}Sr or ^{137}Cs using this scheme would be 25 mrem, however workers at such levels are typically subject to more sensitive periodic bioassay measurements.

Documentation by field dosimetry of the air sample representativeness is required for inclusion in a dose assignment based on DAC-hours. Facility air samples are not always representative of air breathed. Lapel sample data may generally be considered representative or conservative. General room or facility air sample data from fixed heads must be subjectively interpreted for representativeness based on investigation of the unique aspects of the potential exposure.

5.3.4 Worker Group Monitoring

Worker group monitoring can be a suitable alternative to individual worker monitoring for working situations in which the potential for intakes is very low or doses from any intakes would be quite small. The approach is to monitor only a representative portion of the workers on a rotating basis. With this program design, it is assumed that all workers have the same risk for exposure in any period, and that a bioassay result for one worker can be taken as characteristic for the entire group.

Worker group monitoring can be used in one of two ways. First, it can be used as an expedient method of confirmatory monitoring to verify that

workers do not require an individual-specific bioassay program. Secondly, it can be used to provide data for low-level chronic exposure situations in which a combined set of bioassay data from many workers is used to assign doses to individual workers.

For confirmatory monitoring, not all workers in the group need to receive bioassay. Consistent with recommendations of the NCRP (1987), the following guidance is offered for establishing the scope of a bioassay monitoring program for a group:

Worker Population	Number Monitored
≥120	10%
12 to 120	12
<12	All

If a screening level applied to a worker group is exceeded and an intake is confirmed, then all members of the group should be placed on individual bioassay programs, unless an investigation shows that just the one worker was exposed due to unusual circumstances.

5.3.5 Environmental Restoration and Remediation Activities

Special criteria have been developed for application to environmental restoration and remediation (ER) work at Hanford. This work may involve short-term soil sampling activities, excavation of dirt, transport of contaminated soil, or sample well or monitoring borehole drilling operations. The soil involved may range from essentially uncontaminated overburden at burial grounds to soil contaminated with a wide range and magnitude of radionuclides at liquid effluent disposal sites, such as cribs or ponds.

Criteria for two types of exposure conditions have been addressed: the single job involving acute exposure to very high dust loadings in air (i.e., near the worker tolerance level for dust), and the long-term job involving chronic exposure to moderately high dust loadings. The acute exposure assumed a 360-mg inhalation intake (e.g., 2 hours exposure to 150-mg/m^3 dust loading) of 1-µm-AMAD dust. The chronic exposure assumed an inhalation intake rate of 48 mg/day of 1-µm-AMAD dust for 250 working days/year (e.g., 2-h/day exposure to a 20-mg/m^3 dust loading.

Soil contamination criteria are shown in Table 5.3. As long as the geometric mean soil concentrations do not exceed those listed, worker bioassay measurements are not required. Use of the arithmetic mean soil concentration (as a convenient substitute for the geometric mean) is acceptable, and will result in conservative determinations of the need for bioassay. The soil concentration values shown are for the most restrictive inhalation class considered likely to be encountered.

In addition, based on the highest measured tritium contamination levels in Hanford groundwater, there is no need for workers to be on a tritium bioassay program. Tritium bioassay for ER work need not be considered unless concentrations in water exceed 1000 µCi/L.

Exposure to multiple radionuclides must address the additive impact of all nuclides. The need for bioassay can then be established by calculating an "index for bioassay" value as the sum of the ratios of each nuclide to its respective criterion value, as shown below:

$$\text{Index for Bioassay} = \frac{\text{conc.1}}{\text{criteria 1}} + \frac{\text{conc.2}}{\text{criteria 2}} + \text{etc.}$$

If the index value exceeds one, a bioassay program should be established. The issue of what type of bioassay to perform remains. Where sources consist of a single contaminant, the choice is generally obvious. If multiple contaminants are involved, the predominant nuclide may be the best choice. However, some bioassay procedures are substantially more sensitive than others, and if one nuclide can be used as an indicator for another (because of known source inter-relationships), then a more sensitive bioassay procedure for a less predominant radionuclide may be adequate. IDP staff can be consulted for advice on specific situations.

Further details on these criteria are provided in the supporting report.[(a)]

5.3.6 Long-Term Follow-Up of a Prior Deposition

A worker who has been assessed as having a long-term internal deposition of radioactive material may be recommended by Internal Dosimetry for a specialized follow-up bioassay monitoring program to verify the accuracy of the assessment and identify any potential need for revision. This provision results from the need to update long-term body burdens and associated doses from well-retained radionuclides, and should apply regardless of present work assignment or origin of the occupational exposure.

Better understanding of the biokinetic behavior of retained material and improved estimates of dose can be obtained from long-term follow-up bioassay measurements. For example, a small, very long-term component of material in the lung may be masked for several years by short-term components until the short-term components are removed. However, the long-term component may add significantly to the 50-year committed dose.

Long-term follow-up monitoring is most likely to be associated with depositions of plutonium and americium, although other nuclides may also warrant it.

(a) Letter report to T. J. Kelly (WHC) from Eugene H. Carbaugh (PNL) dated December 3, 1991, "Bioassay Criteria for Environmental Restoration Workers." A copy is maintained in the permanent files of the Hanford Radiological Records Program.

5.3.7 Baseline and Ending Work Bioassay

Baseline (or contractor request) and end-of-assignment samples or measurements should be obtained for a worker whose work assignments will require, or have required, routine bioassay monitoring (NCRP 1987; HPS 1997). Such samples should provide a better estimate of the time and nature of an intake, prevent the improper assignment of a prior intake to the present task, and provide accurate feedback on the effectiveness of radiation protection measures for specific work assignments.

Baseline and end-of-assignment measurements may be a suitable alternative to the routine bioassay monitoring associated with work assignments of limited duration. Consult with Internal Dosimetry to determine whether this option is appropriate.

End-of-assignment measurements may be performed in lieu of and at the scheduled time of routine measurements. This option does not apply to visitors and terminating employees who should have specially scheduled measurements.

5.3.8 Offsite Intake Monitoring

Bioassay programs designed for monitoring intakes and work at Hanford may not necessarily be adequate for monitoring at offsite facilities. Internal Dosimetry should be contacted to determine the appropriate bioassay if offsite intake is a possibility.

5.3.9 Visitors and Minors

Routine bioassay programs for plutonium, thorium, and insoluble uranium are not capable of demonstrating compliance with the 100-mrem CEDE limit for minors and visitors. Therefore, it is recommended that RWPs prohibit minors and visitors from being exposed to these materials such that they would be at risk for an intake which could exceed the 100-mrem CEDE limit. If there is potential for external dose as well, then the potential intake must be at a level less than 100 mrem to assure that the TEDE doesn't exceed 100 mrem. If necessary, fecal sampling performed immediately after an acute or short-term exposure can demonstrate compliance with the limit.

Bioassay monitoring is required by 10 CFR 835 if it is likely that visitors or minors will receive over 50-mrem CEDE from an intake. Although monitoring may be required, as noted in the preceding paragraph, there are nuclides for which routine monitoring is not capable of demonstrating compliance with the dose limits. For purposes of determining the need for bioassay, the radioactive material levels in Tables 5.2 and 5.3 are adequate to meet the 50-mrem criteria for visitors and minors, as well as the 100-mrem criteria for radiological workers.

Special bioassays will be performed if conditions encountered while at Hanford require them. If measurements are performed at the beginning or end of the visit, any abnormal results will be reported to the responsible Hanford contractor. Internal doses for detectable baseline results will be assessed only if a specific request is made by the contractor.

5.3.10 Declared Pregnancy

The 10 CFR 835 dose limit for declared pregnant women is substantially more restrictive than those for occupational workers.

When a worker on a routine bioassay schedule declares her pregnancy, IDP should be notified and special bioassay obtained as soon as possible. This is necessary to determine the possible internal dose to the fetus from conception to the date of declaration. These special measurements should be scheduled as Contractor Requests (CR) with priority processing and include a note or comment that the measurement is pregnancy-related.

If the worker continues to be exposed to possible intakes, the contractor must schedule another bioassay measurement at the conclusion of the pregnancy. The same scheduling protocol should be used. The minimum detectable doses for embryo-fetus bioassay programs are shown in Exhibit 5.8. Doses to the embryo-fetus are based on the gestation period dose and not the CEDE.

The 10-mrem screening levels of Appendix A will be used as a basis for determining the need for evaluation.

5.4 SELECTION OF NUCLIDES FOR BIOASSAY

Any radionuclide or mixture of radionuclides that may contribute more than 25% to the 100-mrem committed effective dose equivalent criterion should be included in the bioassay monitoring program.

As a rule of thumb, it may be assumed that workers are not likely to be exposed to more than four reference mixtures of radionuclides.
Radionuclides do not require specific bioassay monitoring if they are adequately monitored by indicator nuclides for a reference mixture.
In some cases, it is possible to use indicator radionuclides for established mixtures to optimize the number of bioassay measurements performed. For example, mixtures containing ^{90}Sr and ^{137}Cs may be sufficiently monitored by using whole body measurements of ^{137}Cs as an indicator of exposure. (See Table 5.1 for guidance.)

Once a worker is placed on a routine program, that program should be reviewed on a regular basis to ensure that potentially significant nuclides are adequately addressed.

A "broad-base" bioassay program involving multiple analyses may be appropriate for workers who rotate between facilities on occasional or short-notice assignments. Such a program is intended to satisfy current baseline requirements for many facilities, rather than imply a worker is likely to incur intakes individually or collectively totalling 100-mrem CEDE.

5.5 BIOASSAY MEASUREMENT FREQUENCY

The frequency of bioassay measurements is dictated by two objectives. The first is to assure that significant acute intakes are detected for dose evaluation and appropriate corrections to the working conditions (NCRP 1987). The second is to monitor the accumulation of radioactive material in the body from low- level chronic intakes.

In general, significant acute intakes are discovered by workplace monitoring (e.g., air monitoring, and clothing and body surveys) and are investigated according to the protocol discussed in Chapter 7.0. Nevertheless, a properly chosen bioassay frequency is important both to account for undetected, acute intakes and to monitor the effectiveness of workplace monitoring.

The choice of frequency depends on the following:

- the purpose of the measurement (i.e., to monitor for accumulation from chronic intakes, for potential acute intakes undetected by first-line monitoring methods, or for acute intakes that occur simultaneously with a known chronic intake)
- the ability to meet the 100-mrem CEDE objective stated in Section 2.3
- MDAs for various radionuclides and bioassay measurements
- the likelihood and ratios of combinations of radionuclides associated with an intake for a particular facility or task the cost of bioassay measurements and the cost of lost productive time while workers are participating in the bioassay program.

Longest Interval Between Bioassays

Generally, annual measurements are suggested as a convenient minimum frequency to match annual reporting requirements for worker doses. Routine bioassay measurement periods longer than five effective half-lives are also generally not recommended, because the potential deviation of individuals from assumed retention or excretion patterns can substantially affect doses associated with the program design.

For mixtures of nuclides (e.g., ^{90}Sr and ^{137}Cs), an annual individual bioassay measurement (e.g., whole body count) may be used in combination with a less frequent radionuclide-specific measurement (e.g., biennial ^{90}Sr urine sample analysis.

5.6 TECHNICAL DISCUSSION FOR RECOMMENDED PROGRAMS

The recommended bioassay programs of Table 5.1 were established based on considerations discussed below and in the exhibits at the end of this section. Additional discussion of capabilities is contained in the internal manual, *Methods and Models fo the Hanford Internal Dosimetry Program,* (PNNL-MA-860).

5.6.1 Plutonium Mixtures

Periodic programs are not capable of meeting the 100-mrem CEDE bioassay goal. Annual urine sampling is recommended for all Pu workers. Urinalysis for mixtures known to consist of high-fired Pu oxides should use the low-level plutonium urinalysis procedure (analysis code IPUL). Workers with the highest risk for Pu intake should also receive annual chest counts. Legacy dry Pu contamination in facilities should be considered Class Y regardless of original form.

Prompt detection of an intake by use of workplace indicators is essential to provide capability to detect 100 mrem CEDE by timely initiation of special bioassay monitoring. Special monitoring should emphasize early fecal samples analyzed for isotopic Pu (IPU code) or Pu and ^{241}Am (IPA code) to provide maximum sensitivity to detection of intakes. Special Pu urinalysis, though less sensitive to intake detection than fecal sampling, is very important to help discriminate between class W and class Y forms of Pu.

5.6.2 Uranium Mixtures

Monitoring for uranium poses special problems for the following reasons:

- Uranium presents both chemical and radiological toxicity risks, the relative importance of which depends on its transportability from the lung.
- Uranium can exist in mixed transportability classes.
- Small, recent intakes easily mask larger, older intakes because nearly 50% of the uranium going to blood is cleared immediately through the urine.
- An intake of class Y material potentially resulting in a CEDE of 100 mrem generally cannot be detected by routine bioassay monitoring. Monitoring of the workplace to document the working environment and to provide immediate indication of an intake is essential.
- Low-level chronic intakes are possible for certain types of work, so the bioassay program may need to monitor for long-term buildup as well as for potentially significant acute intakes.
- Individual and temporal variability in the environmental background of uranium complicates interpretation of urinalysis results.

Consequently, the proper bioassay monitoring program for uranium workers is best determined on a case-by-case basis in consultation with Internal Dosimetry.

5.6.3 Strontium-Cesium Mixtures Bioassay

Mixtures of ^{90}Sr and ^{137}Cs are not uncommon at Hanford and may be found in facilities associated with fission product waste management. The composition of these mixtures can vary from essentially pure ^{90}Sr to essentially pure ^{137}Cs. Where the composition can be well-characterized, e.g., a potential intake identified at the time by field indicators, then whole body counting of ^{137}Cs may be adequate for intake assessment if a smear sample can be analyzed for the ^{90}Sr:^{137}Cs ratio.

In other circumstances, notably a high-routine whole body exam, there may not be any obvious specific material to which the worker might have been exposed. For many years 1:1 ratio was assumed based on the typical fission product yields. However, the wide range of waste management practices which have occurred at Hanford do not provide assurance that the 1:1 ratio is valid. Thus, for high-routine whole body exams, a recommended follow-up practice is to include a ^{90}Sr urinalysis unless it is clear that the worker could only have been exposed to pure ^{137}Cs or the dose consequences are quite small. The ^{90}Sr urinalysis can also help distinguish between environmental and occupational exposures of ^{137}Cs.

The issue of when to place a worker on both a whole body exam and using the ^{90}Sr urinalysis is slightly more complex. The minimum detectable doses associated with ^{137}Cs and ^{90}Sr urinalysis bioassay minimum detectable activities for several ^{90}Sr:^{137}Cs ratios are shown in Exhibit 5.6. Based on this table, an annual whole body exam using the stand-up counter is capable of meeting the 100-mrem CEDE bioassay goal for minimum detectable dose for mixtures up to about a 20:1 ^{90}Sr:^{137}Cs ratio. Supplemental ^{90}Sr urinalysis is recommended when the ^{90}Sr:^{137}Cs ratio exceeds 20:1.

5.6.4 Cesium-Plutonium Mixtures

Mixtures of ^{137}Cs and Pu may be found at Hanford in facilities associated with fuel irradiation, storage or handling of irradiated fuel, and wastes associated with such facilities. Examples include spent fuel basins, fuel processing hot cells, and waste tank sludges. By radioactivity, these mixtures are likely to be mostly ^{137}Cs, with Cs:Pu ratios ranging from perhaps 1000:1 to 1:1. Until the mid-1990s, little attention was given to trace amounts of Pu in predominantly Cs contamination. However, a recognition of the dosimetric importance of the trace Pu has developed with the implementation of the committed dose system and as more detailed facility contamination characterization data have become available.

Where the composition can be well-characterized, e.g., a potential intake identified at the time by field indicators, then whole body counting of ^{137}Cs may be adequate for intake assessment if a representative sample can be analyzed for the ^{137}Cs:Pu ratio. Such a sample might be a nasal smear or surface wipe of the contamination.

In other circumstances, notably a high-routine whole body exam, there may not be any obvious specific material to which the worker might have been exposed. The assumption of any kind of default Cs:Pu ratio is premature at this time, and this renders difficult the investigation of high routine ^{137}Cs whole body counts for workers in those facilities.

To help determine appropriate bioassay monitoring for workers in facilities with Cs-Pu mixtures, the information in Exhibit 5.7 led to the guidelines below. For convenience, it is considered irrelevant as to whether the Pu is ^{239}Pu, ^{238}Pu, or Pu-alpha: the isotopic differences are relatively small compared to the issue of class W or Y forms and the general uncertainty of Cs:Pu ratio.

Cs:Pu >100:1

Annual ^{137}Cs whole body counting using either the stand-up counter or the coax counter is capable of meeting the 100 mrem CEDE bioassay goal. This applies to either class W or class Y forms of Pu.

Between 100:1 and 10:1

Between Cs:Pu ratios of 10:1 and about 100:1, annual ^{137}Cs whole body counting using the coaxial germanium detector system is preferred over the stand-up counter. At about the 50:1 ratio, the coax system can meet the 100-mrem CEDE bioassay goal. Both easily demonstrate compliance with the 10 CFR 835 dose limits. However, as the ratio decreases, a technical shortfall in the ability to meet the 100-mrem goal exists

Cs:Pu < 10:1

Below 10:1 the ability of whole body counting to provide adequate bioassay is weak, and the worker should be placed on a plutonium bioassay program supplemented by an annual whole body count.

High Routines

Investigation of high routine whole body counts that detect ^{137}Cs should consider the possibility of plutonium if the worker is associated with facilities having Cs-Pu mixtures. For such workers, investigation should include plutonium urinalysis as a minimum. Assuming a Pu intake had occurred within approximately the past year, the urine sample can be used to demonstrate regulatory compliance with 10 CFR 835 dose limits. Fecal samples can demonstrate compliance for class Y material (MDD of 300-400 mrem CEDE). If neither the urine nor fecal sample detect Pu, a dose assessment can be performed assuming ^{137}Cs alone, with the recognition that the worker has been evaluated against the MDDs for routine Pu bioassay, and has demonstrated a margin of safety comparable to plutonium workers with regard to the dose limits.

5.6.5 Strontium-Plutonium Mixtures

Strontium and plutonium mixtures can be found in such waste sources as tank farm or spent fuel storage basin sludges. Exhibit 5.7 provides additional details on the capability of screening measurements.

Sr:Pu >600:1

Annual ^{90}Sr urinalysis provides capability of detecting CEDE of 100 mrem or less.

Sr:Pu between 600:1 and	Annual ^{90}Sr urinalysis provided nominal minimum detectable CEDE of 100 to 500 mrem. Consider annual Pu Urinalysis as a supplement.
Sr:Pu < 100:1	The ability to use ^{90}Sr as an indicator for Pu is weak. The worker should be placed on a Pu bioassay program supplemented with annual ^{90}Sr urinalysis.

5.6.6 Special Forms of Nuclides

Special forms of radionuclides (e.g., tritium or ^{14}C-labeled materials) can behave much differently than the normal compounds for which routine bioassay programs are designed. Case-specific bioassay monitoring programs for situations such as these should be established through consultation with Internal Dosimetry

EXHIBIT 5.1

BIOASSAY CAPABILITY FOR TRITIUM

Urine Bioassay Analysis

Tritium (H3) MDA: 20 dpm/mL

The tritium monitoring program is based on liquid scintillation analysis for tritium oxide in urine. Because only 1 mL is analyzed, virtually any volume of sample can be used. For convenience, single void or simulated 12-hr samples are generally collected and a small aliquot analyzed. Program capability is shown below.

Minimum Detectable Effective Dose Equivalent (CEDE) for Acute and Chronic (365 d/y) Exposures to Tritium Oxide

Days Post-Intake or Interval Length	Single Acute Exposure (mrem)	Multiple[a] Acute Exposure (mrem)	Chronic Exposure[b] (mrem)
1	0.027	NA	0.64
2	0.029	NA	0.64
7	0.041	2.1	0.64
14	0.066	1.7	0.64
30	0.20	2.4	0.64
60	1.6	9.7	0.64
90	13	52	0.64
180	6,600(NA)	(NA)	0.64
365	NA	NA	0.64

a. Assuming one intake per interval
b. Assumed constant equilibrium in body water at 20 dpm/mL.
NA = Not Applicable

EXHIBIT 5.2

IN VIVO BIOASSAY CAPABILITY FOR HIGH-ENERGY GAMMA EMITTERS

Whole Body Counting

Bioassay measurements for high-energy gamma-emitting radionuclides are performed using the IVRRF preview counter, or other systems of comparable or better sensitivity (e.g., coaxial germanium whole body counter, remote whole body counter). The minimum detectable doses for single nuclides or selected mixtures of mixed fission or activation products based on single nuclide measurement are shown below for the chemical forms commonly encountered at Hanford.

Minimum Detectable CEDEs for Single Acute 5-µm AMAD Inhalation Intake Based on MDA Detection in Preview Counter at the Indicated Day Post-Intake

Nuclide	Class	MDA[a] (nCi)	DPI[b]	Measurement Interval	CEDE (mrem)[c]
^{6O}Co	Y	1.3	365	Annual	2.9
^{137}Cs	D	1.3	365 730	Annual Biennial[d]	0.75 7.5
^{154}Eu + ^{155}Eu[e]	W	3.7 (of ^{154}Eu)	365	Annual	12
^{131}I	D	15	30	Monthly	34

(a) MDA = minimum detectable activity.
(b) DPI = day post-intake.
(c) Assumes inhalation of 5-µm AMAD aerosol
(d) Not recommended.
(e) Assumes that the activity ratio for ^{154}Eu:^{155}Eu is 4.7:1 at times of intake, based on 14 years of decay following operating N-Reactor equilibrium condition of 2:1.

EXHIBIT 5.2. (contd)

Thyroid Counting for Radioiodine

Thyroid counting for ^{125}I and ^{129}I is the recommended bioassay over urine sample analysis for those nuclides. Thyroid counting for ^{131}I is significantly more sensitive than whole body counting for that nuclide. Thyroid counts are performed with planar germanium detectors. The program capability for thyroid counting is shown below:

Minimum Detectable CEDEs for Single Acute 5-µm AMAD Inhalation Class D Intake Based on MDA Detection in Thyroid Counter at the Indicated Day Post.Intake

Nuclide	MDA (nCi)	Day Post-Intake	Measurement Interval	CEDE (mrem)
^{125}I	0.8	30	Monthly	0.16
		90	Quarterly	0.47
		180	Semiannual	2.3
		365	Annual[(a)]	60
^{129}I	0.8	30	Monthly	0.80
		90	Quarterly	1.2
		180	Semiannual	2.0
		365	Annual[(a)]	6.3
^{131}I	0.1	30	Monthly	0.25
		60	Bimonthly	3.8
		90	Quarterly	54

(a) Recommended frequency supplemented by workplace screening using portable survey meter with NaI detector.

EXHIBIT 5.3

BIOASSAY CAPABILITY FOR STRONTIUM

Strontium-90 Bioassay Monitoring

Urine sample analysis is the preferred method for ^{90}Sr bioassay monitoring. For low-risk potential exposure situations, it may be convenient to use an annual whole body exam to monitor for ^{137}Cs as an indicator for the presence of ^{90}Sr. Program capabilities are shown below for pure ^{90}Sr. See Exhibit 5.6 for mixtures of ^{90}Sr and ^{137}Cs.

Minimum Detectable CEDEs for Single Acute 5-µm AMAD Inhalation Class D Intake Based on MDA Detection (10 dpm/d) in Urine at the Indicated Day Post-Intake

Day Post-Intake	Measurement Interval	CEDE (mrem)
1	Special	0.02
7	Special	0.07
30	Monthly	1.8
90	Quarterly	8.1
180	Semiannual	13
365	Annual[(a)]	26
730	Biennial	61

(a) Recommended frequency

EXHIBIT 5.4

BIOASSAY CAPABILITY FOR URANIUM

Urine Bioassay Analyses

Elemental Uranium (U)MDA: 0.06 µg

Used for natural, depleted, or recycled uranium mixtures, in any chemical form. Simulated 24-hour sample collected. A screening level of 0.2 µg/d is used as an upper range of the normal expected excretion rate, implying an occupationally attributable excretion rate of 0.18 µg/d may exist above the geometric mean environmental level of 0.02 µg/d, established for the Hanford work force. Minimum detectable dose analyses for natural uranium mixtures and various intake scenarios are shown in Tables IV.1 through IV.4.

Isotopic Uranium (IU)MDA: 0.02 dpm

Used for single isotopes of uranium or mixtures enriched to greater than 5% (by weight) of ^{235}U. Simulated 24-hour sample collected. Screening levels of 0.15 dpm are used for $^{233+234}U$ and ^{238}U, and anything >Lc for ^{235}U, corresponding to 0.2 µg/d for natural uranium; thus, the minimum detectable dose analyses for uranium mixtures are comparable to those for the elemental uranium procedure.

In Vivo Measurements

	Chest Count (3000 s)	Implied Uranium Present (nCi of uranium mixture)		
Isotope	MDA	Natural U	Depleted U	Recycled U
^{235}U	0.20 nCi	8.6	13	8.6
^{234}Th	2.0 nCi	4.1	2.1	5.4

Detection of uranium in the lungs is generally used only for relatively insoluble (class W or Y) forms. The ^{235}U and ^{234}Th measurements can be used as independent checks on potentially positive results. The ^{234}Th (assumed to be in secular equilibrium with ^{238}U) is slightly more sensitive in terms of total uranium than ^{235}U detection for most Hanford mixtures, and is the basis for the minimum detectable dose analyses.

TABLE IV.1. Minimum Detectable CEDEs for 5-µm AMAD Class W Acute Inhalation Intakes of Recycled Uranium [(a)] for Elemental Uranium in Urine or Chest Counting

		CEDE (mrem)	
Day Post-Intake	Measurement Interval	Elemental U in Urine[(b)]	^{234}Th by Chest Count[(c)]
1	Special	0.031	200
2	Special	0.10	240
7	Special	0.24	310
14	Special	0.44	350
30	Monthly	1.1	430
90	Quarterly	5.1	900
180	Semiannual	18	2900
365	Annual	150	NA
730	Biennial	1200	NA

(a) Multiply doses by 0.68 for natural uranium and by 0.32 for depleted uranium.
(b) Based on screening level of 0.2 µg/d urine excretion, implying an occupationally attributed 0.18 µg/d above the environmental geometric mean level of 0.02 µg/d.
(c) Based on detection of 1.5 nCi of ^{234}Th by chest counting, implying the presence of 2.7 nCi recycled uranium in the lungs.

NA=Not Applicable

TABLE IV.2. Minimum Detectable CEDEs for 5-µm AMAD Class Y Acute Inhalation Intakes of Recycled Uranium Mixture,[a] Detected by Elemental Uranium in Urine or Chest Counting

		CEDE (mrem)	
Day Post-Intake	Measurement Interval	Elemental U in Urine[b]	^{234}Th by Chest Count[c]
1	Special	4.6	2400
2	Special	15	2900
7	Special	39	3500
14	Special	67	3600
30	Monthly	190	3600
90	Quarterly	790	3900
180	Semiannual	1100	4200
365	Annual	1100	5100
730	Biennial	1200	7100

(a) Multiply doses by 0.76 for natural uranium and 0.39 for depleted uranium.
(b) Based on screening level of 0.2 µg/d urine excretion, implying an occupationally attributed 0.18 µg/d above the environmental geometric mean level of 0.02 µg/d.
(c) Based on detection of 1.5 nCi of ^{234}Th by chest counting, implying the presence of 2.7 nCi recycled uranium mixture in the lungs.

TABLE IV.3. Minimum Detectable CEDEs for 5-µm AMAD Class D Acute Inhalation Intakes of Recycled Uranium [a] Based on Elemental Uranium Detected in Urine[b]

Day Post-Intake	Measurement Interval	Intake mg)	CEDE (mrem)
1	Special	.0021	0.007
2	Special	.0064	0.021
7	Special	.018	0.059
14	Special	.033	0.11
30	Monthly[c]	.095	0.31
90	Quarterly	1.1	3.5
180	Semiannual	19	63
365	Annual	95	310
730	Biennial	110	350

(a) Multiply doses by 0.67 for natural uranium and 0.33 for depleted uranium.
(b) Based on screening level of 0.2 µg/d urine excretion, implying an occupationally attributed 0.18 µg/d above the environmental geometric mean level of 0.02 µg/d.
(c) Recommended frequency based on potential chemical toxicity of intakes

EXHIBIT 5.5

BIOASSAY CAPABILITY FOR PLUTONIUM

In Vivo Lung Counting

MDA: 0.16 nCi for ^{241}Am for 3000-s count

Plutonium in the lungs can be monitored by measuring the ^{241}Am daughter of ^{241}Pu using planar germanium-detector chest-counting techniques. This method is state-of-the-art for in vivo detection in the lungs, but is limited in usefulness to aged plutonium mixtures, where sufficient time has elapsed to allow significant ^{241}Am ingrowth. Program capabilities for chest counting are shown in Tables V.1 and V.2. The capability in terms of minimum detectable dose assumes that material at the time of intake is either 6% ^{24O}Pu or 12% ^{24O}Pu mixture, aged 20 years to allow ^{241}Am ingrowth as discussed in the *Methods and Models of the Hanford Internal Doismetry Program (PNNL-MA-860)*. Urine sampling is generally more effective than chest counting for routine monitoring of class W forms of plutonium. Chest counting is primarily of value immediately following intakes, or as a monitoring technique for class Y (or less soluble) forms of plutonium.

Urine Bioassay Analyses

Plutonium in Urine (IPU)

MDA = 0.02 dpm/sample $^{239+24O}$Pu
(assumed 0.02 dpm/d)

Isotopic plutonium is normally analyzed in a simulated 24-hr urine sample. The MDA is assumed to apply to a daily excretion rate. The minimum detectable doses for fresh and aged plutonium mixtures are shown in Table V.3.

Low-Level Plutonium in Urine (IPUL)

MDA = 0.005 dpm ^{239}Pu/sample
(0.0025 dpm/d)

This procedure has been proposed primarily for application to class Y forms of plutonium where the IPU MDA does not provide adequate capability. The minimum detectable doses for fresh and aged plutonium mixtures are shown in Table V.4.

TABLE V.1. Minimum Detectable CEDEs for Acute 5-µm AMAD Inhalation Intakes of Class Y Plutonium Mixtures Based on MDA Chest Count of ^{241}Am (0.16 nCi) at Indicated Day Post-Intake

Day Post-Intake	Measurement Interval	CEDE (rem) 20-Y Aged Weapons-Grade Pu	CEDE (rem) 20-Y Aged Fuel-Grade Pu
1	Special	1.8	0.78
2	Special	2.0	0.96
7	Special	2.4	1.1
14	Special	2.5	1.1
30	Monthly	2.5	1.2
60	Bimonthly	2.6	1.2
90	Quarterly	2.6	1.3
180	Semiannual	2.9	1.4
365	Annual[(a)]	3.4	1.6
730	Biennial	4.8	2.2

(a) Recommended frequency.

TABLE V.2. Minimum Detectable CEDEs for Acute 5-µm AMAD Inhalation Intakes of Class W Plutonium Mixtures Based on MDA Chest Count of ^{241}Am (0.16 nCi at the Indicated Day Post Intake

Day Post-Intake	Measurement Interval	CEDE (rem) 20-Y Aged Weapons-Grade Pu	CEDE (rem) 20-Y Aged Fuel-Grade Pu
1	Special	5.9	3.0
2	Special	7.0	3.5
7	Special	8.8	4.6
14	Special	9.6	4.9
30	Monthly	12	6.3
60	Bimonthly	18	8.8
90	Quarterly	26	13
180	Semiannual	80	42
365	Annual	880	440
730	Biennial	1.0E+5	5.5E+4

TABLE V.3. Minimum Detectable CEDEs for 5-µm AMAD Aged Weapons-Grade Pu Mixtures[(a)] Based on MDA Detection (0.02 dpm/d) of ^{239}Pu in Urine by Isotopic Plutonium Analysis (IPU)

Day Post-Intake	Measurement Interval	CEDE (rem)	
		Class W Inhalation	Class Y Inhalation
1	Special	0.017	0.068
2	Special	0.026	0.11
7	Special	0.13	0.55
14	Special	0.21	0.89
30	Monthly	0.29	1.2
60	Bimonthly	0.41	1.8
90	Quarterly	0.53	2.1
180	Semiannual	0.72	2.6
365	Annual[(b)]	1.2	3.3
730	Biennial	2.2	3.8

(a) For 5-µm AMAD, 20-y aged Fuel Grade Pu mixture, multiply Weapons-Grade values by 1.6 to give an approximate minimum detectable CEDE. Contact the IDP staff for unusual mixtures.:

(b) Recommended frequency.

EXHIBIT 5.6

BIOASSAY CAPABILITY FOR STRONTIUM-CESIUM MIXTURES

Bioassay for mixtures of ^{90}Sr and ^{137}Cs may include whole body counting for ^{137}Cs, urinalysis for ^{90}Sr, or a combination of both. The minimum detectable doses shown below assume acute intakes of 5-µm AMAD class D forms of these materials.

Days Post Intake	Bioassay Type	1:1	10:1	20:1	40:1	100:1	1000:1
1	WBC[(a)]	0.46	4.0	8.0	16	40	400
	Urine[(b)]	0.03	0.02	0.02	0.02	0.02	0.02
2	WBC[(a)]	0.48	4.2	8.2	16	41	410
	Urine[(b)]	0.03	0.03	0.03	0.03	0.03	0.03
7	WBC[(a)]	0.52	4.5	9.0	18	45	440
	Urine[(b)]	0.08	0.07	0.07	0.07	0.07	0.07
14	WBC[(a)]	0.55	4.8	9.4	19	47	470
	Urine[(b)]	0.25	0.22	0.22	0.21	0.21	0.21
30	WBC[(a)]	0.60	5.2	10	21	52	520
	Urine[(b)]	2.2	1.9	1.9	1.9	1.8	1.8
90	WBC[(a)]	0.89	7.8	15	31	76	760
	Urine[(b)]	9.5	8.2	8.2	8.1	8.1	8.1
180	WBC[(a)]	1.6	14	27	54	140	1400
	Urine[(b)]	15	13	13	13	13	13
365	WBC[(a)]	5.1	45	88	180	440	4400
	Urine[(b)]	30	26	26	26	26	26
730	WBC[(a)]	52	450	900	1800	4500	44000
	Urine[(b)]	71	62	61	61	61	61

(a) Based on 1.3 nCi ^{137}Cs MDA for NaI preview whole body counter. Multiply by 0.62 for coaxial system MDA of 0.8nCi ^{137}Cs.
(b) Based on 10 dpm MDA for ^{90}Sr urinalysis.

EXHIBIT 5.7

BIOASSAY CAPABILITY FOR CESIUM-PLUTONIUM MIXTURES AND STRONTIUM-PLUTONIUM MIXTURES

Waste mixtures such as are found in tank farm facilities or storage basins often contain relatively large quantities of fission product activity (^{137}Cs and/or ^{90}Sr) and trace quantities of plutonium. Because periodic bioassay for plutonium is relatively insensitive, cost-effective bioassay programs can sometimes make us of ^{137}Cs and/or ^{90}Sr as an indicator radionuclide for the possible presence of plutonium. The indicator bioassay concept involves a screening measurement for the indicator nuclide. If the indicator nuclide is present, inference is made that plutonium may also be present, initiating an investigation which may include special follow-up bioassay measurements. The capability and adequacy of indictor bioassay programs for the mixture depends on the activity ratio of the indicator relative to plutonium.

Tabulations are provided in this exhibit for ^{137}Cs + ^{239}Pu mixtures and ^{90}Sr + ^{239}Pu mixtures. Various activity ratios for the mixtures at intake are addressed. In both sets of tabulations, the indicator nuclide (^{137}Cs or ^{90}Sr) is assumed to be inhalation class D form and ^{239}Pu is assumed to be class W. These assumptions are considered reasonable because the mixtures involved typically are of an aqueous or semi-aqueous nature (waste tank contents, storage basin sludges, etc). The minimum detectable doses for class Y plutonium would be substantially lower than those tabulated for class W. It was also assumed that all intakes were by inhalation of 5-µm AMAD aerosols. The activity ratios of the indicator relative to ^{239}Pu are suitable for gross alpha activity smear or air sample results and can also be extended to pure isotopes (including ^{241}Am) for the purposes of bioassay program design. Minimum detectable doses would vary slightly between plutonium isotopes but would generally be less than a 10 percent variation.

Bioassay for mixtures of ^{137}Cs and alpha-emitting isotopes of Pu can be accomplished by using whole body counting as a screening tool for many mixtures, if there is reasonable assurance about the likely or worst-case activity ratios. If nothing is detected by the screening whole body count, no additional bioassay need be performed. If ^{137}Cs is detected, then at least one supplemental urinalysis should be performed to provide monitoring capability approximately comparable to those workers on periodic plutonium bioassays. More in-depth evaluation may include plutonium fecal samples, as might be performed for suspected plutonium intakes.

In a similar approach, screening bioassay for mixtures of ^{90}Sr and plutonium can be accomplished by a ^{90}Sr urinalysis. This screening technique may be particularly suitable for waste tank sludges that tend to be rich in ^{90}Sr and plutonium but somewhat reduced in ^{137}Cs.

^{137}Cs and Pu Mixtures

Days Post Intake	Minimum detectable dose (CEDE) for ^{137}Cs: ^{239}Pu ratios at intake (mrem)[a]				
	1:1	10:1	40:1	100:1	1,000:1
1	700	70	18	7.1	0.77
2	730	73	18	7.3	0.80
7	790	79	20	8.0	0.87
14	830	83	21	8.4	0.91
30	920	92	23	9.3	1.0
90	1,400	140	34	14	1.5
180	2,400	240	60	24	2.6
365	7,800	780	200	79	8.5
730	79,000	7,900	2,000	800	8.7

(a) Based on 1.3nCi^{137}Cs MDA for NaI preview whole body counter, assuming 5-µm AMAD aerosol, class D Cs and class W Pu. For coaxial Ge whole body counter (MDA of 0.8 nCi), multiply doses by 0.62.

^{90}Sr and Pu Mixtures

Days Post Intake	Minimum detectable dose (CEDE) for ^{90}Sr: ^{239}Pu ratios at intake (mrem)[b]			
	1000:1	600:1	100:1	10:1
1	0.06	0.1	0.4	4.0
2	0.08	0.1	0.5	4.9
7	0.2	0.3	1.3	13
14	0.59	0.8	4.0	38
30	5.1	7.3	35	330
90	23	32	150	1,500
180	36	52	250	2,300
365	72	100	490	4,600
730	170	240	1,100	11,000

(b) Based on 10 dpm ^{90}Sr MDA for ond-day urine sample, assuming 5-µm AMAD aerosol, class D Sr and class W Pu..

EXHIBIT 5.8

PRENATAL BIOASSAY PROGRAM

For most radionuclides the dose to embryo/fetus will be similar to or less than the dose to the corresponding maternal tissues, but current guidance requires the dose to the embryo/fetus to be calculated separately. Bioassay results from shortly after the date the pregnancy was declared and following the end of the pregnancy are adequate to demonstrate compliance with dose limits. The following table shows the maximum dose received by the embryo/fetus following an inhalation intake by the mother that results in an excretion or retention of radioactive material at the end of pregnancy equal to the minimum detectable activity for the bioassay analysis used.

Minimum Detectable Dose for Prenatal Bioassay Program

Inhalation				Minimum Detectable Dose[(a)], mrem	
Nuclide	Class	Analysis[(b)]	MDA	Acute Intake	Chronic Intake
^{238}Pu	W	Urine	0.02 dpm	0.1	1E-4
^{238}Pu	Y	Urine	0.02 dpm	0.7	3E-4
^{239}Pu	W	Urine	0.02 dpm	0.1	1E-4
^{239}Pu	Y	Urine	0.02 dpm	0.7	3E-4
U	D	Urine	0.2 µg	0.001	2E-7
U	Y	Urine	0.2 µg	0.2	4E-5
^{90}Sr	D	Urine	30 dpm	0.004	3E-6
^{90}Sr	Y	Urine	30 dpm	10	6E-3
^{137}Cs	D	In Vivo	3 nCi	1	3E-4

(a) Effective dose equivalent to the embryo/fetus for the 9-month gestation period.
(b) All urinalyses assumed to represent total 24-hour excretion.

EXHIBIT 5.9

Grace Period Technical Justification

The adoption of a grace period for routine bioassay measurements, consisting of the scheduled month and the next month following, implies that as much as two months may pass beyond the scheduled date of a measurement and the date that it is actually obtained. The impact of this potential delay on the minimum detectable dose (committed effective dose equivalent) as an indication of bioassay program sensitivity for various circumstances is discussed below. All inhalation intakes were based on 5-µm AMAD particle size.

Annual Bioassays

Class Y Pu Urinalysis:	No significant change in MDD from semi-annual to biennial (MDD goes from 2.6 rem semi-annual to 3.8 rem biennial). Thus, choice of grace period date for this case is independent of technical considerations about MDD.
Class W Pu Urinalysis:	Change from annual to biennial results in doubling of MDD (1.2 to 2.2 rem). A grace period of even a year would still provide an adequate safety net with regard to compliance with the dose limit.
Class Y U Urinalysis:	Change from semi-annual to biennial results in <10% change in MDD (1.1 rem to 1.2 rem for recycled uranium). Grace period choice is independent of technical MDD considerations.
Class W U Urinalysis:	Change from annual (150 mrem) to biennial (1,200 mrem) is a significant impact on the MDD, but still provides an adequate safety net with regard to the dose limit. A lengthy grace period (i.e., several months for an annual sample, can still be ok.)
Class D Sr Urinalysis:	Change from annual (26 mrem) to biennial (61 mrem) has no significant impact on MDD. Thus, choice of grace period date for this case is independent of technical considerations about MDD.
Acute Class Y Pu Chest Counts	Shifting from annual to biennial chest counts changes the MDD from (4.2 rem to 6 rem for 20-y aged weapons grade Pu and 2.0 rem to 2.7 rem for 20-y aged fuel grade Pu. A two month grace period date for this case has no significant technical impact on MDD.
Acute Class Y Recycled U Chest Counts	Shifting from annual chest counts (5.1 rem) to biennial (7.1 rem) has minor impact on MDD. A two month grace period date for this case has no significant technical impact on MDD.

10:1 Cs to Pu Mixtures Whole Body Count	(For ratios <10:1, Pu bioassay is recommended) Shifting from annual WBC (780 mrem for NaI; 480 mrem for Coax) to 14 months (1,400 mrem for NaI; 750 mrem for Coax) has modest impact on MDD but does not affect the ability to show compliance with the dose limit. A two-month grace period date for this case would seem acceptable from a technical standpoint.

Semi-Annual Bioassays

No present bioassay programs are recommended with semi-annual urinalyses.

Quarterly Bioassays

Infrequent / acute Class W U Urinalysis:	Quarterly (5.1 mrem) to semi-annual (18 mrem) has no significant impact on MDD. Thus, choice of grace period date for this case is independent of technical considerations about MDD.
Chronic / multiple acute Class Y U Urinalysis:	Quarterly 790 mrem) to semi-annual (1,100 mrem) has modest impact on MDD but does not affect the ability to show compliance with the dose limit. Thus, choice of grace period date for this case is independent of technical considerations about MDD.

Monthly Bioassays

Tritium	Shift from biweekly (0.07 mrem) to bimonthly (1.1 mrem) has no significant impact on MDD. Thus, choice of grace period date for this case is independent of technical considerations about MDD. If a bi-weekly or monthly sample is missed, there is no problem with waiting until the next one comes up. Missing two in a row is reasonable grounds for work restriction.
Soluble U Urinalysis:	None of these are currently being performed, and chemical toxicity, not internal dose, is not the driving technical factor for the measurements. Changing from monthly (12 ug/d screening level for chemical toxicity) to a quarterly sample (1.1 ug/d for chemical toxicity) is not likely to have a major impact.
Post Job	The selection of a sampling time following completion of a job is not a significant technical issue for Pu, U, ^{90}Sr, or even ^{3}H. Because routine monitoring programs are typically at much longer frequencies, a suggested sample late date is one-month following completion of the work.