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BIOASSAY CRITERIA FOR ENVIRONMENTAL RESTORATION WORKERS

E. H. Carbaugh
D. E. Bihl

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Pacific Northwest Laboratory
Richland, Washington 99352

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E. H. Carbaugh and D. E. Bihl
Pacific Northwest Laboratory
PO Box 999
Richland, Washington

ABSTRACT

Environmental restoration (ER) work at the U. S. Department of Energy Hanford Site posed questions concerning when to perform bioassay monitoring of workers for potential intakes of radioactivity. Application of criteria originally developed for use inside radionuclide processing facilities to ER work resulted in overly restrictive bioassay requirements. ER work typically involves site characterization or excavating large quantities of potentially contaminated soil, rather than working with concentrated quantities of radioactivity as in a processing facility. An improved approach, tailored to ER work, provided soil contamination concentrations above which worker bioassay would be required. Soil concentrations were derived assuming acute or chronic intakes of 2% of an Annual Limit on Intake (ALI), or a potential committed effective dose equivalent of 100 mrem, and conservative dust loading of air from the work. When planning ER work, the anticipated soil concentration and corresponding need for bioassay could be estimated from work-site historical records. Once site work commenced, soil sampling and work-place surveys could be used to determine bioassay needs. This approach substantially reduced the required number of bioassay samples with corresponding reductions in analytical costs, schedules, and more flexible work-force management. (Work supported by the U.S. Department of Energy under contract DOE-AC06-76RLO 1830.)

INTRODUCTION

The Hanford environmental restoration and remediation (ER) work poses questions about bioassay that have not been sufficiently addressed in prior Hanford activities. The U. S. Department of Energy (DOE) requires that workers be placed on a bioassay monitoring program if they are likely to incur a committed effective dose equivalent of 100 mrem from all intakes of radioactivity occurring within a year (DOE 1992). The criteria provided to Hanford contractors for identifying such workers is contained in the Hanford Internal Dosimetry Program Manual (Carbaugh et al. 1989), but the criteria, as presented, were developed primarily for indoor contaminated processing facilities.

The nature of ER work typically involves the excavation of large quantities of contaminated or potentially contaminated soil, relatively short-term soil sampling activities, transport of contaminated soil, and exposure to relatively small quantities of potentially contaminated soil during sample well or borehole monitoring 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. Future work may include intentional excavation of highly contaminated objects or accidental intrusion into contaminated burial boxes or barrels.

In light of the scale of planned ER work, the "shotgun approach" to bioassay, in which all workers are monitored for all nuclides of potential exposure regardless of job location and duration, would be an extremely expensive and technically unjustifiable program design. This report defines criteria for identifying those conditions under which bioassay should be performed. It then applies this approach to nuclides most likely to be of significance to environmental restoration and remediation work at Hanford. The result is a set of work-site conditions that, if exceeded, would warrant placing workers on a bioassay program. The type of bioassays that might be considered appropriate are briefly addressed, however, the specifics regarding types of bioassay, frequency of bioassay measurements, and the associated sensitivity of any program with regard to minimum detected dose are beyond the scope of this brief paper.

APPROACH TO THE PROBLEM

The possibility of radionuclide intakes totaling 2% of the Annual Limit on Intake (ALI) was used as the starting point for determining the need for bioassay. The ALI is widely recognized as a useful concept for radiation protection planning purposes, and is readily accessible in published form (ICRP 1979; EPA 1988), although the term has not been in wide use at DOE facilities.

An ALI is the amount of a radionuclide that, if inhaled or ingested in one year, would result in a committed dose equivalent equal to the limiting value of the DOE Radiation Protection Standards (RPS). Where the ALI is determined by the stochastic limit of 5 rem/y, 2% of the ALI would correspond to a 100-mrem committed effective dose equivalent (CEDE), thus indicating compliance with the 100-mrem CEDE level at which bioassay monitoring is required by DOE. Where the ALI is determined by the nonstochastic limit of 50 rem/y, 2% of the ALI would correspond to a maximum committed dose equivalent to a single organ or tissue equal to 1 rem and a committed effective dose equivalent below 100 mrem, again demonstrating compliance with the DOE requirements.

Acute and chronic scenarios that would result in the intake of 2% of an ALI were postulated for analysis, and criteria were derived from those analyses to be used with pre-job site characterization data and during-the-job surveillance. These criteria encompass both inhalation and ingestion modes of intake.

EXPOSURE TO AIRBORNE DUSTS

Exposure to airborne dusts was considered to result from activities such as heavy equipment operation for moving dirt, manual labor such as shoveling, sorting, or filling sample bottles with dirt, or well-drilling operations. Inhalation and ingestion were both considered as possible modes of intake; inhalation resulting from breathing the respirable particles in the airborne dust, and ingestion of nonrespirable particles either by direct intake from the air or by brushing one's lips with contaminated clothing.

Inhalation Intake

The magnitude of airborne dust inhalation intake can be calculated as follows:

$$I_{dust} = ADL \times BR \times T$$

where,
I_{dust} = the total dust intake (mg)
ADL = the airborne dust loading (mgm^{-3})
BR = the "light activity" breathing rate for ICRP Reference Man (1.2 m^3h^{-3})
T = the exposure time (h)

Two types of exposure conditions were addressed, the single job involving short-term exposure to very high dust loadings, and the long-term job involving daily exposure to moderately high dust loadings. The working conditions associated with the two types of exposures are described below:

- Acute. A single 2-hour exposure to very high dust loadings (as much as 150-mgm^{-3}) as might be associated with manual digging in the unsuppressed dust cloud generated by excavation using heavy equipment, or the dust cloud generated by an agricultural tractor tilling soil. Industrial hygiene staff indicated that such an exposure would represent the upper limit of unprotected worker tolerance (i.e., sneezing or gagging would significantly impair worker comfort and productivity). This exposure represents a dust intake of 360mg.

- Chronic. A daily exposure to high dust loadings on a continuing basis. An average daily intake rate of 48-mgd^{-1} was calculated, assuming exposure to 20-mgm^{-3} for 2-hd^{-1}. Such a dust loading would likely appear as a distinct haze in light beams with dust particles visible, and would result in visible dust on clothing, shoulders, hair, and glasses. This intake rate was assumed for 250 working days per year to give a total annual dust intake of 12,000 mg.

As a basis for comparison, the ambient dust loading levels associated with very intense 1990 and 1991 dust storms in the Benton-Franklin counties region of Washington state were on the order of 1 to 2 mgm^{-3}. Dust loadings in the 1 to 5 mgm^{-3} range can be expected to result in minor eye irritation.

The airborne dust was assumed to consist of respirable particles (1-μm AMAD). This is a substantially conservative assumption because, for most situations, the dust will probably consist primarily of re-suspended sand particles (60 μm to 2 mm) and silt particles (2 μm to 60 μm) and very little clay (less than 2 μm in diameter)(Eisenbud 1987). The concentration of radioactivity in the airborne dust was assumed to be the same as the concentration in the soil.

The soil contamination levels for establishing bioassay criteria are shown in Table 1. These values were derived by dividing 2% of the pertinent nuclide ALI by the magnitude of the acute or chronic dust intakes, rounded upward to one significant figure. The ALIs used were the conventional unit (μCi) values found in Federal Guidance Report No. 11 (EPA 1988). The ALIs and the calculated values are shown in Table 2. The upward rounding was considered reasonable given the substantial compounding of conservative assumptions of dust loading, exposure time, and particle size, which occurred in the calculations. Such upward rounding would not result in more than a factor of two reduction in the overall conservativeness.

Soil contamination levels for soluble (i.e., class D) uranium were also calculated based on the potential threshold for kidney toxicity (a 15-mg acute intake, or a chronic intake kidney burden of 1.1 μgg^{-1}), as well as for an intake of 2% of the ALI. For acute intakes, the class D chemical toxicity criterion is not significantly different than the criterion for the class W inhalation scenario. For chronic exposure, the class D results were much less restrictive than for class W. The class Y uranium criteria provide a high degree of conservatism with regard to dose or chemical toxicity concerns compared to either class W of class D forms of uranium. Because information is often not available regarding the actual chemical form in which uranium might be encountered, the use of class Y acute and chronic conditions is a reasonable basis for initiating bioassay. If it is known that uranium will likely be in a soluble form, then the use of the less restrictive class D or class W uranium criteria would be appropriate.

It was assumed that the soil contamination is lognormally distributed, as is common with environmental distributions. The soil concentrations in Table 1 represent the geometric mean value, i.e, 50% of the contamination present would be expected to be associated with lower soil concentrations, and 50% would be associated with higher soil concentrations. If the arithmetic mean value is calculated for a set of soil samples, this will give a result likely to be substantially below the geometric mean value. Thus, use of the arithmetic mean soil concentration by personnel not familiar with lognormal distribution analysis techniques will result in conservative determinations of the need for bioassay.

Ingestion Intake

The ingestion ALIs for uranium, plutonium, and thorium are typically two orders of magnitude larger than the inhalation ALIs. This implies that 10 - 100 gd^{-1} quantities of soil would have to be ingested to achieve 2% of an ALI. Such soil intakes are unrealistic.

For Cs-137, Sr-90, and Co-60 the ingestion ALIs are about the same (within a factor of two or three) as the inhalation ALIs. Chronic daily ingestions of 5 to 20 g of soil would still be required to result in 2% of an ALI. These levels also represent very large ingestions of dirt. The likelihood of ingestion of these quantities was considered quite remote because the concentrations represent levels that would be readily detectable on field survey instruments. Normal radiation work practices would either preclude such intakes or readily detect them, resulting in the initiation of special bioassay monitoring.

Multiple Radionuclides

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 soil concentration to its respective criterion value, as shown below:

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

If the Index value exceeds one, then participation in the bioassay program should be required. 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.

EXPOSURE TO TRITIUM

The most likely mode of intake for tritium was considered to be accidental ingestion of groundwater contaminated with relatively low levels of tritium. The inhalation pathway was considered insignificant. The ALI for tritium is 80 mCi; 2% of the ALI is 1,600 μCi.

To achieve such an acute intake would require ingestion of an unusually large amount of contaminated water (e.g., 1L of water at 1,600 μCiL^{-1} or 250 mL of water at 6,400 μCiL^{-1} water). Such levels are two-to-three orders of magnitude higher than the highest recent tritium contamination level (5 μCiL^{-1}) detected in groundwater underlying Hanford (Jaquish and Bryce 1990).

Chronic exposure would only be expected to result from direct skin contact with contaminated water or occasional ingestion of small quantities of water. Because contaminated groundwater is not being intentionally consumed, it is unlikely that more than a few milliLiters per day might be absorbed or ingested during normal work activities. The daily uptake rate for a 250-d working year required to result in 2% of an ALI (the basis for chronic exposure bioassay) would be 6-μCid^{-1}. Based on the highest recent tritium contamination level in groundwater reported at Hanford, such an intake was not considered possible.

The conclusion from the above analysis was that tritium bioassay of well-drillers and other, ER workers was not warranted.

SUITABLE BIOASSAY MEASUREMENTS

Routine bioassay measurements suitable for ER work, as indicated based on the soil concentration criteria, include annual whole body exams (for high-energy gamma-emitting nuclides such as Cs-137 and Co-60), or annual Sr-90 in urine analyses. Chest counting and urinalyses are common for uranium or plutonium, however they are not likely to be capable of detecting 2% of an ALI for insoluble forms of these compounds. Fecal sampling is the most sensitive bioassay indicator of intake, particularly if samples are obtained shortly following the intake, however, the natural presence of uranium in the environment and in human excreta may complicate interpretation of measurements.

Personal air sampling is probably the most effective form of monitoring potential exposure of outdoor workers, particularly if the air sample discriminates between respirable and nonrespirable particles and has an enclosed filter to minimize the chances of contamination by external contact. These air samplers would be particularly valuable if used as initiators for special urine, feces, and in vivo bioassay monitoring.

In the event that work-place monitoring practices indicate unanticipated intakes (i.e., beyond the scope of the foregoing criteria), then special bioassay monitoring would be performed. Appropriate special monitoring is determined on a case-by-case basis.

CONCLUSIONS

The potential exposure to dust generated by ER work at Hanford could be suspected (though not necessarily expected) to possibly result in inhalation or ingestion intakes of radioactive material. Provided that average soil contamination levels are below those indicated in Table 1, and the index for multiple radionuclide exposures described in this report is below one, there is no need for ER workers to be placed on routine bioassay.

The above conclusion does not alter the need for special bioassay procedures in the event of significant work-place indications of potential intake (e.g., detectable nasal contamination or major facial or skin contamination).

Bioassay for tritium is not warranted for workers potentially exposed to tritium-contaminated soil or groundwater at Hanford.

This approach to establishing bioassay criteria should be generally applicable to a wide range of outdoor work at many sites.

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TABLE 1. Criteria for Bioassay Monitoring for Work Involving Exposure to Contaminated Soil

NUCLIDE AND FORM		SOIL CONCENTRATION ($pCig^{-1}$) ACUTE INTAKE[a]	CHRONIC INTAKE[b]
Uranium - Total [c]			
	Class D or W	4E+04	2,000
	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	1E+06	4E+04
Cs-137	Class D	2E+07	4E+05
Co-60	Class Y	2E+06	5E+04
Tritium in groundwater[d]		5,000 μCiL^{-1}	1,000 μCiL^{-1}

(a) Assumes a 360-mg inhalation intake of dust in a single exposure.

(b) Assumes a 48-mgd^{-1} inhalation intake rate for 250 working days/year.

(c) Natural, U-234, U-235, or U-238 in any combination. Based on the ALI for U-234. Same numbers apply for units of ppm or μgg^{-1} for soil.

(d) Assumes consumption of 250 mL (acute) or 250 mLd^{-1} (chronic).

TABLE 2. Assumed Exposure Conditions and Calculated Values

	ACUTE EXPOSURE	CHRONIC EXPOSURE
Times per year:	1	250
Exposure Time:	2 h	2 hd^{-1}
Dust Loading:	150 mgm^{-3}	20 mgm^{-3}
Breathing Rate:	1.2 m^3h^{-1}	1.2 m^3h^{-1}
Dust Intake Rate:	360 mgd^{-1}	48 mgd^{-1}
Annual Intake:	360 mg	12,000 mg
Potentially Missed Intake and Dose[a]:	2 % of ALI ≤100 mrem	2 % of ALI ≤100 mrem

NUCLIDE AND FORM	ALI[b] (uCi)	SOIL CONCENTRATION ($pCig^{-1}$) CASE 1 ACUTE	CASE 2 CHRONIC
Uranium - Total [c]			
Soluble Uranium (Class D)			
Chemical Toxicity[d]		3.8E+04	2,000
2% ALI	1	8.6E+04	2,600
Class W	0.7	3.9E+04	1,200
Class Y	0.04	2,200	67
Pu-238 Class W	0.007	390	12
Pu-239 Class W	0.006	330	10
Pu-238 or -239 Class Y	0.02	1,100	33
Th-232 Class W	0.001	56	1.7
Class Y	0.003	170	5
Th-228 Class W	0.01	560	17
Class Y	0.02	1,100	33
Sr-90 Class D	20	1.1E+6	3.3E+04
Class Y	4	2.2E+5	6,700
Cs-137 Class D	200	1.1E+7	3.3E+5
Co-60 Class W	200	1.1E+7	3.3E+5
Class Y	30	1.7E+6	5.0E+4

(a) The potentially missed CEDE for ALIs based on stochastic effects is 100 mrem. For ALIs based on nonstochastic effects it is <100 mrem.
(b) The source for ALIs is EPA Federal Guidance Report No. 11 (EPA 1980).
(c) Natural, U-234, U-235, or U-238 in any combination. Based on the ALI for U-234.
(d) The threshold for chemical toxicity is assumed to be a 15-mg acute intake of soluble uranium, or a chronic intake resulting in a sustained kidney burden of 1.1 μgg^{-1}.

END

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