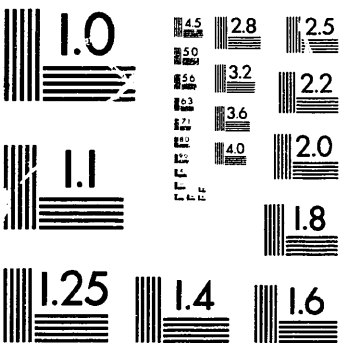
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INTERNAL DOSIMETRY
Performing Dose Assessments via Bioassay Measurements

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INTRODUCTION

The Internal Dosimetry Department at the Y-12 Plant maintains a state-of-the-art bioassay program managed under the guidance and regulations of the Department of Energy. The guidelines are outlined in the Radiation Control Manual (RADCON) which superseded DOE Order 5480.11. In addition, criteria for the accreditation of radiobioassay service laboratories are given in ANSI N13.30 (draft). The bioassay program consists of an *in vitro* and *in vivo* program, both of which are used to monitor and assess dose evaluations.

As mentioned the two major bioassay techniques currently used at Y-12 are the *in vitro* (urinalysis) and *in vivo* (lung counting) programs. Fecal analysis (as part of the in vitro program) is another alternative; however, since both urine and fecal analysis provide essentially the same capabilities for detecting exposures to uranium, the urinalysis is the main choice primarily for aesthetic reasons. The bioassay frequency is based on meeting NCRP 87 objectives which are to monitor the accumulation of radioactive material in exposed individuals, and to ensure that significant depositions are detected.

Internal dosimetry programs are required where individuals are likely to receive intakes greater than 2% of the DOE limit (5 Rem) which corresponds to 100 millirem committed effective dose equivalent (CEDE). The objective of the program is to perform assessments for intakes which occur plus initiation of a workplace investigation when an intake has been confirmed.

The status of engineering controls in place at the work site is monitored using air samplers, which are the primary means to indicate a breach of control. The work areas are monitored by several types of air samplers - permanent air samplers, high or low volume air samplers, and personal breathing zone (lapel) samplers. The majority of the air sampling performed is a retrospective type which utilizes fixed sampling heads at locations to determine the average airborne radioactivity during the sampling period. This sampling process is conducted in normally occupied areas where an individual is likely to receive an exposure to airborne radioactive material. The special sampling using low volume, high volume, and lapel air samplers are generally used when tasks are performed in

a work area that is not presently monitored by the fixed air samplers.

By identifying the derived air concentration (DAC) in a work area the results of the air monitoring are used to determine if a worker has been exposed to airborne radioactivity. If the air sampler result is elevated in a work area, it is first determined who was working in that area and was any respiratory protection worn at the time of work. If no respiratory protection was worn, or if the activity level was greater than the respiratory protection afforded that person, then special bioassay measurements are requested of the employee. In other words, the bioassay measurements are performed as a precaution when a failure in workplace control has been detected.

According to NCRP 87, when average airborne radioactive material concentrations exceed 10% of the derived air concentration (DAC) or spikes greater than 30% of the DAC can be expected, the frequency of routine bioassay should be based on ensuring that significant depositions do not go undetected. A frequency program was established with derived investigation levels (DIL) set up which allow 100 millirem CEDE acute intakes to be detected, even in the presence of activity excreted due to chronic intakes. When routine bioassay results exceed the DIL, a radiological incident investigation and special dose assessment are performed.

The goal of the bioassay program is to detect significant depositions therefore bioassay measurements must be scheduled on an appropriate frequency. This frequency will depend on factors such as the solubility/transportability of inhaled material, the type of bioassay which is to be performed, what is considered to be a "significant deposition", and how much activity can be expected to be in bioassay measurements due to chronic intake. In effect, a "significant deposition" has been defined as 2% of the DOE Radiation Protection Standard of 5000 millirem.

The expected activity in the urine can be calculated as a function of days since intake corresponding to 100 millirem CEDE. However, this becomes a little more difficult at the Y-12 Plant because acute intakes are riding on the back of chronic exposures. Were it not for chronic intake it would be possible to detect a 100 millirem CEDE acute intake at more than 6 months after the original exposure (DIL = 0.8 dpm/day, MDA approximately 0.15 dpm/day). The level of chronic uranium intake exceeds this DIL on monthly sample results. This makes assessments a little more challenging with a chronic intake present. Under conditions of chronic exposure, the quantity of uranium excreted reaches a constant value after two or three years. However, this rate of excretion reaches over 90% of this equilibrium value (approximately 12.5 dpm/day) in only 90 days. Therefore, a conservative DIL was set at 10 dpm/day.

In Vitro Bioassay

Once the uranium urinalysis frequency is established for employees, each employee required to leave samples receives training on where to pick up sample collection kits, how to collect urine, what information to enter on the sample labels, how to follow the chain-of-custody procedure, and how to return the kit for analysis.

A participant in the urinalysis program is required to collect either all voids during a 24-hour period, or, collect their last void before going to bed, all voids during the night, and the first void of the morning on 2 consecutive days in which the employee is off site. The urinalysis kit is then brought back to the plant for routine evaluation. Approximately 50,000 uranium urinalysis measurements have been collected since the fourth quarter of 1989. These results are carefully monitored, reported, and followed for any possible trends.

The Analytical Services Organization Bioassay Department provides bioassay capabilities for uranium in urine or feces. A tracer is added, several acid wash treatments, then a series of chemical precipitations and ion exchange resins are used to separate the uranium. Fecal samples are first ashed in a muffle furnace and digested in a stronger organic acid. Uranium isotopes are then coprecipitated with neodymium fluoride (NdF-3). The precipitate is captured on a 1 micron filter, dried and mounted on a planchet for Alpha spectroscopy.

In Vivo Bioassay

Lung counting is currently the only form of *in vivo* bioassay performed at the Y-12 Plant. However, the *in vivo* system has the capabilities required to perform *in vivo* analyses on organs such as the kidneys and bone whenever "standardized" phantoms for these organs become available.

The low-level chronic intakes of uranium which occur at the Y-12 Plant are typically not detectable by the *in vivo* bioassay program. This program is maintained to assist in the rapid assessment of possible acute intakes and to survey for unexpected significant intakes of insoluble uranium which could escape detection by the *in vitro* program. While the results from uranium urinalysis measurements can be delayed for some time after an incident, *in vivo* measurement results can allow an "upper boundary" on any possible acute inhalation of uranium to be established quickly. For *in vivo* measurements, MDAs are "person specific" depending primarily on the individual's chest wall thickness.

Assuming low level chronic exposure, Table 1 shows the minimum detectable "effective" dose equivalent for this system, based on typical MDAs, at various times post intake, for enriched uranium (EU) and depleted uranium (DU) intakes of both Class Q (Y-12 hybrid class) and Class Y uranium with an activity median aerodynamic diameter (AMAD) equal to 8 microns. The 8 micron AMAD is based on particle size studies conducted on aerosols at the Y-12 Plant.

Table 1: Minimum Detectable Committed Effective Dose Equivalents for Lung Counting

Days Post Acute Intake	Q (millirem) EU	Q (millirem) DU	Y (millirem) EU	Y (millirem) DU
1	850	600	3300	2400
2	1000	730	4000	2900
3	1100	810	4500	3200
4	1200	860	4700	3400
5	1300	890	4800	3400
6	1300	900	4900	3500
7	1300	930	4900	3500
14	1400	1000	5000	3600
30	1700	1200	5000	3600
90	3200	2300	5400	3900
180	7000	5000	5900	4200
360	16,000	11,120	7100	5100

The current lung counting chamber was custom built by on-site employees in the early to mid 1980's. The chamber is approximately an 8 x 8 foot room with walls constructed by utilizing layers consisting of concrete, then a lead liner, followed by a layer of copper which lines the inside walls. The copper (a low Z material) was used to minimize the gamma ray interaction being detected within the chamber. The door to the chamber is likewise made of the same construction making weight a big factor in operation, so the door is controlled electronically for employee ease. A shadow box was constructed to allow for ventilation and wiring entries.

The detectors currently in use are High Purity Germanium (HPGe) which must be cooled and maintained at the temperature of liquid nitrogen. The fill of the detectors is automatic at 12 hour intervals. The Canberra detectors are equipped with Beryllium windows of 0.5 mm. thickness. If a detector begins to warm up, perhaps due to improper fill, the counting system is shut down and the detector must be allowed to warm at room temperature for 4 days before re-cooling again with liquid nitrogen. After refill, all quality assurance criteria must be met before the system is activated again.

For quality assurance purposes, daily energy calibrations and yearly efficiency calibrations are performed. A daily calibration is performed using a Lawrence Livermore tissue equivalent phantom (reflecting "reference man") containing spiked lungs of a known quantity. The daily energy calibration is performed to ensure that the MCA pulse storage locations (channels) are correlated with photon energy. This correlation is obtained by regression analysis and is typically expressed as an equation of the following form:

$$y = A_1x + B_1x^2 + K$$

where:

A_1 = the linear coefficient of regression
A_2 = the quadratic coefficient of regression
K = the y-intercept term
x = the channel number.

Software from Nuclear Data - Canberra is used to perform the energy calibration and store the regression information for each detector in use. A yearly efficiency calibration is also performed using tissue equivalent chest wall overlays of varied known thicknesses and lungs of different isotopes in known quantities. During this annual calibration the relationship between chest-wall thickness and efficiency is determined. For each line energy of interest used to calibrate the system, several counts are performed with the various chest overlays to simulate different CWTs. As attenuation is an exponential process, the efficiency data may be fit to a function of the following form:

$$eff = a_1e^{-a_2t}$$

where:

eff = efficiency as a function of CWT
a_1 and a_2 = fitting parameters (estimated by software)
t = CWT.

All lungs used in calibration procedures are National Institute of Standards and Technology (NIST) traceable.

Obviously surface contamination is detrimental to a successful count, therefore, employees are requested to shower prior to a count, and wear only a TYVEK protective paper suit. Through testing, these paper suits have been found to have no contribution to the background. The employee is surveyed for surface contamination over their arms, hands, hair and chest area and then weighed and measured. The height and weight are used for formulating a chest wall thickness attenuation factor as previously mentioned. The employee is then placed in the counting chair inside the chamber and the 4 detectors strategically placed on the chest area (See Figure 1). A 30-minute count is made while the employee remains in this position.

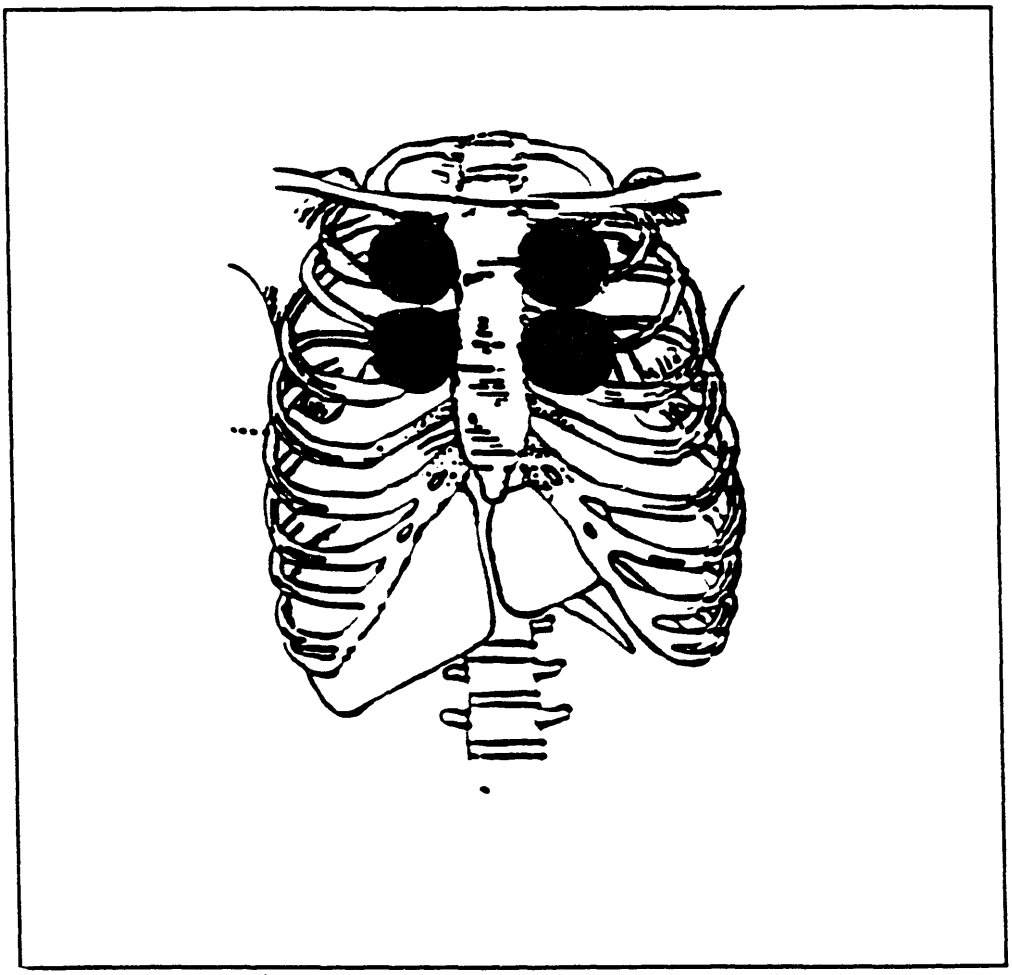

Figure 1: Diagram of proper placement of HPGe detectors for lung counting.

Dose Assessments

Intakes and uptakes (via wounds) cannot be measured directly but must be inferred from bioassay. NUREG/CR-4884 "Interpretation of Bioassay Measurements" contains tables of acute inhalation and ingestion Intake Retention Fractions (IRF(t)'s) for various bioassay measurement techniques. The values in these tables are based on biokinetic models and can be used to convert bioassay measurements into intake estimates. Given a result from a single bioassay measurement at time, t, post intake, the intake is calculated by using the following equation:

$$I = \frac{Y}{IRF(t)}$$

where:

I = intake
Y = bioassay measurement result
IRF = Intake Retention Fraction for the given bioassay measurement technique.

Biokinetic models assume that activity is continuously removed from the body of an exposed individual. *In vitro* IRF(t) values, based on these models, give the fraction of an initial intake expected to be collected in an excretion compartment during a specified time period. Typically sampling is over a 24-hour period, however, if excretion data is collected over a period of time other than 1 day, it is necessary to normalize the activity so it approximates the total amount of activity that would have been excreted in 1 day. If sample time is less than 1 day these samples are normalized as follows: sample mass is converted to volume by using the specific gravity of urine (ICRP 23, 1.02 g/cm), the result is expressed as the ratio of activity to volume (dpm/liter), and the ratio is converted to dpm/24 hours by multiplying by the volume of urine excreted in one day by a "standard" person. From ICRP 23, a "standard" male excretes 1.4 liters of urine, while a "standard" female excretes 1 liter of urine, in a 24-hour period, but for the sake of simplicity, it is normally assumed that a female also excretes 1.4 liters per day. For fecal samples, the activity in a single fecal void is taken to represent the total activity excreted by an individual in a day; no normalization is performed. The tables in NUREG/CR -4884 include acute IRF(t) values for the 3 standard lung clearance classes of uranium for a 1 micron AMAD. IFR(t) values are normally generated as part of an intake/dose assessment using either the INDOS or DOSEXPRT computer codes (called "expected E_u (t)," for urinary excretion, or "expected E_f (t)", for fecal excretion, "from a unit intake at t=0").

For many acute intakes, several bioassay measurements are made as a part of the dose assessment. With multiple bioassay measurements it is possible to generate an intake estimate based on a least-squares fit of the bioassay data to the biokinetic model used in the assessment. To perform such a fit it is necessary to make an assumption regarding the nature of the bioassay measurements' variance. There are 3 common assumptions regarding this variance, and hence there are 3 different fitting techniques which are commonly used to generate intake estimates based on repetitive bioassay measurements. The fitting technique generally used to generate intake estimates at Y-12 is the iteratively-weighted fit. With this fit, it is assumed that the variance in a measurement, σ_i^2, is proportional to the measurement's expectation value based on the biokinetic model:

$$\sigma_i^2 \propto I \times IRF_i$$

When this assumption is used, an intake may be estimated from the following equation:

$$I = \frac{\sum_{i=1}^{N} Y_i}{\sum_{i=1}^{N} IRF_i}$$

Using a macro-driven spreadsheet, developed at Y-12, it is possible to generate intake estimates using the above equation for Class D, W, Y, and any hybrid class, and to graphically compare "expected" bioassay data based on these models with actual bioassay data. Such graphical representations are sometimes used to assist in choosing the appropriate model and to consider whether or not the default assumptions made in the intake assessment are reasonable.

Acute intake estimates are also generated by DOSEXPRT, a computer program written by Dr. Keith Eckerman, and Herbert Ward at the Oak Ridge National Laboratory. With this computer code, intake estimates are generated for each bioassay measurement separately, using an algorithm identical to the above equation. DOSEXPRT then reports the average of these "single point" intake estimates as the final intake estimate. (Since the reader of this report is likewise the author of DOSEXPRT, I will not delineate the DOSEXPRT program.) DOSEXPRT is derived using the lung model presented in ICRP-30.

In order to estimate intakes due to chronic exposure, additional assumptions are required, and the calculations can become more complicated. The DOSEXPRT computer code is the primary tool used

to analyze routine (chronic) bioassay data. To understand what makes DOSEXPRT's algorithm different, it is necessary to first consider what goes into a chronic intake assessment. A biokinetic model can be used to predict the fraction of a continuous intake of one unit of activity per day expected in a "compartment" at some point in time. If the bioassay measurement result from an individual chronically exposed at a constant rate is divided by this "chronic" IRF(t) value (where t is equal to the number of days since the beginning of intake), the quotient is the intake rate during the period. The total intake is calculated by multiplying this rate by the number of days in the chronic intake period. Multiple "routine" bioassay measurements can be used to estimate the "best fit" intake rate over the time period, but it still must be assumed that the rate remained constant during the period.

Individuals occasionally receive internal uptakes due to wound contamination. These uptakes may be assessed by using methods similar to those used to assess intakes. There are two main differences between these types of assessments. With wound uptakes, only the systemic retention portion of the appropriate biokinetic model is used (as opposed to the systemic retention function coupled with one or both of the GI tract and lung models), and it may be desirable to model the uptake of activity to the systemic compartment from the wound site. In an uptake assessment, the half-time for uptake of activity from the wound is estimated, and another computer program for internal assessments called INDOS is used to produce an uptake estimate in a manner very much analogous to that used to generate an estimate of intake - multiple bioassay measurement results are fit to the systemic retention model using the iterative-weighted-fit option. Uptake estimates can also be used with the model to predict bioassay measurements which in turn can be graphically compared with actual bioassay data.

Presently the Y-12 Bioassay Program cannot perform a wound assessment via the *in vivo* method due to geometry considerations during calibration procedures; however, there are plans to secure wound phantoms which model the tissue equivalent of extremities which will then make quantitative analyses possible.

In order to maintain credibility and compliance with ANSI N13.30 requirements for sensitivity and precision, the Y-12 *In Vivo* facility participates in two comparison studies. One is a program with DOE in which a torso, containing spiked lungs of an unknown activity, is sent from Pacific Northwest Laboratory for quantification. Last year, upon completion of the study by Y-12, the activity assessed by Y-12 against DOE was found to be within a 2% range of error. The second study is with the University of Cincinnati which is scheduled to begin in June, 1993.

The counting facility is not solely used for lung counting, it can be used for other tasks as well. Although the system can not

quantify unknown sources, an identification can be made because every isotope does have a particular energy emission signature. Unknown sources are occasionally brought to the lung counter in an emergency for rapid identification followed with chemical analyses by the plant lab for accurate quantification.

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