# DEVELOPMENT AND APPLICATION OF A BETA-GAMMA DETECTOR ASSEMBLY FOR RADIOLOGICAL CHARACTERIZATION OF A HIGH-LEVEL WASTE STORAGE TANK AT THE WEST VALLEY DEMONSTRATION PROJECT

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## ABSTRACT

The West Valley Demonstration Project (WVDP) has completed the radiological characterization of residual activity remaining in large underground high-level waste (HLW) storage tanks. This multi-year characterization project encompassed the application of many new and innovative technologies to perform in situ characterization of radionuclide inventories for the tanks during the final stages of HLW retrieval operations. These innovative characterization technologies deployed in the HLW tanks include a shielded multi-array beta-gamma detector assembly, a specially modified gamma camera that provides two-dimensional spatial mapping of $^{137}Cs$ accumulation in the tank, and a burnishing sampler that spot faces the tank surfaces and captures the removed material for analysis.

This paper discusses the application of the shielded multi-array beta-gamma detector assembly developed in support of characterization of radiological surface contamination on the internal tank walls and structures in the 750,000-gallon HLW Storage Tank 8D-2. Particular attention is given to the underlying motivations and assumptions impacting the development and design of the assembly, the approach developed for calibration of the assembly, and the effectiveness of this detector to provide accurate results alleviating the need for extensive physical sampling of the tank internals.

## INTRODUCTION

High-Level Waste Storage Tank 8D-2 originally contained approximately 600,000 gallons of neutralized plutonium-uranium extraction (PUREX) waste from both commercial and defense nuclear fuel reprocessing operations at the Western New York Nuclear Service Center (WNYNSC) from 1966 to 1972. Neutralization and concentration of the tanks contents caused insoluble hydroxides and other salts to precipitate out of the liquid supernatant and form sludge layers in the bottom of Tank 8D-2. Over 99 percent of the radioactivity has been retrieved and blended into solid glass through a process known as vitrification. The objective of the HLW Tank Radiological Characterization Program was to verify that waste retrieval targets have been met.

## DATA COLLECTION DESIGN

Radiological characterization of Tank 8D-2 was accomplished per the requirements of a Data Collection and Analysis Plan (DAP) prepared by WVNSCO which provided the structured and systematic approach and a technically sound basis for the collection, evaluation, and reporting of field data. As part of the DAP, Data Quality Objectives (DQOs) were also developed to establish that the right type, quantity, and quality of data are collected that would support defensible decision making.

As required by the Tank 8D-2 data collection requirements described in the DAP, characterization of radiological surface contamination on the internal tank walls and structures was needed. Initially, it was believed that extensive physical sampling of the tank=s internal surfaces would be necessary to fully characterize the tank. However, an alternative was developed using a short stand-off shielded multi-array beta-gamma detector assembly to measure the beta and gamma activity in vertical scans down the interior of the 8D-2 tank wall. Advantages of the beta-gamma detector over a physical sampling program were that large amounts of data could be collected rapidly, cost-effectively, and non-intrusively. Deployment of the beta-gamma detector was accomplished by a custom-designed remote arm and tool delivery system which positions the detector assembly to remotely perform the in-tank surveys.

Based on Tank 8D-2 process knowledge and video inspections of the tank interior walls, three regions of internal contamination were anticipated with distinct physical, chemical, and radiological differences: a vapor region, liquid region, and a sludge region. The residual activity remaining in the three regions was believed to be minor compared to the total tank source term.

The initial approach for the radiological characterization of Tank 8D-2 internal surface contamination was to calculate the cesium and strontium areal concentrations from the dose rate surveys and relating these values to the key radionuclides through the use of scaling factors derived from the WVDP waste characterization program. Determination of $^{90}Sr$ and $^{137}Cs$ areal surface concentrations ($Ci/m^2$) would be calculated using the beta-gamma, gamma, and background activity measurements from the in situ beta-gamma detector assembly.

It was subsequently determined that calculation of $^{137}Cs$ concentrations using the beta-gamma detector surveys is difficult due to possible Bremsstrahlung effects on the gamma measurement. Determining the magnitude of this effect was thought to be a nontrivial task. As a result, only the $^{90}Sr$ radiological surface contamination would be estimated from the beta-gamma detector survey data and the $^{137}Cs$ areal concentrations would then be derived from Cs/Sr scaling factors.

## BETA-GAMMA DETECTOR ASSEMBLY

The predominant sources of beta and gamma radiation in the HLW tanks are $^{137}Cs$ and its daughter $^{137}Ba$ m, and $^{90}Sr$ and its daughter $^{90}Y$. $^{137}Cs$, $^{90}Sr$, and $^{90}Y$ emit essentially only beta radiation; $^{137}Ba$ m emits mainly gamma radiation. The purpose of the beta-gamma detector system is to measure both the beta-emitting and gamma-emitting radioactivity on the interior surfaces of the HLW tanks. Two systems were deployed in Tank
8D-2: a three-detector array system and a two-detector array system for deployment in more confined locations.

The three-detector system has gamma, beta-gamma, and background detectors. All three probes are housed in a box-like module that provides shielding on all sides except the face of the unit. The shield module face has two conical depressions leading to the end-windows of the two measurement probes. Short stand-offs aid in remotely positioning the detector face 3/8 inches (0.92 cm) from the surface to be surveyed, which results in a tank surface to probe distance of 7.24 cm. The background probe is completely encased in shielding provided by the shield module. The shield module is comprised of a stainless steel shell and a lead-filled interior with detector cavities and cable chases for ease of initial placement and potential replacement of the three probes. Figure 1 shows the configuration of the beta-gamma three-detector system.

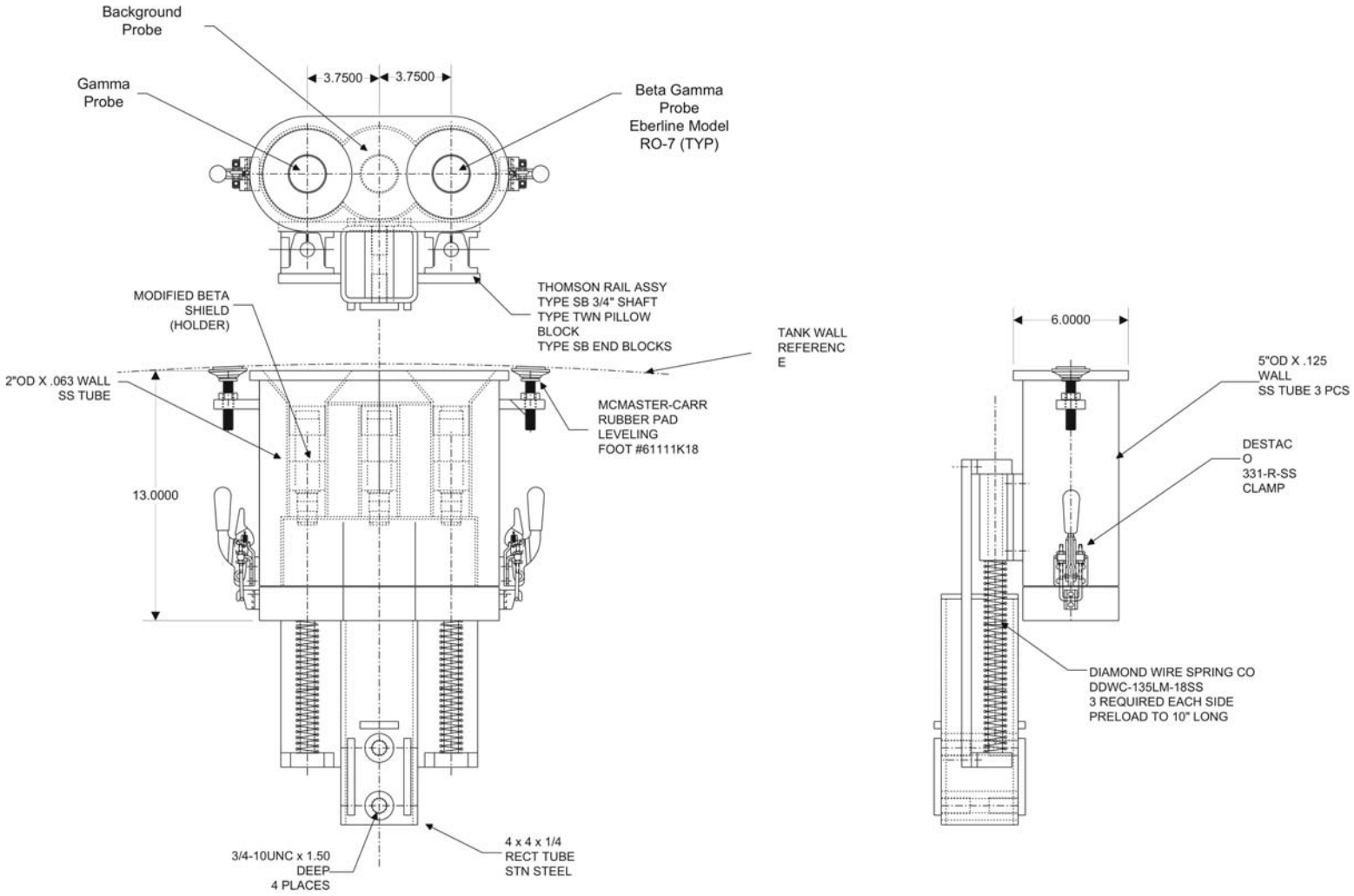


Fig. 1 Three-detector beta-gamma array

The two-detector system is similar in design to the three-detector system without the background detector. Initial deployment of the three-detector system demonstrated that background dose rates were insignificant in comparison to the dose rates being measured on the tank walls. Removal of the need for the background detector allowed the detector footprint to be reduced to improve accessibility into the tank.

All of the detectors are ion chambers that are sensitive to beta and gamma radiation. The shield configurations determine the type of radiation detected. The gamma probe has a one-centimeter (cm) thick LuciteJ or Plexiglas[7] shield or window over the detector. This window completely attenuates all the beta particles including the high-energy beta particles associated with $^{90}$Y decay. The $^{90}$Y is a short-lived daughter of $^{90}$Sr (a major constituent of the HLW) and produces the highest energy beta particle likely to be encountered by the measurement devices in the HLW tanks. The absorber causes the detector to be sensitive to only the gamma component of radiation emitted from the tank interior surfaces. The beta-gamma probe is shielded by a thin aluminum attenuator (0.0673 cm thick) that attenuates all but the high-energy beta particles emitted by the $^{90}$Y and also eliminates most of the $^{137}$Cs beta particles. Both the gamma and beta-gamma probes have a one-mil-thick MylarJ cover to protect the probes from moisture and contamination. The third detector (in the case of the three-detector system) is a background detector used to estimate the influence on the other two measurement detectors of gamma radiation from adjacent tank internal surfaces that are outside the field-of-view. The background measurements are subtracted from the measurement detector results in order to quantify the radiation intensity attributable solely to the surfaces under inspection, including a small incremental quantity from backscatter in this direction. As noted above, the two-detector system does not have a dedicated background probe as the background measurement was found to be insignificant in comparison to the dose rates being measured on the tank walls.

The addition of an aluminum attenuator over the beta-gamma probe was a modification to the system initially deployed for filtering the lower $^{137}$Cs and $^{90}$Sr beta energies from the higher $^{90}$Y beta energy. This modification was made to address the effect of self-shielding within the contamination deposited on the tank walls. Due to the long half-life of $^{90}$Sr and the relatively short half-life of $^{90}$Y, $^{90}$Sr and $^{90}$Y are in equilibrium. As a result, all beta radiation measured is attributed solely to $^{90}$Y and can therefore be used to estimate $^{90}$Sr areal concentrations.

All probes in the detector systems were Eberline Model RO-7 probes and were calibrated prior to deployment to correctly respond to the radiation exposure rate in units of roentgen per hour (R/hr) attributable to a $^{137}$Cs calibration source.

## DOSE-TO-CURIE ANALYTICAL MODEL

The methodology initially used to determine the $^{90}$Sr areal concentration from the beta-gamma detector dose rate surveys is described below.

Calculation of the $^{90}$Sr areal concentration is divided into two distinct tasks. The first task determines which of the beta particles have sufficient energy or range to reach the detector. The second determines the areal concentration at the measured locations.

### Range Determination

$^{90}$Sr is a beta emitter and decays to $^{90}$Y, which is also a beta emitter. Due to the long half-life of $^{90}$Sr and relatively short half-life of $^{90}$Y, $^{90}$Sr and $^{90}$Y are in equilibrium. $^{90}$Sr emits one beta particle and $^{90}$Y emits two.

To determine the areal concentration that produces the measured dose rate, the beta particles with sufficient energy to be measured by the beta-gamma detector are determined. This begins by estimating the range of the

beta particles emitted by $^{90}$Sr and $^{90}$Y. The range is an estimate of the distance a particle will travel in a material, and is usually given in density thickness so it can be applied to different materials.

The beta-gamma probe has aluminum and mylar shields as well as the attenuation due to the air gap of 7.24 cm between the detector and the tank wall. This results in a total density thickness of about 190 mg/cm$^2$. By comparing this density thickness of the detector system to the range of the $^{90}$Sr and $^{90}$Y beta particles, the 2.3 MeV beta particle emitted by $^{90}$Y is the only beta particle with sufficient energy to reach the sensitive area of the detector. Therefore, all beta radiation measured during the tank survey is attributed to $^{90}$Y and can, therefore, be used to estimate the $^{90}$Sr areal concentration.

**Areal Concentration Calculation**

Calculation of the $^{90}$Y areal concentrations required determination of the beta dose rate, which is calculated by subtracting the gamma probe reading from the beta-gamma probe reading and applying a beta correction factor. Because the instrument used to measure the beta component of the radiation is calibrated for exposure rates and exposure rates are only defined for gamma and x-rays, a beta correction factor must be applied to convert the exposure rate to a dose rate. The beta dose rate was calculated using the following equation:

$$D_\beta = \left(X_{\beta\gamma} - X_\gamma\right)B \qquad \text{(Eq. 1)}$$

where

$D_\beta$ = Dose rate due to beta radiation $\frac{rad}{h}$

$X_{\beta\gamma}$ = "Exposure" rate due to beta and gamma radiation $\frac{R}{h}$

$X_\gamma$ = Exposure rate due to gamma radiation, $\frac{R}{h}$

$B$ = Beta correction factor, $\frac{rad}{R}$

Once the beta dose rate has been determined, the $^{90}$Y areal concentration is calculated. This calculation uses an analytical model for calculation of the beta dose rate, $D_B$, at a point centered above a uniformly contaminated disk given by:

$$D_\beta = 53.35 \cdot C \cdot 1n\left(\frac{r^2 + h^2}{h^2}\right) fE_a\left(\frac{\mu}{\rho}\right) \cdot \exp\left[-\left(\frac{\mu}{\rho}\right)\rho\tau\right] \qquad \text{(Eq 2)}$$

where

$D_\beta$ = beta dose rate, $\frac{rad}{h}$

53.35 = the product of numerous unit conversion factors,

$$= \left(\frac{1}{4}\right) 3.7 \cdot 10^{10} \left[\frac{d}{Ci \cdot s}\right] \cdot 1.6 \cdot 10^{-13} \left[\frac{J}{MeV}\right] \cdot 10 \left[\frac{rad \cdot g \cdot m^2}{J \cdot cm^2}\right]$$

$r$ = the radius of the disk, cm

$h$ = the distance from the disk to the point of interest, cm

$C$ = areal concentration $\frac{Ci}{m^2}$

$f$ = yield of beta particle, unitless

$E_a$ = average energy of beta particle, MeV

$\left(\frac{\mu}{\rho}\right)$ = beta particle mass attenuation coefficient of shielding material, $\frac{cm^2}{g}$

$\rho$ = density of the shielding material, $\frac{g}{cm^3}$

$\tau$ = thickness of shielding material, cm

Rearranging to solve for $C$, the areal concentration of $^{90}$Y, is determined.

Uncertainties in this theoretical model have been estimated to be about 100 percent. This would be expected as the ability to relate beta-gamma detector system measurements to a beta surface concentration (i.e., $^{90}$Sr) is a complex model based on beta absorption theory requiring many assumptions about beta interactions in matter (e.g., beta backscatter and particle energy losses) and system geometries (detector field-of-view, and distance to detector Apoint of interaction@. However, based on the levels of surface contamination originally expected, the uncertainty associated with this model were deemed to be acceptable as established in the project=s Data Quality Objectives.

**DEPLOYMENT OF BETA-GAMMA DETECTOR**

The two- and three-detector assemblies were deployed in Tank 8D-2 a total of seven times between July 2000 and January 2002. Twenty-one vertical scans of the tank wall and internal support columns were collected from three areas of the tank resulting in over 900 survey measurements. Vertical scans of the tank wall were spaced approximately two feet apart and measurements were collected vertically every six inches. Three vertical scans of the tank internal support columns were also collected using the two-detector system and measurements taken vertically every three inches. A plot of the dose rate measurements as a function of height in the tank from a typical deployment is shown in Fig. 2. As can be seen from Fig. 2, in addition to the three regions of contamination anticipated, a forth region of elevated activity was observed. This elevated region appeared to be a six-foot-wide Aring@ in the area between 14 and 20 feet (4.27 and 6.10 m) off the tank bottom containing elevated $^{90}$Sr contamination. This delineates the area where the tank level fluctuated due to waste volume reduction by evaporation during Nuclear Fuel Services Company operations, which resulted in dissolved and suspended solids in the waste depositing on the walls as the liquids evaporated.

As a result of the much higher-than-expected activity on the tank internals, the uncertainties associated with the beta-gamma detector theoretical model calculations proved to be unacceptable to demonstrate that the waste retrieval goals have been met. In order to reduce the uncertainty associated with the beta-gamma detector model and preclude the need for an extensive sampling program, the need to calibrate the detector system was recognized.

## DETECTOR CALIBRATION APPROACH

By calibration of the detector assembly to known levels of surface contamination, the accuracy of both the concentration and uncertainties could be improved. The system geometry calibration reduces dependence upon theory and creates a basis for the direct correlation of the beta-gamma measurements to radioactive concentration standards traceable to the National Institute for Standards and Technology (NIST). Calibration sources of known concentrations were used to establish a technical basis for the determination of surface concentration directly traceable to NIST.

Calibration is in respect to the detector system geometry. Interpretation of detector system response to surface concentration can be inferred from calibration curves. With a linear response, simple factors can be used for calibration correction.

### Source Design

As a minimum, three sources were determined to be necessary to establish a calibration curve for each detector. Sources were designed specifically for beta-gamma detector system calibration. The calibration sources consist of radioactivity deposited onto 1/8-inch (0.32 cm) thick, Type 304, square stainless steel plates having outside dimensions of 10 inches by 10 inches (25.4 cm square). The sources have active areas of 8 inches by 8 inches square (20.32 cm square) for the three-detector system, and 1.5 inches by 1.5 inches square (3.81 cm square) for the two-detector system. The source activities are traceable to NIST and the total uncertainty in the source activity, stated by the manufacturer, is 4.0 percent at the 99 percent confidence level. The sources also contain $^{90}$Y in secular equilibrium with $^{90}$Sr. That is, the $^{90}$Y activity is equal to the $^{90}$Sr activity. A description of the sources is summarized in Table I.

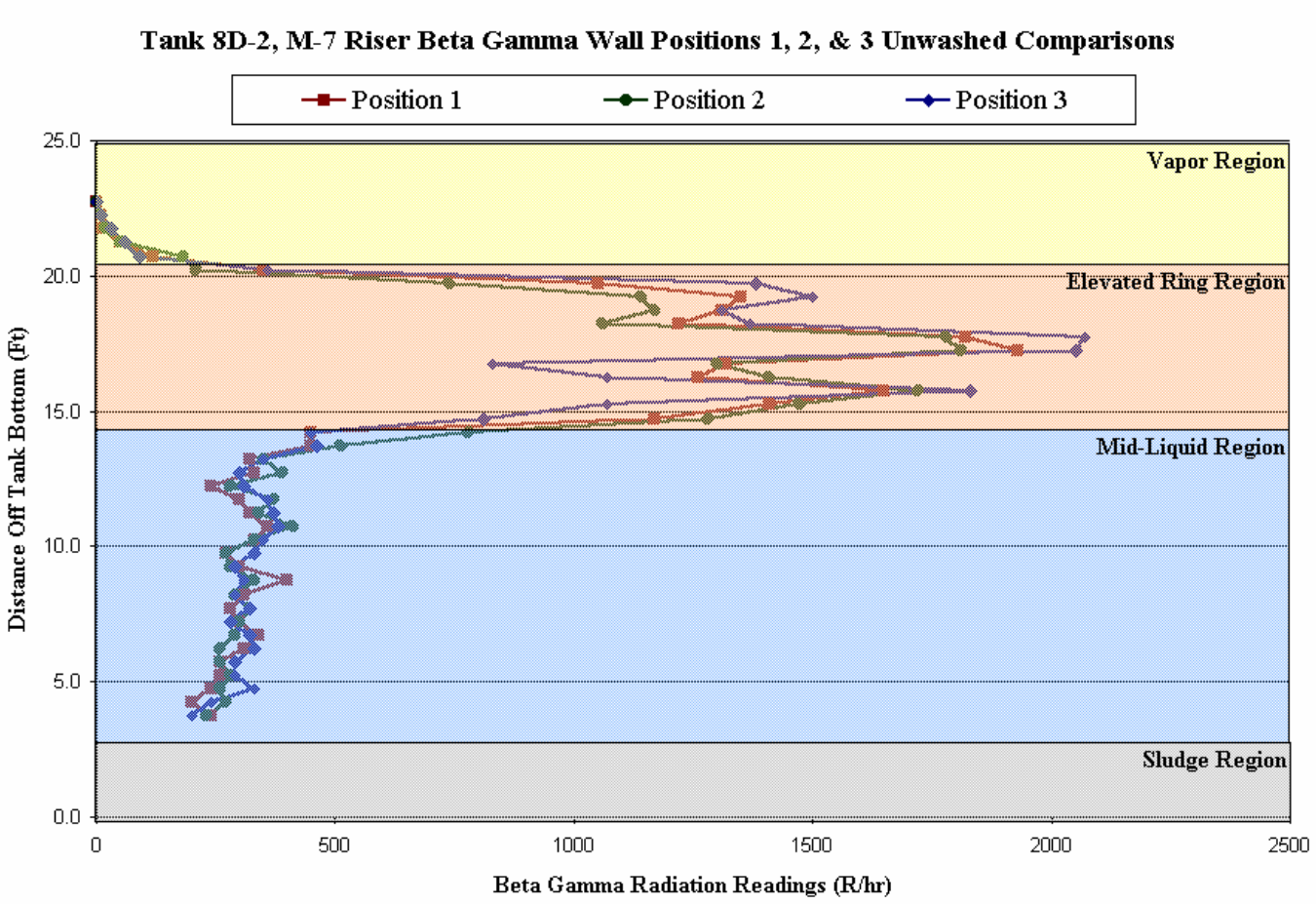


Fig. 2 Surface contamination profile of Tank 8D-2

Table I Source Descriptions

| Analytics, Inc. Source Identification S/N | | $^{90}$Sr Activity | | Concentration | Total Uncertainty in Activity at 99% Confidence |
|---|---|---|---|---|---|
| | | dps | ΦCi | ΦCi/cm$^2$ | |
| 8" by 8" Active Area | 62830-226 | 1.589 E7* | 429.4* | 1.040 | 4.0% |
| | 62829-226 | 2.915 E7* | 787.8* | 1.908 | 4.0% |
| | 62828-226 | 5.598 E7* | 1513* | 3.664 | 4.0% |
| 1.5" by 1.5" Active Area | 63409-226 | 1.728 E7** | 467.0** | 32.43 | 4.0% |
| | 63408-226 | 3.020 E7** | 816.2** | 56.68 | 4.0% |
| | 63407-226 | 6.041 E7** | 1633** | 113.4 | 4.0% |

* As of 12/4/01 @ 12:00 EST
** As of 3/25/02 @ 12:00 EST

These planar sources were designed to adequately simulate an Ainfinite plane@ of surface radioactivity in order to simulate the dose rate contribution to detector response of contaminated surfaces of large areas, such as those being measured in the waste tanks. Stainless steel, having essentially the same effective atomic number as that of carbon steel, is assumed to have similar backscatter and Bremsstrahlung characteristics as the carbon steel of the tanks while providing a higher degree of corrosion resistance and source integrity during use and storage. The 1/8-inch (0.32 cm) thick stainless steel backing plate is thinner than the tank walls, which vary from 7/16 to 5/8 inches (1.11 to 1.58 cm), but exceed the range of the most energetic beta in steel.

The radioactive material was deposited onto the steel backing plate as a pattern of uniformly spaced dots. The dot spacing is a nominal 3 mm for the 8-inch by 8-inch square (20.32 cm square) and the 1.5-inch by 1.5-inch square (3.81 cm square) active area sources. The sources have a Kapton cover, that is more radiation resistant than aluminized mylar, of a nominal 1.2 mg/cm$^2$ density that has been Aglued@ to the plate by a very thin adhesive spray coating. A thin top frame secures the Kapton cover to the source plate and resists source edge leakage.

X-ray production (bremsstrahlung) from high-energy beta particle interactions with the stainless steel source backing plate was estimated by computational means using Monte Carlo N-Particle Transport Code (MCNPJ - LANL, 1993). Dose rate at contact with the Plexiglas[7] source holder, used to shield the beta particles from the highest concentration calibration source anticipated, was estimated not to exceed 30 mR/h over the center of the source. Dose rates at short distances, centered over the unshielded calibration sources, as measured by the manufacturer, are reported in Table II. Dose rates at contact with the source active area of several of the unshielded calibration sources were estimated to exceed several thousand rads per hour.

Source concentrations necessary for the calibration are shown later in this report in Tables VI and VII. These concentrations were determined by theoretical calculation of detector dose rate response using the dose to curie methodology presented previously. Source vendors limited total activity to a maximum of approximately 1.6 mCi per source.

Table II Manufacturer=s Source Measurement Data

| Analytics, Inc. Source Identification S/N | Removable Surface Contamination at Time of Manufacture | Measured Beta+Gamma Dose Rate (Eberline EO-2) from Source Surface |
|---|---|---|
| 62828-226 | 29 dpm | 5 rad/h @ 11 cm* |
| 62829-226 | 31 dpm | 5 rad/h @ 3 cm* |
| 62830-226 | 57 dpm | 3 rad/h @ 2 cm* |
| 63409-226 | < 5 dpm | 0.18 rad/h @ 37 cm** |
| 63408-226 | < 5 dpm | 0.3 rad/h @ 37 cm** |
| 63407-226 | < 5 dpm | 0.7 rad/h @ 37 cm** |

* Measured by Analytics, Inc. on January 2, 2002.
** Measured by Analytics, Inc. on April 3, 2002.

**Source Holder**

The source holder was designed to minimize personnel beta dose during storage and handling. It consists of 1.1-cm-thick Plexiglas[7] panels that entirely surround the source plate. This thickness will completely attenuate the most energetic beta particles from $^{90}$Sr-$^{90}$Y. It incorporates a sliding PlexiglasJ lid that is remotely opened to expose the detector. The source holder has a lock-pin mechanism to prevent the top from inadvertently sliding open during handling and storage, avoiding accidental beta dose from the high beta dose rates present directly above the source.

**Calibration Jig**

The calibration jig shown in Fig. 3, was designed with a Plexiglas[7] outer housing and the equipment necessary to create reproducible positioning for source and detector geometries. The calibration jig housing completely shields personnel during calibration. The outer housing has walls of 1.1-cm-thick Plexiglas[7] that exceed the range of the highest energy beta particles emitted and eliminates potential beta dose to personnel during calibration activities with the exposed source. Remote adjustment tools that are operated from outside the shield were also provided.

Inside the jig, the detector was positioned over the source by a lead screw device that raised or lowered the detector with respect to the source. This allowed study of the effect of small changes in distance on detector response to determine the most effective distance to the tank surfaces and estimation of uncertainty from positioning (distance) error. Locking collets attached to the detector system mounting shafts ensured reproducible detector-to-source distances and allowed presetting of this distance for calibration. The source rested on top of a compound-slide milling table which allowed motion of the source in the X and Y (in-plane) directions. This was used to determine source plating uniformity and allowed for precise positioning of detector relative to the source activity dot matrix (most useful with smaller fields of view). All source and detector positioning was performed remotely while the source was in the Aexposed@ position, using mechanical rod connectors operated outside the jig housing. During calibration, the source was separately positioned under each of the detectors in the detector system. This was accomplished by in-plane adjustment of the milling table via the remote X-Y lead screws.

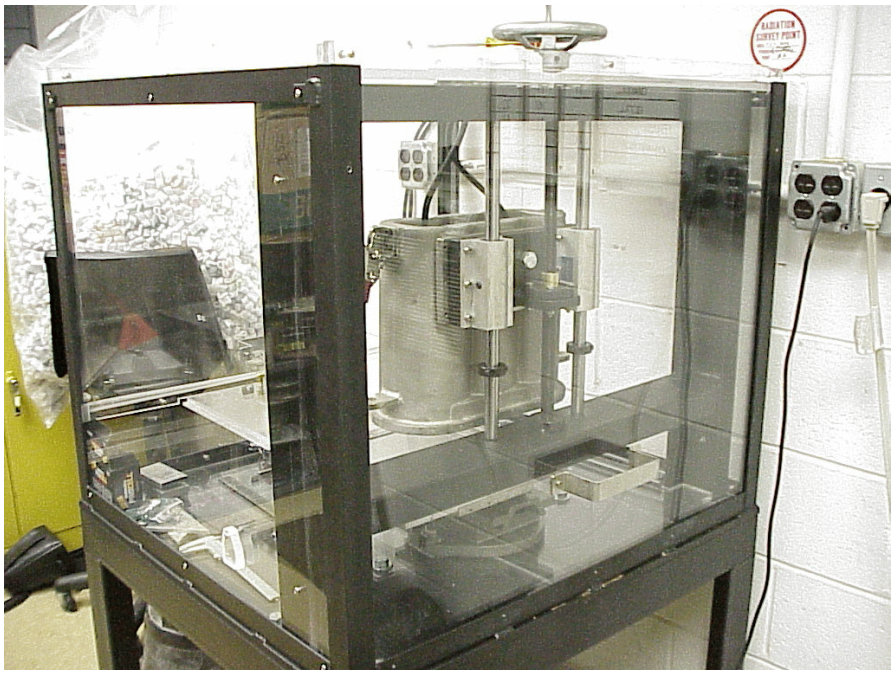

Fig. 3 Calibration Jig for Beta-Gamma Detector Assembly

**Low As Reasonably Achievable (ALARA)**

At distances close to the calibration sources, the unshielded beta dose rates could approach several thousand rads/h. In order to minimize beta dose to personnel as per the ALARA principle, the calibration design utilized PlexiglasJ source holders for the storage and handling/transport of calibration sources, remote handling techniques for on-line calibration adjustments, and a Plexiglas[7] jig outer housing for shielding during calibration. Personnel remained shielded by the Plexiglas[7] jig housing after the source holder lid is remotely removed for detector measurement.

**CALIBRATION RESULTS**

Tables III and IV list detector system response data results for the two- and three-detector systems. The tables also include theoretical detector response calculated as discussed earlier.

**Regression Analysis - Response Linearity**

The response of the two-detector system, the comparison of the source concentration with the measured dose rate, was found to be linear. The adjusted R Square value for the measured response to the three calibration sources is 0.9972. The response of the three-detector system was also linear. The adjusted R Square value for the response to the three calibration sources is 1.0000.

Table III Theoretical and Measured Net Beta-Detector Dose Rates versus Source Concentrations for the Two-Detector Beta-Gamma System

| Source S/N | Total Activity (ΦCi) | Concentration (ΦCi/cm$^2$) | Calculated Dose Rate Response (R/h) | Measured Net Beta-Detector Dose Rate Response (R/h) |
|---|---|---|---|---|
| 62828-226* | 1513 | 3.664 | 0.0206 | 0.02 |
| 63409-226 | 467.0 | 32.43 | 0.1810 | 0.12 |
| 63408-226 | 816.2 | 56.68 | 0.3164 | 0.23 |
| 63407-226 | 1633 | 113.4 | 0.6329 | 0.45 |

* 8 inch x 8 inch square (20.32 cm square) source - included for informational purposes.

Table IV Theoretical and Measured Net Beta-Detector Dose Rates versus Source Concentrations for the Three-Detector Beta-Gamma System

| Source S/N | Total Activity (ΦCi) | Concentration (ΦCi/cm$^2$) | Calculated Dose Rate Response (R/h) | Measured Net Beta-Detector Dose Rate Response (R/h) |
|---|---|---|---|---|
| 62830-226 | 429.4 | 1.040 | 0.5357 | 0.25 |
| 62829-226 | 787.8 | 1.908 | 0.9828 | 0.46 |
| 62828-226 | 1513 | 3.664 | 1.887 | 0.89 |

Unextrapolated results (three data points each) for the three-detector system is shown in Fig. 4. Extrapolation of detector response to high surface concentrations can be completed by incorporating a far data point determined from the regression analysis equation shown in Fig. 4.

**Study of the Linearity of the RO-7 Detector Series**

Linearity of detector series response was studied using the three-detector system and RO-7 probes of differing ranges. The linearity of the RO-7 detector series was empirically confirmed, however, results are limited by the differing minimum resolutions (readouts) of the detector series and restrictions on maximum calibration source activity.

The aluminum beta absorber was removed from the beta detector for this study, in order to maximize detector response for the higher range detectors. The results of the study are presented in Table V. These results are interpreted to mean that the detector series properly and with fair linearity, respond to established dose rates and Atruncates readout@ appropriately within the limits of the detector minimum resolutions.

Table V Linearity of the RO-7 Detector Series

| Source Concentration ($\Phi Ci/cm^2$) | RO-7 Detector Range and Response | | |
|---|---|---|---|
| | 0-19.99 R/h (Minimum Resolution 10 mR/h) | 0-199.9 R/h (Minimum Resolution 100 mR/h) | 0-1999 R/h (Minimum Resolution 1 R/h) |
| 1.040 | 1.67 R/h | 01.7 R/h | 002 R/h |
| 1.908 | 3.17 R/h | 03.2 R/h | 003 R/h |
| 3.664 | 6.04 R/h | 06.2 R/h | 006 R/h |

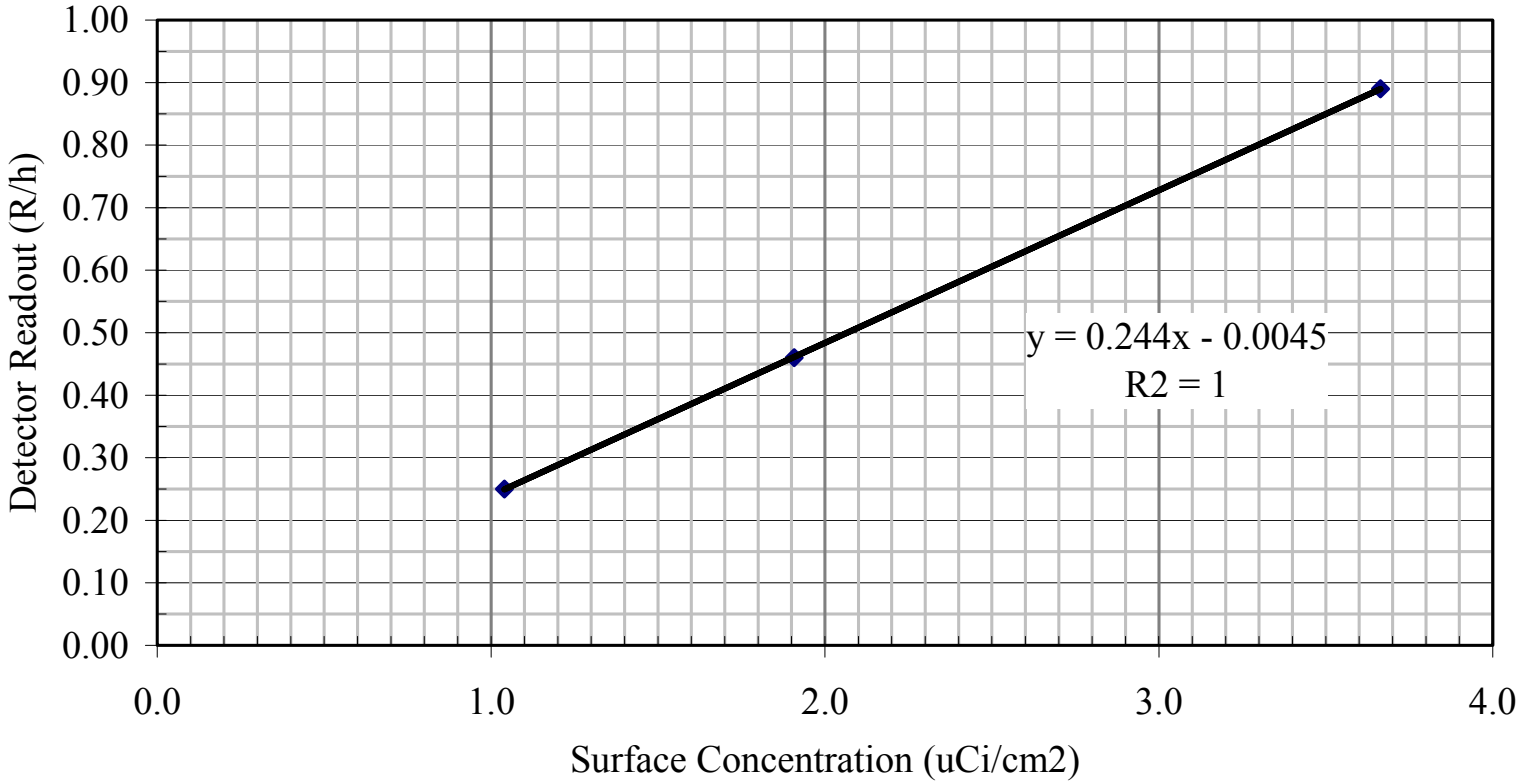


Fig. 4 Three-detector beta-gamma system unextrapolated dose rate response

**Detector Response Versus Distance Changes**

Measurements taken with the two- and three-detector systems established that changes in dose rate response of the beta-gamma detector system are negligible with relatively small increases in the normal 3/8-inch (0.95 cm) surface-to-detector distance. The two-detector response was reduced by 5 percent for an additional 0.6 inches (1.52 cm) (1-inch (2.54 cm) source surface to detector system face); and 10 percent for an additional 1.3 inches (3.3 cm) (1.7 inch (4.32 cm) source surface to detector system face). The three-detector system response was reduced 5 percent for an additional 0.9 inches (2.29 cm) (1.3 inch (3.30 cm)) source surface to detector system face); and 10 percent for an additional 1.1 inches (2.79 cm) (1.5 inch (3.81 cm) source surface to detector system face). For both detector systems, more than a 3-inch (7.62 cm) increase in source surface to detector system face distance is necessary to achieve a response reduction of at least 50 percent.

**Calibration Geometry Factors**

Detector system response to surface concentration can be inferred from the calibration curve for the three-detector system shown in Fig. 5. Since response is linear, simple correction factors are reported herein. Detector system geometry factors (Tables VI and VII) are calculated for each detector system by taking the average of the three ratios of source concentration to detector response. For the three-detector system, the mean geometry factor is 0.041 $Ci/m^2$ per R/h and has a standard deviation of 0.00022 $Ci/m^2$ per R/h. The mean geometry factor calculated for the two-detector system is 2.6 $Ci/m^2$ per R/h with a standard deviation of 0.12 $Ci/m^2$ per R/h.

Table VI Two-Detector System Geometry Factor

| Concentration ($\Phi Ci/cm^2$) | Detector Response (R/h) | Geometry Factor ($Ci/m^2/R/h$) | Mean Geometry Factor ($Ci/m^2/R/h$) | Standard Deviation ($Ci/m^2/R/h$) |
|---|---|---|---|---|
| 32.43 | 0.12 | 2.7 | | |
| 56.68 | 0.23 | 2.5 | | |
| 113.4 | 0.45 | 2.5 | 2.6 | 0.12 |

Table VII Three-Detector System Geometry Factor

| Concentration ($\Phi Ci/cm^2$) | Detector Response (R/h) | Geometry Factor ($Ci/m^2$ per R/h) | Mean Geometry Factor ($Ci/m^2/R/h$) | Standard Deviation ($Ci/m^2/R/h$) |
|---|---|---|---|---|
| 1.040 | 0.25 | .042 | | |
| 1.908 | 0.46 | .041 | | |
| 3.664 | 0.89 | .041 | 0.041 | 0.00022 |

## SUMMARY OF RESULTS AND CONCLUSIONS

The in situ beta-gamma detector system is a relatively inexpensive approach for characterizing residual radiological surface contamination when combined with limited physical sampling. The non-intrusive acquisition of large amounts of survey data makes this system very cost-effective. In a single deployment, large vertical surfaces can be surveyed to obtain an immediate understanding of the contamination profile requiring characterization. In the case of Tank 8D-2 this led to targeted sampling of four distinct contamination regions symmetrical about the axis of the tank minimizing the number of samples required.

The need for calibration of the detector system to reduce the uncertainty in the quantification methodology became more important to the overall tank characterization program as more specific knowledge about the contamination in the tank became available. The discovery of an elevated ring of $^{90}Sr$ contamination on the tanks vertical surfaces revealed a radiological picture more complex than initially presumed.

By calibration of the beta-gamma detector assembly, system-specific geometry factors were successfully developed which when applied to the detector response, significantly reduced the uncertainty associated with the surface contamination of Tank 8D-2. As a result, the need to collect additional physical samples was eliminated.

## FOOTNOTES