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# RADIOLOGICAL SITE CHARACTERIZATION AND RADON BARRIER DESIGN


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## 1.0 SITE CHARACTERIZATION DESIGN

This section presents the rationale for obtaining the data necessary for defining the extent of the contamination of the sites and designing the radon barrier necessary to meet the radon flux standard. For piles or portions of piles that are to be moved from their present location, the depth below the pile that must be excavated in order to meet the soil contamination limits must also be determined. This depth along with the off-pile volumes of contaminated material are collectively referred to as the "limits of excavation."

## 2.0 APPROACH TO DATA ACQUISITION FOR DEFINING THE LIMITS OF EXCAVATION

This section presents the rationale for obtaining data for defining the extent of contamination and is primarily based on a previously published paper (TAC, 1985a).

Certain considerations are made prior to designing a radiological data acquisition plan for each of the 24 inactive mill tailings sites. First, it is recognized that large scrapers and other earth-moving equipment will be used to transport off-pile material to the disposal site. Since excavation lifts of less than four to eight inches are not practical, and the excavation length is normally a minimum of 75 feet, the use of large equipment limits the density of data necessary for defining the limits of excavation to approximately a 50-foot grid and six-inch incremental depths. For areas with relatively constant contamination levels and depths, data from grid points a few hundred feet apart are adequate.

The second consideration in planning a radiological site characterization survey is the characteristic size of the contaminated volume. A review of the use of a processing site, including old photographs, provides an indication of the degree of disturbance of the site. Experience to date reveals that at some processing sites the mill and ore storage areas were significantly recontoured during the life of the facility. Extensive regrading of these areas normally results in contaminant dispersal with depth, but possibly over small areas. Therefore, a sampling density of at least one point per anticipated characteristic size is desirable if a high degree of accuracy in locating the contaminated material is desired.

A third consideration is the accuracy that is desired in defining the location and volume of contaminated material prior to the remedial action. For the UMTRA Project, it was decided that an attempt would be made to define the extent and volume of off-pile contaminated materials to be excavated to within roughly 20 percent. Reliance on radiological monitoring during excavation would subsequently assure that EPA standards are met.

The considerations presented above are general. Site-specific considerations, normally related to cost, can significantly alter the radiological characterization approach. Better definition of the contamination prevents over-excavation and is particularly justified in situations where the material may be transported for long distances to an alternate disposal site. If the excavated area will require costly restoration, or if smaller earth-moving equipment is used, better definition of the contamination may also be cost effective.

### 2.1 Elements of radiological site characterization

#### Site grid and land survey

A site coordinate system is first established using reference elevations and state plane coordinates. All data to be collected for engineering designs are reported relative to the site coordinate system and are provided on a magnetic data tape in a format that is compatible with the UMTRA Project Technical Data Management System. Land topography on two-foot contours is digitized and also placed in the Technical Data Management System. Overlay maps are computer-developed to aid in interpretation of data for limits of excavation.

Borehole Drilling and Logging

For areas of known or suspected deeply-buried contamination, holes are augered at five-foot-depth increments and downhole-logging with a gamma scintillometer (NaI) is performed through the hollow-stem auger. In cases where rotary drilling is necessary, the hole may require casing prior to downhole logging. The downhole-logging instrumentation is calibrated to pads of known radium-226 concentrations in order to derive a radium-226 measurement in pCi/g. Split-barrel samples are collected from a percentage of bore holes to analyze for radium-226 by gamma spectroscopy and for thorium-230 and natural uranium by radiochemical separation and alpha spectroscopy in the Unified Soil Classification System where visual soil classification is recorded on standard report forms. A land survey to obtain the horizontal coordinates and elevations of all boreholes is done following the radiological survey.

If adequate data are not available, a drilling study is done to determine the depth of contamination beneath the tailings pile interface. Split-barrel samples are collected and analyzed for radium-226 concentration. Selected sub-interface samples are also analyzed for thorium-230 and heavy metals. Data from some sites indicate that some heavy metals such as arsenic and molybdenum migrate to a greater depth beneath the tailings than does radium-226.

Gamma exposure rate measurements

For a gridded area off the pile and away from known contamination, gamma exposure rate measurements are made at each grid point at three feet above the surface and at ground level. If the ground level measurement is higher, then localized surface contamination is suspected. Along each horizontal and vertical grid line, a traverse is made with gamma measurements recorded at three feet above the surface to determine anomalous hot spots and the approximate boundary of off-pile contamination in relation to the 5 pCi/g radium-226 standard. A scintillometer reading of five to 10 microR/hr above ambient levels is used as a guide to estimate the 5 pCi/g radium-226 perimeter. The gamma survey is carried out to near-background levels to ensure that the areal extent of all windblown contamination has been found. Anomalous locations are recorded and marked for subsequent soil sampling. Significant anomalous areas are investigated further and the areal extent is defined by four 3-foot gamma measurements along the perimeter of the anomalous area and one along the traverse line. Gamma traverse measurements are also done along suspected areas such as drainage washes, railroad and highway beds, and tops of bluffs. Potential sources of contamination such as old equipment or junk piles are gammaand alpha-scanned. Gamma surveys are conducted using a scintillometer capable of detecting 5 microR/hr and calibrated against a pressurized ionization chamber in the field. Daily source checks are done to ensure proper operation of each instrument.

Radium-226 concentration determination by soil sampling and in-situ measurements

For gridded areas off the pile, surface soil samples are taken at approximately 50 percent of the grid locations in order to acquire a non-biased distribution of contamination. Soil samples are analyzed for radium-226 and thorium-232 in the laboratory by gamma spectroscopy, following drying and preparation of the sample. At grid points where a surface soil sample is taken, an in-situ "delta" measurement is made at a depth of six inches. A delta measurement consists of a collimated scintillometer (NaI) calibrated to provide an in-the-field estimate of localized radium-226 concentration. Soil gamma emissions are counted with and without an absorber placed between the soil and the collimated scintillometer. The difference in count rates indicates the gamma emissions from beneath the detector. The delta unit is calibrated on pads which have known radium-226 concentrations in order to derive a radium-226 measurement in pCi/g. The delta measurement is used as a guide for determining soil sample locations to better define areal boundaries and depths of contamination. The delta measurement is particularly useful at locations in high gamma-shine areas such as near a tailings pile. If the delta measurement at a depth of six inches indicates levels above 5 pCi/g radium-226, a soil sample is taken at the interval from six to 12 inches, followed by a delta measurement at a depth of 12 inches. This procedure continues until the delta measurement decreases below 5 pCi/g radium-226 or a delta measurement has been taken at a depth of 18 inches. An in-situ measurement equal to or less than 5 pCi/g radium-226 normally indicates that the actual concentration is less than the 15 pCi/g limit for subsurface contamination. If the 18-inch delta measurement indicates levels above 5 pCi/g radium-226, a bore hole is drilled at that location and downhole-logged to determine the depth of contamination. Biased soil samples and delta measurements are taken to determine contamination levels to a depth of 18 inches at anomalous locations as detected by gamma exposure rate measurements. The purpose of these measurements is to determine if contamination levels below surface meet the EPA standard of 15 pCi/g radium-226.

In areas where gamma exposure rate measurements diminish to less than 10 microR/hr above background, biased surface delta measurements and soil samples are taken to better define the 5 pCi/g radium-226 perimeter. In this case, staggered delta measurements are taken in order to determine additional soil sample locations along the estimated 5 pCi/g radium-226 perimeter line. Subsequent gamma spectroscopy analyses of soil samples provide a measure of the accuracy and precision of in-situ measurements. The purpose of these measurements is to determine the extent of surface contamination exceeding the EPA standard of 5 pCi/g radium-226 in the first six inches of soil.

A percentage of the soil samples over a range of activities are analyzed for thorium-230 and natural uranium in order to compare the concentration to that of radium-226. In some cases, excavation criteria are based on uranium or thorium rather than radium-226. One particular example of this is where a preferential separation of thorium-230 occurred under acidic slurry conditions, resulting in the depth of excavation in the evaporation ponds being dependent on thorium-230, rather than the radium-226 concentration.

Building surveys

For building surveys, measurements are taken for surface alpha contamination (removable and total), gamma-ray exposure rate, and radon daughter concentration. Two different plans exist for surveying buildings; one plan is for structures to be demolished, and another for structures that are to be decontaminated. A limited survey is done indoors and around the exterior of structures that have no salvage value. Surface alpha contamination levels are measured in these buildings in areas suspected of being contaminated in order to obtain a measure of the degreee of potential hazard to workers during the demolition period. The gamma exposure rate at three feet above the surface in the center of each room is recorded.

For structures with salvage value, more extensive suface alpha and gamma exposure rate surveys are done on a grid of approximately 10 to 20 feet to determine areas where decontamination is necessary. In addition, biased alpha contamination sampling is done at locations likely to be contaminated such as flat ledges or other dust collection points. If elevated surface alpha or gamma levels are indicated near large quantities of loose materials, the surface is swept and a sample is taken to be analyzed by gamma spectroscopy. Radon daughter concentration (RDC) measurements are made to determine levels in relation to the EPA indoor RDC standard of 0.02 Working Level. If the building was constructed during or subsequent to milling operations, bore holes may be drilled through the flooring, especially near anomalously high gamma exposure rate readings to detect substructure contamination.

## 2.2 UNCERTAINTIES IN VOLUMES OF EXCAVATION

Contraints on site characterization efforts and site characterization sampling designs impact upon the ability to define both limits of contamination and limits of excavation. Current site characterization designs have two basic components; one component is aimed at identifying the boundaries of areas, another at estimating depths and material volumes. The boundary investigation is primarily "deterministic" in that it attempts to define, on a given spatial resolution, where a concentration boundary falls. The depth or volume investigation is more "statistical" in nature; it uses "systematic sampling with random start" to obtain an estimate of the average depth and volume of material in an area. The site characterization of contamination depth is not conducted on a spatial interval sufficient to precisely define the pattern of contaminant depth changes in an area.

At this point there is an apparent problem. Site characterization is done, the site is divided into areas having similar contaminant depths, and the average contaminant depth estimated. Excavation control monitoring is expected to guide the actual excavation depth in any particular location to give a volume comparable to the volume based on the average depth. On the other hand, excavation control is not always considered practicial at such a level in a large earth moving, construction site environment; first cut excavation on an area is generally expected to be to the average depth specified in the design. Since the excavation depth is an estimate of the average required depth, it should

be no surprise that areas of deeper contamination will be found after excavation. Also it should be clear that in cutting the entire area to the depth given in the design, there will have been removed a considerable volume of uncontaminated material.

The resolution of this problem is not clear. Site characterization to provide excavation guidance of sufficient resolution would be prohibitively expensive (approximately 10 times the present cost); however, but intensive excavation control can interfere with effective construction management of the excavation work (again large cost factors are involved).

In lieu of a resolution to the problem, it is clear the basis on which estimates of contaminated areas, depths, and volumes are made must be defined. Further, an attempt must be made to account for the excavation process and to factor into the volumes of contamination a reasonable estimate of the actual volumes of excavation.

Conservative overestimation of contaminated volumes has been done for most sites to date. Conservative features that have been applied include:

- o Where limits are defined using in-situ measurements of radium-226, measurements of 2 pCi/g and 10 pCi/g have been used as cutoff values rather than 5 pCi/g and 15 pCi/g, at some sites. This is intended to allow for uncertainties of in-situ measurements.

- o Excavation depths are sometimes increased by six inches beyond the estimated required depth. This is sometimes done when a distinct contamination depth can be defined, to allow for mechanical mixing during excavation.

- o Excavation depths for areas of variable contaminant depth are set deeper than would be a real average depth. This accounts for the presence of unidentified areas of deeper contamination, and gives some buffer for mechanical mixing.

It is likely that these conservative features used in estimating excavation volumes will help bring the volumes actually excavated into line with the volumes used in engineering design; however, it is still likely that volumes actually excavated will be greater. This statement is based on two premises:

- o The excess excavation by earth-moving equipment on areas with a distinct and well-defined contaminant interface is more likely to be one foot rather than six inches.

- o First-cut excavation in an area is likely to be to the average area-wide depth given in the design, leaving some area of deeper contamination to be excavated as an excess.

As an exercise, the concepts described above were applied to the volumes of excavation calculated from the site characterization data from an actual site (TAC, 1985b). Two estimates were attempted:

- o Predicted maximum error in the conservative design excavation volume, accounting both for errors in site characterization and for excess excavation due to the use of heavy equipment and infrequent excavation control measurements.

- o Actual contaminant volume compared to the conservative excavation volume specified in the design.

In the first case, it was estimated that the maximum error in the design volume compared to the excavated volume is expected to be approximately 15 percent for the off-pile material. If the pile is to be moved and the volume of the pile is also included in the volume, the maximum error is in the range of five to 10 percent. In both situations, the excavated volume is expected to be larger than the design volume.

For the second estimate, an analysis of the actual contamination volume was made and compared to the design volume. The results indicate that the design volume is probably larger than the actual volume by up to 15 percent for the off-pile material and five percent for the total volume, including the pile.

Considering the results of the two estimates above, it would be expected that the actual excavated volumes would be higher than the actual contaminated volumes by up to 30 percent for the off-pile areas or by up to 15 percent for the total volumes, including the pile. This, of course, assumes excavation with large machines and not so stringent excavation control. These errors could be reduced by using smaller machines and better excavation control monitoring. The balance, of course, should be determined by weighing the disposal cost against the increased excavation and monitoring costs.

## 3.0 APPROACH TO DESIGNING THE RADON BARRIER

The thickness of cover material required to limit radon flux to 20 $pCi/m^2sec$ is calculated using the computer code RAECOM (NRC, 1984). The mathematical model implemented in RAECOM describes one-dimensional steady-state radon diffusion through a two-phase multilayer system of porous media, representing the tailings pile and its cover.

Multiple layers of tailings and cover are allowed, with difference in physical, radiological, and diffusional properties represented by seven layer-specific input parameters. Radon concentrations in both soil-air and soil-water phases are treated, as well as the exchange between phases. Boundary conditions are the radon flux into the bottom of the pile and the air concentration of radon at the surface of the pile. In addition, interface conditions are applied, requiring continuity of both flux and concentration in both phases at layer interfaces. The exact simultaneous solution to the coupled radon mass balance and flux equations for the two phases is performed using matrix algebra for the general n-layer case.

The seven values required for each layer of the tailings pile system modeled by RAECOM are:

- o Thickness of layer (cm).
- o Bulk density ($g/cm^3$).
- o Porosity (fractional).
- o Moisture content (percent dry weight basis).
- o Emanating fraction of radon (fractional).
- o Radon diffusion coefficient ($cm^2/sec$).
- o Radium concentration (pCi/g).

In addition to these parameters describing the layers of the stabilized pile, RAECOM requires input of the total number of layers in the pile and the layer to be optimized in meeting the specific flux limit (20 $pCi/m^2sec$) at the surface. Also, the radon boundary conditions at the top and bottom of the pile must be specified. The bottom condition is always an incoming flux equal to zero $pCi/m^2sec$ for tailings piles. The top condition is the observed ambient radon concentration (pCi/l) in the air near the site.

The selected values for each parameter listed above are discussed briefly below.

<u>Layer thickness</u>. The proposed structure of the stabilized pile has four layers: a layer composed of a mixture of the tailings with the existing pile cover and the contaminated soil from beneath the pile; a layer of windblown, evaporation pond, and other contaminated materials; a compacted radon barrier cover; and a rock and gravel erosion protection cover. The erosion protection layer is ignored for radon barrier design. The modelled structure of the stabilized pile consists of:

- o One layer of tailings represented by the average radium concentration of the tailings, the existing pile cover, and the contaminated soil from beneath the pile (thickness: 42 feet maximum).

- o A layer of windblown, evaporation pond, and other contaminated materials (thickness: 20 feet average).

- o A layer of compacted cover forming a radon barrier, of a thickness to be determined from this analysis.

Bulk density. The bulk densities of tailings and cover are based on standard Proctor tests and reflect the design compaction.

Porosity. The tailings and cover porosities are calculated from the bulk densities at the design compaction, using the specific gravity of the material, which is measured or estimated along with other geotechnical parameters. The equation used is:

Porosity = 1-(bulk density)/(specific gravity).

Moisture content. The moisture contents for the pile and cover are based on calculations of the long-term average moisture content using site-specific data.

Radon emanation. Radon emanating fractions are measured over a range of moisture contents. The overall average of these values is normally used in modelling the tailings pile.

Radon diffusion coefficients. Radon diffusion coefficients for tailings are measured for samples from the site. Measurements are made with the moisture content at or near the predicted long-term moisture of the stabilized tailings.

Radon diffusion coeficients for locally available cover materials are measured at the direct long-term predicted moisture content in order to develop the Site Conceptual Deisgn. For the final design, these measurements are made on the actual borrow materials used (see Section 5.0).

Radium content. The radium concentrations are measured on samples taken from each area of the site. Windblown, evaporation pond, and mill site areas are normally characterized in addition to the tailings piles.

Ambient radon. The ambient radon concentration in air is the top-of-the-pile boundary condition for RAECOM and is based on actual measurements near the site.

The cover design for the pile is intended to give a long-term annual average flux of 20 $pCi/m^2sec$. However, some conservative assumptions are implicit which indicate the actual flux should, in fact, be less.

The design moisture content of the pile is intended to be the driest long-term moisture content maintained by the pile materials considering climate, the consistency and compaction of the material, and the depth of the material in the pile. To the degree the actual moisture content remains above the design moisture content, the actual flux will be less than the design flux.

Any periods of harsh winter will add an additional degree of safety not reflected in the design. Whenever the soil is very wet, frozen, or covered with snow, the radon is effectively blocked from escaping into the atmosphere. Depending on the period over which such conditions exist, there will be a reduction in the actual annual average flux as compared to the design flux.

In the design of the pile, no radon flux attenuation is attributed to the rock and gravel cover applied to the pile as erosional protection. There is some decrease in the radon flux due to this cover; thus, a safety factor is present, although it may be a factor which is not available over the entire life of the pile.

No safety factors are intentionally applied in the design of the radon barrier, which is in agreement with the design nature of the radon flux standard as expressed by the EPA in its comments on the basis of the regulations. It is the intent, however, of this disucssion to make clear that there are reasons to expect that the annual average flux measured around a stabilized pile would be lower than the design flux.

## 3.1 APPROACH TO DATA ACQUISITION FOR DEFINING THE PILE AND RADON BARRIER CHARACTERISTICS

The previous section provided information on the parameters required to assess the radon source term and calculate the thickness of radon barrier material required to meet the radon flux standard. A sensitivity analysis was conducted and published by Smith et al. (TAC,1985c), where the effect on cover thickness was assessed for changes in each of the parameters. In addition, the range and variability of the radium concentration and emanating fraction in UMTRA Project tailings piles was studied by Nelson et al. (TAC, 1985d). From the information gained from these two studies, it is possible to develop a characterization plan where resources for characterizing the pile and radon barrier can be allocated to minimize the uncertainty in the predicted radon flux from the disposal site.

The parameters in order of decreasing importance are listed as follows:

- o Radon barrier radon diffusion coefficient (including the long-term predicted moisture).
- o Pile radium concentration.
- o Emanating fraction of radon for the tailings.
- o Radon diffusion coefficient of the tailings.
- o Cover and tailings porosity, tailings moisture.

## 3.2 COVER SAMPLING

The overall residual uncertainty in the radon barrier thickness is dominated by the cover moisture content and the cover diffusion coefficient which is a sensitive function of the moisture (see Section for a discussion of the method for predicting long-term moisture).

The cover diffusion estimates used for preliminary radon barrier design are measured for several materials typical of the site. The number of the measurements is limited to conserve funds for measurements on the final borrow. In addition, the preliminary cover measurements are made over a wide range of moisture contents so a diffusion coefficient value may be estimated for any long-term moisture content.

The small number of preliminary measurements of cover diffusion coefficient does not allow the overall uncertainty on cover thickness to be reduced to a desirably low level.

It is intended that measurements of final borrow materials will be sufficiently intensive that the uncertainty in required cover thickness will be reduced to a reasonable level. Based on the statistical study by Smith et al. (TAC, 1985c), about 40 to 50 measurements of final cover diffusion coefficient would be appropriate in view of the cost of the measurements.

The final cover design is done considerably before construction on a site begins. It may be necessary that measurements of the diffusion coefficient of the final borrow be made before the final design is approved. Once the final borrow site has been selected, 10 samples representative of the material that will be removed from the site and placed as cover should be taken. These samples should be about five kg each. If special seiving or admixtures will be used in preparing the cover material, the samples should be likewise prepared. Measurements of diffusion coefficient will be made at the long-term moisture content and estimated as-placed compaction of the cover.

It is expected the some difference in diffusion coefficient will be found between soil samples compacted in the laboratory and those compacted by heavy machinery in the field. To assure that the cover thickness to be applied is entirely appropriate, it is considered necessary to take undisturbed samples of the placed cover for diffusion coefficient analysis. During the course of cover placement, approximately 40 undisturbed samples will be taken with a special sampling tool. These will be analyzed for diffusion coefficient at the field compaction after adjusting the moisture content to the predicted long-term average.

The data from these measurements will be used to assess the variability in the diffusion coefficient of the cover at a particular moisture content, and early results may allow final changes to the required cover thicknesses.

## 3.3 PILE SAMPLING

In the previously cited studies of the characteristics of the UMTRA Project piles, it was pointed out that the mean, standard deviation, and the standard error are all important statistical parameters to know for each of the design parameters of interest. It was also pointed out that since the flux standard was written as an average over the disposal site, the mean value of the design parameter for each layer of pile or cover is of interest and the uncertainty in the mean parameter is measured by the standard error. Since the standard error is obtained by dividing the standard deviation by the square root of the number of measurements, the uncertainty in the design can be reduced to any desired level by increasing the number of measurements.

In order to limit the uncertainty of the design to within one to two feet for most of the UMTRA Project piles, it is normally necessary to limit the combined uncertainty in the cover thickness due to the uncertainty in all the tailings properties to less than one foot. This normally requires limiting the uncertainty in the cover arising from uncertainties in the tailings radium content and emanating fractions to approximately three inches. The number of samples necessary to accomplish this uncertainty is determined on a site-specific basis and depends on the available cover material, predicted long-term moisture, and mean design parameter values and their variability within the tailings pile. The typical number of samples required are 100 to 300 for radium concentration, 10 to 30 for emanating fraction, and fewer than 10 for the remaining design input tailings parameters.

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