APPENDIX C

Technical Information on Radioactive Materials, Decay, Measuring Techniques, and Instrumentation

C-1. Decay Chains.

a. Many radioactive materials decay to other radioactive materials, which may in turn, also decay to other radioactive materials. When the parent radionuclide decays to a radioactive progeny, it is said to be part of a radioactive decay chain. Two very common decay chains are the uranium-238 decay chain, which includes, among other radionuclides, thorium-230, radium-226, and radon-222, and the thorium-232 decay chain, which includes radium-228 and radon-220.

b. Because of the existence of decay chains, a number of things important to contaminant characterization can happen. First, if a parent radionuclide is found on-site, the progeny radionuclide can be expected to be on-site, and inversely, if a progeny radionuclide is present, the presence of its parent radionuclide may be inferred. For example, if you have detected cesium-137 on a site, you will always find its progeny, barium-137m on the site, and its activity will be in equilibrium with the activity of the cesium-137.

C-2. Identifying Radionuclides.

a. Radionuclides are identifiable by the radiation they emit, and by their atomic properties. Most radionuclides found on USACE projects emit multiple types and energies of radiation. The types and energies of the all the radiations emitted by a radionuclide are a unique characteristic of that radionuclide.

b. Example: cesium-137 (^{137}Cs) decays by two pathways. 94.6% of the time ^{137}Cs will emit a beta particle with a maximum energy of 511.6 keV. 5.4% of the time ^{137}Cs will decay by emitting a beta particle with a maximum energy of 1173.2 keV. In both cases it decays to metastable barium-137m (^{137m}Ba), which is also radioactive. ^{137m}Ba decays to stable barium-137, 89.98% of the time by emitting a 661.649 keV gamma ray.

c. So anytime we have Cs-137 contamination on-site, we will be able to measure a spectrum of beta activity with a maximum beta energy of 1173 keV, and a ^{137m}Ba gamma peak with an energy of 662 keV.

d. An unknown sample of a radioactive material can be analyzed by determining what type of radiation it emits, determining at what energy the radiation is emitted, then looking up in tables which particular radionuclides emit that type of radiation at that particular energy. In the example above, ^{137}Cs could be analyzed using a liquid scintillation counter to

determine the beta spectrum, and the maximum beta energy. The area under the curve of the beta spectrum is proportional to the activity of the ^{137}Cs. Noting that ^{137}Cs is part of a decay chain, one could also use a gamma counter to count the gamma rays at an energy of 662 keV from the ^{137m}Ba and divide the result by the gamma intensity of 89.98% to calculate the activity of the ^{137}Cs. Since gamma counting is much easier and cheaper to perform, this method is more commonly used. Many of the radionuclides of concern at USACE sites are parts of decay chains.

e. Surrogates can be used because, when a parent radionuclide has a half-life very much larger than its progeny, the progeny decay at a rate faster than it is generated, so it appears than the activity of the progeny is equal to the activity of the parent after sufficient in-growth. As a rule of thumb, seven half-lives of the progeny is considered sufficient time for this in-growth to be achieved.

f. This practice of measuring a surrogate radionuclide and calculating the activity of another radionuclide in the same decay chain is common, but there are a number of pitfalls that must be avoided. There are a number of actions that can invalidate this use of surrogates. Many of these involve actions that chemically separate the radionuclide from its progeny or not permit enough time for adequate in-growth of the surrogate. It is important to discover at which point in the decay chain materials were brought to the site or removed from the site.

g. A number of decay progeny may be gamma emitters but either the percent of time the gammas are emitted or the percent of time the decay chain goes by their path may be too small to make them useful at activities near remediation guidelines. All use of surrogates for determination of the presence and activity of a radioactive contaminant must be thoroughly investigated, documented and agreed to by the regulators.

h. Because the act of sampling soil or water can disrupt the concentrations of ingrown progeny, samples must be held for a number of days or weeks to ensure that the surrogate being measured has had sufficient time to approach equilibrium with the parent radionuclide being analyzed.

i. As an example, Ra-226 is commonly analyzed using gamma spectroscopy and measuring the activity of Bi-214. The decay chain is Ra-226 to Rn-222 to Po-218 to Pb-214 to Bi-214 to Po-214. The act of soil sampling often causes the Rn-222, which is a gas, to escape. This disrupts the decay chain and the sample should be held undisturbed for seven half-lives for each of the progeny to re-establish equilibrium. The half-lives of the progeny are Rn-222-3.82 days, Po-218-3.05 min., Pb-214-26.8 min., and Bi-214-19.9 min. This totals 3.85 days. The sample should be held for seven half lives, 27 days, to ensure that the Bi-214 activity is the same as the Ra-226 activity. Note that under certain conditions, ratio charts can be constructed to allow counting before the seven half-lives have passed. There are a

number of factors that can influence the accuracy of the ratio chart. The project health physicist should be consulted to check if the method may be accurately used on any particular phase of a project.

j. Bi-214 emits a 0.609 MeV gamma 46.1% of the time when it decays. The gamma spectrometer will count the number of these gamma emitted. The radiochemist will divide the number of counts by the efficiency and the intensity to determine the number of disintegrations during the counting period. This is then assumed to be the number of disintegrations of the parent radionuclide over the same time period.

k. Since radionuclides can be measured by their atomic properties, some chemical quantification methods may be used to quantify the radionuclides. One common example is use of inductively coupled plasma-mass spectrometry to determine the isotopic abundance of enriched or depleted uranium isotopes.

C-3. Background.

a. A large number of radionuclides are present in the environment at concentrations that can interfere with the measurement of the contamination at a site. The radiation emitted by these radionuclides - mostly naturally occurring but some man-made is collectively referred to as background radiation. Primary radionuclides found in background include:

- The uranium (U) decay chain [U-238, thorium (Th)-234, protactinium (Pa)-234, U-234, Th-230, radium (Ra)-226, radon (Rn)-222, polonium (Po)-218, lead (Pb)-214, bismuth (Bi)-214, Po-214, Pb-210, Bi-210, and Po-210].
- The thorium decay chain [Th-232, Ra-228, actinium (Ac)-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212 and Po-212].
- Potassium-40 (K-40), tritium (H-3) and carbon-14 (C-14).
- Mixed fission products from above ground nuclear testing (Cs-137, Sr-90, etc.).

b. The concentrations of radionuclides in background are highly variable, depending on types of soil throughout the entire soil column, precipitation, water table, temperature, and latitude. Concentrations can vary by orders of magnitude. For example, uranium found in igneous rock averages about 0.6 ppm, but uranium found in Florida phosphate rock averages about 120 ppm.

c. Because of this variability, it is important to select an area from which to take background survey readings and samples that has the same soil and water characteristics, and as near the physical location, of the contaminant as is possible. Additionally, when determining background concentrations, enough background samples must be obtained to determine the variability and standard deviation of the concentration at an acceptable confidence limit. MARSSIM, Sec. 4.5, provides guidance on selection of a background

reference area, and a health physicist must be consulted to determine the proper number of background samples to take. This number may be as high as the total number of samples taken at the site, i.e., one background sample per contaminant sample.

C-4. Regulated Contaminants. Because of the nature of the regulatory process, radioactive contamination is regulated under a number of statutes. A more detailed description of the regulations and their interaction can be found in Chapter 9. Ongoing legislative changes have followed changes in the philosophy of radiation safety, but a number of older statutes are still applicable, and have led to a few confusing remediation goals at some sites. The Uranium Mill Tailings Control Act was one of the first acts specifically addressing radioactive contamination in the soil. This act set the remediation goal for uranium mill sites at 5 pCi/g of radium in the top 6 inches of soil and 15 pCi/g radium in each subsequent 15 inches of soil. Because there were no other promulgated standards on soil contamination, this prescriptive remediation goal was cited as relevant and appropriate and applied to other sites where the contaminants were not uranium mill tailings.