Chapter 3
Useability Criteria for Baseline Risk Assessments

This chapter discusses data useability criteria and preliminary sampling and analysis issues. This information can be used to plan data collection efforts in order to maximize the useability of environmental radioanalytical data in baseline risk assessments.

3.1 DATA USEABILITY CRITERIA

The data useability criteria presented in Part A, Section 3.1 are generally applicable to analytical data required for baseline risk assessment, including radioanalytical data.

3.1.1 Data Sources

The data source considerations given in Part A, Section 3.1.1 also apply to radioactively contaminated sites. Since radioactive contamination can often be detected in the survey process, preliminary assessment/site inspection (PA/SI) and any other field measurements may be of particular importance. Field measurements that provide data for external exposure rates, while usually considered screening, can be used for risk assessment purposes directly, provided they meet the data useability requirements. Also of potential importance are the operating history of the site, handling and disposal manifests, and U.S. Nuclear Regulatory Commission (USNRC) licenses or state agency permits regulating the possession of radioactive materials.

3.1.2 Documentation

The four major types of documentation discussed in Part A, Section 3.1.2 apply equally to radionuclides:

- Sampling and analysis plan (SAP) and quality assurance project plan (QAPjP).
- Standard operating procedures (SOPs), particularly those for the calibration and use of all field survey instruments.
- Field and analytical records, including all survey information relating to radiation or radioactivity concentrations.
- Chain-of-custody records.

3.1.3 Analytical Methods and Detection Limits

The importance of selecting proper analytical methods based on detection limits that meet risk assessment requirements is discussed for chemical analyses in Part A, Section 3.1. A discussion of detection limits for radiation detection instruments can be found in Section 3.2. A strategy for selecting radioanalytical methods that meet risk assessment requirements is described in Section 4.2.

3.1.4 Data Quality Indicators

Data quality indicators are the performance measurements of data quality objectives (DQOs). These objectives should be a function of the desired confidence level of the risk assessment and not based on the availability or capability of specific analytical methods. DQOs must be clearly defined for all radiation and radioactivity measurements.

Quantitative data quality indicators for radioanalytical measurements may include a lower limit of detection, minimum detectable concentration, precision, accuracy, and completeness. Qualitative data quality indicators can be expressed as goals but cannot be demonstrated quantitatively. Such qualitative data quality indicators might include representativeness and comparability.

In setting DQOs, the relationship to the decision-making process is paramount. The primary rationale for setting DQOs is to ensure that the data will be of sufficient quality to support the planned decisions and/or actions to be taken based on those data.

The DQO process involves three stages: defining the decision, reviewing the existing data to determine what new data are required, and designing the sampling and analytical program to obtain the required data. Data

Acronyms

CLP	Contract Laboratory Program
DOT	U.S. Department of Transportation
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
G-M	Geiger-Muller
HP	health physics
IDL	instrument detection limit
LLD	lower limit of detection
MDC	minimum detectable concentration
PA	preliminary assessment
PC	pressurized ion chamber
QAPjP	quality assurance project plan
QC	quality control
RPM	remedial project manager
SAP	sampling and analysis plan
SI	site inspection
SOP	standard operating procedure
SQL	sample quantitation limit
TCL	Target Compound List
TIC	tentatively identified compound
USNRC	U.S. Nuclear Regulatory Commission

quality will be a function of the chemical preparation, measurement system, selection of sampling and counting parameters, and the control limits set for the data quality indicators. After the establishment of the isotope-pathway combinations of interest, the risk assessor must develop the maximum uncertainties that can be tolerated in the assessment of the activity for an isotope in each media. These parameters define the data quality indicators which in turn determine the available procedures.

3.1.5 Data Review

While the RPM or other personnel can perform many aspects of basic data review, an individual experienced in radiochemistry or health physics must perform the detailed technical review of both the field and laboratory data. Such a review should be performed on preliminary data as they are collected and should continue throughout the risk assessment process.

Special attention must be paid to all reports prepared by data reviewers to ensure that there is a narrative summary in addition to the data summary tables provided. The additional, clarifying information in the narrative summary will be of particular importance to reviewers unfamiliar with radioanalytical data.

3.2 PRELIMINARY SAMPLING AND ANALYSIS ISSUES

A discussion of issues affecting sampling and analysis for baseline risk assessment is beyond the scope of this document. A framework of key issues, tools, and guidance used in the design and assessment of environmental sampling and analysis procedures is described in Part A, Section 3.2. This section concentrates on the differences between sampling and analysis for radioactive contamination compared to sampling and analysis for chemical contamination.

3.2.1 Radionuclides of Potential Concern

EPA classifies all radioactive substances as Class A carcinogens (i.e., known human carcinogens). Any radioactive substance detected or suspected of being present at or released from a site will be considered to be of potential concern and evaluated accordingly. The risk assessor should review the list of radionuclides of concern for each migration pathway. These lists should contain the following information for each radionuclide listed (see Appendix I for a more detailed discussion of each of the factors):

Atomic number and atomic weight. The elemental identity of a radioisotope is determined by the number of protons in its nucleus (i.e., its atomic number), and its isotopic identity is determined by the total number of protons plus neutrons (i.e., its atomic weight). For example, plutonium has an atomic number of 94. Isotopes of plutonium, such as Pu-238, Pu-239, Pu-240, Pu-241, and Pu-242, have identical atomic numbers but different atomic weights. The origin, use, isotopic abundance, radioactive (and perhaps physical) properties, and cancer potency of each plutonium isotope are unique. Thus, it is imperative that each radionuclide be properly identified.

Radioactive half-life. The radioactive half-life of a radioisotope is the time required for the activity of that isotope to be reduced by one half. Half-life is a unique characteristic of each radioisotope and is not affected by chemical or physical processes. Knowledge of the half-life of a radioisotope is important for the following reasons:

- The half-life determines the activity and cancer potency of the isotope.
- The half-life affects holding times for analyses (radionuclides with shorter half-lives must be analyzed in a shorter time frame than longer-lived radionuclides).
- The half-life determines the degree of activity equilibrium between decay products (radionuclides in equilibrium maintain equal levels of radioactivity, if the equilibrium is disturbed the activity levels of the progeny need to be measured separately).

Principal decay modes, radiation decay modes, energies, and abundances. Radioisotopes emit radiation in the form of alpha, beta, and neutron particles, as well as gamma photons and x-rays. The type, abundance, and energies of the radiations emitted by a radioisotope are unique to that isotope. Consequently, the selection and use of sampling and analysis procedures, radiochemical methods, and radiation detection instruments must be consistent with the decay mode (i.e., alpha, beta, neutron, or photon) and radiation energies and abundances of the radionuclide of concern.

Chemical and physical forms. The mobility, bioaccumulation, metabolic behavior, and toxicity of a radioisotope are governed by its chemical and physical form, not by its radioactive properties. Radioisotopes in the environment may exist as solids, liquids, or gases in a variety of chemical forms, oxidation states, and complexes. Information should be provided in the data package describing the most likely chemical and physical form(s) of each radionuclide at the time of production, disposal, release, and measurement.

Decay products. Radioactive decay of an isotope of one element results in the formation of an isotope of a different element. This newly formed isotope, the

decay product, will possess physical and chemical properties different from the parent isotope. For example, Ra-226 may be present as a solid in the form of radium sulfate while its daughter Rn-222 is a noble gas. Often, a decay product is also radioactive and decays to form a different radioisotope. It is important to consider all radioisotopes for the following reasons:

- The total activity content (and thus, the potential hazard) of a radioactive source or sample may be underestimated if progeny are excluded.
- An isotope's progeny may be more toxic, either alone or in combination, than the parent radioisotope. For example, Ra-226 decays to Rn-222 by alpha particle emission with a half-life of 1600 years, while Rn-222 and its daughters emit three additional alpha particles and two beta particles through the principle decay modes with a combined half-life of less than four days.
- The environmental transport, fate, and bioaccumulation characteristics of the progeny may be substantially different from those of the parent isotope.

The site records, including the operating history, handling and disposal manifests, and radioactive materials licenses or permits, will be useful in determining if the initial list of radionuclides of concern derived from these records and those radionuclides identified in media samples are consistent. All omissions or inconsistencies in the expected versus the observed radioisotopes at the site should be noted, and additional information should be sought to explain these discrepancies.

At sites containing both radioactive and other hazardous substances, the list of chemicals of concern should be reviewed for each sample medium for consistency and completeness. The manner in which radioactive substances are associated with nonradioactive hazardous substances on the site should be described by the RPM or risk assessor, to the extent that such information is available. This description also should include a discussion of the possible effects that these chemicals may have on radionuclide mobility and bioaccumulation.

3.2.2 Tentatively Identified Radionuclides

Because radionuclides are not included on the Target Compound List (TCL), they may be classified as tentatively identified compounds (TICs) under Contract Laboratory Program (CLP) protocols. In reality, however, radioanalytical techniques are sufficiently sensitive that the identity and quantity of radionuclides of potential concern at a site can be determined with a high degree of confidence. In cases where a radionuclide's identity is not sufficiently well-defined by the available data set: (1) further analyses may be performed using more sensitive methods, or (2) the tentatively identified radionuclide may be included in the risk assessment as a contaminant of potential concern with notation of the uncertainty in its identity and concentration. A health physicist or radiochemist should review the identification of any radionuclide to determine if the radionuclide is actually present or is an artifact of the sample analysis.

3.2.3 Detection and Quantitation Limits

The terms used to describe detection limits for radioanalytical data are different than the terms used for chemical data. Detection limits must be specified by the equations and confidence limits desired as well as being defined numerically. Normally, detection limits will be requested as the detection limits with a 5% chance each of Type I and Type II errors. Exhibit 1 lists typically achievable sensitivity limits for routine environmental monitoring.

In order to satisfy these purposes, two concepts are used. The first level is an estimated detection limit that is related to the characteristics of the counting instrument. This limit is not dependent on other factors in the analytical method or the sample characteristics. The limit, termed the lower limit of detection (LLD), is analogous to the instrument detection limit (IDL). The second limit corresponds to a level of activity that is practically achievable with a given instrument, analytical method, and type of sample. This level, termed the minimum detectable concentration (MDC), is analogous to the sample quantitation limit (SQL) and is the most useful for regulatory purposes.

3.2.4 The Estimated Lower Limit of Detection

The LLD may be defined on the basis of statistical hypothesis testing for the presence of activity. This approach is common to many authors and has been described extensively (Pasternack and Harley 1971, Altshuler 1963, Currie 1968, NCRP 1978).

The LLD is an *a priori* estimate of the detection capabilities of a given instrument system. This limit is based on the premise that from a knowledge of the background count and measurement of system parameters (e.g., detection efficiency), an *a priori* limit can be established for a particular measurement. The LLD considers both the α and β errors. In statistical hypothesis testing, α and β are the probabilities for what are frequently referred to as Type I (false detection) and

EXHIBIT 1. EXAMPLES OF TYPICAL MINIMUM DETECTION CONCENTRATION (MDC) VALUES FOR ENVIRONMENTAL RADIOANALYSES*

Media	Approximate Sample Size	Isotope	MDC	Reporting Units	Method[a]
Soil	200 grams	^{137}Cs	1	pCi/g (dry)	1
	200 grams	^{60}Co	1	pCi/g (dry)	1
	200 grams	^{226}Ra	0.1	pCi/g (dry)	1
	10 grams	^{90}Sr	1	pCi/g (dry)	2
	10 gram	U Isotopes	0.1	pCi/g (dry)	3
	10 gram	Th Isotopes	0.1	pCi/g (dry)	3
	10 gram	Pu Isotopes	0.1	pCi/g (dry)	3
Water	50 mls	^{3}H	400	pCi/L	4
	4 liters	^{137}Cs	1	pCi/L	1
	4 liters	^{60}Co	1	pCi/L	1
	1 liter	^{226}Ra	0.1	pCi/L	5
	1 liter	^{90}Sr	1	pCi/L	2
	1 liter	U Isotopes	0.1	pCi/L	3
	1 liter	Th Isotopes	0.1	pCi/L	3
	1 liter	Pu Isotopes	0.1	pCi/L	3
Air	300 m^3	^{137}Cs	0.01	pCi/m^3	1
	300 m^3	^{60}Co	0.01	pCi/m^3	1
	300 m^3	^{226}Ra	0.01	pCi/m^3	5
	300 m^3	^{90}Sr	0.05	pCi/m^3	2
	300 m^3	U Isotopes	0.0002	pCi/m^3	3
	300 m^3	Th Isotopes	0.0002	pCi/m^3	3
	300 m^3	Pu Isotopes	0.0002	pCi/m^3	3
Biota	1000 g (ash)	^{137}Cs	1	pCi/Kg (wet)	1
	1000 g (ash)	^{60}Co	1	pCi/Kg (wet)	1
	1000 g (ash)	^{226}Ra	1	pCi/Kg (wet)	1
	1000 g (ash)	^{90}Sr	1	pCi/Kg (wet)	2
	1000 g (ash)	U Isotopes	0.1	pCi/Kg (wet)	3
	1000 g (ash)	Th Isotopes	0.1	pCi/Kg (wet)	3
	1000 g (ash)	Pu Isotopes	0.1	pCi/Kg (wet)	3

* For purposes of illustration only. Actual MDCs for listed radionuclides in the media shown will vary, depending on sample specific preparation and analytical variables.

a) Methods
1 = High Resolution Gamma Spectrometry
2 = Chemical Separtion followed by Gas Proportional Counting
3 = Chemical Separation followed by Alpha Spectrometry
4 = Liquid Scintillation Counting
5 = Radon Emanation

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Type II (false non-detection) errors, respectively. A common practice is to set both risks equal and accept a 5% chance of incorrectly detecting activity when it is absent ($\alpha = 0.05$) and a 95% confidence that activity will be detected when it is present ($1 - \beta = 0.95$). The expression for the LLD becomes:

$$LLD = K * (4.65 * s_b)$$

where:

K = the proportionality constant relating the detector response (counts) to the activity, such as K=1/e, where e is an overall detection efficiency or $K=1/I_\tau e_\tau$, where I_τ is the photon emission probability per disintegration and e_τ is the detection efficiency for the photon

s_b = the estimated standard deviation of the background count (assumed to be equal to the standard deviation of the sample count near the LLD)

3.2.5 The Estimated Minimum Detectable Concentration

The MDC is a level of activity at which detection can be achieved practically by an overall measurement method. As distinguished from the LLD, the MDC considers not only the instrument characteristics (background and efficiency), but all other factors and conditions that affect the measurement. The MDC is also an *a priori* estimate of the activity concentration that can be achieved practically under a set of typical measurement conditions. These conditions include sample size, net counting time, self-absorption and decay corrections, chemical yield, and any other factors that comprise the activity concentration determination. The MDC is useful for establishing that some minimum overall measurement conditions are met. Any of several factors, such as sample size or counting time, may be varied to meet a specific MDC value. Exhibit 1 lists typical MDCs for radionuclides in several media.

Expressions for the MDC are similar to those for the LLD. For the MDC, the proportionality constant K would include not only the factors for the LLD but also the factors that relate the detector response (counts) to the activity concentration in a sample for a typical set of measurement conditions.

3.2.6 Media Variability Versus Measurement Error

Sampling and analysis variability and measurement error are two key issues involved in planning and assessing data collection efforts. Part A, Exhibit 31 lists field quality control (QC) samples that are used in defining variation and bias. These QC sample types have similar purposes for radioactively contaminated samples with one exception. The trip blank is not required for radioactively contaminated samples because there is less likelihood of contamination from direct exposure to air than for samples of volatile organic chemicals. Confidence level, power, and minimum detectable relative difference are defined in Part A, Section 4.1, and these definitions also apply in radionuclide sampling.

3.2.7 Sample Preparation and Sample Preservation

Proper sample preparation and preservation are essential parts of any radioactivity sampling program. The sampling requirements must be specified in the SAP before sampling activities begin. Precise records of handling are required to ensure that data obtained from different locations or time frames are correctly compared.

The appropriateness of sample preparation is a function of the required analysis. Some examples of sample treatment to be avoided or performed with great care include:

- Aliquots of samples selected for H-3 should not be dried, ashed or acidified.
- Aliquots of samples selected for C-14 should not be ashed or leached with acid.
- Aliquots of samples selected for elements with volatile oxidized forms, such as Iodine, should not be treated with oxidizing acids.
- Aliquots of samples selected for Ra-226 analysis by gamma spectrometry should be dried, crushed and/or sieved, but an appropriate post-preparation holding time must be included to allow the attainment of equilibrium with radon daughters.
- Aliquots of samples selected for elements with volatilized forms at high temperatures (e.g., I, Cs, Ru) should not be ashed, or ashed with great care. A radiochemist or health physicist should be consulted on the proper handling of the samples from a specific site.

The requirements of sample preservation are determined by the required analysis as well as the chemical characteristics of the radionuclide to be analyzed. The purpose of preserving a sample is to maintain the

sample in the condition required for analysis between the time the sample is collected and the time the sample is analyzed. Many of the radiochemical species of interest behave like trace metals, and the preservation of water samples is easily achieved by acidification. This prevents metallic species from depositing on the walls of the container. Usually, nitric acid is used to maintain a pH of less than 2.0. Water samples preserved in this manner have a holding time of six months. The exceptions to this general rule are given below:

- Samples for H-3 and C-14 analysis should be unpreserved.
- Samples for analysis of elements with volatile oxidized forms (e.g., I-129, I-131) should not be preserved with oxidizing acids.
- Certain laboratories may require samples for uranium analysis to be preserved with hydrochloric acid.

The container material for stored samples can also be a factor in sample preservation. Metals have an affinity for glass when preserved with nitric acid. Iodine and transition metals such as iron and cobalt have shown an affinity for polyethylene and polypropylene under certain conditions (Bernabee 1980). The selection of containers for different sample types should be specified in the SAP.

Soil samples are generally collected and shipped to the analytical laboratory "wet," meaning their inherent moisture has not been deliberately removed. The SAP should address the questions regarding if, how (air or oven), and when (prior to or after aliquotting) the sample will be dried. Often, a soil sample contains much extraneous matter, e.g., root matter, rocks, stones, organisms. The question arises whether these "extraneous" materials are just that, or whether they constitute part of the sample itself. These issues should be specified in the analytical program design, and the risk assessor must ensure that sample preservation has not compromised the sample's integrity.

Samples of contaminated structural samples may be collected at some sites. For structural material the data may be reported as fixed or as removable contamination. Fixed contamination refers to contamination that is incorporated in the material or is firmly bound on the surface of the material. Fixed contamination is measured by cleaning the surface of the material and using a field survey instrument to measure the activity of the material. Removable contamination is contamination that can be transferred from the surface of the material to another object. Removable contamination is measured by smearing the surface of the material with a small piece of paper or cloth and measuring the amount of activity on the smear. Special handling and analysis procedures for these types of samples should be included in the SAP.

The presence of radioactive and hazardous chemical wastes (mixed wastes) at a site can influence the quality of the analytical data obtained for that site. Two general areas are affected by the special considerations of mixed wastes. First, the radioactive nature of the waste necessitates special plans and operations for on-site measurements and sampling. Second, the radioactivity in the samples may limit the number of laboratories that can receive the samples or the types of analyses that can be performed. The nature of such influences is not always self-evident. Data users should be aware of the potential effects on data quality resulting from the complications of mixed waste characterization.

Field work demands that the on-site staff be able to make decisions at the job site, a necessary prerequisite if the sampling and measurement teams are to be capable of reacting to unforeseen circumstances. It is also true that in those circumstances, personnel tend to make judgments based on their best, most applicable experience. The experience of a worker who has handled hazardous wastes will be biased toward the chemical handling aspects, and decisions appropriate to those types of wastes are to be expected. The opposite may be true of workers experienced with handling radioactive materials. It will be up to the data user to critically review the field records to ensure that such on-site decisions properly considered the data validity of both sample components and that data were not compromised.

The design of the sample collection program may require compromises due to the differences in sample handling and staff experience required for the principal components of the waste. Mixed waste is only a small fraction of all the low-level radioactive waste generated in the country and an infinitesimal fraction of the total hazardous waste. Therefore, staff with the appropriate experience in both areas may not be available. The requirements for special training and staff may conflict with limitations in potential resources. Any given risk assessment may be required to use staff that are very experienced in one area (e.g., radiochemical sampling) but may have only minimal training in the other mixed waste component (e.g., sampling for organics). Data recipients need to be especially alert to potential problems caused by large discrepancies in the experience of staff working such programs.

The external exposure rates or radioactivity concentration of a specific sample may limit the time that workers will be permitted to remain in intimate contact with the samples. Possibly, collection personnel

could take large samples and then split them into specific analytical aliquots in a radioactively "cold" area. This area may be "cold" with respect to radioactive contamination but may still be contaminated chemically. This process increases both the chances of nonequivalent samples being sent for different analyses and the potential for cross-contamination between samples or from the area chosen for sample splitting. Additionally, external exposure rates from individual samples may require that smaller samples be taken and special holding areas be provided. Special handling requirements may conflict with the size requirements for the analytical protocol, normal sampling procedures, or equipment. For example, sampling for hazardous waste constituents or properties may require that samples be kept refrigerated. Samples containing radioactive materials may have to be kept in a restricted area to prevent personnel radiation exposure or the spread of alpha and/or beta contamination. The shielding requirements for radioactive samples depend on their external exposure rate, and confinement is based on the potential for removable contamination. Such decisions will be made by site health physics (HP) personnel who may be unaware of temperature or holding time requirements. In some cases, samples will have to be physically surrendered to HP personnel for clearance prior to removal from the site. Again, data recipients need to be alert for potential handling errors arising from these types of situations.

Varying requirements for storage, preservation, and special shipping complicate the logistics of mixed waste programs. While most radiochemical procedures have holding times and preservation methods in common with metals analysis, they differ greatly with organic analyses. Holding times for radioactively contaminated samples are also affected by the half-life of the radionuclide to be analyzed. After seven half-lives, less than 1% of the original activity would remain in the sample. Separate samples should be taken for the analyses requiring different handling and preservation.

Less obvious is the potential for biasing sampling programs by selecting samples that can be safely handled or legally shipped to the support laboratories. There will be a human bias in the direction of handling samples with the least shipping and storage complications. This selection process can involve several assumptions about the waste distribution which may or may not be acknowledged. In an effort to ship the most convenient samples, workers may assume that the chemical contamination is not related to the radioactivity levels in any way. The assumptions may also be made that there are no qualitative differences in the radioactivity content at different concentrations and that the low activity samples can be quantitatively analyzed and scaled to the higher activity areas by the use of a simple ratio, of external exposure rates, for example. Without documentary support, all of these assumptions may be unwarranted, and sampling and analysis schemes based on such assumptions may compromise data integrity. The risk assessor must ensure that such assumptions were not part of the sample selection process by reviewing the appropriate plans and records.

3.2.8 Fixed Laboratory Versus Field Analysis

Fixed laboratory and field analyses are compared in Part A, Section 3.2.9. A major factor to be considered in this decision for radioactively contaminated sites is the type of radiation present. Alpha-emitting radionuclides often cannot be measured in the field because of the attenuation of the alpha particles by the sample matrix. Attenuation can also cause problems for beta measurements under certain conditions. Gamma-emitting radionuclides can generally be measured in the field if the data can be confirmed by fixed laboratory measurements.

> ☛ *Field measurements must be made using instruments sensitive to the type of radioactivity present.*

Selection of a radiometric method depends on the number of radionuclides of interest and their activities and types of radiations emitted, as well as on the level of sensitivity required and the sample size available. Exhibit 2 provides information on field survey instruments for measuring gamma radiation, including the advantages and disadvantages associated with each type of instrument. Exhibit 3 provides similar information for alpha and beta field survey instruments.

Measurements of external gamma radiation exposure rates are used to delineate areas of contamination and areas of observed contamination. Exposure rates are usually measured with hand-held radiation survey meters that utilize ion chambers, Geiger-Muller (G-M) tubes, or gamma scintillation probes.

Surface gamma readings provide data only on radiation levels at the surface, and they may miss contamination from radionuclides at a greater depth that are shielded by soil cover. In order to accurately characterize the depth distribution of the radioactive contamination, boreholes are augured or driven through key areas of the site. Detectors, generally gamma scintillators, are lowered into these boreholes, and readings of the gamma exposure rate or gamma count-rate are obtained at regular predetermined depths. Exhibit 4 shows a typical borehole apparatus. The risk assessor should consider several issues pertaining to down-hole gamma profiling.

EXHIBIT 2. FIELD SURVEY INSTRUMENTS FOR MEASURING GAMMA RADIATION

Detection	Specifications	Advantages	Disadvantages
Ion Chamber	• Moderate to high range, approximately 0-2,000 mR/hour. • Accuracy ±5% at the high end of the scale.	• Reading is directly proportional to radiation field. • Suitable for use in high radiation fields. • Very portable.	• Poor sensitivity, not adequate for near-background radiation rates.
Pressurized Ion Chamber (PIC)	• Range 1-500 µR/hour. • Accuracy ±5% full scale.	• Suitable for near-background radiation rates. • Reading is directly proportional to radiation field.	• Not as portable as Ion Chamber, therefore, fewer measurements per day can be recorded.
"Modern" Geiger-Muller (GM) Tube	• Moderate to high range: 0-5,000 mR/hour. • Accuracy ±10% full scale.	• Very portable. • Can also be used for beta radiation detection.	• Poor sensitivity, not adequate for near-background radiation rates. • Reading is not directly proportional to radiation field unless an energy compensated tube is used.
Gamma Scintillation Detectors	• Low range 0-5,000 µR/hour. • Accuracy ±10% at high end to ±30% at low end of scale.	• Suitable for background radiation rates. • Very portable.	• Reading is not directly proportional to radiation field; response varies with energy.
Organic Scintillators	• Low range 0-25 uR/hour. • Accuracy ±10% full scale.	• Suitable for background radiation rates. • Very portable.	• Response is generally linear with energy.

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EXHIBIT 3. SURVEY INSTRUMENTS FOR MEASURING ALPHA AND BETA RADIATION

Detection	Radiation Detected	Advantages	Disadvantages
Alpha Scintillation Probe*	• alpha only	• High detection efficiency. • Useful for many screening applications. • Very portable.	• Delicate window may be easily broken. • Measures only alpha particles.
Air Proportional Detector	• alpha only	• Large surface area. • High detection efficiency.	• Delicate window may be easily broken. • Measures only alpha particles. • Can be affected by mositure.
Geiger-Muller (GM) Pancake Type Probe*	• alpha, beta and gamma	• Large surface area. • Can be used to detect all types of radiation. • Good for general screening.	• Sensitivity to all types of radiation decreases ability to discriminate between radiation types.
Side-Shielded GM Probe*	• beta and gamma	• Discriminates between gamma and beta radiation. • Good in high gamma radiation fields.	• Gamma reading is not directly proportional to radiation field; response varies with energy.

* All probes are attached to the appropriate rate meter or scaler.

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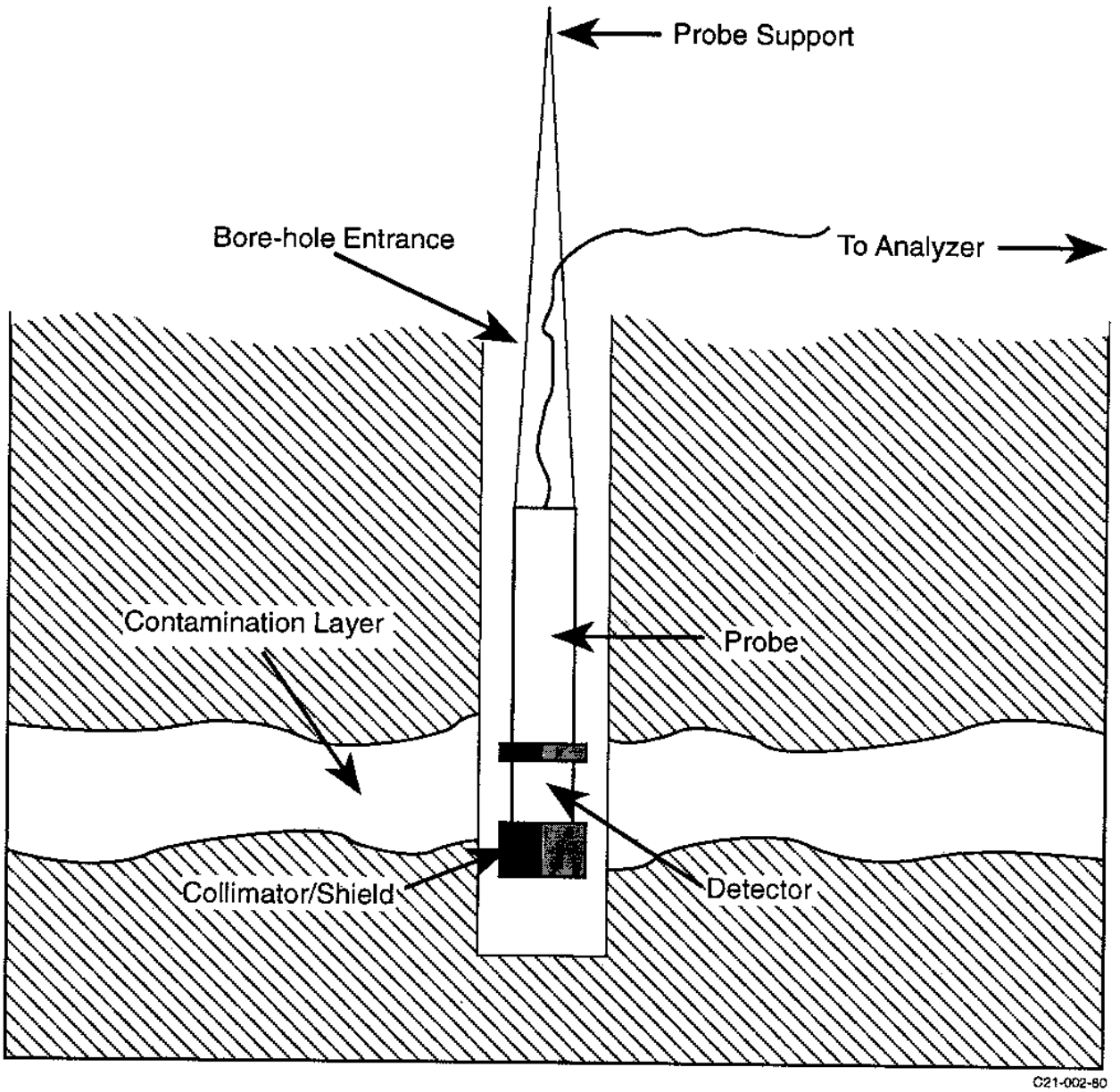
These include the calibration conditions for the detector, the energy range the instrument is set to measure, and variations in background caused by heterogeneous layers of naturally occurring radioactivity.

Alpha and beta radiations lack the penetrating ability and range of gamma radiation, making their detection in the field more difficult, but equally important, to characterize. Preliminary radiation screening of samples for alpha- or beta-emitting radionuclides must be

EXHIBIT 4. ILLUSTRATION OF BORE-HOLE GAMMA PROFILING



performed using instruments sensitive to the type of radiation being measured and must be performed much closer to the contamination source. These results, usually referred to as screening, can be used to identify samples or areas containing radioactive contamination, to establish that all samples leaving the site comply with applicable U.S. Department of Transportation (DOT) regulations, and to estimate the radioactivity content of samples sent off site for analysis to ensure compliance with the recipients radioactive materials license limits.