5.0 RADIOLOGICAL INSTRUMENTATION

Surveys for decommissioning will typically require the collection of two types of radiological data: (1) direct field measurements using portable instruments and (2) sample analyses using fixed laboratory equipment or systems. For either type of measurement, the selection and proper use of appropriate instruments will likely be the most critical factors in assuring that the survey accurately determines the radiological status of the site. Radiological instrumentation consists of two components — a radiation detector and the electronic equipment needed to provide the power to the detector and to display or record the radiation events. This section identifies and very briefly describes the types of radiation detectors and associated display or recording equipment that are applicable to survey activities leading to license termination. Information concerning instrument selection, application, and use is provided in this section. A checklist to assist the surveyor in selection of appropriate instrumentation is included at the end of this Section. Additional information on survey techniques and laboratory procedures using instrumentation described here is available in Sections 6.0 and 7.0 of this Manual.

5.1 Instrument Types

5.1.1 Radiation Detectors

Radiation detectors can be divided into three general categories based on the detector material with which radiation interacts to produce a measured event. These categories are:

1. Gas-Filled Detectors in which radiation interacts with the filling gas, producing ion-pairs which are collected by charged electrodes. Gas-filled detectors are usually categorized as ionization, proportional, or Geiger-Mueller (GM), referring to the region of gas amplification in which they are operated.

2. Scintillation Detectors in which interaction of radiation with a solid or liquid medium results in a small flash of light (known as a scintillation), which is converted to an electrical signal by a photomultiplier tube.

3. <u>Solid-State Detectors</u> where radiation interactions with germanium or silicon semi-conductor material create ion-pairs which are collected by charged electrodes.

The design and the conditions under which a specific detector is operated determine the types of radiations (alpha, beta, and/or gamma) that can be measured, the sensitivity level for measurements, and the ability of the detector both to differentiate between different types of radiations and to distinguish the energies of the interacting radiations. The particular capabilities of a radiation detector will, in turn, establish its potential applications in conducting a survey for license termination. Lists of radiation detectors, along with their usual applications, are provided in Table 5-1 through 5-3.

5.1.2 Display and Recording Equipment

Radiation detectors are connected to some type of electronic device to (1) provide a source of power for detector operation and (2) enable measurement of the quantity and/or quality of the radiation interactions that are occurring in the detector. The most common recording or display device used for radiation measurement is known as a **ratemeter**. A ratemeter provides a display on an analog meter, representative of the number of events occurring over some time period, e.g. counts per minute.

The number of events can also be accumulated over a preset time period using a **digital scaling device**. The resulting information from the scaling device is also events per unit time; however, the scaler provides a definite value whereas the ratemeter display will vary with time. Also determining the average level on a ratemeter will require a judgment by the user, especially when a low frequency of events results in significant variations in the meter reading.

Pulse height analyzers are specialized electronic devices designed to measure and record the number of pulses or events which occur at different energy levels. They can be used to record only those events in the detector within a single range of energies or can simultaneously record the events in multiple energy ranges. In the former case, the equipment is known as a **single-channel spectrometer**; the latter application is referred to as a **multichannel spectrometer** or **multichannel analyzer**.

TABLE 5-1

RADIATION DETECTORS WITH APPLICATIONS TO ALPHA SURVEYS

Detector Type	Detector Description	Application	Remarks
gas proportional	<1 mg/cm^2 window; probe face area 50 to 1000 cm^2.	surface scanning; surface activity measurement; field evaluation of smears	
	<0.1 mg/cm^2 window; probe face area 10 to 20 cm^2	laboratory measurement of water, air, and smear samples	
	no window (internal proportional); probe face area 10 to 20 cm^2	laboratory measurement of water, air, and smear samples	
scintillation	ZnS(Ag) scintillator; probe face area 50 to 100 cm^2	surface scanning; surface activity measurement; field evaluation of smears	
	ZnS(Ag) scintillator; probe face area 10 to 20 cm^2	laboratory measurement of water, air, and smear samples	
	Lucas scintillation flask	laboratory measurement for low levels of radium	
solid state	silicon surface barrier detector	laboratory analysis by alpha spectrometry	

TABLE 5-2

RADIATION DETECTORS WITH APPLICATIONS TO BETA SURVEYS

Detector Type	Detector Description	Application	Remarks
gas proportional	<1 mg/cm^2 window; probe face area 50 to 1000 cm^2.	surface scanning; surface activity measurement; field evaluation of smears	
	<0.1 mg/cm^2 window; probe face area 10 to 20 cm^2	laboratory measurement of water, air, smear, and other samples	
	no window (internal proportional); probe face area 10 to 20 cm^2	laboratory measurement of water, air, and smear samples	better measurement sensitivity for low energy beta particles than detectors with windows
Geiger-Mueller	1.4 mg/cm^2 window; probe area 10 to 100cm^2	surface scanning; surface activity measurement; laboratory measurement of samples	
	various window thickness; few cm^2 probe face	special scanning applications	
scintillation	liquid scintillation cocktail containing sample	laboratory analysis; spectrometry capabilities	

TABLE 5-3

RADIATION DETECTORS WITH APPLICATIONS TO GAMMA SURVEYS

Detector Type	Detector Description	Application	Remarks
gas ionization	pressurized ionization chamber	exposure rate measurements	detector and electronics are integrated systems
Geiger-Mueller	pancake (1.4 mg/cm^2 window) or side window (30 mg/cm^2)	surface scanning; surface activity measurement	
scintillation	NaI(Tl) scintillator; up to 5 x 5 cm.	surface scanning; surface activity measurement	cross calibrate with pressurized ionization chamber or for specific site gamma energy mixture
	NaI(Tl) scintillator; large-crystal and "well" configurations	laboratory gamma spectrometry	
	CsI or NaI scintillator; thin crystal	scanning; direct measurement of gamma radiation from plutonium	FIDLER (Field Instrument for Detection of Low Energy Radiation)
solid state	germanium semi conductor	laboratory gamma spectrometry	

5.2 Instrument Detection Sensitivity

The **detection sensitivity** of a measurement system refers to the statistically determined quantity of radioactive material or radiation that can be measured or detected at a preselected confidence level. This sensitivity is a factor of both the instrumentation and the technique or procedure being used. Typically, detection sensitivity has been defined (EPA 1980) as that level above which there is less than a 5% probability that radioactivity will be reported present when it is really absent (Type I error) or reported absent when it really is present (Type II error). This definition has been adopted for the purposes of this Manual.

Two terms used when referring to detection sensitivity are the lower limit of detection and the minimum detectable activity (EPA 1980, CURRIE 1968). The **lower limit of detection** is an *a priori* estimated detection capability, related to the characteristics of the instrumentation. **Minimum detectable activity (MDA)** is an *a priori* estimate of the minimum activity level which is practically measureable with a specific instrument, and sampling and/or measurement technique. Of the two concepts, the MDA is used in this Manual for radiological survey applications. The basic relationship for estimating the MDA is:

$$MDA = K(2.71 + 4.65\ s_b) \tag{5-1}$$

where

K = a proportionality constant relating the detector response (in counts) to an activity concentration.

s_b = the standard deviation of the background count.

Several practical radiological survey applications of this relationship are presented here.

Surface Activity Measurement

For an integrated measurement over a preset time, the MDA for surface activity can be approximated by:

$$MDA = \frac{2.71 + 4.65\sqrt{B_R \cdot t}}{t \cdot E \cdot \frac{A}{100}} \tag{5-2}$$

where

MDA	=	activity level in disintegrations/minute/100 cm^2
B_R	=	background rate in counts/minute
t	=	counting time in minutes
E	=	detector efficiency in counts/disintegration
A	=	active probe area in cm^2

Sample Calculation:

B_R	=	40 counts/minute
t	=	1 minute
E	=	0.20 counts/disintegration
A	=	15 cm^2

$$MDA = \frac{2.71 + 4.65\sqrt{40 \cdot 1}}{1 \cdot 0.20 \cdot \frac{15}{100}}$$

$$= 1100^{*} \text{ disintegrations/minute/100 cm}^2$$

* Rounded to two significant figures.

The MDA of a ratemeter instrument for surface activity measurements can be approximated by taking twice the time constant of the meter as the counting time and using the relationship (KNOLL 1979):

$$MDA = \frac{4.65\sqrt{B_R/2t_c}}{E \bullet \frac{A}{100}} \tag{5-3}$$

where

MDA	=	activity level in disintegrations/minute/100 cm^2
B_R	=	background rate in counts/minute
t_c	=	meter time constant in minutes
E	=	detector efficiency in counts/disintegration
A	=	active probe area in cm^2

<u>Sample Calculation</u>: (for t_c = 4 seconds)

$$MDA = \frac{4.65\sqrt{40/2 \bullet 0.0667}}{0.20 \bullet \frac{15}{100}}$$

= 2700* disintegrations/minute/100 cm^2

* Rounded to two significant figures.

<u>Scanning</u>

The ability to identify a small region or area of slightly elevated radiation during surface scanning (refer to Section 6.4.2) is dependent upon the surveyor's skill in recognizing an increase in the audible output of the instrument. Experience has shown that a 25% to 50% increase may be easily identifiable at ambient background levels of several thousand counts per minute, whereas, at ambient levels of a few counts per minute, a two to three fold increase in the audible signal is required before a change is readily recognizable. The detection sensitivity of scanning is dependent upon a number of other factors, such as detector speed, size of elevated activity region, level of activity, detector/surface distance; therefore, the ability to detect an elevated region of activity using a particular survey scanning technique should be determined empirically. A rough estimate of the MDA can be calculated by substituting the audibly discernable increase in count rate for the numerator in equation 5-3.

Sample Calculation:

B_R = 40 counts/minute

E = 0.20 counts/disintegration

A = 15 cm^2

Three times the background rate (B_R) is audibly discernable as an increase in instrument response by the surveyor using the particular technique selected for the procedure.

$$MDA = \frac{3 \bullet B_R}{0.20 \bullet \frac{15}{100}}$$

$$= \quad 4000 \text{ disintegrations/minute/100 cm}^2$$

Laboratory Analyses

Additional factors may be introduced into the calculation for estimating detection sensitivities for laboratory analyses. Examples of such factors are chemical recovery, sample size, and emission abundances for specific radiations of interest in the analytical process. An example of a calculation for a typical lab procedure for soil analysis would be:

$$MDA = \frac{2.71 + 4.65 \sqrt{B_R \bullet t}}{t \bullet E \bullet S \bullet Y \bullet 2.22} \tag{5-4}$$

where

MDA	=	activity in pCi/g
B_R	=	background rate in counts/minute
t	=	counting time in minutes
E	=	detector efficiency in counts/disintegration
S	=	samples size in grams
Y	=	other factors such as percent chemical recovery and number of emissions of radiation being measured per disintegration of the radionuclide
2.22	=	conversion from disintegrations/minute to pCi.

Sample Calculation:

B_R	=	2 counts/minute
t	=	30 minutes
E	=	0.02 counts/disintegration
S	=	750 grams
Y	=	0.25 (emissions per disintegration)

$$MDA = \frac{2.71 + 4.65\sqrt{2 \cdot 30}}{30 \cdot 0.02 \cdot 750 \cdot 0.25 \cdot 2.22}$$

$$= 1.55 \text{ pCi/g}$$

General Considerations

In application, the system should be capable of measuring levels below 75%, and preferably at or below 10%, of an established guideline value. It should be noted that many of the radiological instruments and monitoring techniques typically used for applied health physics activities in an operating facility may not provide the detection sensitivities necessary to demonstrate compliance with the guideline levels for license termination. As described above, parameters which will determine the detection sensitivity of a system are background level, detection efficiency, measurement (or counting) time, and sample size or area.

The detection sensitivity for a given application can be improved, (i.e. lowered) by (1) selecting an instrument with a higher efficiency or a lower background; (2) increasing the counting time; (3) increasing chemical recovery; and (4) increasing the size of the sample or the effective probe area. Increasing efficiency, recovery, and sample or area size has the effect of lowering the MDA in direct proportion to the amount of change. For example, selecting a detector with twice the active probe area will decrease the MDA by a factor of 2 (assuming all other parameters remain unchanged). Changes in background rate or counting time a ~~e~~ffect the MDA proportional to the square root of the change. If, for example, the background rate is increased by a factor of two and all other parameters remain unchanged, the MDA will be increased by a factor of $\sqrt{2}$ or 1.414; doubling the counting time has the net effect of lowering the MDA by a factor of 1.414. Tables 5-4 through 5-6 provide information on the approximate detection sensitivities for some of the commonly used field survey instruments using nominal background levels and detection efficiencies as well as standard survey procedures. Information on detection sensitivities for laboratory procedures is provided in Section 7.0.

5.3 Instrument Selection and Use

Radiological conditions that should be determined for license termination purposes include total surface activities, removable surface activities, exposure rates, radionuclide concentrations in soil, and/or induced activity levels. To determine these conditions, field measurements and laboratory analyses may be necessary. For certain radionuclides or radionuclide mixtures both alpha and beta radiations may have to be measured. In addition to assessing the average radiological conditions, small areas with elevated levels of residual contamination should be identified and their extents and activities determined. With so many variable applications, it is highly unlikely that any single instrument (detector and readout combination) will be capable of adequately measuring all of the radiological parameters required to demonstrate that criteria for unrestricted release have been satisfied. It is usually necessary therefore to select multiple instruments to perform the variety of measurements required.

Selection of instruments will require an evaluation of a number of situations or conditions. Instruments must be stable and reliable under the environmental and physical conditions where they will be used, and their physical characteristics (size and weight) should be compatible with the intended application. The instrument must be able to detect the type of radiation of interest, and must, in relation to the survey or analytical technique, be capable of measuring levels which are less than the guideline values. There are numerous commercial firms, offering a wide variety of detectors, readout devices, and detector/readout systems, appropriate for measurements described in this Manual. These vendors can provide thorough information regarding capabilities, operating characteristics, limitations, etc. for specific equipment.

This Section provides assistance on selection of instrumentation for surveys associated with license termination. A flow chart (Figure 5-1) and checklist to assist the Manual user in the instrument selection process are included at the end of this Section.

This section describes the primary applications of instrumentation to field radiological measurements for license termination surveys. The reader should refer to Section 7.0 for information on laboratory applications.

TABLE 5-4

APPROXIMATE DETECTION SENSITIVITIES FOR ALPHA FIELD SURVEY INSTRUMENTATION

Detector Type	Readout Device	Technique	Approximate Detection Sensitivity
proportional; 50 cm^2 probe area	countrate meter	scanning - monitoring audible output	200 dpm/100 cm^2
	countrate meter	static count	150-200 dpm/100 cm^2
	digital scaler	static count (1 min)	100 dpm/100 cm^2
proportional; 500 cm^2 probe area	countrate meter	scanning - monitoring audible output	25-50 dpm/100 cm^2
scintillation; 50 cm^2 probe area	countrate meter	scanning - monitoring audible output	200 dpm/100 cm^2
	countrate meter	static count	150-200 dpm/100 cm^2
	digital scaler	static count (1 min)	100 dpm/100 cm^2

TABLE 5-5

APPROXIMATE DETECTION SENSITIVITIES FOR BETA FIELD SURVEY INSTRUMENTATION

Detector Type	Readout Device	Technique	Approximate Detection Sensitivity
proportional; 50 cm^2 probe area	countrate meter	scanning - monitoring audible output	1000-2000 dpm/100 cm^2
	countrate meter	static count	1000-1500 dpm/100 cm^2
	digital scaler	static count (1 min)	400- 600 dpm/100 cm^2
proportional; 500 cm^2 probe area	countrate meter	scanning - monitoring audible output	350- 700 dpm/100 cm^2
Geiger-Mueller; Pancake; 10 cm^2 probe area	countrate meter	scanning - monitoring audible output	2000-3000 dpm/100 cm^2
	countrate meter	static count	1500-3000 dpm/100 cm^2
	digital scaler	static count (1 min)	500-1000 dpm/100 cm^2

TABLE 5-6

APPROXIMATE DETECTION SENSITIVITIES FOR GAMMA FIELD SURVEY INSTRUMENTATION

Detector Type	Readout Device	Technique	Approximate Detection Sensitivity
Geiger-Mueller, 30 mg/cm^2, window tube	countrate meter	static count	50 $\mu R/h$
pressurized ionization chamber	digital display	static measurement	1 $\mu R/h$ (less if integration is used)
scintillation	countrate meter	static count	1 $\mu R/h$
	countrate meter	scanning - monitoring audible output	2-5 $\mu R/h$

When conducting a final status survey, two basic questions are to be answered:

(1) Is the average residual activity level below the established guideline value?

(2) Do small localized areas (elevated areas) of residual activity in excess of the average guideline value, satisfy the established conditions (Section 2.2)?

This latter issue is the one that experience has shown is often inadequately addressed. The reason is that these smaller areas of residual activity typically represent a very small portion of the site, and random or systematic measurements or sampling on the commonly used grid spacing has a very low probability of identifying such small areas. For this reason a survey technique called scanning is used to locate areas of activity that are above ambient or general site levels before actual measurements are conducted. This scanning technique should employ the most sensitive instrumentation available.

For gamma radiation scanning, a scintillation detector/countrate meter combination is the usual instrument of choice. A large-area proportional detector with a ratemeter is recommended for scanning for alpha and beta radiations where surface conditions and locations permit; otherwise an alpha scintillation or thin-window GM detector for beta may be used. When scanning, the detector is kept as close to the surface as possible (1 cm is a distance typically considered practical) and moved at a slow speed, noting any increases in radioactivity level by changes in the audible signal from the instruments headphones. Additional details on scanning procedures are provided in Sections 6.4.2 and 6.5.2.

For fixed measurements of radiation or radioactivity levels the recommended instruments are:

Alpha - Proportional detector or ZnS(Ag) scintillator with portable digital scaling meter.

Beta - Proportional detector or pancake GM detector with portable digital scaling meter.

Gamma- Pressurized ionization chamber (PIC) is preferred for exposure rate measurements if portability is not a concern. Otherwise, NaI(Tl) scintillation detectors with countrate meters, cross calibrated to a PIC or calibrated for the energy of interest.

Additional information on performing such measurements is presented in Sections 6.4.3 and 6.5.3.

There are certain radionuclides which, because of the types, energies, and abundances of their radiations, will be essentially impossible to measure at the guideline levels, under field conditions, using current state-of-the-art instrumentation and techniques. Examples of such radionuclides include very low energy, pure beta emitters such as H-3 and Ni-63 and low-energy gamma emitters such as Fe-55 and I-125. Pure alpha emitters dispersed in soil or covered with some absorbing layer will not be detectable because the alpha radiation will not penetrate through the media or covering to reach the detector. A common example of such a condition would be Pu-239 surface contamination, covered by paint, dust, oil, or moisture. In such circumstances sampling and laboratory analysis are used to measure the residual activity levels.

5.4 Instrument Calibration

Each instrument must be calibrated to enable the readout (usually in counts or counts per minute) to be converted to units in which the guideline levels are expressed. Calibrations should be traceable to National Institute of Standards and Technology (NIST) standards. In those cases where NIST-traceable standards are not available, standards of an industry-recognized organization (e.g., the New Brunswick Laboratory for various uranium standards) may be utilized. The instrument user may decide to perform calibrations, following industry-recognized procedures (ANSI 1978, NCRP 1978, NCRP 1985) or may choose to obtain calibration by an outside service, such as a major instrument manufacturer or one of the health physics services organizations.

Calibration for activity must be in terms of response to the 4π (total) emission rate from the source. Calibrations for point-source and large-area source geometries may differ and both may be necessary, if areas of activity smaller than the effective probe area and regions larger than the probe area are present. Many instruments will have responses which are dependent upon the energy of the radiation. This may be due to (1) the ability of the radiation to penetrate the outer surface of the detector, (2) intrinsic interaction probabilities for different energy regions, and (3) electronic instrument settings which accept or reject pulses representing selected radiation types and/or energies. Because of the variables involved, calibration should either be performed with the radionuclide of concern or appropriate correction factors developed for the different radionuclides present. In the case of energy-dependent gamma scintillation instruments which are commonly used to measure low-level gamma exposure rates, calibration for the gamma energy spectrum at a specific site may be accomplished by comparing the instrument response to that of a pressurized ionization chamber at different locations on the site. If the energy spectrum varies at different site locations, calibration factors may also vary; in such a case, a separate calibration is necessary for each such location.

It is recommended that field instruments be calibrated a minimum of semi-annually and following maintenance, which could affect calibration. Pressurized ionization chambers for gamma exposure rate measurement are calibrated every 2 years, as recommended by the manufacturer.

Periodic checks of instrument response are necessary to assure that the calibration and background have not changed. Following calibration, the background and response to a check source is determined and an acceptable range of levels established. For analog readout (countrate) instruments, a variation of $\pm$ 20% is usually considered acceptable. For instruments which integrate events and display the total on a digital readout, a series (10 or more is suggested) of repetitive measurements of background and check source response is performed, and the average and standard deviation of those measurements are determined. An acceptable response range of the average $\pm 2\sigma$ or 3σ is then established.

Instrument response (background and check source) is tested and recorded a minimum of once daily — typically prior to beginning the days measurements — to assure continued acceptable operation. If the instrument response does not satisfy the established acceptable range, the instrument is removed from use until the reason for the deviation can be determined and resolved and acceptable response again demonstrated. If repair and/or recalibration is necessary, acceptable response ranges must be reestablished and documented.

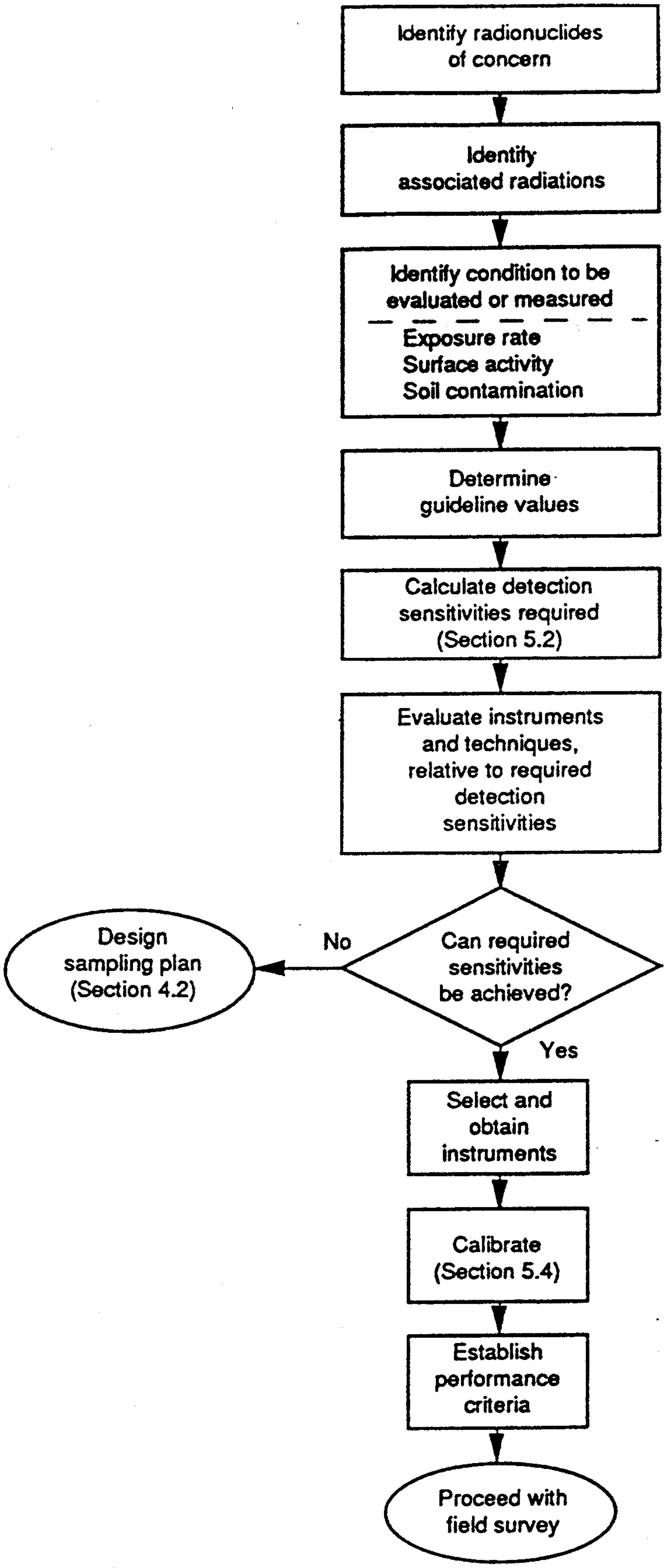

FIGURE 5-1: Flow Diagram for Selection of Field Survey Instrumentation

CHECKLIST FOR FIELD INSTRUMENT SELECTION

____ 1. Identify principle radionuclides of concern.

____ 2. Determine radiations (alpha, beta, gamma) associated with potential contaminants.

____ 3. Identify category of potential contamination (soil, building surfaces, piping and other inaccessible interior surfaces, activated components).

____ 4. Determine types of direct measurement radiological data to be collected (scans for general conditions and identification of elevated activity levels, building surface activity levels, exposure rates).

____ 5. Establish guideline values for each radionuclide and category of contamination. Develop site-specific guideline values as appropriate.

____ 6. Calculate desired detection sensitivities of measurements.

____ 7. Select instrument and survey techniques to achieve desired detection sensitivities.

____ 8. Calibrate measurement systems.

____ 9. Determine MDA for each instrument/technique sytem.