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Manual for Conducting Radiological Surveys in Support of License Termination

Draft Report for Comment

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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

This document describes a process for conducting radiological surveys during decommissioning, to demonstrate that residual radioactive material satisfies criteria established by the U.S. Nuclear Regulatory Commission (NRC) for termination of a license. The Manual describes procedures for design and conduct of surveys in a manner which will provide a high degree of assurance that NRC guidelines and conditions have been satisfied. The manual also describes methods for documenting the survey findings in a final report to the NRC. This Manual updates information contained in NUREG/CR-2082, *Monitoring for Compliance With Decommissioning Termination Survey Criteria*, (ORNL 1981). It incorporates statistical approaches to survey design and data interpretation used by the Environmental Protection Agency for evaluation of hazardous materials sites under Superfund (CERCLA). Quality assurance is emphasized throughout.

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1.0 INTRODUCTION

Sites that use radioactive material for any activity — manufacturing, research and development, education and training, or power production — all face the same eventuality:

- That activity will one day be concluded, and

- Precautions must be taken to ensure that future occupants and the environment are not subjected to unacceptable risks from residual radioactivity.

Many operations which have the potential to pose radiological risks are licensed by the U.S. Nuclear Regulatory Commission (NRC). As part of its regulatory responsibilities, the NRC has also established requirements for ceasing operations, removing residual radioactivity, and terminating the license. This process is known as **decommissioning**. Generally, in order for a license to be terminated the residual radioactivity must satisfy criteria which the NRC has determined to be environmentally acceptable. These criteria, known as **release criteria**, include numerical guideline levels for direct radiation radioactivity in soil and on surfaces and a set of conditions for applicaton of the guidelines. If the residual activity concentrations and amounts are below the release criteria, a site is considered acceptable for **unrestricted use**, i.e. without need for future radiological controls. The release criteria NRC has been using for license termination include those found in the following:

- Regulatory Guide 1.86, *Termination of Operating Licenses for Nuclear Reactors* (NRC 1974),

- *Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Materials* (NRC 1987), Office of Nuclear Material Safety and Safeguards (NMSS), and

- *Branch Technical Position for Disposal or Onsite Storage of Thorium or Uranium Water from Past Operations* (46 FR 52061, October 23, 1981).

A site or facility is considered to be **contaminated**, when the radioactivity levels exceed the established release criteria. Usually, a site ceasing licensed operations can be adequately **decontaminated**, or **remediated**, i.e. the residual contamination reduced to acceptable levels for unrestricted release. However, some situations are encountered where decontamination to release criteria is not practical (for example, where the quantity of contaminated material is extremely large). In these cases, an alternative method of closure will be developed. An example of such a case is the cleanup of uranium mill tailings by stabilizing them in an engineered containment cell.

Over the years, many licensed sites used as facilities have been decommissioned. Occasionally, however, follow-up surveys have revealed residual radioactive contamination at levels exceeding the release criteria. This condition was usually attributed to an inadequate final radiological survey; problems primarily resulted because:

- Contaminated portions of the site were not all adequately surveyed, and/or
- Survey equipment and techniques were either inappropriate or were not sufficiently sensitive to measure specific potential contaminants at the levels established for release.

In addition, documentation was often incomplete, preventing independent assessment of conditions. The need for more detailed instructions for both performing and documenting a final survey in support of license termination became apparent.

1.1 Purpose

This Manual, contains procedures for conducting radiological surveys during decommissioning, to demonstrate that residual radioactive material satisfies release criteria. The purpose of this Manual is to assist the licensee in:

- Designing and conducting radiological surveys in a manner which will provide a high degree of assurance that NRC criteria have been satisfied, and
- Documenting the survey findings in a final survey report to NRC.

This Manual updates information contained in NUREG/CR-2082, *Monitoring for Compliance With Decommissioning Termination Survey Criteria*, (ORNL 1981). It incorporates statistical approaches to survey design and data interpretation, used by the Environmental Protection Agency for evaluation of hazardous materials sites under Superfund (CERCLA). Quality assurance is emphasized throughout. Survey methodologies described in the Manual utilize state-of-the-art, commercially available instrumentation and procedures for conducting radiological surveys for decommissioning purposes.

Although this Manual is written primarily to assist the licensee in conducting radiological surveys for decommissioning purposes, its principles and methodologies will be useful for conducting other types of radiological surveys performed by licensees, NRC inspectors, and their contractors. It may also be useful for advanced planning by current nuclear facility operators or by those in the process of bringing a new facility on line. Surveys for certain purposes, however, such as providing radiological control in an operating facility; determining suitability for release or recycle of contaminated material; and designing decontamination or remedial actions plans, are outside the scope of this document.

1.2 Using This Manual

This Manual is intended to provide instructions for performing survey procedures that will generate sound data to support a facility's license termination application. It has been assumed that the user possesses a basic knowledge of radiation terms and fundamentals because, without such a background, authorization to possess and use radioactive material would not have been granted by the NRC. The Manual could not presume to anticipate all the possible combinations of operational, geological, financial, and personnel constraints that may affect each site's decommissioning process. Nevertheless, the basic steps that are required for decommissioning, regardless of the complexity of the facility, are outlined in the Manual (Section 2.0), and survey activities related to those various decommissioning steps are described.

The sections in the Manual are modular, and each module contains information related to a particular aspect of the surveys in support of the license termination process. While this modular approach creates some redundancy in information, it should allow each reader to concentrate only on those portions of the Manual that apply to his or her responsibilities. In addition, since the procedures within each module are listed in order of performance, options are provided to guide the user past portions of the Manual that may not be specifically applicable to his/her particular situation. Where appropriate, checklists, which condense and summarize each major point in the procedure, are provided. These checklists may be used to verify that all suggested procedures were followed or used to flag a condition where documentation would be required to explain why that step was unnecessary.

Examples of calculations are included to assist the user in application of the various mathematical formulae. A glossary of terms used in this Manual is provided in Section 12.0. Finally, a sample survey plan and a sample final survey report for a hypothetical reference uranium fuel fabrication facility, based on the methodologies and procedures presented in this Manual, are provided as Appendices C and D, respectively.

Throughout the manual, specific parameter values (e.g. grid sizes) are specified for use when conducting and documenting surveys. This is done to encourage standardization to the extent practicable and to facilitate evaluation of survey results. Where the parameter used is critical to the quality of the survey or is specified to ensure a minimum level of statistical accuracy, this is so stated. However, in many cases parameter values were selected either because they have become standard practice over the years and there appears to be no compelling reason to change them, or because the authors have found them to be practical, based on extensive field experience in conducting and documenting these types of surveys. Users are encouraged to comment on the usefulness of parameter values in this draft manual and to suggest alternatives.

2.0 THE DECOMMISSIONING PROCESS

2.1 General

Decommissioning is an interactive process between the NRC and the licensee leading to the termination of a facility license and release of the facility for unrestricted use. This process may be simple or complex, depending upon the composite topography (the type and number of buildings, the amount of open or paved ground, or the combination of the two); the type of facility and its general use; the type and variety of radionuclides used in its processes and operations; and the extent to which the facility may have become contaminated. These same factors also affect the complexity of radiological surveys required to provide the necessary information to eventually demonstrate that residual radioactivity levels satisfy the criteria for license termination. The decommissioning process and the relationship of radiological surveys to that process are illustrated in flow chart format in Figure 2-1. This Manual is intended to assist the user in design and performance of surveys required for decommissioning, regardless of the level of complexity.

Responsibilities of the licensee are detailed in regulations concerning byproduct, source, and special nuclear materials as set forth in Title 10 of the Code of Federal Regulations (10 CFR); Parts 30.36 for byproduct material, 40.42 for source material, 50.82 for reactors, 70.38 for special nuclear material, and 72.54 for spent fuel and high-level waste storage facilities. These regulations provide that if a licensee does not renew a license, that licensee shall, on or before the expiration date of the license, perform the activities required for decommissioning a nuclear facility. The licensee must request in writing that the license be terminated. In most cases, this request must also be accompanied by a written decommissioning plan (see applicable 10 CFR section for conditions that may provide for alternative actions). The licensee then:

- Terminates the use of the licensed material,
- Removes radioactive contamination from the facility to the extent practicable,
- Properly disposes of any radioactive material removed,

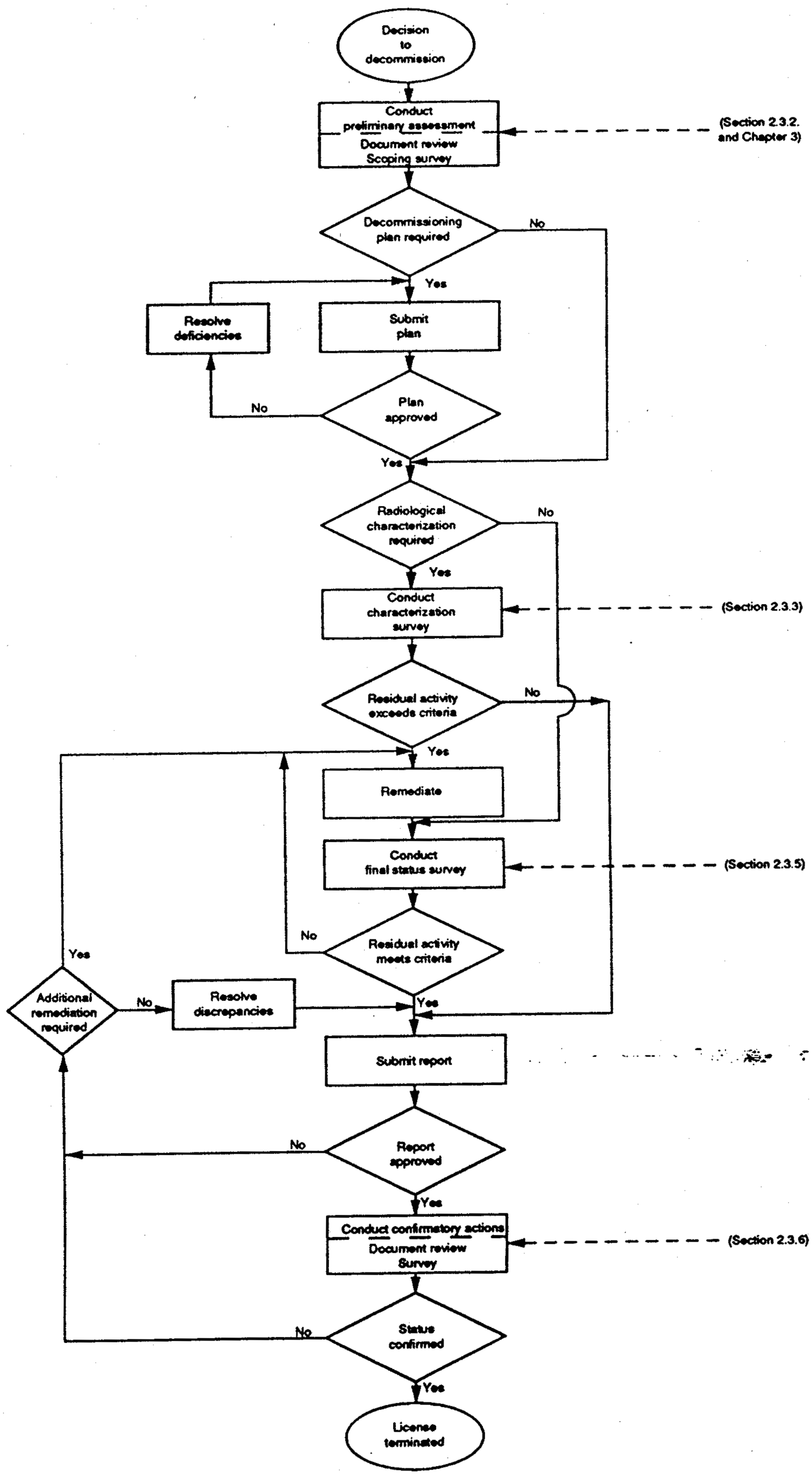


FIGURE 2-1: Flow Diagram Illustrating General Decommissioning Process

- Submits a report form NRC-314, which certifies information concerning the disposition of licensed materials,

- Conducts a radiation survey and/or evaluation of the premises where licensed activities were carried out, and

- Submits to the NRC a report of the final survey or other information to sufficiently demonstrate that the premises are suitable for release for unrestricted use.

The NRC reviews and evaluates the information provided by the licensee; performs independent confirmation of site conditions, as appropriate; and makes a determination on termination of the license.

2.2 Decommissioning Criteria and Guidelines

The ultimate goal of the decommissioning process is to assure that future uses of any licensed facility will not result in individuals being exposed to unacceptable levels of radiation and/or radioactive materials. The NRC establishes the acceptable radiation dose to a potentially exposed individual, based on considerations of risk and scientific data relating dose to risk. (For the purpose of this Manual, the terms dose and radiation dose refer to total effective dose equivalent.) Residual levels of radioactive material that could be present and still assure that an individual would not exceed that acceptable radiation dose are then calculated by the analyses of various pathways and scenarios (direct radiation, inhalation, ingestion, etc.) through which exposure could occur. These derived levels, known as guideline values, **release guidelines**, or simply, **guidelines**, are presented in terms of direct radiation levels, surface activity levels, volume concentrations of radioactive material in soil and building materials, and site inventory limits. These guideline values refer to radiation and radioactivity above normal background levels. Guidelines for direct radiation levels are expressed in units of exposure rate, i.e. microroentgens per hour (μR/h). Surface activity guideline values, applicable to building or equipment surfaces, are expressed in units of activity per surface area [typically disintegrations per minute per 100 cm^2 (dpm/100 cm^2)]. Volume concentration guideline values, which apply to soil, induced activity, and debris, are expressed in terms of activity per unit mass [typically, picocuries per gram (pCi/g)]. Site inventory limit refers to the total quantity of residual radioactive material from formerly licensed operations, permitted to remain on the site following decommissioning; this value is expressed in units of activity, i.e. microcuries (μCi) or millicuries (mCi). The guideline value for direct radiation is not a function of the source of the radiation, i.e., it is independent of the specific radionuclide or its chemical/physical form. However, because of differences in environmental behavior and associated radiation doses through other exposure pathways, the guideline values for surface activity, volume concentration, and site inventory will depend upon the specific radionuclide or radionuclides present. If more than one radionuclide is present, the individual contributions from each radionuclide are limited, such that the sum of the radiation doses from all sources does not, over time, exceed the established acceptable dose.

This Manual assumes the following conditions for application of guideline values to decommissioning.

Surface Activity

Average surface activity levels (total of fixed and removable activity) are at or below guideline values established as acceptable by NRC.

- Reasonable efforts have been made to identify, evaluate, and remove, if necessary, areas of residual activity exceeding the guideline values. Small areas of residual activity exceeding the guideline value, known as **elevated areas**, may be acceptable to the NRC. This Manual assumes that activity levels of elevated areas, less than three times the guideline values when averaged over a surface region of 100 cm^2, are acceptable, provided the average level within a 1 m^2 area containing the elevated area is within the guideline value.

- Reasonable efforts have been made to clean up removable activity and removable activity in any 100 cm^2 area does not exceed 20% of the average surface activity guideline values.

Soil Activity

- Average radionuclide concentrations are at or below guideline values, established as acceptable by the NRC. For your land areas, averaging is based on a 100 m^2 (10 m x 10 m) grid area.

- Reasonable efforts have been made to identify, evaluate, and remove, if necessary, areas of residual activity exceeding the guideline values. This Manual assumes that areas of residual activity exceeding the guideline value, known as elevated areas, are acceptable, provided they do not exceed the guideline value by greater than a factor of $(100/A)^{1/2}$, where A is the area of residual activity in m^2, and provided the activity level at any location does not exceed three times the guideline value.

Exposure Rate

- Exposure rates do not exceed background levels by greater than the exposure rate limit, at 1 m from the surface. In occupiable building locations, exposure rates are measured at 1 m from floor/lower wall surfaces and may be averaged over floor areas, not to exceed the size of a small office (i.e., about 10 m^2.) For open land areas, exposure rates are measured at 1 m above the surface and may be averaged over 100 m^2 grid areas. This Manual assumes that maximum exposure rates over any discrete area may not exceed two times the limit, above background.

The objective of the survey, as presented in this Manual, is to demonstrate at a 95% (minimum) level of confidence, that the above conditions have been met. For the purpose of this demonstration, each survey unit (Section 4.2.2) is independently evaluated.

Finally, the total inventory of residual radioactive material from licensed operations may require calculation. It is assumed that this calculation will include surface activity, activity in surface and subsurface soil, activity induced in building materials and components, and activity that may remain from previous onsite disposals.

2.3 Radiological Surveys Supporting Decommissioning

Several different surveys may be required as part of the decommissioning process. Since each is intended to provide radiological data for different primary applications or objectives, the survey techniques, thoroughness, data accuracy, and documentation requirements may vary. This section identifies and briefly describes the types of radiological surveys. Additional details on conducting surveys are provided in Section 6.0.

The major steps in the decommissioning process are sequential and each step builds on information gathered from earlier activities. Although the various surveys may appear to be independent, survey results may, in practice, serve multiple purposes. For example, survey measurements obtained during the scoping phase or the characterization phase, may be useable in describing the final site conditions, if the location where those measurements were performed has not experienced subsequent activities which may have altered the radiological status. Conversely, data obtained following remedial action may, if they indicate residual contamination, serve as characterization information to guide further cleanup. Survey activities should be planned to enable optimum use of the data, thereby reducing the level of survey effort associated with a decommissioning project. Such planning should consider the accuracy and specificity of measurements, relative to time constraints and cost, at each stage of the survey.

2.3.1 Background Survey

Because guidelines for residual radioactivity at decommissioned sites are presented in terms of radiation levels or activity levels above normal background for the area or facility, it will also be necessary to perform a **background survey**. This survey will require measuring both direct radiation levels (usually gamma exposure rates) and concentrations of the potential radionuclide contaminants in construction materials and in soil (and sometimes in groundwater) in the vicinity of the site. Where only gamma emitting contaminants are present and soils are not affected, it may be adequate to perform only background exposure rate determinations. It is useful to perform such a survey prior to commencing licensed operations; such surveys may be part of the environmental baseline surveys required at some of the more complex types of facilities. If such information is already available, it may be used. Otherwise, a survey to establish background will have to be conducted.

Background is determined by measurements and/or sampling at locations on site or in the immediate vicinity of the site (out to several kilometers from the site boundary), which are unaffected by site operations. Preferable locations for interior background determinations are within on-site buildings of similar construction, but having no history of licensed operations. Background direct radiation levels within buildings may differ from those in open land areas, because of the presence of naturally occurring radioactive materials in construction materials and the shielding effect that construction materials may also provide. Background samples and measurements for land areas should be collected at locations which are unaffected by effluent releases (upwind and upstream) and other site operations (upgradient from disposal areas). Locations of potential runoff from areas of surface contamination should also be avoided. Other locations which may have been affected or disturbed by non-site activities and should be avoided include waste management areas and their drainage pathways; roads, parking lots, and other large paved surfaces; storm drains and ditches, receiving industrial or agricultural runoff; railroad tracks; material handling areas such as truck and rail loading facilities; and fill areas.

Because the background levels will be subtracted from total radiation or radioactivity levels to determine the net residual activity from licensed operations, it is necessary that backgrounds be determined with a detection sensitivity and accuracy at least equivalent to data from which it will be subtracted. This can be achieved by using the same instruments and techniques for background surveys as are used in assessing final site conditions.

The degree to which the average background of a particular radiological parameter, determined for a specific site, is representative of the true background level is a factor in determining the number of background measurements required for that determination. Many radionuclides are not present in the environment at levels which are sufficient to be either quantifiable using reasonable, standard measurement techniques or which are significant, relative to the guideline values for unrestricted release. On the other hand, levels of direct radiation (exposure rates) and some naturally occurring (uranium and thorium decay series) or man-made (Cs-137) radionuclides are typically present in the environment at levels which are easily quantifiable and may have background levels which are significant, relative to guideline values. Experience has indicated the variance in the average background value from a set of 6 to 10 measurements will usually not exceed $\pm$ 40% to 60% of the average at the 95% confidence level. However, localized geologic formations, different types of soil, and construction materials at the background measurement locations may result in individual background values which have greater variability. Consequently, additional measurements and samples may be required to assure a representative average value.

For practical purposes, it is recommended that 6 to 10 measurements for each parameter of concern be initially performed and the average and 95% confidence level be determined. If the upper 95% level bound on the background average is less than 10% of the guideline value for that parameter, variations in background may be considered insignificant and no further determination are necessary. However, if the upper 95% level bound on the background average is greater than 10% of the guideline value, the background data should be tested to assure that the average represents the true mean to within $\pm$ 20% at the 95% confidence level. If necessary, additional background determinations should be performed to satisfy this level of representativeness. The procedure for testing the data and determining the number of additional samples needed is described in Section 8.7.

2.3.2 Scoping Survey

Early in the decommissioning process, it will be necessary to identify the potential radionuclide contaminants at the site; the relative ratios of these nuclides; and the general extent of contamination (if any) — both in activity levels and affected area or volume. Although the license and operational history documentation will assist to varying degrees in providing this information, it will usually be necessary to supplement that information with actual survey data. A scoping survey is therefore performed. The scoping survey typically consists of limited direct measurements (exposure rates and surface activity levels) and samples (smears, soil, water, and material with induced activity), obtained from site locations considered to be the most likely to contain residual activity, and from other site locations both immediately adjacent to the radioactive materials use areas and in areas not expected to have been affected by the site operations. This survey provides a preliminary assessment of site conditions, relative to guideline values, and enables initial guidance in classification of the site into "affected" and "unaffected" areas (see Section 4.2.1 for further information on classification of areas by contamination potential). The scoping survey provides the basis for initial estimates of the level of effort required for decommissioning and for planning the characterization survey.

Measurements and sampling in known areas of residual contamination need not be as comprehensive or be performed to the same sensitivity level as will be required for the characterization or final status surveys. However, when planning and conducting this scoping survey, the licensee should remember that some of the data, particularly that from locations not affected by site operations, may be used as final status results or to supplement the characterization and/or final survey results. Similar measuring and sampling techniques as used for those categories of surveys may, therefore, be warranted.

2.3.3 Characterization Survey

After locations which may require decontamination have been identified, a **characterization survey** is performed to more precisely define the extent and magnitude of contamination. The characterization survey should be in sufficient detail to provide data for planning the decontamination effort, including the decontamination techniques, schedules, costs, and waste volumes and necessary health and safety considerations during decontamination. Characterization is typically concentrated on those portions of the site which are known to have been or are suspected of having been affected by site operations involving radioactive materials. The type of information obtained from a characterization survey is often limited to that necessary to differentiate a surface or area as contaminated or non-contaminated. A high degree of accuracy may not be required for such a decision, when the data indicate levels well above the guidelines. On the other hand, when data are near the guideline values, a higher degree of accuracy is usually necessary to assure the appropriate decision regarding the true radiological conditions. Also, one category of radiological data, such as soil radionuclide concentration or total surface activity, may be sufficient to determine the status as contaminated, and other measurements, e.g. exposure rates or removable contamination levels, may therefore not be performed during characterization.

As was the situation with the scoping survey, the choice of survey technique should be commensurate with the intended use of the data, including considerations for possible future use of the results to supplement the final status survey data.

2.3.4 Remediation Control Survey

The effectiveness of decontamination efforts in reducing residual radioactivity to acceptable levels is monitored as the decontamination is in progress by a **remediation control survey**. This type of survey activity guides the cleanup in a real-time mode; it also assures that remediation workers, the public, and the environment are adequately protected against exposures to radiation and radioactive materials arising from the decontamination activities. The remediation control survey typically provides a simple radiological parameter, such as direct radiation near the surface being decontaminated. The level of radiation, below which there is reasonable assurance that the guideline values have been attained, is determined and used for immediate, in-field decisions. Such a survey is intended for expediency and does not provide thorough or accurate data describing the final radiological status of the site. The remediation control survey is applicable to monitoring of surfaces and soils or other bulk materials only if the radionuclides of concern are detectable by field survey techniques. For radionuclides and media which cannot be evaluated at guideline values by field procedures, samples are be collected and analyzed to evaluate effectiveness of decontamination efforts. For large projects, use of mobile field laboratories can provide more timely decisions regarding the effectiveness of remedial actions. Examples of situations for which remediations control surveys would not be practicable are soil contaminated with pure alpha or beta emitting radionuclides and surfaces with very low energy beta contamination such as H-3.

2.3.5 Final Status Survey

A survey to determine the final condition of the site is performed after decontamination activities (if any were required), are complete. This survey is known by several titles, including **termination survey, post remedial-action survey, final status survey** and **final survey**. The term final status survey is used in this Manual. It is this survey which provides data to demonstrate that all radiological parameters (total surface activity, removable surface activity, exposure rate, and radionuclide concentrations in soil and other bulk materials) satisfy the established guideline values and conditions. Results of the survey are documented in a detailed report, which becomes part of the licensee's application to terminate a license and thereby release the facility for unrestricted use. This type of survey is the principal focus of this Manual.

Although the final status survey is discussed here as if it were an activity performed at a single specified stage of the documenting process, this may not be the case. Data from surveys conducted at other stages of the decommissioning, such as the scoping survey and characterization survey, can, under proper conditions, be incorporated into the final status survey.

2.3.6 Confirmatory Survey

After acceptance of the licensee's termination survey report, the NRC may perform (or arrange for its agent to perform) a confirmatory survey. As the name implies, a **confirmatory survey** is performed to confirm the adequacy and accuracy of the licensee's final status survey. The confirmatory survey develops radiological data of the same type as that presented by the licensee, but is usually limited in scope to spot-checking conditions at selected site locations, comparing findings with those of the licensee, and performing independent statistical evaluations of the data developed by the confirmatory survey and the licensee's final status survey. Although the scope may vary, a confirmatory survey typically addresses from 1 to 10% of the site, but may be extended, if questions or anomalies develop or are identified. The NRC uses the report of this survey in supporting a decision on the licensee's application to terminate a license and release the facility for unrestricted use.

3.0 ASSESSING THE RADIOLOGICAL STATUS OF THE SITE

The initial step in the decommissioning process is a preliminary assessment of the radiological status of the site. This assessment consists of:

- Identifying potential residual radioactive materials,
- Establishing the applicable release criteria,
- Determining the general locations and extent of activity, and
- Estimating the levels of activity.

Information from this assessment provides the basis for the licensee's decommissioning plan and the design for subsequent radiological surveys. This section describes the scoping of the site status. A flow diagram (Figure 3-1) and a checklist to assist the user in this assessment are included at the end of the section.

3.1 Document and History Review

The starting point in this assessment is a review of the site license and supporting or associated documentation, e.g. license conditions, license amendment applications, inspection records, material acquisition and disposal records, site maps and facility drawings, process flow charts, etc. These documents will specify quantities and chemical and physical forms of radioactive material authorized for possession, operations for which the materials could be used, locations of these operations at the site, and total quantities of material used at the site during its operating lifetime. Such records must be maintained by licensees, per provisions of 10 CFR 30.35 (g) 40.36 (f), and 70.25 (g), until the license is terminated by the NRC. Operating records will provide information on spills, fires or other incidents that may have resulted in the release or spread of radioactive contamination.

These records may also include previous radiological surveys, which will assist in identifying potentially contaminated areas. Records should also identify the locations of potential subsurface radioactivity from former waste processing and disposal operations which may have been conducted in accordance with previous provisions of 10 CFR 20.302 and 10 CFR 20.304.

Information concerning past site activities and potential residual activity beyond expected locations is often available from unofficial sources, such as interviews with senior or former employees and area residents, old photographs, and local newspaper articles. Ingenuity will be required in identifying such sources and extracting and evaluating the information obtained.

Sometimes facilities, particularly those that used radioactive materials prior to the advent of the Atomic Energy Commission licensing, have residual material on site from prior, unlicensed operations. In these cases, records may be sketchy or non-existent, but knowledge of the general type of operations at that site will assist in determining the radionuclides which would most likely be present.

3.2 Identifying Potential Contaminants

After the radioactive materials that were used at the site have been identified, the potential for residual contamination by these materials is evaluated. Site operations greatly influence the potential for residual contamination. An operation which only handled encapsulated sources, for example, would be expected to have a low potential for contamination, assuming that the integrity of the sources was not compromised. A review of leak-test records for such sources may be adequate to dispel concern for residual contamination. A chemical manufacturing process facility would likely have contaminated piping, ductwork, and process areas, with soil/land area contamination limited to locations where spills or leaks may have occurred. Sites using large quantities of radioactive ores and those with outside waste collection and treatment systems are more likely to have contaminated grounds. If loose, dispersible materials were stored outside or process ventilation systems were poorly controlled, then windblown surface contamination may be possible.

Consideration should be given to the amount of time that has passed since the site was in operation. Radionuclides with short half-lives may no longer be present in significant quantities, if enough time has elapsed since the site discontinued operations to allow for radioactive decay. In this case, calculations to prove that residual activity could not exceed guideline values may suffice, and surveys may not be required to demonstrate the site's radiological status, relative to license termination criteria. On the other hand, certain radionuclides, such as Th-232, may experience significant daughter product ingrowth, which must be considered in evaluating the potential residual contaminants at the time of decommissioning.

3.3 Identifying Potentially Contaminated Locations

Using information gathered from document and site history reviews and evaluation of potential contaminants, locations of likely residual contamination are identified. Such locations will include facilities or areas where radioactive materials were processed; where wastes were handled, stored, or disposed of; and where spills, fires, or other incidents occurred which may have released or spread contamination. These locations will be the principal targets for the scoping survey.

3.4 Performing the Scoping Survey

The scoping survey is performed to substantiate and, where necessary, better define the identity of potential radioactive contaminants and the general extent of residual activity. Based on the anticipated radionuclides, appropriate survey instruments are selected (refer to Section 5.0), and cursory measurements are conducted in suspect locations. These measurements typically consist of surface **scanning** (moving the detector at a consistent speed and distance near the surface) and measuring levels of direct radiation (surface activity and exposure rate) at representative points. Samples of surface soil and residues from surfaces, cracks, pipes, ducts, and other areas where contaminated material may have accumulated are collected and analyzed (refer to Section 7.0) for specific radionuclides. Bear in mind that these survey activities are more of a screening nature and are not intended to be as comprehensive or stringent as those required to demonstrate that final site conditions satisfy the release criteria. Results can, however, be utilized as valid data to supplement the final status survey reports, if appropriate procedures are followed and the subsequent decommissioning activities have not altered the survey location.

One of the most difficult situations to evaluate is the presence of buried materials or possible subsurface contamination. Such subsurface material is usually covered by several feet of soil and the surface may be paved over or may be the site of a building. Such conditions prevent detection of the residual activity by surface surveys only. Methods, such as ground penetrating radar or electromagnetic measurements,to identify subsurface anomalies or disturbances, are used. Subsurface sampling can also be performed. These procedures are, however, usually beyond the scope of the scoping survey; such information is typically collected during the characterization and/or final status survey.

3.5 Establishing Site Guideline Values

Evaluation of license and document review and analyses of samples from the scoping survey are used to identify the residual radionuclides at the site. If a single radioactive material or a combination of radioactive materials with the same guideline values were used at the site, the guidelines can then be selected from tables developed by the NRC. In many cases, however, multiple radionuclides with different guideline values are present at the site; site-specific guidelines should then be established. The procedure for determining site-specific guideline values is described in Appendix A.

3.6 Comparison of Radiological Conditions with Guideline Values

Scoping survey results are compared with the site guideline values, and locations of contamination, if any, are identified. Findings of the assessment, describing the review and evaluation of pertinent documents and results of the scoping survey are documented for submission to the NRC. If, based on the radionuclides used and activities conducted, it can be demonstrated that residual contamination would not be possible, the NRC may determine that no further actions by the licensee are necessary. If residual contamination is possible, but no conditions exceeding guidelines have been identified, plans for conducting additional surveys to demonstrate that the final site status satisfied release criteria should be developed. If residual site contamination is identified, the licensee should develop and submit plans for characterizing and remediating contaminated locations and for conducting surveys to demonstrate that the final site status meets the guideline values and conditions.

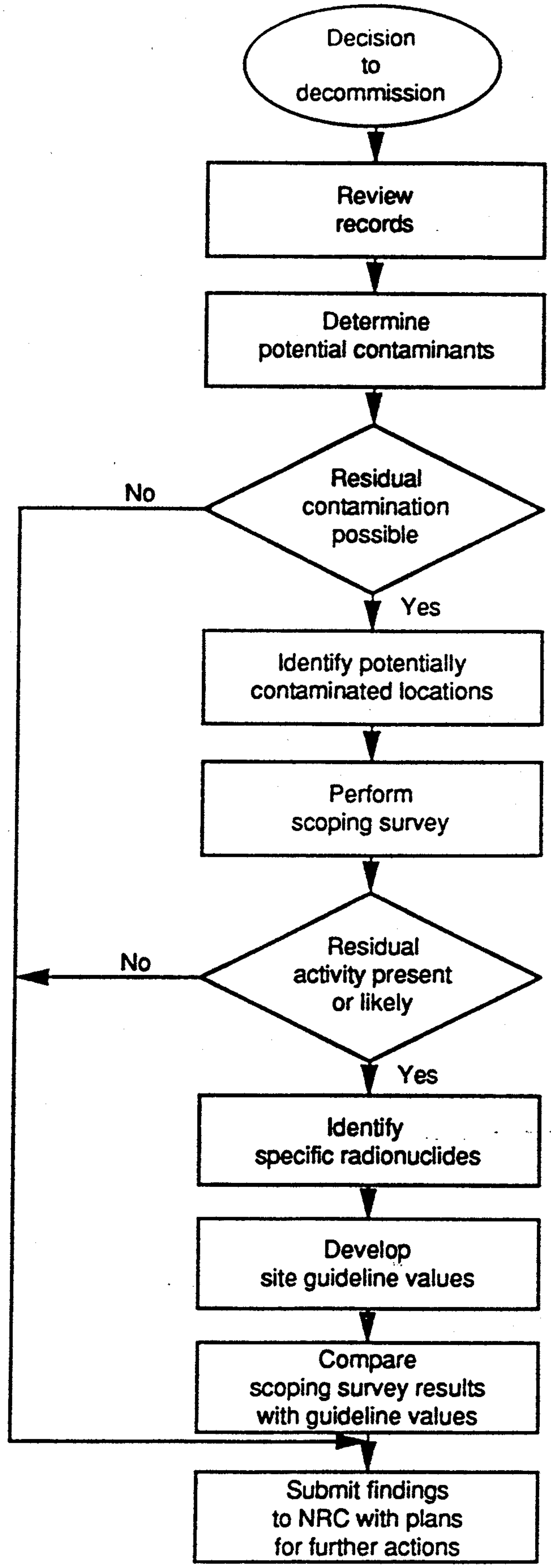


FIGURE 3-1: Flow Diagram for Assessing Site Status

Checklist for Conducting Assessment of Site Radiological Status

_____ 1. Review license operating records, documentation supporting license ammendment applications, and other pertinent documents.

_____ 2. Discuss site history with senior and former employees and others who may have information on past operations.

_____ 3. Identify radionuclides used.

_____ 4. Determine which radionuclides could be site contaminants.

_____ 5. Identify locations of likely residual activity.

_____ 6. Perform scoping survey.

_____ 7. Identify specific radionuclides at site.

_____ 8. Establish guideline values; develop site-specific guidelines if applicable.

_____ 9. Compare scoping survey findings with guideline values.

_____ 10. Prepare report to NRC identifying locations of contamination (if any) and describing plans for decontamination and/or further survey actions.

4.0 Planning and Designing the Final Status Survey

The purpose of the final status survey is to demonstrate that the release criteria established by the NRC have been met. Demonstrating that this has been achieved requires collection of data for determining surface activity levels, direct exposure rates, and radionuclide concentrations in soil. In addition, supplemental information, such as radionuclide concentrations in ground water and total site inventory of radioactive material, may be required by the NRC. The data should be accurate and reliable and should be adequate to satisfy other conditions and considerations which the NRC may impose. A well-documented, statistically based survey plan will be the basis for meeting these objectives.

The survey plan should describe the survey design in detail. The plan should include:

- A list of the types, numbers, and locations of measurements and samples to be obtained;
- Information on the equipment and techniques to be used for measuring, sampling, and analyzing data;
- The methods to be used to interpret and evaluate the survey data; and;
- Quality control procedures for ensuring the validity of the data.

This section discusses considerations for developing such a plan, including quality control procedures, and site information required to plan and design the survey. This section also describes how to select measurement/sampling locations and to determine the sampling frequency that will be required to assure the statistical significance of the data. A general flow chart for a radiological survey supporting license termination is provided in Figure 4-6; detailed flow charts for various activities related to the survey process are provided in Section 6.0. Appendix B provides a sample survey plan for a hypothetical reference fuel fabrication facility.

4.1 General Considerations for Survey Planning

4.1.1 Quality Assurance

Because the purpose of the final status survey is to demonstrate that a facility meets the established release criteria, the survey should be performed in a manner that assures the results are accurate and that uncertainties have been adequately considered. An effective QA program will define the data quality objectives of the survey and thereby determine, to a significant extent, the survey design. This program will operate in all stages of the survey through final validation of the data and the interpretation of the results.

The consensus nuclear industry standard for quality assurance is ANSI/ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities (ANSI 1989). The NRC has also issued guidance for an acceptable QA program in Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Program — Effluent Streams and the Environment (NRC 1979). A quality assurance program, consistent with the information contained in these documents, should be developed.

Surveys should be performed by trained individuals who are following standard, written procedures, and are using properly calibrated instruments which are sensitive to the suspected contaminant. The custody of samples should be tracked from collection to analysis. Data should be recorded in an orderly and verifiable way and reviewed for accuracy and consistency. Every step of the decommissioning process, from training personnel to calculating and interpreting the data, should be documented in a way that lends itself to audit. These requirements are achieved through a formal program of quality assurance. Failure to follow such requirements may limit the usefulness of portions of the survey data.

<u>QA Plans</u>

The decommissioning plan should include a written QA plan that describes the organizational structure under which the decommissioning efforts — and particularly the final status survey — will be conducted. Functional and administrative responsibilities and interfaces of key individuals should be clearly delineated. Education, experience, and any other requirements for each key position should be specified. The size and complexity of the organizational structure will be determined by the magnitude of the decommissioning action.

QA Coordination

One individual should be designated as the QA officer or QA coordinator. This individual should not be involved in survey activities that generate data and should report directly to the project manager. The QA officer/coordinator should be responsible for ensuring that all QA objectives of the survey are met, should review selected field and analytical data to ensure adherence to procedures, and should approve the quality of data before it us used to test hypotheses regarding attainment of cleanup standards. Specifically, this individual:

- Serves as the focal point for survey QA activities and ensures that they are conducted in accordance with established policies and procedures

- Oversees survey activities by conducting internal audits and/or surveillance.

Documentation Requirements

All aspects of the survey should be documented in detail. For certain field or laboratory activities, consensus or industry-wide procedures, such as those developed by the Environmental Protection Agency (EPA), American Society of Testing and Materials (ASTM), DOE's Environmental Measurements Laboratory (EML), or other such organizations may be either adopted in whole or adapted to meet the requirements of the specific decommissioning action. These procedures become part of the administrative record of the survey. The procedures should be approved by the individual responsible for the decommissioning project and the effective date of the procedure should be indicated. Changes or exceptions to established procedures are likely to be required; and these also should be properly documented, signed, and dated.

Training/Certification of Survey Staff

All personnel conducting the surveys should receive training to qualify in the procedures being performed. The extent of training and qualifications should be commensurate with the education, experience, and proficiency of the individual and the scope, complexity, and nature of the activity. Training should be designed to achieve initial proficiency and to maintain that proficiency at least over the course of the decommissioning process. Records of training, including testing to demonstrate qualification, should be maintained.

Equipment Maintenance and Calibration

Measuring equipment should be maintained, calibrated, and tested to assure the validity of the survey data. Further, the procedures, responsibilities, and schedules for calibrating and testing equipment should be documented.

Proper maintenance of equipment varies, but maintenance information and use limitations should be provided in the vendor documentation. All measurement and analytical equipment should be tested and calibrated before initial use and should be recalibrated if maintenance or modifications could invalidate earlier calibrations. Field and laboratory equipment should be calibrated based on standards traceable to the National Institute of Standards and Technology (NIST). In those cases where NIST-traceable standards are not available, standards of an industry-recognized organization (for example, the New Brunswick Laboratory for various uranium standards) may be used. Minimum frequencies for calibrating equipment should be established and documented.

Measuring equipment should be tested at least once each day the equipment is used. Test results should be recorded in tabular or graphic form and compared to predetermined, acceptable performance ranges. Equipment that does not conform to the performance criteria should be immediately removed from service until the deficiencies can be resolved.

Data Management

A consistent method of data generation, handling, computations, evaluation, and reporting should be developed and documented as part of the survey plan. In general, information and data should be recorded in bound logs or on standardized field and laboratory record forms. Analytical data should not be obliterated by erasing or the use of whiteout. Incorrect entries should be corrected by striking a single line across the entry and entering new data. The correction or change should be initialed and dated by the person making the entry.

A system of data review and validation is important to ensure consistency, thoroughness, and acceptability. This begins with regular (daily or weekly) reviews of calculations based on field data; and reviews of final reports by survey and laboratory supervisors, QA officials, and project managers. All reviews should be signed and dated. Any questionable or invalid data should be identified in project records and in the survey report. Active records should remain under direct control of a designated individual during report preparation; inactive records should be protected from loss or destruction by storage in access-controlled areas or files and in facilities with fire protection. It is also recommended that copies (microfilm, computer disc, photostats, etc.) of critical data be produced and stored at a separate location.

Sample Chain-of-Custody

One of the most important aspects of sample management is to ensure that the integrity of the sample is maintained; that is, that there is an accurate record of sample collection, transport, analysis, and disposal. This ensures that samples are neither lost nor tampered with and that the sample analyzed in the laboratory is actually and verifiably the sample taken from a specific location in the field.

Sample custody should be assigned to one individual at a time. This will prevent confusion of responsibility. Custody is maintained when (1) the sample is under direct surveillance by the assigned individual, (2) the sample is maintained in a tamper-free container, or (3) the sample is within a controlled-access facility.

A chain-of-custody record (a standard form) should be initiated by the individual collecting or overseeing the collection of samples. A copy of this form should accompany the samples throughout transportation and analyses; and any break in custody or evidence of tampering should be documented.

Audits

Periodic audits should be performed to verify that survey activities comply with established procedures and other aspects of the QA plan and to evaluate the overall effectiveness of the QA program. The audits should be conducted in accordance with written guidelines or checklists, and should be performed by individuals not actively participating in the activities being audited. Audit results are reported to responsible management in writing, and actions to resolve identified deficiencies should be tracked and appropriately documented.

4.1.2 Health and Safety

Consistent with the approach for any operation, decommissioning activities should be planned and monitored to assure the health and safety of the worker and other personnel, both on- and off-site, are adequately protected.

Contamination control and radiation control support surveys are conducted for protection of personnel performing decontamination activities. These surveys are operational in nature, as opposed to determining the radiological status of a facility, and are typically conducted as part of a licensee's ongoing radiation protection program. However, at the stage of determining the final status of the site, residual radioactivity is expected to be below the guideline values for unrestricted release; therefore, the final status survey should not require radiation protection controls.

The primary health and safety concerns during a final survey are the common potential industrial hazards typically found at a construction site. These include exposed electrical circuitry, excavations, enclosed work spaces, sharp objects or surfaces, falling objects, tripping hazards, and working at heights. The survey plan should incorporate requirements and procedures for eliminating, avoiding, or minimizing these potential safety hazards.

4.1.3 Physical Characteristics of Site

The physical characteristics of the site will have a significant impact on the complexity, schedule, and cost of a survey. These characteristics include the number and size of buildings, type of building construction, building condition, total area of grounds, topography, and ground cover.

<u>Building Interiors</u>

Building design and condition will have a marked influence on the survey efforts. The time required to conduct a survey of building interior surface is essentially directly proportional to the total surface area. For this reason the degree of survey coverage is decreased as the potential for residual activity decreases.

Building construction features such as ceiling height and incorporation of ducts, piping, and certain other services into the construction will determine the ease of accessibility of various surfaces. Scaffolding, cranes, manlifts, or ladders may be necessary to reach some surfaces. Accessing some locations may actually require dismantling portions of the building. If the building is constructed of porous materials, such as wood or concrete, and the surface was not sealed, contamination may have found its way into the walls, floors, and other surfaces. It may be necessary to obtain cores for laboratory analysis. Another common difficulty is the presence of contamination beneath tile or other floor coverings. This occurs because the covering placed over contaminated surfaces or the joints in tile were not sealed to prevent penetration. It has been the practice in some facilities to "fix" contamination (particularly alpha emitters) by painting over the surface of the contaminated area. All this should be addressed in surveys.

The condition of surfaces after decontamination may affect the survey process. Removing contamination that has penetrated a surface usually involves removing the surface as well. As a result, the floors and walls of decontaminated facilities are frequently badly scarred or broken up and are often very uneven. Such surfaces are more difficult to survey, because it is not possible to maintain a fixed distance between the detector and the surface and pitted or porous surfaces may significantly attenuate radiations — particularly alpha and low-energy beta particles. Use of monitoring equipment on wheels is precluded by rough surfaces, and such surfaces also pose an increased risk of damage to fragile detector probe faces.

The presence of furnishings and equipment will restrict access to building surfaces and add additional items which the survey should address. Equipment that was used directly for processes or activities involving radioactive materials will likely have been removed; however, in cases where such equipment remains, relatively inaccessible surfaces may require evaluation. It may also become necessary to remove or relocate certain furnishings such as lab benches and hoods, to obtain access to potentially contaminated floors and walls.

Piping, drains, sewers, sumps, tanks and other components of liquid handling systems present special difficulties because of the inaccessibility of interior surfaces. Process information, operating history, and preliminary monitoring at available access points will assist in evaluating the extent of sampling and measurements that will be required. Evaluation of inaccessible surfaces is addressed in Sections 6.4.3 - 6.4.5

Expansion joints, stress cracks, and penetrations into floors and walls for piping, conduit, anchor bolts, etc. are potential sites for accumulation of contamination and pathways for migration into subfloor soil and hollow wall spaces. Wall/floor interfaces are also likely locations for residual contamination. Coring, drilling, or other such methods may be necessary to gain access for survey.

<u>Building Exteriors</u>

Exterior building surfaces will typically have a low potential for residual contamination; however, there are several locations which should be surveyed. If there were roof exhausts or the facility is in proximity to the air effluent discharge points, the possibility of roof contamination should be considered. Because roofs are periodically resurfaced, contaminants may have been trapped in roofing material, and samples of this material may have to be obtained. Wall penetrations for process equipment, piping, and exhaust ventilation are potential locations for exterior contamination. Roof drainage points such as driplines along overhangs, downspouts, and gutters are also important survey locations. Window ledges and outside exits (doors, doorways, landings, stairways, etc.) from former contamination control areas are also building exterior surfaces which should be addressed.

<u>Grounds</u>

Depending upon site processes and operating history, the radiological survey may include varying portions of the land areas. At a minimum, those areas immediately adjacent to facilities where radioactive materials were handled should be surveyed. Other potentially contaminated open land or paved areas to be considered include equipment, product, waste, and raw material storage areas; liquid waste collection lagoons; areas downwind (based on predominant wind directions on an average annual basis, if possible) of stack release points; surface drainage pathways; and roadways that may have been used for transport of radioactive or contaminated materials.

Buried piping and underground tanks, spills, and septic leach fields which may have received contaminated liquids are locations of possible contamination that will require sampling of subsurface soil. Information regarding soil type (e.g. clay, sand, etc.) may provide insight into the retention or migration characteristics of specific radionuclides. The need for special sampling by coring or split-spoon equipment, usually by a commercial firm, should be anticipated.

Disposition of on-site, low-level waste burials, authorized under AEC/NRC regulations, will require a decision by the NRC following review of the licensee's decommissioning plan. If radioactive waste has been removed, surveys of excavations will be necessary before backfilling. If such material is to be left in place, the NRC may request subsurface sampling around the burial site perimeter to assess the potential for future migration.

If ground cover should be removed or if there are other obstacles that limit access by either survey personnel or by any needed special equipment (electromagnetic scanners and subsurface sampling rigs) the time and expense of making land areas accessible should be considered. In addition, precautionary procedures should be developed to prevent spreading surface contamination during ground cover removal and/or the use of heavy equipment.

4.2 Designing the Survey

4.2.1 Classification of Areas by Contamination Potential

All areas of the site will not have the same potential for residual contamination and therefore do not require the same level of survey coverage to achieve an acceptable level of confidence that the site satisfies the established release criteria. By designing the survey such that areas with higher potential for contamination receive a higher degree of survey effort, the process will be both effective and efficient.

Two classifications of areas are used in this Manual; these are termed **affected** and **unaffected** areas. These classifications are defined as follows:

- **affected areas:** Areas that have potential radioactive contamination (based on plant operating history) or known radioactive contamination (based on past or preliminary radiological surveillance). This would normally include areas where radioactive materials were used and stored, where records indicate spills or other unusual occurrences that could have resulted in spread of contamination, and where radioactive materials were buried. Areas immediately surrounding or adjacent to locations where radioactive materials were used or stored, spilled, or buried are included in this classification because of the potential for inadvertent spread of contamination.

- **unaffected areas:** All areas not classified as affected. These areas are not expected to contain residual radioactivity, based on a knowledge of site history and previous survey information.

Segregation of the site into these two classifications should be justified by the licensee in the decommissioning plan (in those cases where a decommissioning plan is required to be submitted) and in the final survey report. It should be emphasized that review and concurrence by the NRC of the classification of areas is to the advantage of the licensee at the early stages of planning the final survey. It should also be recognized that as the final survey progresses, an area's classification may require changing, based on accumulated survey data.

4.2.2 Establishing Reference Grid Systems

Grid systems are established at the site to:

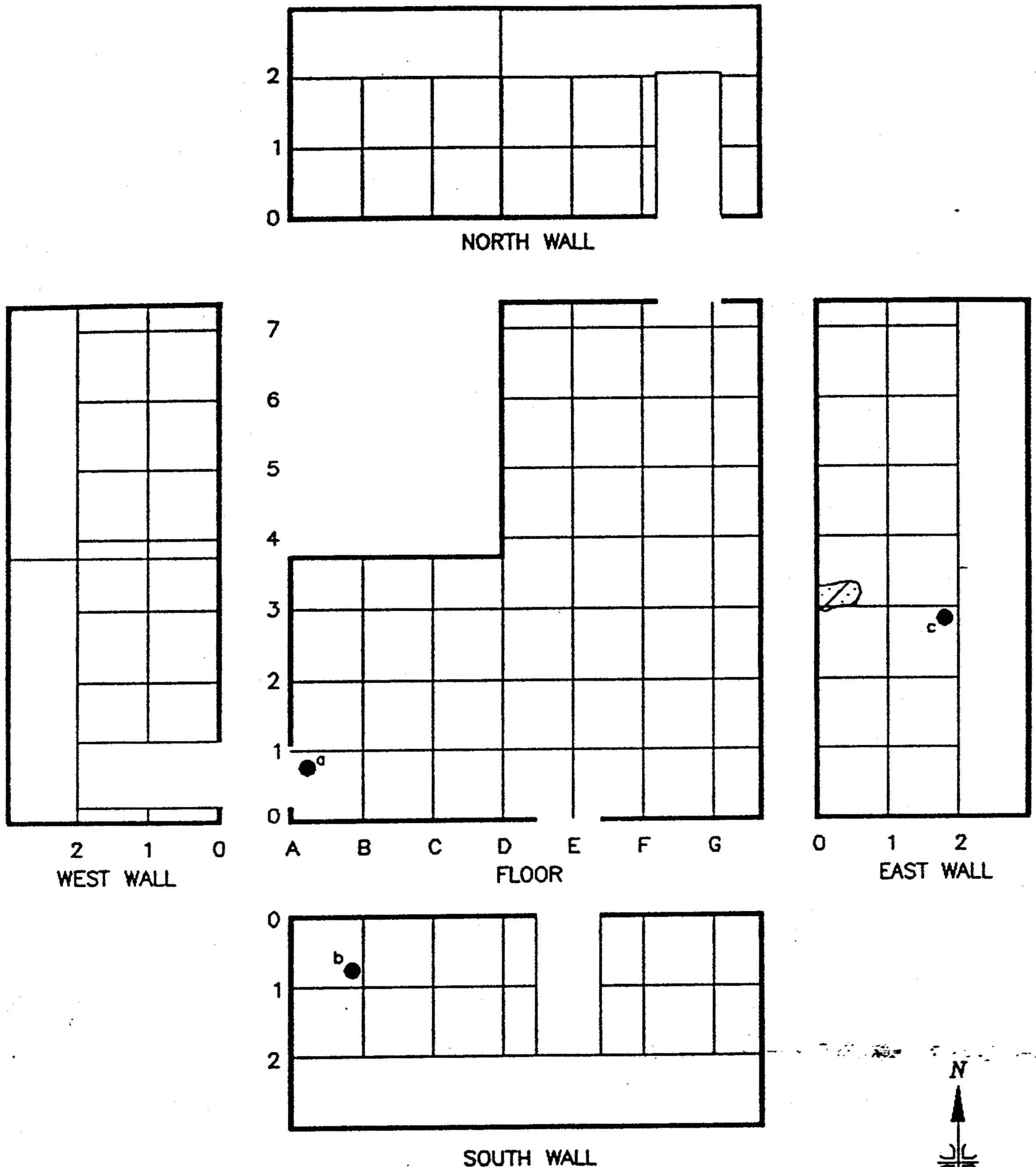
- Facilitate systematic selection of measuring/sampling locations,

- Provide a mechanism for referencing a measurement/sample back to a specific location so that the same survey point can be relocated, and

- Provide a convenient means for determining average activity levels.

A **grid** consists of a system of intersecting lines, referenced to a fixed site location or bench mark. Typically, the grid lines are arranged in a perpendicular pattern, dividing the survey location into squares or blocks of equal area; however, other types of patterns (triangular, rectangular, hexagonal) have been used for survey reference purposes.

Grid patterns on horizontal surfaces are usually identified numerically on one axis and alphabetically on the other axis or in distances in different compass directions from the grid origin. Examples of building interior and land area grids are shown in Figures 4-1 and 4-2, respectively. Grids on vertical surfaces include a third designator, indicating position relative to floor or ground level. Figure 4-1 provides examples of designating grid locations in three dimensions.



EXAMPLE OF
GRID POINT DESIGNATION

POINT	GRID DESIGNATION
a	A+0.2, 0.8
b	A+0.8, 0, 0.8
c	G+0.6, 2.9, 1.9

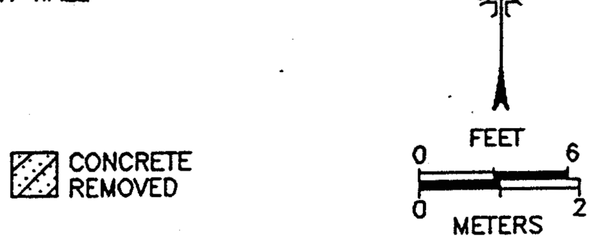
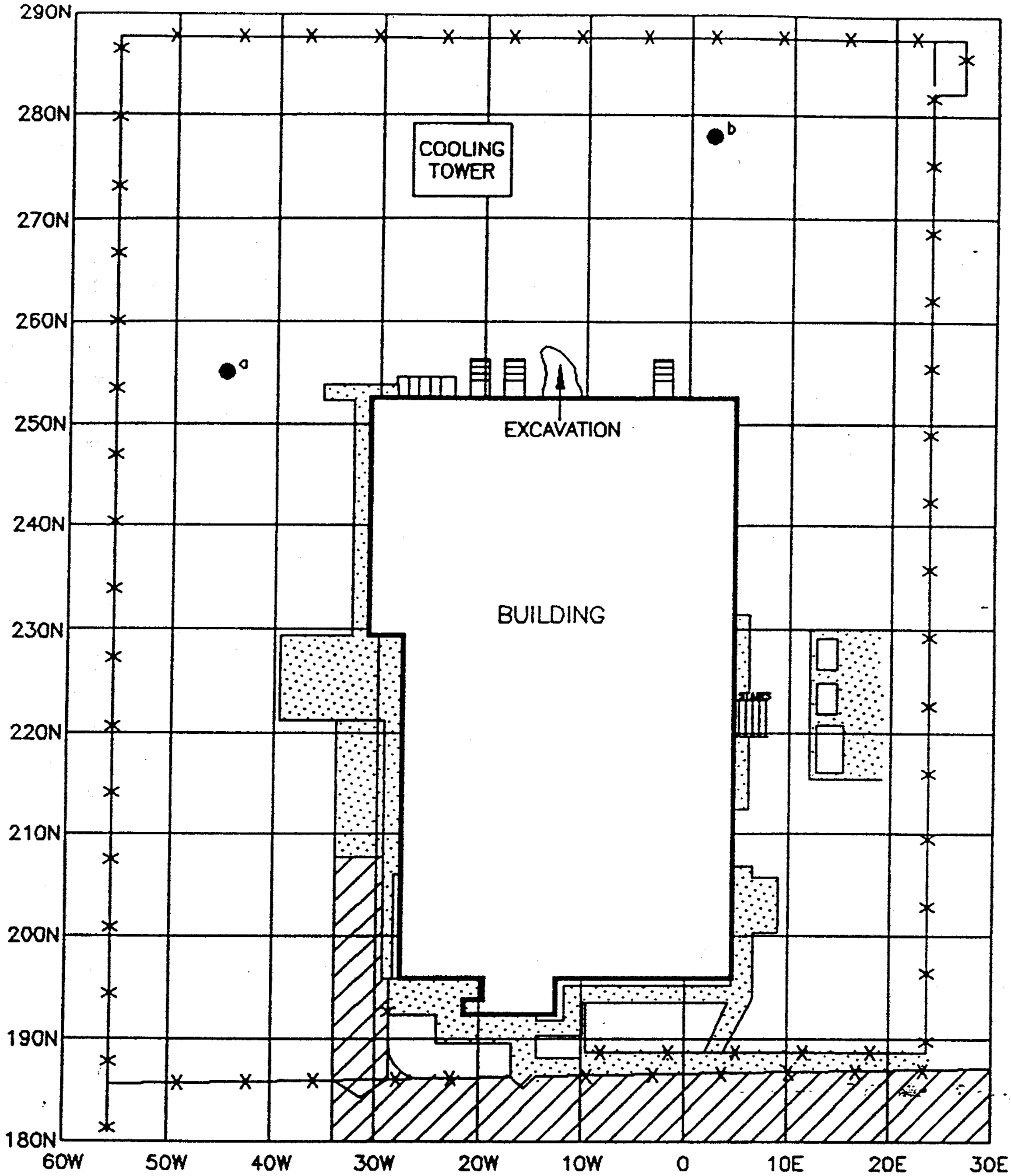


FIGURE 4–1: Example of a Grid System Used for Building Interior Survey



EXAMPLE OF
GRID POINT DESIGNATION

POINT	GRID DESIGNATION
a	255N, 45W
b	278N, 2E

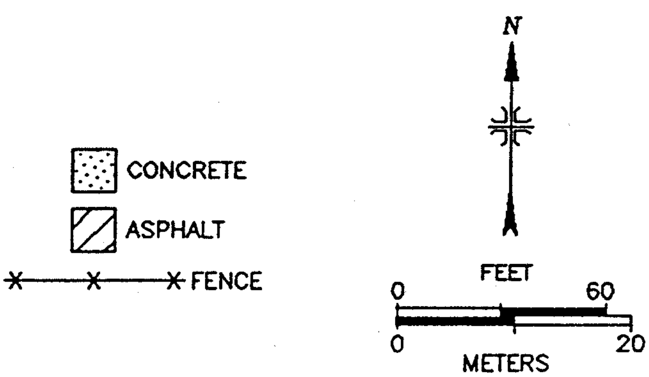


FIGURE 4–2: Example of Grid System for Survey of Site Grounds

For surveys of structures the basic grid system for affected areas is 1 m. Gridding may be limited to the floor and lower (up to 2 m height) walls, unless there is also a potential for upper wall and ceiling area contamination. Survey locations are referenced to the grid system; surveys of ungridded surfaces are referenced to the floor grid (if one exists) or to prominent building features.

Grounds and open land areas classified as affected areas are gridded at 10 meter intervals.

Unaffected areas do not require gridding for the purposes of establishing measurement or sampling locations; however, grids systems of larger spacing, e.g. 5 to 10 m for large structural surfaces and 20 to 50 m for land areas, may be helpful to the licensee by facilitating the referencing of survey locations in those areas to a common site reference system.

The grids described above are intended primarily for reference purposes and do not necessarily dictate the spacing of survey measurements or sampling. Closer spaced survey locations may be required to demonstrate that average and *elevated area* guideline values are met to the required level of confidence. Larger spacing may be acceptable, based on the capabilities of survey techniques. Considerations for determining measurement/sampling spacing are provided in Sections 4.2.3 and 8.5.

To facilitate survey design and assure that the number of survey data points from an area is sufficient to enable statistical evaluation, the area may be divided into survey "units" which have common history or other characteristics or are naturally distinguishable from other portions of the site. Such **survey units** may combine contiguous rooms or land areas having the same potential contamination classification. The size of a survey unit should be chosen to assure that the total number of data points and/or the spacing (frequency) of measurement/sampling satisfy the requirements of Section 4.2.3. The maximum survey unit size for building surface areas classified as affected, limited to 100 m². A survey unit cannot include both affected and unaffected areas.

4.2.3 Selecting Measurement/Sampling Locations

It is not possible to perform measurements or conduct sampling at the theoretically infinite number of locations on a site. Instead, a survey should have as its objective the collection of quality radiological data from sufficient representative site locations, such that a statistically sound conclusion regarding the radiological status of the entire site can be developed. Meeting this objective requires a statistically based plan for selecting measurement and sampling locations.

Experience has indicated that residual contamination on a former radioactive material site is typically concentrated in a relatively small portion of the site. The pattern is asymmetrical, with much of the activity often located in small isolated hot-spots. If the licensee's cleanup efforts have been effective, however, essentially all locations will have residual activity below the guideline levels, and many areas will contain levels in the range of natural background and/or below the measurement sensitivities of the survey and analytical procedures. After cleanup, the pattern of residual activity will therefore likely approximate a normal distribution; the approach to survey design described below assumes such a distribution. If, based on site operating history or the results of preliminary surveys, there is reason to believe there may be unusual localized contamination patterns, the licensee should supplement the survey with samples from randomly selected points in the area of suspect localized contamination.

<u>Structure Surveys</u>

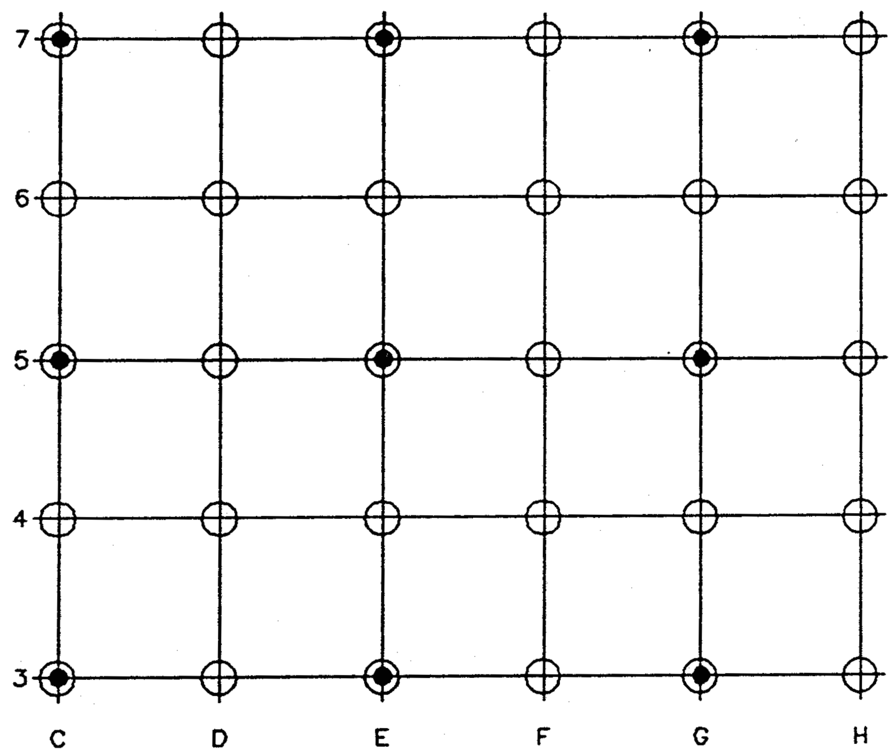
Affected Areas

At a minimum, the floors and lower walls of affected areas should receive 100% coverage during the final status survey. The coverage provided for upper walls and ceilings will be dependent upon the contamination potential for these surfaces. The survey measurements for surface activity will consist of a combination of surface scans, direct measurements, and measurements of removable activity. Procedures for performing these measurements are described in Section 6.4

Scans of 100% of affected area floor and lower wall surfaces are performed for all radiations which may be emitted from the radionuclides of interest. Locations of areas of elevated activity are identified and direct measurements are performed to define their extent and activity levels. Residual activity which exceeds 3 times the guideline value results in external radiation in excess of 2 times the guideline value above background at 1 m from the surface, or results in an average activity above the guideline value in any contiguous 1 m^2 area (refer to Section 8.5.2 for averaging procedures) should be remediated until these conditions are satisfied.

Once all identified elevated areas are evaluated and cleaned up as necessary, systematic measurements of surface activity are performed. If the scanning technique has been demonstrated to have a detection sensitivity for the radionuclide or radiations of interest at $\leq$ 25% of the guideline level, systematic measurements are performed at a spacing of 2 m or less to provide at least 30 data point locations. A recommended approach is to obtain data from grid line intersections (see Figure 4-3) or grid block centers. If the detection sensitivity of the scanning technique is not $\leq$ 25% of the guideline value, systematic measurements are performed at 1 m intervals.

Assuming random placement of grid corners



● MEASUREMENT LOCATIONS IF SCANNING TECHNIQUE IS CAPABLE TO DETECTING ≤ 25% OF GUIDELINE LEVEL.

○ MEASUREMENT LOCATIONS IF SCANNING TECHNIQUE IS NOT CAPABLE TO DETECTING ≤ 25% OF GUIDELINE LEVEL.

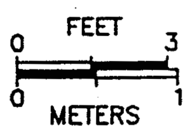


FIGURE 4–3: Standard Measurement/Sampling Pattern For Systematic Grid Survey of Structure Surfaces

The number of data points required to demonstrate that the confidence level of the survey satisfies the 95% objective for a survey unit, is a function of the average and variance of the data. Following the procedures in Sections 8.5 and 8.6, the need for any additional measurements is determined; if additional measurements are required, they should be obtained at approximately evenly-spaced intervals throughout the survey unit.

Upper walls, ceilings, and other overhead surfaces which are suspected of having residual activity at greater than 25% of the guideline value, based on operating history and previous surveys, are surveyed in the same manner as floors and lower walls. If there is no reason to suspect residual activity exceeding 25% of the guideline value on these surfaces, a minimum of 30 measurement locations each, on vertical and horizontal surfaces where radioactive material would likely accumulate, (air exhaust vents and horizontal surfaces where dust would settle) is selected. To assure a reasonable coverage of these surfaces, an average of at least 1 measurement location per 20 m^2 of surface area should be selected. At each location a scan of the immediate area is performed to identify the presence of any elevated activity levels, followed by the measurement. If scans or measurements indicate residual activity exceeding 25% of the guideline, the area is considered potentially contaminated and the surface exhibiting such levels should be surveyed in the same manner as floors and lower walls of affected areas.

If gamma emitting radionuclides are among the potential contaminants, exposure rate measurements at 1 m from floor and lower wall surfaces are performed at a frequency of 1 systematic measurement per every 4 m^2. If potential contaminants did not include gamma emitters, exposure rate measurements should be performed at a minimum spacing of 1 measurement per 10 m^2.

Unaffected Areas

Scans of unaffected surfaces should cover a minimum of 10% of the floor and lower wall surface area. At least 30 randomly selected measurement locations or an average measurement of 1 per 50 m^2 of building surface area, whichever is greater, for total and removable activity, should be performed for each survey unit. These locations should include all building surfaces. Identification of activity levels in excess of 25% of the guideline, either by scans or measurements, will require reclassification of the area to the "affected" category. Testing of the data relative to the confidence level objective is performed in the same manner as for affected areas and any additional measurement locations required should be selected randomly. Exposure rate measurements at 1 m from the floor are performed at each location of surface activity measurement.

Open Land Surveys

Affected Areas

As with structure surfaces, 100% coverage of affected open land areas (paved surfaces and soil) is necessary. Scanning is performed to identify locations of elevated activity levels. Areas of suspected elevated activity, identified in this manner, are evaluated by sampling and analyses to determine their activity level and area l extent, and results are compared with criteria (see Sections 2.2 and 8.5); cleanup is performed, as required, and scanning repeated. After scanning has indicated the guidelines and conditions have been satisfied, systematic soil sampling of each affected area grid block is performed at locations equidistant between the center and each of the four grid block corners (see Figure 4-4). If scanning is not capable of detecting surface areas with activity levels ≤ 75% of the guideline values for the radionuclides of interest, additional sampling will be required to provide an acceptable level of confidence that locations of elevated activity have been identified. An EPA procedure (EPA 1989) recommends a triangular grid with a sampling interval of 5 m on a side (enclosed area of approximately 10.8 m^2) for a 95% assurance that elevated areas in excess of 10 m^2 surface area are identified. By beginning with the standard systematic pattern and including additional sampling points, located along the 10 m grid lines, at block corners and centers, and midway between grid block corners (Figure 4-5), a triangular sampling pattern with spacing of 5 m or less (enclosed area of approximately 6.3 m^2) is obtained.

Paved surfaces are surveyed in the same manner as described above for structure surfaces.

For both soil sampling and paved surface measurements, a minimum of 30 data locations should be used. Data for each of these surface types are tested relative to the guideline value and the confidence level objective; and additional systematic sampling/measurement locations that may be required are obtained at approximately uniformly spaced intervals throughout the survey unit.

Exposure rates are measured at 1 m above the surface on the pattern shown in Figure 4-4.

Unaffected Areas

Unaffected open land area should be uniformly scanned for radiations from the radionuclides of interest. Spacing intervals between scanning paths should be such that a minimum of 10% of the surface is scanned. Soil sampling is performed at a minimum of 30 randomly selected locations. Surface activity measurements on paved areas are also performed at 30 randomly selected locations. Identification of hot-spots or individual locations with activity levels

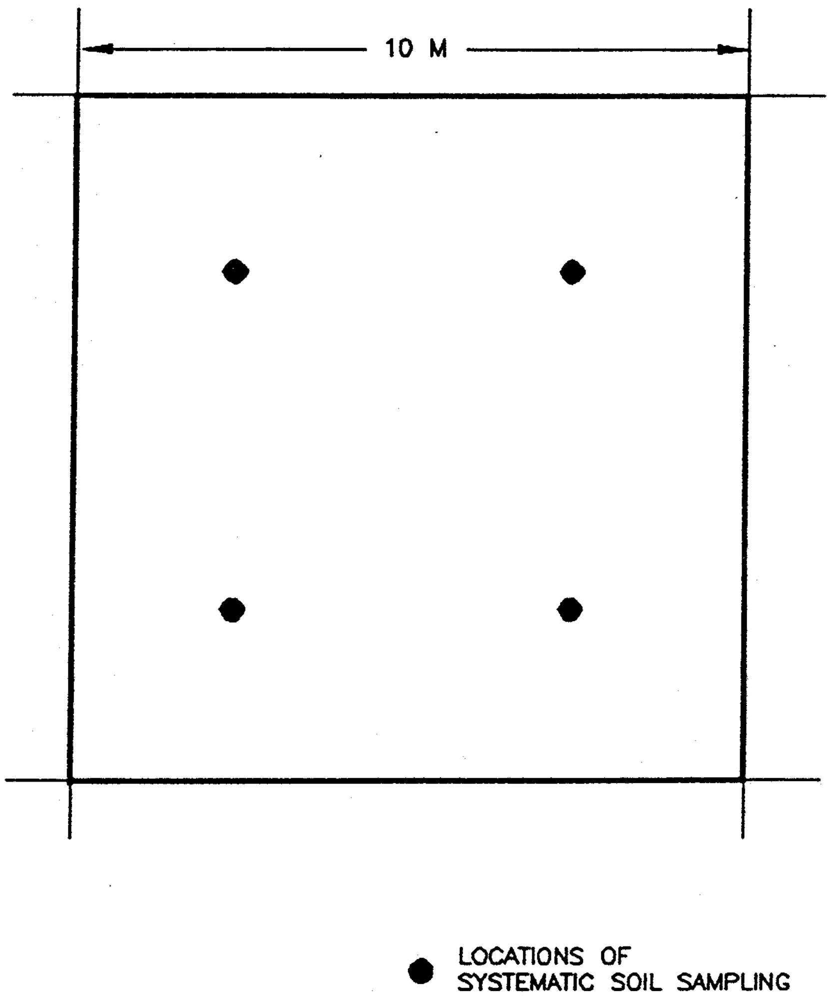
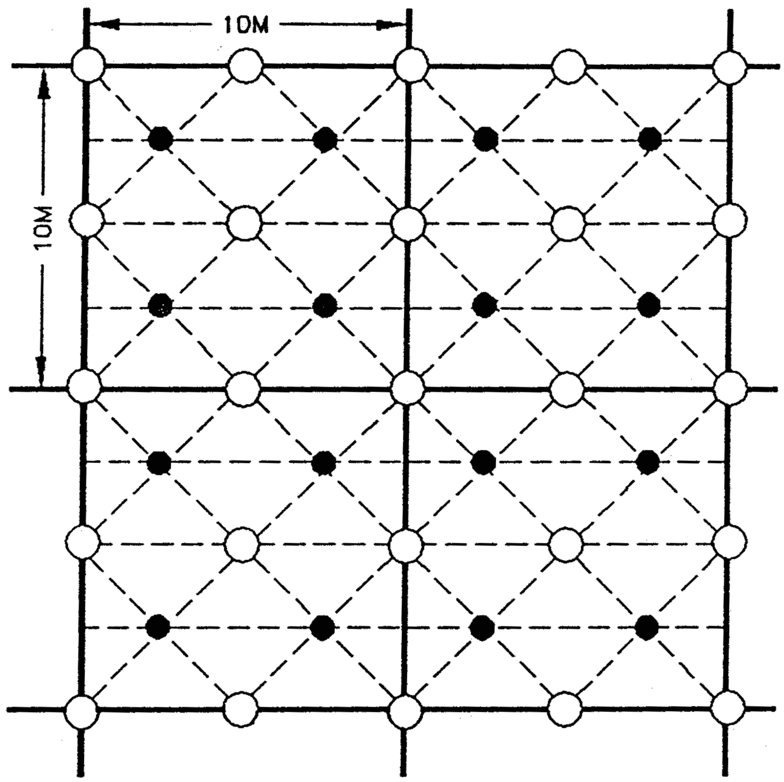


FIGURE 4–4: Standard Sampling Pattern for Systematic Grid Survey of Soil



SYSTEMATIC SAMPLING LOCATIONS

ADDITIONAL SAMPLING LOCATIONS TO PROVIDE CLOSE-SPACED TRIANGULAR GRID PATTERNS

FIGURE 4-5: Sampling Pattern to Identify Soil Areas of Elevated Activity in excess of 75% of the guideline value requires reclassification of the area as "affected".

Testing of results, relative to guidelines and confidence level objectives is performed according to Section 8.6 and any additional samples/measurements required are obtained at randomly selected locations in the survey unit.

Other Measurement/Sampling Locations

In addition to the building and land surface areas described above, there are numerous other locations where measurements and/or sampling should be performed. Examples include items of equipment and furnishings, building fixtures, drains, ducts, and piping. Many of these items or locations have both internal and external surfaces, requiring evaluation.

Each such location classified as affected should be scanned and individual measurements and/or samples obtained at representative points. Unaffected locations can, as with the building and land surfaces in such areas, be surveyed at lower frequencies, consistent with the contamination potential, the capability of scanning techniques to identify activity levels at or above guidelines, and findings as the survey progresses. Surveys of these types of locations are discussed in more detail in Section 6.0.

4.2.4 Subsurface Sampling

At the stage where the final status survey is being conducted, contaminated subsurface soil should already have been identified, characterized, and remediated, if necessary. Subsurface activity data may be required for determination of residual site inventory. In addition, if there is potential for residual activity below the surface layer, the survey plan should include subsurface sampling. The number and locations of samples should follow the same pattern as described above in section 4.2.3 sampling depth of surface soil. As an initial evaluation, samples may be collected at 1 m intervals, starting at the surface and continuing to at least 1 m below the suspected or potential region of activity. Shallow sampling may be conducted using manual equipment (post-hole diggers, small-diameter split barrel or Shelby tube samplers, and portable hand-operated or motorized augers). For depths below several meters, heavier equipment, such as a drill rig with an auger and/or a core sampler will be required. Use of electromagnetic sensing techniques, such as ground penetrating radar and magnetrometry will assist in locating potential sampling areas and also should be a safety consideration if buried utilities or containers of potentially hazardous material (radiological or chemical) may be present. Use of a subsurface sampling technique which results in a borehole or soil face, accessible with a gamma sensitive detector, also enables scanning of the exposed soil surface to identify the presence and distribution of subsurface activity.

If a potential exists for activity to enter subsurface water, samples of water should be collected (if available) from the same locations as the subsurface soil samples. Knowledge of expected constituents is necessary when collecting subsurface water to determine whether special precautions for sample handling and collection are required to ensure representative samples. Expertise of hydrology specialists and those knowledgeable in subsurface water sampling technique should be sought, when such conditions are anticipated.

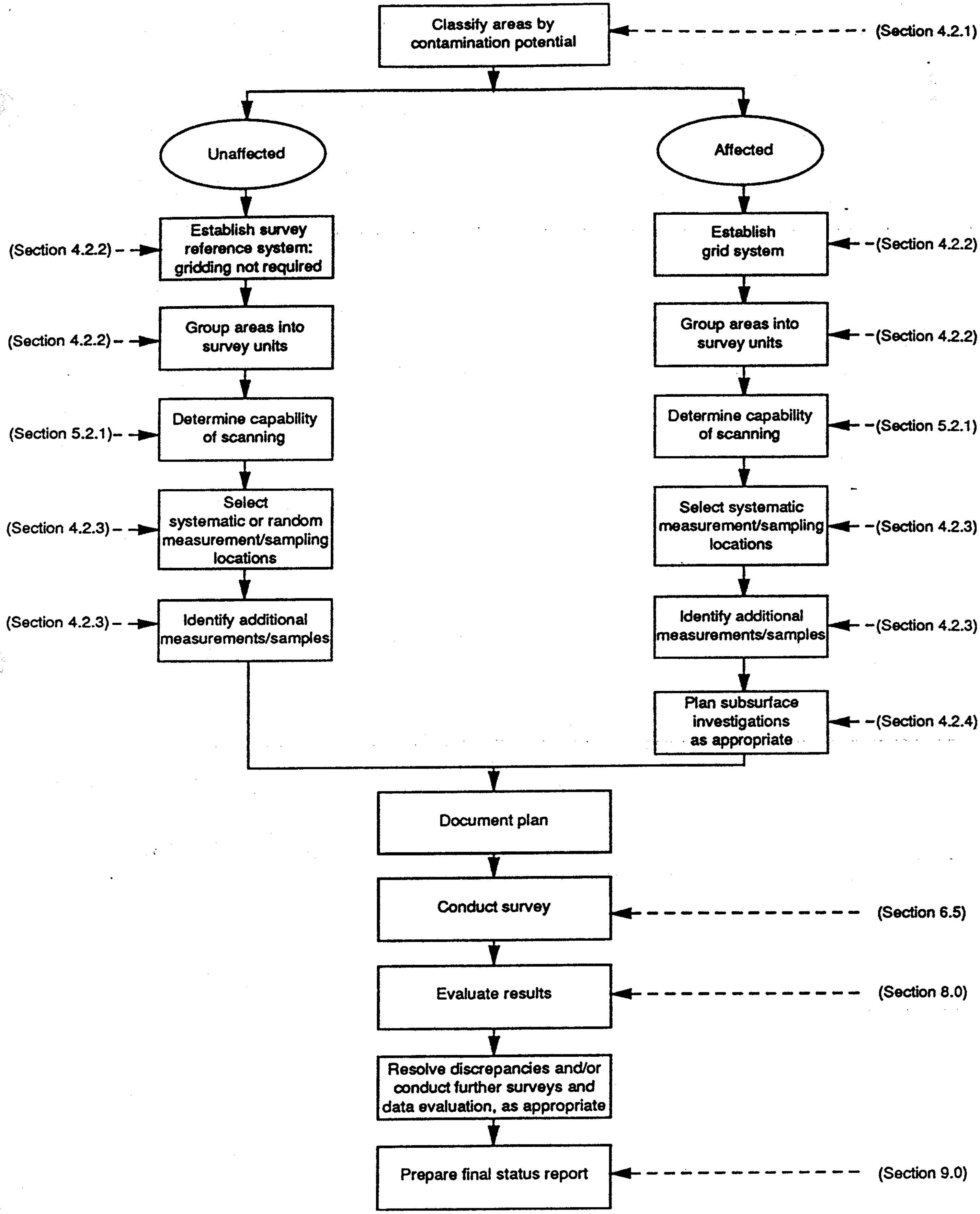


FIGURE 4.6: Flow Diagram for Planning Final Status Surveys

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. Solid-State Detectors 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/cm² window; probe face area 50 to 1000 cm².	surface scanning; surface activity measurement; field evaluation of smears	
	<0.1 mg/cm² window; probe face area 10 to 20 cm²	laboratory measurement of water, air, and smear samples	
	no window (internal proportional); probe face area 10 to 20 cm²	laboratory measurement of water, air, and smear samples	
scintillation	ZnS(Ag) scintillator; probe face area 50 to 100 cm²	surface scanning; surface activity measurement; field evaluation of smears	
	ZnS(Ag) scintillator; probe face area 10 to 20 cm²	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:

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

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* 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

Sample Calculation: (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.

Scanning

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.

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

= 4000 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:

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

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 effect 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 $\pm$ 2σ 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.

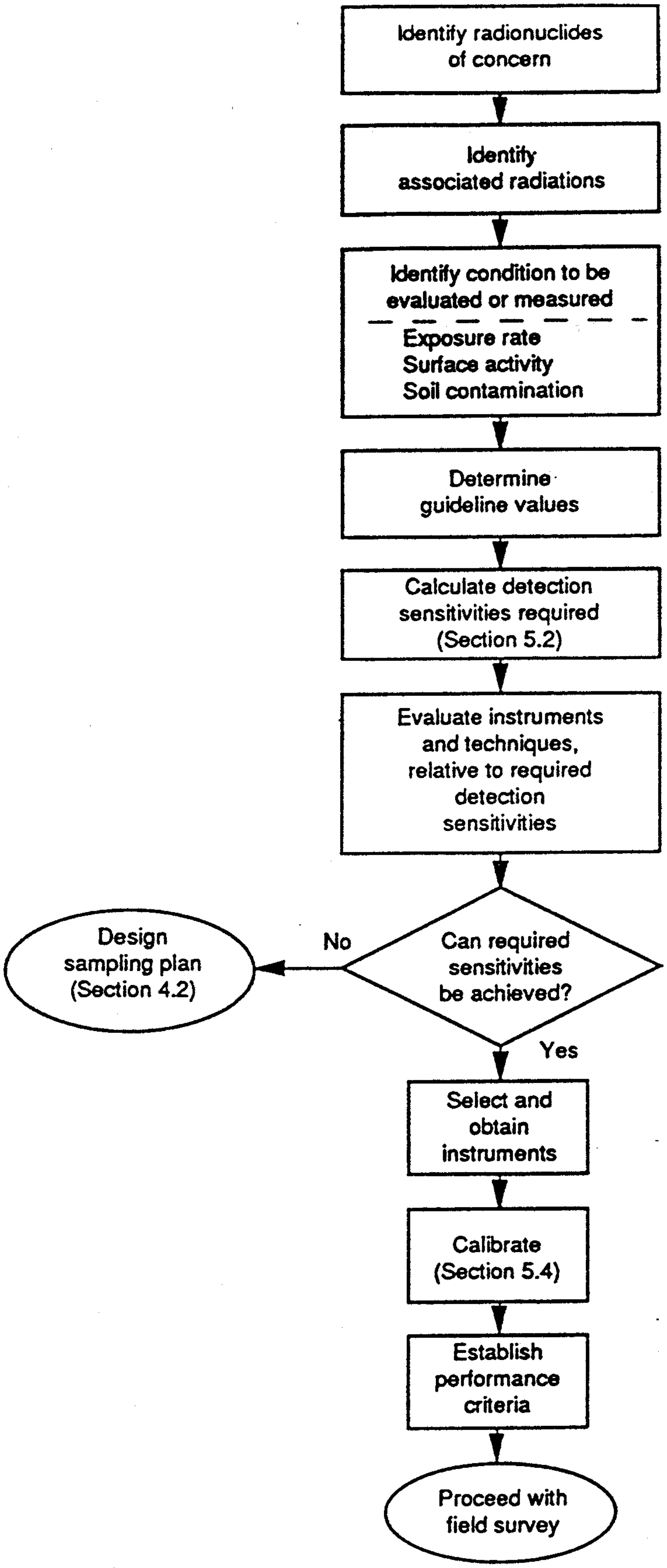


FIGURE 5-1: Flow Diagram for Selection of Field Survey Instrumentation

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.

6.0 Survey Techniques

6.1 General Considerations

6.1.1 Survey Plans and Procedures

The survey should be conducted in accordance with documented plans and procedures. The survey plan describes the survey objectives, the design to meet those objectives, and the general approach to performing measurements and sampling; the quality assurance plan establishes the basis for assuring the adequacy and quality of the survey data. Specific survey techniques are detailed in procedures, which may be included in the plan or incorporated by reference. Flow charts for conducting surveys of buildings and site grounds are provided in Figures 6-1 and 6-2. Personnel conducting the survey should be trained and qualified in the procedures they will use. Changes in plans and procedures will frequently be necessary, based on unanticipated findings or conditions encountered as the survey progresses. The individual responsible for onsite direction of the survey should have authority to make such changes; deviations from plans and procedures should be documented.

6.1.2 Records

Records should be legible, thorough, and unambiguous. Records are prepared in indelible ink, signed, and dated; records should be adequate to enable an independent evaluation of the site status. Changes are made by striking through the item to be changed with a single line, entering the corrected information, and initialing the change. Where practical, survey data should be recorded on standardized forms; other information, for which forms are not appropriate, is recorded in a bound logbook. All data and supporting information, necessary to substantiate the survey findings, are considered permanent legal records and, as such, should be protected from damage or loss and retained for a time period appropriate for such records.

6.1.3 Cross Contamination

Minimal residual activity should be present at a site at the time of the final status survey. There is therefore usually little concern for direct exposure or personal contamination during the survey. However, prudent standard contamination control practices should still be followed to minimize the possibility of personal contamination and to prevent cross-contamination of samples. Instruments and equipment should not be allowed to come into contact with surfaces which might contain loose activity; if they do, they should be cleaned and monitored. Sampling equipment may retain deposits of the sample media. Visible material can be removed by wiping with a cloth or brush, followed by rinsing in clean water. Gloves are recommended for those operations where hand contamination is possible. Clothing, hands, and shoes should be periodically checked for contamination, and good personal hygiene should be practiced. Avoid eating drinking, or smoking in potentially contaminated areas; wash hands after activities that may have resulted in skin contamination.

6.1.4 Allow for the Unexpected

Regardless of the effort devoted to the development of the survey plan, all conditions, situations, and findings will not be as anticipated. Weather and site surface conditions may require changes in survey procedures, patterns, and schedules. Previously unknown areas of residual contamination, may be found. Radionuclides which were not expected to be present at significant levels may be identified. Be flexible and adaptable; be prepared to modify the plan, based on situations and findings as the survey progresses.

6.2 Instrument Selection

Choose instruments which are reliable, suited to the physical and environmental conditions at the site, and capable of detecting the radiations of concern. As a general practice the instrument and survey technique should be able to measure a level of radiation or radioactivity, i.e. have an MDA which is less than 25% of the guideline value for structure surveys and less than 75% of the guideline value for open land surveys, and, preferable, as low as 10% of the guideline value. The instrument must be calibrated for the radiations and energies of interest at the site; this calibration must be referenceable to an accepted standards organization such as NIST. Routine operational checks of instrument performance are conducted to assure that the background and response are maintained within acceptable ranges.

6.3 Establishing Background Levels

NRC guideline values for residual activity are levels above the naturally occurring background. It is therefore necessary to determine the site background levels of direct radiation and radionuclide concentrations in soil, to enable a comparison of site radiological conditions with the acceptable guideline values. Additional information on determining background levels is provided in Section 2.3.1.

6.4 Building Surveys

6.4.1 Preparations

Preparations for surveys of building surfaces involve accessing the surfaces of interest and establishing a survey reference system. Arrangements for movement of equipment and materials that may remain in the facility are necessary and other actions to obtain access to potentially contamination surfaces, e.g. removing wall and floor coverings, including paint and wax or sealer, and opening drains and ducts, should be initiated when required to enable representative measurements of the contaminant. If alpha radiation or very low energy beta radiation is to be measured, the surface must be free of overlying material, such as dust and water, which would attenuate the alpha particles. Preliminary measurement should be conducted to ensure that such preparation will not result in spread of contamination.

The reference grid is then established, where appropriate, based on the contamination potential classification of the area (Section 4.2.1). Grids may be marked by paint, chalk line, or markers at grid block corners. Consideration should be given to the physical condition and future use of the facility in choosing a grid marking system, such that major cleanup for its removal will not be required during restoration.

The final preparation step is to develop scale drawings of the survey areas, indicating facility features and superimposing the grid reference system.

6.4.2 Scanning

Before conducting any fixed measurements, surfaces are scanned to identify the presence of elevated direct radiation which might indicate residual gross activity or hot-spots. Scans are conducted for all radiations potentially present, based on the operational history. The scanning detector is kept as close as possible to the surface and moved across the surface at a slow speed. Nominally, the distance between the detector and the surface is maintained at less than two centimeters, with exception of alpha scanning for which the distance should be less than 1 cm. For particulate radiations (alpha and beta) which may have very limited ranges, the scan speed should not exceed 1 detector width per second; this speed should be reduced to as low as 1/3 detector width per second for those situations when relatively low count rates may be indicative of residual activity exceeding guideline values. For gamma radiation the scanning speed may be greater; the probe is typically moved in a serpentine pattern while advancing at a speed of about 0.5 m per second.

For optimum detection sensitivity, changes in the instrument response are monitored via the audible output (use of headphones is recommended), rather than by observing fluctuations in the analog meter reading. This use of an audible signal negates concern for the time constant related to the meter response. Locations of direct radiation, discernable above the ambient level (typically 2 to 3 times the ambient count rate), are marked on facility maps and identified for further measurements and/or sampling.

An important factor in evaluating the potential effectiveness of scanning in identifying the presence of hot-spots is the detector sensitivity of the scanning techniques (see Section 5.2). The survey plan and final status report should include information on the sensitivity of the scanning technique.

6.4.3 Direct Measurements

To conduct direct measurements of surface alpha and beta activity, instruments and techniques providing the required detection sensitivity (Section 5.0) are selected. Experience has shown that a 1 minute integrated count, using a large area (100 cm^2) detector, is a practical field survey procedure and will provide detection sensitivities that are below most guideline levels. At the stage of the final survey little residual loose activity should be anticipated, and unless scanning has indicated the presence of gross activity, the probe can normally be placed in direct contact with the surface, without concern for contaminating the instrument.

All potential radiations should be measured. Some radionuclides or decay chains i.e. natural uranium and natural thorium, may emit more than one type of particulate radiation, i.e. alpha and beta particles. Although alpha radiation may provide a measure of the activity level of such materials, the alpha radiations may be attenuated by overlying dust and moisture, or due to imbedding in porous surfaces; in such cases the beta radiation associated with these same radioactive materials will be a better indicator of the true activity level. Because of the difficulties inherent in measuring alpha radiations on dirty or covered surfaces, reasonable efforts should be made to clean the surface or remove coverings prior to survey.

Surface activity measurements are performed at systematically and randomly selected locations (Section 4.2.3) and at locations of elevated direct radiation, identified by surface scans. If the measurement exceeds an action level, determined on the basis of the potential contaminant and the detector and survey parameters, the location is noted for further remediation or resolution. Localized scanning and measurements are repeated after any additional remediation.

Gamma exposure rate measurements are conducted at 1 m above the floor at systematically and randomly selected locations (Section 4.2.3) and at locations of elevated radiation, identified by area gamma scans.

6.4.4 Removable Contamination Measurements

Smears for removable surface activity are obtained by wiping an area of approximately 100 cm^2, using a dry filter paper, such as Whatman 50 or equivalent, while applying moderate pressure. A 47 mm diameter filter is typically used, although, for surveys for low-energy beta emitters, smaller sizes may be more appropriate because they can be placed directly into a liquid scintillation vial for counting. Small pieces of styrofoam are occasionally used for smears for tritium. A smear for removable contamination is obtained at each location of direct surface activity measurement.

For surveys of small penetrations, such as cracks or anchor-bolt holes, cotton swabs are used to wipe the area of concern. Samples (smears or swabs) are placed into envelopes or other individual containers, to prevent cross-contamination while awaiting analysis. Smears for alpha and medium- or high-energy beta activity can be evaluated in the field by counting them on an integrating scaler unit with appropriate detectors; the same detectors utilized for direct measurements may be used for this purpose. However, the more common practice is to return the smears to the laboratory, where analysis can be conducted using more sensitive techniques.

6.4.5 Samples

Samples from a variety of locations may be required, depending upon the specific facility conditions and the results of scans and direct measurements. Inaccessible surfaces cannot be adequately evaluated by direct measurements on external surfaces alone; therefore those locations which could contain residual radioactive material should be accessed for survey. Residue can be collected from drains using a piece of wire or plumbers "snake" with a strip of cloth attached to the end; deposits on the pipe interior can be loosened by scraping with a hard tipped tool that can be inserted into the drain opening. Particular attention should be given to "low-points" or "traps" where activity would likely accumulate. The need for further internal monitoring and sampling is determined on the basis of residue samples and direct measurements at the inlet, outlet, cleanouts, and other access points to the pipe interior.

Residual activity will often accumulate in cracks and joints in the floor. These are sampled by scraping the crack or joint with a pointed tool, such as a screwdriver or chisel. Samples of the residue can then be analyzed; positive results of such an analysis may indicate possible subfloor contamination. Checking for activity below the floor will require accessing a crawl space (if one is present) or removal of a section of the flooring. Coring, using a commercially available unit, is a common approach to accessing the subfloor soil. After the core, ranging in diameter from a few cm to 20 cm, is removed, direct monitoring of the underlying surface can be performed and samples of soil collected.

Coring is also useful for collecting samples of construction material which may contain activity, which has penetrated to below the surface, or activity, induced by neutron activation. This type of sampling is also applicable to roofing material which may contain imbedded or entrapped contaminants. The profile of the distribution and the total radionuclide content can be determined by analyzing horizontal sections of the core.

If residual activity has been coated by paint or some other treatment, the underlying surface and the coating itself may be contaminated. If the activity is a pure alpha or low-energy beta emitter, measurements at the surface will probably not be representative of the actual residual activity level. In this case the surface layer is removed from a known area - usually 100 cm^2 - using a commercial stripping agent or by physically abrading the surface. The removed coating material is analyzed for activity content and the level converted to units of dpm/100 cm^2 for comparison with guidelines for surface activity. Direct measurements are performed on the underlying surface, after removal of the coating.

6.5 Grounds Surveys

6.5.1 Preparations

Similar considerations and actions to those taken for building surveys are necessary for preparing for surveys of site grounds. Equipment and materials which restrict surface access should be relocated; heavy ground cover should be removed and areas of standing water drained. (Sampling and analysis of standing water may be necessary to assure that it does not contain radioactive contaminants.) The reference grid is then established, as appropriate, based on the contamination potential of the area (Sections 4.2.1 and 4.2.2). Grids are usually marked by wooden or metal stakes, driven into the surface at grid line intersections. Where surface coverings prevent installation of stakes, the grid intersection can be marked by painting. The last step in site preparation is to prepare scale drawings of the survey areas, indicating facility features and the grid reference systems.

6.5.2 Scanning

Prior to sampling, surfaces are gamma scanned to identify the presence of elevated direct radiation, which might indicate residual gross activity or hot-spots. The most sensitive detection system available is used for these scans. The detector is kept as close as possible to the surface and is moved back and forth, while walking over the surface at a speed of about 0.5 m per second. For optimum detection sensitivity changes in the instrument response are monitored via the audible output, rather than by noting fluctuations in the analog meter reading. Locations of direct radiation, discernable above the ambient level, are marked on facility maps and identified for further measurements and/or sampling.

In addition to the gamma scans, paved areas are scanned for alpha and/or beta radiations. The same techniques are used as described in Section 6.4.2 for scans of building surfaces.

6.5.3 Direct Measurements

Direct measurements of surface activity levels are performed on paved surfaces, following the procedures described in Section 6.4.3 for building surfaces.

Exposure rate measurements are conducted at 1 m above the ground at systematic and random locations (Section 4.2.3) and at locations of elevated radiation, identified by area gamma scans. For high-energy gamma emitters, for which the predominant exposure pathway is direct gamma radiation (for example Co-60 and Cs-137), the exposure rate measurement above may be sufficient to demonstrate the guideline is satisfied. Some limited sampling will, however, be required to identify the radionuclide and to demonstrate that the residual activity is distributed in the surface layer of soil. Measurements of alpha and beta radiations on soil surfaces are generally not meaningful and are therefore not recommended for surveys to determine the final site status.

6.5.4 Removable Activity Measurements

It is unlikely that outside surfaces, exposed to wind and rain, will have significant levels of removable surface activity. If removable activity is suspected smears or swabs may be obtained and evaluated as described in Section 6.4.4.

6.5.5 Soil Sampling

Surface soil samples are collected from the top 15 cm of soil at locations established in Section 4.2.3. A sample size of approximately 1 kg is usually desirable, if gamma spectrometry is to be performed; if only wet chemistry analyses are to be performed, a sample size of 100 grams or less may be adequate, depending upon the specific laboratory procedures and the detection sensitivities required. The possibility of compositing certain groups of samples should also be considered when determining the quantity of sample to be obtained. Sampling may be conducted using a variety of simple hand tools, such as a shovel or trowel. If the sample is to be representative of a known surface area (for example when distribution patterns from airborne activity are of interest), special "cookie-cutter" type tools are used. Sampling tools are cleaned and monitored, as appropriate, after each use.

If there is a potential for soil activity beneath paved surfaces, the surface can be removed by coring and the underlying soil sampled, as described above for surface soils.

Grass, rocks, sticks, and foreign objects are removed from soil samples to the degree practical at the time of sampling. If there is reason to believe these materials contain activity they should be retained as separate samples.

Locations of known or suspected subsurface activity are sampled using the same grid block spacing and systematic pattern as used for surface areas of high contamination-potential. Subsurface soil may be sampled using portable manual equipment or, if the sampling depth is greater than several meters, heavier truck-mounted sampling rigs. For shallow subsurface sampling the hole is advanced to the desired starting depth, using a post-hole digger, shovel, twist auger, motorized auger, or punch-type shelby tube sampler. Loose material is removed from the hole and the sample collected over the next 15 or 30 cm depth. Continuous coring samplers or split-barrel samplers, advanced through hollow-stem augers, are usually used for obtaining deeper subsurface samples. The entire core can be retained and monitored, intact, to determine if layers of activity are present, or sections of the core can be removed for analysis. Unless there is prior information regarding the depth and distribution of subsurface activity, samples should be obtained at approximately 1 m intervals from the surface to below the suspected depth of the residual activity. Samples of subsurface water should also be collected, where available, to assist in evaluation of the migration of activity into the water table; expertise in such sampling should be sought to assure the validity of the resulting data.

Gamma logging of boreholes is performed to identify the presence of subsurface deposits of gamma-emitting radionuclides. A sensitive gamma detector such as a NaI gamma scintillation probe is lowered into the hole and a count rate determined at about 0.3 to 0.5 m intervals. The sensitivity and specificity cf this technique may be improved by placing the detector inside a shielded collimator assembly.

As was indicated in Section 4.2.5, electromagnetic sensing techniques are useful in locating potential areas of subsurface activity, due to buried piping, tanks, and former waste disposals. These techniques also increase surveyor safety by identifying buried utilities or containers of potentially hazardous material (radiological or chemical) which the surveyor will want to avoid disturbing.

Federal, state, and local agencies may have regulations restricting the drilling of boreholes and requiring special handling of drilling spoils and backfilling of holes. Surveyors should consult these agencies before initiating subsurface investigations.

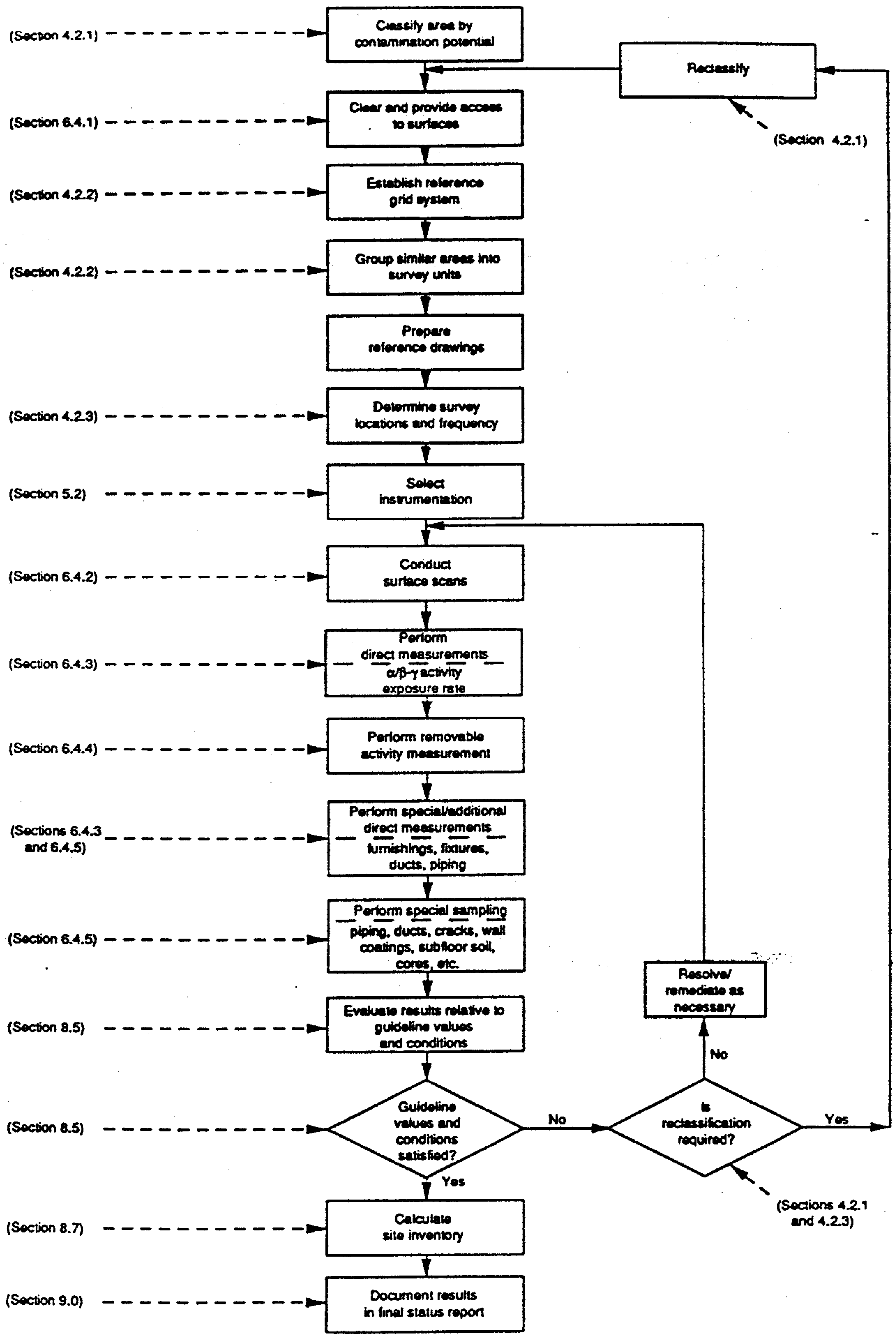


FIGURE 6-1: Flow Diagram for Final Status Survey of Buildings

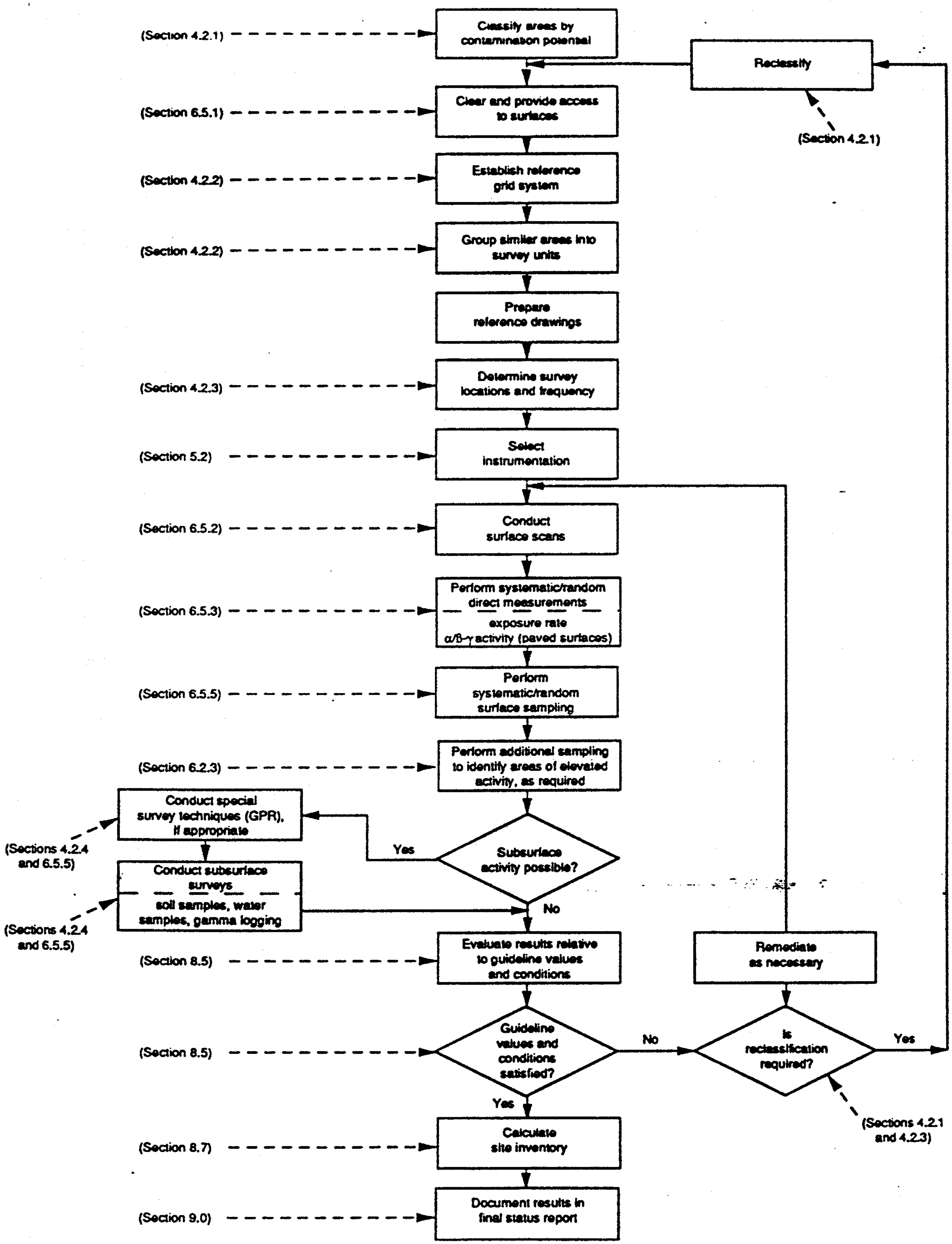


FIGURE 6-2: Flow Diagram for Final Status Survey of Site Grounds

7.0 SAMPLE ANALYSIS

7.1 Introduction

Samples collected during surveys for decommissioning purposes should be analyzed by trained individuals using the appropriate equipment and procedures. This manual assumes that the samples taken during the survey will be submitted to a well-established laboratory for analysis, using either in-house or contractor laboratory services. Whether the licensee uses in-house or contractor laboratory support, there should be written procedures that document the laboratory's analytical capabilities for the radionuclides of interest and a QA/QC program which assures the validity of the analytical results.

The most commonly used radiation detection measuring equipment for survey field applications has been described in Section 5.0. Many of those general types of devices are also used for laboratory analyses, usually under more controlled conditions which provide for lower detection limits and greater delineation between radionuclides. Laboratory methods often also involve combination of both chemical and instrumental technique to quantify the low levels expected to be present in samples from decommissioning facilities. This section describes laboratory methods applicable to most types of radiological surveys supporting license termination to assist the Manual user in selecting appropriate procedures for specific applications.

7.2 Prior Considerations

To reemphasize the point made in Section 3.0, a thorough knowledge of the radionuclides present, along with their chemical and physical forms and their relative abundance, is a prerequisite to selecting laboratory methods. With this information, it may be possible to substitute certain gross, that is, nonradionuclide specific, measurement techniques for the more costly and time-consuming wet chemistry separation procedures, relating the gross data back to the relative quantities of specific contaminants. The individual responsible for the survey should be aware that chemical analyses require lead times which will vary, according to the nature and complexity of the request. For example, a lab may provide fairly quick turnaround on gamma spectrometry analysis because computer-based systems are available for interpretation of gamma spectra. On the other hand, soil samples which must be dried and homogenized will require much longer lead time. Some factors influencing the analysis time include (1) the nuclides of concern, (2) the type of samples to be analyzed, (3) the QA/QC considerations required, (4) the availability of adequate equipment and personnel, and (5) the required detection limits.

For relatively, simple analyses, such as gross alpha and gross beta counting of smears and water samples, liquid scintillation spectrometry for low-energy beta emitters in smear and water samples, and gamma-spectrometry of soil, it is usually practical to establish in-house laboratory capabilities. The more complicated and labor-intensive procedures, such as alpha spectrometry, Sr-90 and low-energy beta emitters (H-3, Ni-63, etc.) samples should be considered candidates for contract laboratory analyses.

Analytical methods should be capable of measuring levels below the established release guidelines, detection sensitivities of 10 to 25% of the guideline should be the target. Although laboratories will state detection limits, these limits are usually based on ideal situations and may not be achievable under actual measurement conditions. Also, remember that detection limits are subject to variation from sample to sample, instrument to instrument, and procedure to procedure depending upon sample size, geometry, background, instrument efficiency, chemical recovery, abundance of the radiations being measured, counting time, self-absorption in the prepared sample, and interferences from other radionuclides present.

7.3 Sample Preparation

Various degrees of sample preparation may be necessary prior to direct measurement and/or wet chemistry procedures. The only treatment for smears (filter papers) before gross alpha/beta counting will be to wait until short-lived naturally occurring radon daughters, which may have been collected along with the other radionuclides of concern, have decayed to negligible levels. For the Ra-222 and the Ra-220 series decay times of 4 hours and 72 hours, respectively, are typically used. If liquid scintillation analyses are necessary, the smears may require oxidizing to separate the carbon-14 and tritium and place it into a liquid form for analysis; or the smears may need to be cut into small pieces before placing into the counting vial, to reduce the chances of attenuation of the scintillations by the smear papers.

Soil and sediment sample preparation includes removal of sticks, vegetation, rocks exceeding about 0.6 cm (1/4 inch) in diameter, and foreign objects. If non-volatile elements are the only contaminants of concern the samples are dried at approximately 110° C for a minimum of 12 hours; volatile radionuclides (H-3, Tc-99, and iodides) must be separated from the sample before drying to avoid loss of the radionuclide of interest. Dried samples are homogenized by mortar and pestle, jaw crusher, ball mill, parallel plate grinder, blender, or a combination of these techniques, and sieved to obtain a uniform sample. Sieve sizes from 35 mesh to 200 mesh are recommended for wet chemistry procedures. In addition, samples for chemical separations are also usually ashed in a muffle furnace to remove any remaining organic materials that may interfere with the procedures. Sample weights must be determined after drying and ashing procedures to enable referencing contamination levels back to weights of dry soil. To reduce the number of analyses required, multiple systematic or random samples from the same averaging region, i.e. equal aliquots from same grid block and same depth layer, may be combined into one composite sample. Traceability of components in a composite sample must be maintained, and the remainder of the individual samples should be retained to enable their analyses, in case the average value suggests the possibility of a hot-spot at one of the systematic or random sampling locations.

Water samples are usually prepared by filtration of suspended material using a 0.45 micrometer filter and acidification with nitric or hydrochloric acid to a pH of less than 2. This permits separate analyses of suspended and dissolved fractions and, if preparation is not performed promptly following collection, prevents loss of dissolved radionuclides by plating out on container surfaces.

7.4 Analytical Procedures

This section briefly describes specific equipment and/or procedures to be used once the medium is prepared for analysis. The results of these analyses, that is, the levels of radioactivity found in these samples, are the values used to determine the level of residual activity at a site. In a decommissioning effort, the release guidelines are expressed in terms of the concentrations of certain nuclides. It is of vital importance, therefore, that the analyses be accurate and of adequate sensitivity for the nuclides of concern.

An excellent source of information on a variety of topics, from detection equipment to chemical procedures, is equipment vendor literature, catalogs, and instrument manuals. Other references that should be considered are available from such organizations as National Council on Radiation Protection and Measurements (NCRP), the U. S. Environmental Protection Agency (EPA), the American Society of Testing and Materials (ASTM), the American Society of Mechanical Engineers (ASME), the DOE Technical Measurements Center (Grand Junction, CO), and the Environmental Measurements Laboratory (EML, formerly the Health and Safety Laboratory) of the U. S. Department of Energy (DOE). Table 7-1 provides a summary of the common laboratory methods with estimated detection limits.

TABLE 7-1
TYPICAL MEASUREMENT SENSITIVITIES FOR LABORATORY RADIOMETRIC PROCEDURES ASSOCIATED WITH TERMINATION SURVEYS

Sample Type	Radionuclides or Radiation Measured	Procedure	Approximate Measurement Sensitivity
Smears (filter paper)	Gross Alpha	Low-background gas proportional counter; 5-min. count	5 dpm
		Alpha scintillation detector with scaler; 5-min. count	20 dpm
	Gross Beta	Low background gas proportional counter; 5-min. count	10 dpm
		End window GM with scaler; 5-min. in count (unshielded detector)	80 dpm
	Low Energy Beta (H-3, C-14, Ni-63)	Liquid scintillation spectrometer; 5-min count	30 dpm
Soil Sediment	Cs-137, Co-60, Ra-226 (Bi-214)*, Th-232 (Ac-228)*, U-235	Gamma Spectrometry- Intrinsic germanium detector (25% relative efficiency); pulse height analyzer; 500-g sample; 15-min. analysis.	1-3 pCi/g
	U-234, 235, 238; Pu-238, 239/240; Th-228, 230, 232; other alpha emitters	Alpha spectrometry - pyrosulfate fusion and solvent extraction; surface barrier detector; pulse height analyzer; 1-g sample; 16-hour count	0.1-0.5 pCi/g
Water	Gross alpha	Low-background gas proportional counter; 100-ml sample, 200- min. count	1 pCi/l
	Gross beta	Low background gas proportional counter; 100-ml sample, 200-min. count	1 pCi/l
	Miscellaneous gamma emitter	Gamma spectrometry - 3.5 l sample 16-hour count	10 pCi/l
	Miscellaneous alpha emitter	Alpha spectrometry - 100 ml sample; 16-hour count	0.1-0.5 pCi/l
	H-3	Liquid scintillation spectrometry; 5-ml sample; 30-minute count	300 pCi/l

*Indicates number of daughter series, measured to determine activity level of parent radionuclide of primary interest.

7.4.1 Smear (Filter Paper) Counting

As a precaution against accidental contamination of the laboratory facility, it is prudent to first screen smears by gamma spectrometry or gross GM counting. If little contamination is expected, all smears collected at the facility (or in a particular survey area) may be assayed at once by placing all the smears on the detector. This will provide a broad screen for expected and unexpected contaminants. If contamination is detected, the smears should be recounted in smaller groups until the contaminated smears are isolated. Since the procedure is nondestructive, it will not interfere with subsequent analysis of the smears. When performing such screening, the smears should be left in their protective "envelopes" to avoid cross contamination.

Gross alpha/gross beta. The most popular method for laboratory smear analysis is to count both gross alpha and gross beta levels in a low-background proportional system; both automatic sampler changer and manual detector instruments are used. Such systems have low backgrounds, relatively good detection sensitivity, and the capability of processing large quantities of samples in a short time. Using counting times of several minutes, measurement sensitivities of less than 10 dpm alpha and 20 dpm beta can be achieved. Filter papers can also be measured using standard field instruments, such as alpha scintillation and thin-window GM detectors with integrating scalers (see Section 6.0 on instrumentation). The measurement sensitivities of such techniques are not nearly as low as the low-background proportional system; however, for 5-minute counting times, alpha and beta levels below 20 dpm and 100 dpm, respectively, can be measured. One of the major drawbacks to such a procedure is that it is very labor intensive.

Filter papers can also be covered with a thin circle of zinc sulfide scintillator and counted for gross alpha using a photomultiplier tube attached to a scaler. While such a system provides a sensitivity comparable to that of the low-background proportional counter, it is not usually automated and is, therefore, a labor intensive method.

Liquid Scintillation. Smears for low-energy beta activity (for example H-3, C-14, and Ni-63) can be placed directly into a scintillation cocktail and counted on a liquid scintillation spectrometer. The counting efficiency may be reduced; but as a screening method, this process will yield reasonable results. With the spectrum capability of the newer instruments, the analyst can (in most cases) identify the specific beta emitter(s) present. The introduction of the sample into the liquid scintillation medium produces **quenching**, a reduction in the efficiency of the scintillator as a result of the introduction of the sample. To evaluate the effect of quenching, an external standard may be used or a known amount of the identified radionuclide (referred to as an internal standard or spike) may be added to the sample after initial measurement and a recount performed to enable determination of the detection efficiency for the specific sample. It should be noted that even with the identification of the nuclide(s) on the smears, this is still a gross analysis; and caution is advised in trying to infer too much from this information.

7.4.2 Soil/Sediment Analysis

Gamma Spectrometry. After the soil or sediment has been prepared and placed in an appropriate container, the samples are counted. The analysis of soil or sediment is dependent on the radionuclides of interest. If the contaminants could include gamma emitters, the sample will be analyzed using gamma spectrometry (a non-destructive analysis that can identify and quantify multiple gamma-emitting nuclides). It is prudent to subject at least a representative number of soil or sediment samples to gamma spectral analysis, even if no gamma emitters are expected, as a check on the reliability of the identification of potential contaminants. Either solid-state germanium detectors or sodium iodide scintillation detectors may be used; a sodium iodide system typically has a higher detection efficiency but is not able to provide the resolution of the solid state detector, which is capable of resolving gamma photopeaks, having energies which differ by as little as 0.5 to 1 keV.

Although state-of-the-art systems include inherent computer-based spectrum analysis capabilities, it is important that an experienced analyst carefully review each spectrum, because at the low concentrations typically encountered in decommissioning surveys, resolutions, interferences, peak shifts, and linearity may not be readily apparent. Spectra should also be reviewed for gamma-photopeaks, not previously identified as principal facility contaminants of concern. Special attention should be given to those radionuclides which may have difficult to resolve photopeaks, for example Ra-226 (186.2 keV) and U-235 (183.7 keV), and select, secondary photopeaks or daughter photopeaks for calculations. An example would be the use of a daughter in the Ra-226 decay series, Bi-214 (609 keV peak), as an alternate for determining the quantity of Ra-226 present. When using such an approach, it is also necessary that the equilibrium status between the parent and the daughters be known.

Soil/sediment analysis by gamma spectrometry can be performed with relatively large samples, using geometries, such as a 0.5-liter Marinelli beaker and 100 to 400 ml cans or jars. With counting times of one-half hour or less, many commonly encountered radionuclides can be measured with measurement sensitivities of several pCi/g when using such sample geometries.

Alpha Spectrometry. Radionuclides emitting primarily alpha particles are best analyzed by wet chemistry separation, followed by counting to determine amounts of specific alpha energies present. Samples are fused at high temperatures into fluoride and pyrosulfate fluxes. This process ensures that all chemical species are in an ionic state that is more readily dissolved. (The process of leaching certain chemical forms of radionuclides from the soil matrix has been found to be less consistent than total dissolution of the sample matrix.) After dissolution, barium sulfate is precipitated to carry the alpha emitters out of solution. The precipitate is dissolved and the various nuclides are separated by oxidation-reduction reactions. After final separation and cleanup, the nuclides of interest are co-precipitated (with either neodymium or cerium fluoride) and collected on a filter paper. This precipitate is then counted using a solid-state surface barrier detector and alpha spectrometer.

A known amount of tracer radionuclide is added to the sample before the chemical separation, to determine the fraction of the radionuclide recovered in the procedure. This also provides a "calibration" of the analytical system for each sample processed. Lower limits of detection are less than 1 pCi/g using standard alpha spectrometry methods. Sample quantities for such procedures are typically a few grams or less.

<u>Liquid Scintillation</u>. If tritium is a radionuclide of concern, the tritium is separated by adding a known amount of low-tritium water and distilling the sample to collect the moisture. An aliquot of the collected moisture is then placed in a scintillation cocktail and counted using a liquid scintillation beta spectrometer. The activity is then related to the quantity of soil in the sample procedure or to the natural moisture content of the sample. Detection sensitivities below 1 pCi/g can be obtained with this method. An alternate technique utilizes an oxidizer to convert tritium to water vapor which is collected in a cryogenic liquid bubble trap. This is a faster method, but the amount of sample which can be processed is smaller and the sensitivity is, therefore, poorer than the distillation method.

A recently introduced analytical technique uses liquid scintillation counting to measure alpha-emitting contaminant concentrations. This system is known as PERALS (photon electron rejecting alpha liquid scintillator). While it does not provide the sensitivity and resolution capabilities of conventional alpha spectrometry, the wet chemistry procedures are less rigorous and results are obtainable in about one fourth of the time.

<u>Other procedures</u>. Analysis of soil/sediment samples for most pure beta radionuclides, such as Sr-90, Tc-99, and Ni-63, requires wet chemistry separation, followed by counting using liquid scintillation or beta proportional instruments. Each radionuclide (element) requires a specific procedure for the chemical separation; such detail is beyond the scope of this manual and the reader should consult the references given above for further information. As with the alpha spectrometry techniques, a known amount of tracer is added to the sample to determine recovery. Lower limits of detection of less than 1 pCi/g are achievable using standard methods.

7.4.3 Water Sample Analysis

Water samples may be directly counted for gamma emitters using equipment described for soil/sediment samples. Because the guideline levels for unrestricted use are much lower for water than for soil, the larger sample volumes (1 to 3.5 liters) and longer count times (up to 12 or 16 hours) may be necessary.

Gross alpha and gross beta analyses are conducted as screening techniques by evaporating a small (10 to 100 ml) volume of water to dryness and counting on a low-background gas proportional system. Measurement sensitivities of 1 pCi/l are obtainable. Because of the substantial sample thickness which may occur, self-absorption may be significant and corrections will be required. Samples containing more than 15 pCi/l gross alpha or 50 pCi/l gross beta should be analyzed for specific radionuclides. Care must be exercised when the water may contain tritium, technetium, or other volatile radionuclides. In such circumstances, direct analyses by liquid scintillation or a combination of wet chemistry and liquid scintillation may be required. Analyses for other specific radionuclides are conducted in a manner similar to that for soil/sediment.

8.0 INTERPRETATION OF SURVEY RESULTS

This Section describes methods for converting survey data to appropriate units for comparison with guideline values and evaluating data, relative to conditions, established for termination of the license. A flow diagram (Figure 8-1) and checklist are provided at the end of this Section to assist the user in these operations.

8.1 Data Conversion

Radiological survey data is usually obtained in units, such as counts per unit time, which have no intrinsic meaning relative to the guideline values. Therefore, the survey data from field and laboratory measurements are converted to units which will enable comparisons. Standard units used for expressing final status survey findings are:

- Surface Contamination — $\frac{dpm}{100\ cm^2}$ (disintegrations per minute per 100 cm^2)
- Soil Radionuclide Concentration — pCi/g (picocuries per gram)
- Exposure Rate — μR/h (microroentgens per hour)

In performing the conversions it is necessary to know several factors; these are:

c	total integrated counts recorded by the measurement
c/m	total countrate from an analog (rate) instrument
t	time period (minutes) over which the count was recorded
B	count during recording period, due only to background levels of radiation
B/m	background count rate on an analog instrument
E	detection efficiency of instrument in counts per disintegration
A	active surface area of the detector in cm^2
M	mass of sample analyzed in grams
2.22	factor to convert a disintegration rate to activity units of picocuries, i.e. dpm/pCi.

These factors are used in the equations in the remainder of Section 8.1.

8.1.1 Surface Activity

A measurement for surface activity is performed over an area, represented by the sensitive surface area of the detector. If the instrument display is in count rate, i.e. counts per minute, the conversion to dpm/100 cm^2 is performed by:

$$\frac{dpm}{100\ cm^2} = \frac{(c/m - B/m)}{E}\left(\frac{100}{A}\right) \tag{8-1}$$

For a technique using an integrated count on a digital instrument the conversion is:

$$\frac{dpm}{100\ cm^2} = \frac{(c-B)}{t \bullet E}\left(\frac{100}{A}\right) \tag{8-2}$$

The level of removable activity collected by a smear is calculated in the same manner, except, the detector area correction factor, $\frac{100}{A}$, is dropped from the equation because the smear is performed over a 100 cm^2 area and the detector area correction is usually considered when determining the efficiency, leaving:

$$\frac{dpm}{100\ cm^2} = \frac{(c-B)}{t \bullet E} \tag{8-3}$$

8.1.2 Soil Radionuclide Concentration

To determine the radionuclide concentration in soil in units of pCi/g the calculation performed is:

$$pCi/g = \frac{(c-B)}{t \bullet E \bullet 2.22 \bullet M} \tag{8-4}$$

If the analytical procedure includes a wet chemistry separation, it will also be necessary to correct for the fractional recovery (R), determined by a spike or tracer added to the sample.

$$pCi/g = \frac{(c-B)}{t \bullet E \bullet 2.22 \bullet M \bullet R} \qquad (8\text{-}5)$$

8.1.3 Exposure Rate

If an instrument, such as a pressurized ionization chamber or a "micro-R" meter is used for measuring exposure rate, the instrument reading will be directly in the desired exposure rate units of μR/h. A gamma scintillation or GM detector with a count rate or digital scaling instrument provides data in units of counts per minute or per some preset time, respectively. Conversion to μR/h is accomplished, using calibration factors developed for the specific instrument and survey site. The background exposure rate is then subtracted from the total to determine the net level, attributed to residual activity from licensed operations. This net level is compared with the guideline value.

$$\mu R/h = \frac{c/m}{\left[\frac{c/m}{\mu R/h}\right]^{*}} \text{ or } \frac{c}{t \bullet \left[\frac{c/m}{\mu R/h}\right]^{*}} \qquad (8\text{-}6)$$

*Site specific calibration factor for detector.

8.2 Measurement Uncertainty

It is recommended (EPA 1980) that each reported value include an assessment of its uncertainty. The rate of radioactive decay is not constant with time and is therefore described by a Poisson probability distribution. Based on such a distribution, the best estimate of the standard deviation (s) on a number of counts (c) is the square root of the counts, i.e.

$$s = \sqrt{c} \qquad (8\text{-}7)$$

and the standard deviation in a count rate over time (t) is therefore:

$$s_r = \frac{\sqrt{c}}{t} \qquad (8\text{-}8)$$

The ratio of the standard deviation to the total count (s/c) obviously decreases with the total count; in other words, the greater the number of counts recorded, the less the relative uncertainty in the measurement.

For the majority of measurements conducted during a final status survey, the number of counts due only to background will be a significant portion of the total count. The background also has an uncertainty associated with it which is taken into consideration by:

$$s_r = \sqrt{\frac{c}{t^2} + \frac{B}{t_B^2}} \qquad (8\text{-}9)$$

where

t_B is the time period over which the background count was determined.

The standard deviation or uncertainty in the count or count rate is converted to the same standard units used to express the measurement value, by use of the equations provided in Section 8.1. For survey and laboratory analytical data the uncertainty is usually given at the 95% confidence level which requires multiplying the standard deviation value by a factor of 1.96.

Unfortunately the uncertainty described above, commonly referred to as the "counting error," is only that due to the uncertainty in the decay process. Other sources of uncertainty will be present in the measurement and in other parameters used in the conversion calculations. Examples include the counting time, distance and area measurements, instrument efficiency, laboratory weights and physical measurements (e.g. pippetting), and chemical recovery factors. The total uncertainty associated with a particular type of measurement can be determined empirically by performing repeat (6 to 10 recommended) measurements of several selected locations and determining the average and standard deviation of the data. This will provide an estimate of the upper bound on the magnitude of systematic uncertainties. Additional guidance on identifying sources of uncertainty and estimating their magnitude is provided in (EPA 1980).

8.3 Minimum Detectable Activity

The concept of detection sensitivities was introduced and discussed in Section 5. For the purposes of thorough data presentation the minimum detectable activity (MDA) for each measurement procedure (and each instrument if more than one instrument is used for a given procedure) is calculated. Data from final status surveys will often be near background levels and/or below the detection sensitivity (MDA) of the procedure. Therefore negative data will be a frequent result of calculations. Use of the MDA for data that has a value less than the MDA is a common practice accepted by EPA (EPA 1989). This approach enables the surveyor to significantly reduce the number of calculations; however, use of the MDA, in place of actual data when calculating averages, will bias the results on the high side and the true conditions of the site will not be described. Substituting MDA's for actual data will also result in overestimates of source inventory and dose assessments, possibly leading to decisions for further actions that may not be justified. Finally, when evaluating data distributions, i.e. in a normalcy test, use of MDA's will result in a skewed distribution and may lead to an incorrect conclusion regarding the distribution. To avoid the pitfalls associated with use of MDA's, it is recommended that actual data be presented and used for calculational purposes. One exception to this approach might be the use of MDA's for averaging site activity levels, when the MDA is small in comparison to the applicable guideline; for the purposes of this manual, small may be considered as less than 10% of the guideline value.

8.4 Format for Data Presentation

All data from final status surveys should be presented in a format which provides (1) the calculated surface activity or specific radionuclide concentration value; (2) the estimated uncertainty at the 95% confidence level for that value; and (3) the estimated MDA for the measurement (EPA 1980). An example of such a format would be:

Sample ID	Radionuclide Concentration (pCi/g)		
	Activity	Uncertainty (95% confidence level)	MDA
001	6.1	1.5	0.6
002	-1.0	1.2	0.5
003	0.1	0.2	0.2

In expressing survey results, the number of significant figures is also of importance. The reason is that data should be reasonable and not mislead or imply a false level of accuracy in reported values. The appropriate number of digits in a value depends upon the magnitude of the uncertainty attached to that value. In general, final survey data, which are usually in the range of environmental data, seldom justify more than two or three significant figures for the value and one or two significant figures for the uncertainty (EPA 1980). The number of significant figures in the uncertainty is first determined and the value is stated to the last place affected by the uncertainty term. For example, if two significant figures are considered appropriate for the uncertainty, values might be reported as:

93	±	12
1060	±	130
0.33	±	0.17

If one significant figure is considered appropriate the same data would be reported as:

90	±	10
1100	±	100
0.3	±	0.2

To avoid truncation during calculations, all figures should be retained during arithmetic operations and the final results rounded to the desired number of significant figure. Rounding is done by increasing the last digit by 1, if the value to be dropped is equal to or greater than ½; if the value is less than ½, the last digit is left as is.

8.5 Comparison With Guideline Values

8.5.1 Removable Activity

Data for removable activity levels are compared directly to the guideline values. The limit for removable activity is 20% of the guideline value for total surface activity. If that level is exceeded, remediation and resurvey is necessary.

8.5.2 Elevated Areas of Activity

Levels of residual activity, i.e. elevated areas, which exceed the guideline value are initially compared directly with the guideline.

- <u>Buildings or Structures</u>

  The limit for activity on a building or structure surface is three times the guideline value, when averaged over an area of 100 cm^2. Residual activity exceeding this limit should be remediated and follow-up surveys performed. Areas of elevated activity between one and three times the guideline value are then tested to assure that the average surface activity level within a contiguous 1 m^2 area containing the elevated area is less than the guideline value.

  To evaluate whether this averaging condition is satisfied, additional measurements are performed, and the activity level and areal extent of the elevated area are determined. The average (weighted average) in the 1 m^2 area is then calculated, taking into consideration the relative fraction of the 1 m^2 occupied by the elevated area(s), using the relationship:

$$\bar{x}_w = \frac{1}{n_s} \sum_{i=1}^{n_s} x_i \left[1 - \sum_{k=1}^{n_k} A_k \right] + \sum_{k=1}^{n_k} y_k A_k \qquad (8\text{-}10)$$

where

$\bar{x}_w$	=	weighted mean including elevated area(s)
x_i	=	systematic and random measurements at point i
n_s	=	number of systematic and random measurements
y_k	=	elevated area activity in area k
A_k	=	fraction of 1 m^2 occupied by elevated area k
n_k	=	number of elevated areas.

Sample Calculation

The survey has identified an area of surface activity, having an average level of 7000 dpm/100 cm^2 and occupying an area of 800 cm^2. Five measurements in the contiguous 1 m^2, outside the elevated area, are each less than the guideline value of 5000 dpm/100 cm^2 and average 2300 dpm/100 cm^2. The weighted mean for the 1 m^2 area containing the elevated area is:

$$\bar{x}_w = 2300 \left[1 - \frac{800}{10000} \right] + 7000 \left[\frac{800}{10000} \right]$$

$$= 2116 + 560$$

$$= 2676 \text{ dpm/100 cm}^2$$

- soil

The limit for soil activity at any location is three times the average guideline value. Residual activity exceeding this level should be remediated and follow-up survey performed. Areas of elevated activity between one and three times the guideline value are then tested to assure that the average concentration is less than $(100/A)^{1/2}$ times the guideline value, where A is the area of the elevated activity in m^2. Levels exceeding this limit should be remediated. If this condition is satisfied, the average activity in the 100 m^2 contiguous area containing the region of elevated is then determined to assure that it is within the guideline value. Equation 8-10 is also used for this calculation, substituting 100 m^2 for the 1 m^2, used when calculating average surface activity.

Sample Calculation

Five systematic soil samples from a 100 m^2 grid block have the following concentrations of a specific radionuclide for which the guideline level is 10 pCi/g:

1.5 pCi/g
2.7 pCi/g
5.0 pCi/g
1.6 pCi/g
3.5 pCi/g

In addition, this area also contains a 20 m^2 elevated area with an average concentration of 15.5 pCi/g. Using the relationship of $(100/A)^{1/2}$ the 20 m^2 area would be permitted to have an average concentration of $(100/20)^{1/2}$ or 2.236 times the guideline value, i.e. 22.36 pCi/g. The activity level of 15.5 pCi/g in this elevated area satisfied this limit. The weighted average for the contiguous 100 m^2, containing the elevated area is:

$$\bar{x}_w = 2.9\left[1 - \frac{20}{100}\right] + 15.5\left[\frac{20}{100}\right]$$

$$= 2.32 \qquad + \qquad 3.10$$

$$= 5.42 \text{ pCi/g}$$

8.5.3 Exposure Rates

Exposure rate levels are compared directly with the guideline value. The maximum exposure rate may not exceed two times the guideline value, above background. If the level is above that value, the area should be remediated and resurveyed.

8.5.4 Calculating Average Levels

General surface activity, soil activity, and exposure rate guideline values are average values, above background, established for areas of survey unit surfaces (surface activity), 100 m^2 (soil activity and open land exposure rates), and 10 m^2 (indoor exposure rates). To enable comparison of the survey data with those guidelines, the mean ($\bar{x}$) of measurements in each of the survey units is calculated using all measurements (n_s) within that area:

$$\bar{x} = \frac{1}{n_s} \sum_{i=1}^{n_s} x_i \qquad (8\text{-}11)$$

8.5.5 Comparisons

Average levels, calculated following the procedures in Section 8.5.4, are compared with the guideline values and conditions. If the averages exceed the applicable guideline values and/or conditions, further remediation is required and follow-up measurements are performed to verify the effectiveness of the actions. After the averages satisfy the guideline values and conditions, the results are further evaluated to determine whether the data for each survey unit (i.e. group of contiguous grids or regions with the same classification of contamination potential), provides a 95% confidence level that the true mean activity level meets the guidelines.

The test is performed by calculating the average (equation 8-11) and standard deviation of the data for a particular radiological parameter in each survey unit using all measurement locations; the standard deviation is calculated by:

$$s_x = \sqrt{\frac{\sum_{i=1}^{n} (\bar{x}-x_i)^2}{n-1}} \qquad (8\text{-}12)$$

If there are areas of elevated activity in the survey unit, the weighted mean $\overline{x_w}$ (equation 8-10) for each 1 m^2 of building surface or 100 m^2 of land, containing an elevated area, is used as one of the x_i's in equations 8-11 and 8-12.

The Environmental Protection Agency (EPA 1989) has recommended the following equation for testing data, relative to a guideline value, at a desired level of confidence.

Caution: Calculator doesn't feed $\bar{x}$ & σ_{n-1} into equations

$$\mu_{\alpha} = \bar{x} + t_{1-\alpha,df} \frac{s_x}{\sqrt{n}} \tag{8-13}$$

where

- $t_{1-\alpha,\ df}$ is the 95% confidence level obtained from Appendix B, Table B-1: df (degrees of freedom) is n-1. α is the false positive probability, i.e. the probability that μ_{α} is less than the guideline value if the true mean activity level is equal to the guideline value.
- $\bar{x}$ is the calculated mean from equation 8-11.
- s_x is the standard deviation from equation 8-12.
- n is the number of individual data points used to determine $\bar{x}$ and s_x.

The value of μ_{α} is compared to the guideline value; if μ_{α} is less than the guideline, the area being tested meets the guideline at a 95% confidence level. This means that the probability is less than 5% that μ_{α} will pass the test, when the true mean activity level exceeds the guideline value.

<u>Sample Calculation 1</u>

Surface activity levels (dpm/100 cm^2) at 35 systematic locations in an affected area are:

4100	2190	<460	4000
3250	1430	1380	<480
2120	4370	1840	2060
2600	2390	2160	1970
4750	3710	4020	2350
2000	1220	2030	
3140	1250	1700	
1790	4390	1510	
2000	<460	2420	
3630	4130	3430	

Instrument background has already been subtracted for this surface activity measurement.

The mean and standard deviation are:

$\bar{x}$ = 2478 dpm/100 cm² (from equation 8-11)* Calculator
s_x = 1196 dpm/100 cm² (from equation 8-12) Calculator > Same

$t_{1-\alpha,\ df}$ = 1.692 for 34 degrees of freedom (Table B-1)

$$\mu_\alpha = 2478 + 1.692\ \frac{1196}{\sqrt{35}} = 2820\ \text{dpm}/100\ \text{cm}^2$$

*Only minimum detectable activity (MDA) values were available for some measurement locations in this example; the MDA values were therefore used as actual activity levels for the purpose of performing this calculation.

The site-specific guideline value for the site is 5000 dpm/100 cm^2. Because μ_α is less than 5000 dpm/100 cm^2, the data for this survey unit satisfy the guideline at the 95% confidence level.

Sample Calculation 2

Concentrations of net (background subtracted) activity at 20 random soil sampling locations are:

1.2	pCi/g	1.5	pCi/g
2.3	pCi/g	2.7	pCi/g
4.4	pCi/g	5.0	pCi/g
2.3	pCi/g	1.6	pCi/g
3.4	pCi/g	3.5	pCi/g
1.6	pCi/g	3.1	pCi/g
0.9	pCi/g	1.7	pCi/g
1.6	pCi/g	1.1	pCi/g
3.3	pCi/g	1.4	pCi/g
2.4	pCi/g	2.2	pCi/g

The guideline value for the site is 4 pCi/g, above background.

Although two of the samples contain activity levels above the guideline value, they satisfy the condition of the maximum concentration being less than three times the guideline value. For the purpose of this example it is assumed that the elevated areas have been tested (Section 8.5.2) and satisfy the conditions for accepting elevated areas.

The mean and standard deviation for this group of data are:

$\bar{x}$ = 2.36 pCi/g (from equation 8-11)
s_x = 1.12 pCi/g (from equation 8-12)

$t_{1-\alpha,\, df}$ = 1.729 for 19 degrees of freedom (Table B-1)

$$\mu_\alpha = 2.36 + 1.729\frac{1.12}{\sqrt{20}} = 2.79 \text{ pCi/g}$$

Comparison of μ_α (2.79 pCi/g) with the guideline value (4 pCi/g) indicates that the guideline has been satisfied at the desired level of confidence.

Areas for which μ_α is $\leq$ the guideline values by this testing procedure are considered acceptable and no further survey actions are required. If the mean value exceeds the guideline value, the area is not acceptable and further cleanup is required. If the mean value is less than the guideline value, but the test of confidence is inconclusive, i.e. $\bar{x}$ < guideline value $< \mu_\alpha$, either (1) further cleanup with follow-up measurements/sampling or (2) additional measurements/sampling may be conducted.

The technique described above provides a conservative approach, because it gives equal weight to systematic and random measurements and to the weighted means of areas of elevated activity, which may be associated with much smaller surface areas than are the systematic and random measurements. An alternate approach to provide a less based estimate of the mean activity level is as follows.

Calculate the sample mean, $\bar{y}_k$, and sample variance, s_{yk}^2, for elevated level, k, of area, A_k.

$$\bar{y}_k = \frac{1}{n_k}\sum_{j=1}^{n_k} y_{kj} \tag{8-14}$$

$$s_{yk}^2 = \frac{1}{n_k - 1}\sum_{j=1}^{n_k} (\bar{y}_k - y_{kj})^2 \tag{8-15}$$

The weighted average $\overline{x_w}$ is then calculated by:

$$\overline{x_w} = \bar{x}(1-A) + \sum_{k=1}^{n_H} A_k \, \overline{y_k} \tag{8-16}$$

and the estimated variance of $\overline{x_w}$ is:

$$s_w^2 = \frac{(1-A)^2 \, s_x^2}{n_s} + \sum_{k=1}^{n_H} \frac{A_k^2 s_{yk}^2}{n_k} \tag{8-17}$$

The value, μ_α, for testing the weighted average is calculated by:

$$\mu_\alpha = \overline{x_w} + t_{1-\alpha,\, df} \bullet s_w \tag{8-18}$$

The value of $t_{1-\alpha,\, df}$ is obtained from Appendix B, Table B-1; the degrees of freedom are determined by:

$$df = \frac{S_w^4}{D} \tag{8-19}$$

and

$$D = \frac{(1 - A)^4 S_x^4}{n_s^2(n_s-1)} + \sum_{k=1}^{n_H} \frac{A_k^4 S_{yk}^4}{n_k^2 \, (n_k-1)} \tag{8-20}$$

8.6 Identifying Additional Measurement/Sampling Needs

If μ_α calculated in the previous section is greater than C_G (NRC guideline value), there are two possibilities. If $\bar{x} \geq C_G$, a cleanup is required. However, if $\bar{x} < C_G$, a larger sample might be able to demonstrate compliance. The sample mean $(\bar{x})$ and standard deviation(s) for a given sample size were calculated in the previous Section using equations 8-11 and 8-12. Using these parameters, the total number of data points (n_1) which would be required to demonstrate that the activity level satisfies the guideline value at the desired level of confidence, is determined by:

$$n_1 = \left[\frac{s_x}{C_G - \bar{x}}\right]^2 [Z_{1-\alpha} + Z_{1-\beta}]^2 \qquad (8\text{-}21)$$

where

n_1	=	number of data points required
C_G	=	guideline value
$\bar{x}$	=	mean
s_x	=	sample standard deviation
$Z_{1-\alpha}$, $Z_{1-\beta}$	=	standard normal variables: α is the false positive probability, i.e. that $\mu_\alpha < C_G$, if the true mean activity is equal to C_G, and β is the false negative probability, i.e. that $\mu_\alpha > C_G$, if the true mean activity is equal to C_G.

Table B-2 (Appendix B) has been provided for ease of estimating the total number of data-points required to demonstrate meeting guidelines at a false positive level of 5% and a false negative level of 10%. Subtracting the number of data points already collected (n) from this total calculated number (n_1), determines the number of additional measurements or samples which will be required to demonstrate the desired confidence of the data. If this calculation indicates that additional data are needed from a survey unit to demonstrate meeting the guideline, it is recommended that they be collected uniformly over the area, using the same sampling methodology as that used for the first samples. To demonstrate compliance, μ_α is based on all data points; thus additional data are combined with the original data and the acceptance testing repeated. The process of determining additional samples to try to meet the guideline can only be done one time. If the additional samples do not bring μ_α below the guideline, additional remediation will be required.

Sample Calculation:

Ten measurements have a mean of 7.0 pCi/g with a standard deviation of 2.8 pCi/g. The guideline value is 8.0 pCi/g.

$$\mu_{\alpha} = 7.0 + 1.833 \frac{2.8}{\sqrt{10}} = 8.6 \ pCi/g$$

Although the mean is less than the guideline value, the test for significance is not satisfied at the 95% confidence level. The total number of measurements (n_1) required to achieve acceptance is determined from Table B-2, for the value of

$$\frac{C_G - \bar{x}}{s_x} = \frac{8.0-7.0}{2.8} = 0.36$$

n_1 = 68 measurements

An additional 58 (68-10) measurements are required to demonstrate acceptance.

Determining Numbers of Background Data Points

As discussed in Section 2.3.1, the average background level determined from an initial 6-10 measurements or samples is adequate for use in evaluating radiological conditions, relative to a specific guideline value, when that average background is insignificant relative to the guideline. For the purposes of this Manual, the background has been considered insignificant if it is <10% of the guideline, although the licensee may use such background levels in determining net residual activity, following the methodology described below. When the background level is significant relative to the guideline value, i.e. >10% of the guideline, however, it is necessary that the average background determined is representative of the true background level to assure correct decisions in the final assessing site conditions. The objective for background determination is that the average level should accurately represent the true background average to within ± 20% at the 95% confidence level. Selection of this criteria for defining an acceptable accuracy for background determinations is arbitrary, based on the natural variations (of background levels) occurring in the environment and the need to keep the effort and cost devoted to background determination reasonable.

The total number of background measurements needed to satisfy the objective is calculated by:

$$n_B = \left[\frac{t_{95.5\%,df} \bullet s_x}{0.2 \bullet \bar{x}_B}\right]^2 \qquad (8\text{-}22)$$

where

n_B	=	number of background measurements required
$\bar{x}_B$	=	mean of initial background measurements
s_x	=	standard deviation of initial background measurements
$t_{95.5\%, df}$	=	t statistic for 95.5% confidence at df=n-1 degrees of freedom, where n is the number of initial background data points

Table B-1 (Appendix B) contains a list of values for the $t_{95.5}$ statistic at various degrees of freedom. Subtracting the number of data points already collected (n) from this total calculated number (n_B), determines the number of additional measurements or samples which will be required to demonstrate the desired confidence of the data. If this calculation indicates that additional background data are needed, it is recommended that they be collected uniformly over the area, using the same sampling methodology as that used for the initial samples. The average background is then recalculated using all data points.

Sample Calculation:

Seven soil samples, collected for determining the background level of U-238, contained the following concentrations:

1.3	pCi/g
0.6	pCi/g
0.9	pCi/g
1.6	pCi/g
1.8	pCi/g
1.5	pCi/g
2.0	pCi/g

The mean (equation 8-11) and standard deviation (equation 8-12) for these data are calculated to be 1.39 pCi/g and 0.50 pCi/g, respectively; the t statistic (Table B-1, column 2) is 2.447 for 6 degrees of freedom. The total number of determinations required to establish the average background to within ± 20% of the true average at the 95% confidence level is calculated by:

$$n_1 = \left[\frac{2.447 \bullet 0.50}{0.2 \bullet 1.39}\right]^2 = 19.4$$

This calculation indicates a need for a total of 20 data points, or 13 additional (20-7) data points to satisfy the statistical objective for this case.

8.7 Calculating Site Inventory

The total residual activity is calculated for each radionuclide by determining the mean level for each survey unit, multiplying that average by the surface area or soil volume of the unit, and then summing all survey unit activities. The inventory will allow comparison of total residual activity at the site with established limits and development of a source term for estimating potential future impacts on public health and safety and on the environment.

Sample Calculation:

A site contains 3 interior building rooms and one land area which have been determined to have residual activity from the licensed operations. The three rooms have mean residual surface activity levels of 4100 dpm/100 cm^2, 2700 dpm/100 cm^2, and 3000 dpm/100 cm^2; the affected surface areas in these three rooms are 900 m^2, 1100 m^2, and 750 m^2, respectively.

The land area has a mean concentration of 7.3 pCi/g in the top 15 cm over 300 m^2 and one deeper region of residual activity occupying a volume of 10 m^3 and having a mean concentration of 30 pCi/g.

The total activity is calculated as follows:

Building Area 1

$$4100 dpm/100 cm^2 \bullet 900 m^2 \bullet \frac{10^4\ cm^2}{m^2} \bullet \frac{1\ pCi}{2.22\ dpm}$$

$$= 1.66 \bullet 10^8 \text{ pCi}$$

Using the same method, Building Area 2 and Building Area 3 contain total activity levels of 1.34 • 10^8 pCi and 1.01 • 10^8 pCi, respectively. Total residual activity in the three Building areas is 4.01 • 10^8 pCi.

Outside Area

Surface:

$$7.3\ pCi/g \bullet 0.15\ m \bullet 300\ m^2 \bullet 10^6 \frac{cm^3}{m^3} \bullet 1.6 \frac{g}{cm^3}$$

$= 5.26 \bullet 10^8$ pCi

Subsurface Region:

$$30\ pCi/g \bullet 10\ m^3 \bullet 10^6 \frac{cm^3}{m^3} \bullet 1.6 \frac{g}{cm^3}$$

$= 4.80 \bullet 10^8$ pCi

Total Site Inventory

$$\begin{array}{rr} & 4.01 \bullet 10^8 \text{ pCi} \\ & 5.26 \bullet 10^8 \text{ pCi} \\ + & 4.80 \bullet 10^8 \text{ pCi} \\ \hline & 14.07 \bullet 10^8 \text{ pCi} \end{array}$$

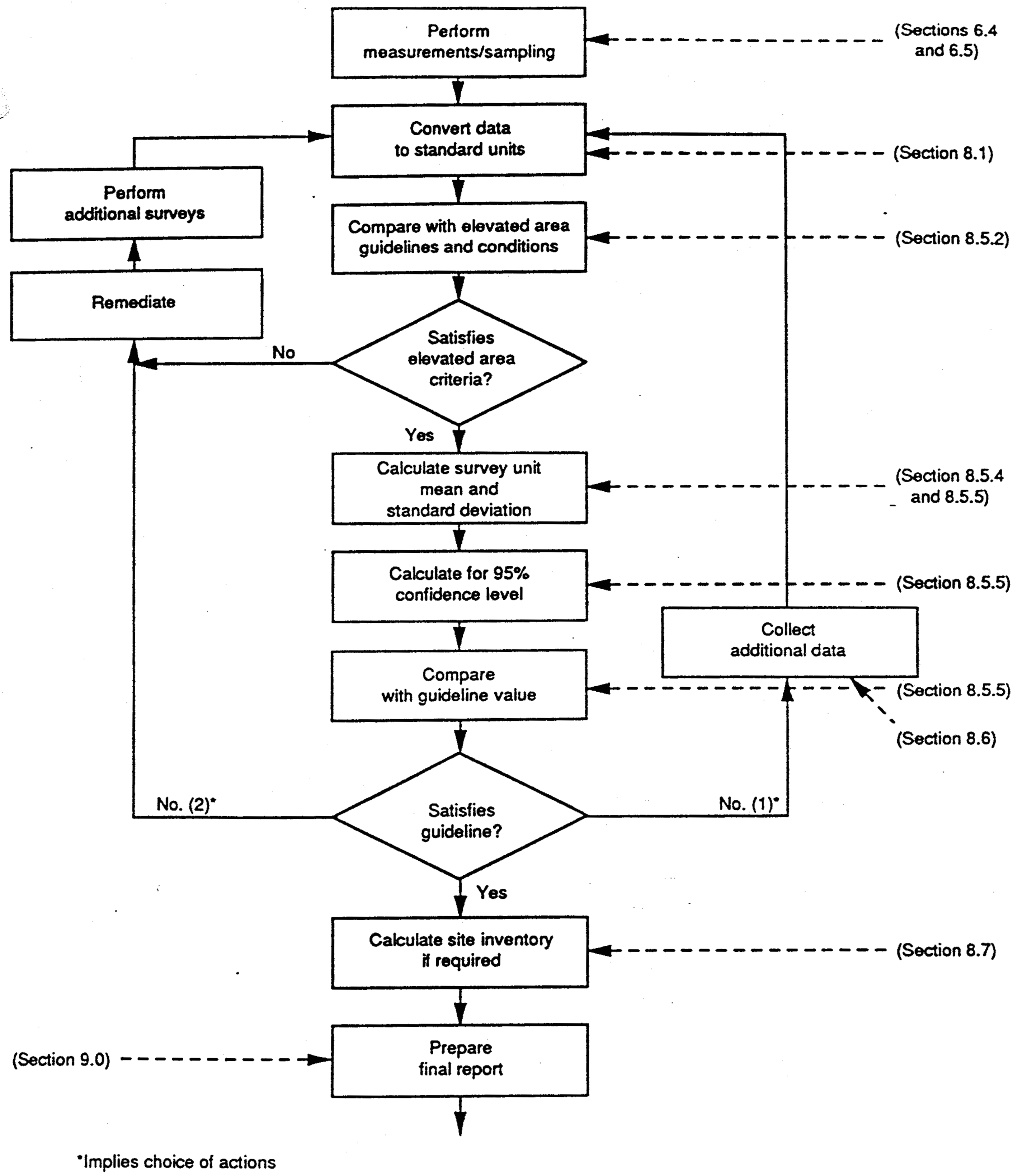


FIGURE 8-1: Flow Diagram for Interpreting and Comparing Survey Data with Guideline Value

CHECKLIST FOR INTERPRETING SURVEY RESULTS

_____ 1. Convert survey results to same units as guidelines.

_____ 2. Compare elevated areas with guideline conditions; if conditions are not satisfied, remediate and resurvey.

_____ 3. Calculate mean and standard deviation of all measurements within survey unit.

_____ 4. Calculate the upper confidence limit (μ_α) for the data set.

_____ 5. Compare μ_α with guideline value; if acceptance criteria is not achieved, determine number of additional measurements required.

_____ 6. Decide whether to perform additional measurements or to conduct further cleanup and follow-up surveys to demonstrate acceptance.

_____ 7. Conduct additional remediation and/or measurements; repeat checklist for new or additional data.

_____ 8. Calculate total site inventory.

9.0 SURVEY DOCUMENTATION AND REPORTS

Documentation for final status surveys should provide a complete and unambiguous record of the radiological status of the site/facility, relative to established guidelines for the license termination. In addition, sufficient information and data should be provided to enable an independent re-creation and evaluation at some future date of both the survey activities and the derived results. Much of the information in the final status report will be available from the decommissioning plan; the written survey plan and/or the survey design document; and the various report requirements inherent in the accountability program of the survey procedures (that is, lab reports, reports of survey findings, QA documentation, chain-of-custody forms, etc.).

To the extent practicable, the final status survey report should stand on its own with minimal information incorporated by reference. This section will assist in determining the basic content of the report by providing a comprehensive, annotated outline. Although site-specific conditions or criteria may require some modification, this basic outline may be used for the report. A sample final status survey report for the hypothetical Reference Uranium Fuel Fabrication Plan is provided in Appendix D. Certain support or related information related to the decommissioning process, such as health physics practices for personnel conducting decontamination and waste volumes generated are provided as part of the decommissioning plan and/or final project report. For convenience, the licensee may also incorporate this information into the final status survey report.

Final Status Survey Report for Decommissioning
[Facility Name]

BACKGROUND

REASON FOR DECOMMISSIONING

[Identify the reason that the facility is to be returned to unrestricted use; for example, age of facility, relocation of process activity, geographic or environmental concerns, planned future uses, etc.]

MANAGEMENT APPROACH

[Provide very broad statements concerning conceptual designs, general considerations, management philosophy, regulatory requirements, reasons for certain approaches, etc. Discuss assigned management responsibilities for QA/QC activities and for health and safety activities during the survey process. List any special training and/or qualifications that the management team may have. (Note: Information concerning cost estimations, funding, or scheduling may be included here.]

SITE DESCRIPTION

[Describe the physical characteristics of the building and provide enough information to distinctly identify which facility or portion of a facility is to be decommissioned. Refer to Manual Section 4.0 for additional details on the types and sources of information to be covered in the site description section.]

TYPE AND LOCATION OF FACILITY

[Discuss the type of facility, such as a research facility, light-water reactor, radiopharmaceutical facility, nuclear laboratory, etc. Include specific activities performed. Identify the location of the facility, including geographic location, state or local vicinity, building-specific information, etc.]

OWNERSHIP

[Identify who owns the facility and how the ownership is structured; that is, state or national government owned, private corporation, parent company, academic institution, etc. If there have been multiple owners, provide a history of the ownership.]

FACILITY DESCRIPTION

[Include information on buildings, grounds, and any relevant topographical information that may have been a factor in the extent of contamination. Submit available drawings or photos that are relevant to the survey.]

BUILDINGS

[Include information on the size; construction materials; contents; roofs and release points; condition of surfaces after decontamination; and special considerations or problems such as inaccessible areas, expansion joints or floor penetrations, and piping. Include locations and use of any buildings that may have been razed or remodeled or whose use has been changed over the life of the facility.]

GROUNDS

[Discuss the size, topography, meteorology, demographics, vegetation, access routes, subsurface features, buried waste, water courses, surface water runoff, outfall, etc. that may affect the area to be surveyed or the location or extent of contamination.]

OPERATING HISTORY

[Identify the types and dates of specific operations and/or uses of particular chemical or radiological processes that have evolved over the life of the facility, including uses of the site before licensed operations. Refer to Sections 3.0 and 4.0 for more details on information to be included in the operating history section of the termination survey report.]

LICENSING AND OPERATIONS

[Include the draft number and license number and issuance date for every license the facility has been issued. Indicate the type of work activity at every operating phase and the buildings and/or geographic locations wherein each licensed activity was performed.]

PROCESSES PERFORMED

[Specify every type (chemical and physical form) of radionuclide used and indicate the quantity required for each operation involved over the life of the facility. Be specific about the processes performed, the specific (and relevant) chemicals and/or radionuclides involved, the locations of each process performed over the life of the plant, related activities, etc. Also, discuss the containment practices for all radiation sources.]

Waste-Disposal Practices

[Discuss any disposal practices that may have impacted the contamination status of the facility. Include any incident reports and significant spills.]

Decommissioning Activities

[Discuss any relevant political, philosophical, or environmental considerations that may have influenced the method of decommissioning selected. Identify any agencies whose philosophy or methodologies (and/or procedures) were chosen for modeling and specify why those were selected.]

Objectives

[Broadly discuss what was to have been accomplished and why. Set the parameters (especially the limitations) within which the decommissioning activities were confined.]

Results of Previous Surveys

[Generalize the results of previous surveys in the chronological sequence in which they were performed. Discuss the activities of subsequent surveys as they address findings in earlier surveys. Include results of preliminary surveys, characterization surveys, etc. Refer to Section 2.0 for additional information on the different types of surveys that may have been performed prior to the final status survey.]

Decontamination Procedures

[Discuss the specific procedures used to decontaminate the facility. Identify the organization who performed the decontamination and discuss their credentials and related expertise. Cover information on demolition and dismantling, including shipping, storage, and disposal of materials at a safe storage facility or landfill approved for radioactive waste. Discuss any security precautions and safeguards that may have been taken.]

Final Survey Procedures

[Discuss general approach and list philosophy of (or reasons for selecting) that approach. Refer to any unique conditions that may have been discovered in earlier surveys which relate to the written survey plan.]

SAMPLING PARAMETERS

[Summarize information concerning grid placement, specific areas scanned, accessibility restrictions, sampling criteria, defining parameters, types of samples taken (soil, water, etc.) and any special precautions taken to ensure readings are accurate. Include procedures used for determining sample analysis. Identify the areas that had low, medium, and high potential for contamination. Discuss how samples were taken at effluent systems (air handling systems, drains, sumps, and sewers. See Sections 2.0 - 7.0 for information to include in this portion of the survey report.]

BACKGROUND/BASELINE LEVELS IDENTIFIED

[Discuss the background and baseline levels established for the site. Identify how these levels were determined. (See Sections 2.0 and 6.0)]

MAJOR CONTAMINANTS IDENTIFIED

[Discuss the major contaminants. Include the concentration levels and locations of each radionuclide of interest. Refer to the sources from the plant history if known.]

GUIDELINES ESTABLISHED

[Discuss each agency whose guidelines had to be met before the facility could be released. Identify all procedures and regulations and define the release criteria that had to be met. See Section 3.0 for additional information.]

EQUIPMENT AND PROCEDURES SELECTED

[Discuss the philosophy behind the selection of instruments and procedures. Cite any special conditions that may have required deviating from normal practices. Define which radionuclides were present and explain how instrumentation was selected to best detect their particle-emitting characteristics. Additional information is available in Sections 3.0 - 7.0.]

INSTRUMENTS AND EQUIPMENT

[Specifically identify all equipment and instrumentation used in the survey procedures. If the criteria upon which each instrument was selected was not included in the previous subheading, elaborate on the radionuclides of interest and the associated detecting instrument chosen. Discuss calibration procedures used as well as instrument sensitivities and detection limits.]

Instrument Use Techniques

[Discuss the procedures and techniques used in operating the instruments or equipment used in the survey.]

Procedures Followed

[Discuss the procedures used in the survey process, including statistical methodologies used to determine the number of samples required, QA/QC procedures, field and laboratory techniques, and methods of sampling and disposing of contaminated materials used during the survey. See Sections 4.0 - 7.0, for additional information that should be discussed in this subsection of the final status survey report.]

Surveying Organization

[Identify the surveying organization and include any particular expertise or credentials that establishes their credibility.]

Survey Findings

[Discuss the general condition of the site as determined by the survey. Evaluate reasons for any significant differences found between the final status survey and any previous surveys. Prepare and reference (1) tables of survey data and (2) graphic representations of findings to be included in this section. Reference techniques for reducing and evaluating the data in the following subsections.]

Techniques for Reducing/Evaluating Data

[Describe the computational methods used to convert raw data into conventional units and to evaluate average and/or "hot spot" activity levels. Include formulas and/or examples where appropriate.]

Statistical Evaluation

[Provide an explanation of the statistical methodology used to evaluate the survey findings. That is, show how the statistical method used provides a true representation of the data in relation to the applicable guideline values.]

Comparison of Findings with Guideline Values and Conditions

[Provide a table and any supporting text that is needed to compare the findings with the release criteria established by the regulatory agencies. Include criteria from any state, local, or other federal agencies who, in addition to NRC, may have jurisdiction. Reiterate how QA/QC procedures, survey procedures, documentation procedures, etc. comply with guidelines established by the NRC or other regulatory agency. Use procedures listed in this document (Sections 2.0 - 8.0) as a resource.]

Summary

[Provide an overview of the entire program. One or two sentence summaries of each section and/or subsection should provide the information that should be included in the summary. The concluding paragraph should state that according to the findings of the final status survey, the release criteria have been met and the license is applying for license termination.]

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12.0 GLOSSARY

Activity: A measure of the rate at which radioactive material is undergoing radioactive decay, usually given in terms of the number of nuclear disintegrations occurring in a given quantity of material over a unit of time. The unit of activity is the curie (Ci) Also, known as **Radioactivity.**

Alpha Particle: A positively charged particle emitted by some radioactive materials undergoing radioactive decay. Alpha particles are the least penetrating of the three common forms of radiation (alpha, beta, gamma); they can be stopped by a sheet of paper and cannot penetrate skin.

Background Radiation: Naturally occurring radiation in the human environment. It includes cosmic rays, radiation from the naturally radioactive elements, and man-made radiation from global fallout.

Beta Particle: An electron emitted from the nucleus during radioactive decay. Beta particles are easily stopped by a thin sheet of metal or plastic.

Byproduct Material: Radioactive materials resulting from the production or processing of nuclear materials.

Characterization Survey: Facility or site sampling, monitoring, and analysis activities to determine the extent and nature of contamination. Characterization provides the basis for acquiring the necessary technical information to develop, analyze, and select appropriate cleanup techniques.

Cleanup: Actions taken to remove a hazardous substance that could affect humans and/or the environment. The term "cleanup" is sometimes used interchangeably with the terms **Remedial Action, Remediation,** and **Decontamination.**

Confirmatory Survey: limited independent (third-party) measurements, sampling, and analyses to verify the findings of a final status survey.

Contamination: The presence of residual radioactivity, in excess of levels which are acceptable for release of a site or facility for unrestricted use.

Criteria (release criteria): Combination of numerical activity guideline levels and conditions for their application. If criteria are satisfied, the site may be released without restrictions.

Curie: A measure of the rate of radioactive decay. One curie (Ci) is equal to 37 billion disintegrations per second (3.7×10^{10} dis/s), which is approximately equal to the decay of one gram of radium-226. Fractions of a curie, e.g. picocurie (pCi) or 10^{-12} Ci and microcurie (μCi) or 10^{-6} Ci, are levels typically encountered in the decommissioning process.

Decay: The spontaneous radioactive transformation of one nuclide into a different nuclide or into a lower energy state of the same nuclide. Also, known as **Radioactive Decay.**

Decommissioning: The process of removing a facility from operation, followed by decontamination, and license termination.

Decontamination: The removal of unwanted radioactive material from facilities, soils, or equipment. Also, known as **Remediation, Remedial Action,** and **Cleanup.**

Derived Guideline: Levels of radioactivity presented in terms of ambient radiation, surface activity levels, and soil activity concentrations; these levels are derived from activity/dose relationships through various exposure pathway scenarios. Also known as Guidelines.

Detection Sensitivity: The ability to identify the presence of radiation or radioactivity. Also see **Minimum Detectable Activity.**

Direct Measurement: Radioactivity measurement obtained by placing the detector against the surface or in the media being surveyed. The resulting radioactivity level is readout directly.

Dose Commitment: The dos that an organ or tissue would receive during a specified period of time (e.g., 50 or 70 years) as a result of intake (as by ingestion or inhalation) of one or more radionuclides from a given release.

Dose Equivalent (Dose): A term used to express the amount of effective radiation when modifying factors have been considered. It is the product of absorbed dose (rads) multiplied by a quality factor and any other modifying factors. It is measured in rem (roentgen equivalent man).

Exposure Rate: The amount of ionization produced per unit time in air by X-rays or gamma rays. The unit of exposure rate is roentgens/hour (R/h); for decommissioning activities the typical units are microroentgens per hour (μR/h), i.e. 10^{-6} R/h.

Final Status Survey: Measurements and sampling to describe the radiological conditions of a site, following completion of decontamination activities (if any) and in preparation for unrestricted release.

Gamma Radiation: Penetrating high-energy, short-wavelength, electromagnetic radiation (similar to X-rays) emitted during radioactive decay. Gamma rays are very penetrating and require dense materials (such as lead or uranium) for shielding.

Grid: System of coordinates established on a site for purposes of referencing survey locations. Also, known as **Reference Grid System.**

Grid Block: Standardized averaging (1 m^2 for building interiors and 100 m^2 for soil areas).

Ground Penetrating Radar (GPR): Electromagnetic radiation, used to identify electrically reflective targets, voids, and differences in moisture content of subsurface soil. GPR is used to identify buried objects and materials for guiding subsoil sampling.

Half-Life: The time it takes for half the atoms of a quantity of a particular radioactive element to decay into another form. Half-lives of different isotopes vary from millionths of a second or less to billions of years.

Hot Spot: Small, isolated location where radiation or radioactivity level is higher than the guideline level but satisfies other conditions (see Sections 2.2 and 8.6.2).

Inventory: Total residual quantity of formerly licensed radioactive material at site.

License: Authorization by NRC to possess, use, transfer, etc. radioactive materials for specified applications and under established conditions.

License Termination: Discontinuation of a license -- the eventual conclusion to decommissioning.

Minimum Detectable Activity (MDA): The minimum level of radiation or radioactivity that can be measured by a specific instrument and technique. The MDA is usually established on the basis of assuring false positive and false negative rates of less than 5%.

Quality Assurance/Quality Control: A system of procedures, checks, audits, and corrective actions to ensure that design, performance, monitoring and sampling, and other technical and reporting activities are of the highest achievable quality.

Radionuclide: An unstable nuclide that undergoes radioactive decay.

Release Criteria: Numerical guidelines for direct radiation levels and levels of radioactivity in soil on surfaces which are considered to be acceptable within a given set of conditions and applications.

REM (<u>R</u>oentgen <u>E</u>quivalent <u>M</u>an): A quantity used in radiation protection to express the effective dose equivalent for all forms of ionizing radiation. It is the product of the absorbed dose in rads and factors related to relative biological effectiveness (see also **Dose Equivalent**).

Remediation: The removal of contamination from a site. Also known as **Remedial Action and decontamination.**

Remediation Control Survey: Monitoring the progress of remedial action by real time measurement of areas being decontaminate to determine whether efforts are being effective and to guide further decontamination activities.

Removable Activity: Surface activity that can be removed and collected for measurement by wiping the surface with moderate pressure.

Restoration: Actions to return a remediated area to a usable state, following decontamination.

Roentgen (R): Unit of exposure. One roentgen is the amount of gamma rays or X-rays required to produce one electrostatic unit (esu) of charge of one sign (either positive or negative) in one cubit centimeter of dry air under standard conditions.

Scanning: An evaluation technique performed by moving a detection device over the surface at some consistent speed and distance above the surface to detect elevated levels of radiation. Scanning provides qualitative or semi-quantitative, rather than quantitative, data.

Scoping Survey: A survey that is conducted to identify which radionuclides are present as contaminants, relative ratios in which they occur, and the general levels and extent of the contaminants.

Soil Activity (Soil Concentration): The level of radioactivity present in soil and expressed in units of activity per soil mass [typically picocuries per gram (pCi/g)].

Surface Activity: Radioactivity found on building or equipment surfaces and expressed in units of activity per surface area [typically disintegrations per minute per 100 cm^2 (dpm/100 cm^2)].

Survey: Evaluation of a representative portion of a population to develop conclusions regarding the population as a whole. In the decommissioning process several different types of surveys are conducted, including **Background, Scoping, Characterization, Remediation Control, Final Status, and Confirmatory.**

Survey Unit: Grouping of contiguous site areas with a similar use history and the same classification of contamination potential. Survey units are established to facilitate the survey process and provide increased data pints for statistical evaluations.

Source Material: Uranium and/or Thorium other than that classified as special nuclear material.

Special Nuclear Material: Plutonium, U-233, and Uranium enriched in U-235. Special nuclear material is generally considered material capable of undergoing a fission reaction.

Unrestricted Use: Use of a former radioactive materials site without requirements for future radiological controls. Also, known as **Unrestricted Release.**

APPENDIX A

Determining Site Specific Guidelines

Appendix A
Determining Site-Specific Guidelines

When multiple radionuclides are present, the sum of ratios of the concentration of each radionuclide to its respective guideline must not exceed 1. That is:

(A-1)

$$\frac{C_1}{G_1} + \frac{C_2}{G_2} + \ldots \frac{C_n}{G_n} \leq 1$$

where

$C_{1,2...n}$ is the concentration of radionuclide 1,2,...n
$G_{1,2...n}$ is the guideline value for radionuclide 1,2,...n

The presence of multiple radionuclides may require the development of site-specific guidelines based on relative ratios of their contributions to the total activity level. These site specific guidelines would provide the basis for comparisons with field measurements and for acceptance testing of survey results. The Manual user should consider that different radionuclides or radionuclide combinations may exist on different portions of the site and more than one set of guidelines may therefore be required.

For sites with multiple radionuclides, only those radionuclides remaining at the time of license termination, which would contribute greater than 10% of the total radiation dose from all contaminants or which are present at concentrations which exceed 10% of their respective guideline values, need be considered as significant contaminants.

Surface Activity Guidelines

For simplicity in application, radionuclides with comparable guidelines may be grouped, so that one guideline can be used for more than one radionuclide. If all significant contaminants are from the same group, the guideline level for that group may be used. For situations where radionuclides from several different groups with different guideline levels are present, a site-specific guideline level can be developed. This approach enables field measurement of gross activity, rather than determination of individual radionuclide activity for comparison to a release guideline. The gross activity guideline for surfaces with radionuclides from different groupings is calculated as follows:

1. Determine the relative fraction (f) of the total activity, contributed by each radionuclide group.

2. Obtain the guideline level (G) for each of the radionuclide group present from the NRC guideline tables.

3. Substitute the values of f and G in the equation.

$$\textit{Gross Activity Guideline} = \frac{1}{\left(\frac{f_1}{G_1} + \frac{f_2}{G_2} + \ldots \frac{f_n}{G_n}\right)} \qquad \text{(A-2)}$$

Sample calculation:

Assume that 40% of the total surface activity was contributed by a radionuclide with a guideline level of 5000 dpm/100 cm²; 40% by a radionuclide with a guideline level of 1000 dpm/100 cm²; and 20% by a radionuclide with a guideline level of 500 dpm/100 cm².

$$\textit{Gross Activity Guideline} = \frac{1}{\frac{0.40}{5000} + \frac{0.40}{1000} + \frac{0.20}{500}}$$

= 2100* dpm/100 cm²

* rounded to 2 significant figures

Soil Concentration Guidelines

Concentrations of specific radionuclides, rather than gross activity, are measured for soil. The combination of all significant radionuclides must satisfy equation A-1. For a mixture of radionuclides present in known, relative fractions of the total activity, the site-specific guidelines for each radionuclide are calculated by first determining the gross activity guideline using equation A-2 and then multiplying that gross guideline by the respective fractional contribution of each radionuclide. For example, if three radionuclides with guideline levels of 50 pCi/g, 25 pCi/g, and 10 pCi/g are present in activity ratios of 40%, 40%, and 20%, respectively, the gross activity guideline:

$$\textit{Gross Activity Guideline} = \frac{1}{\frac{0.40}{50} + \frac{0.40}{25} + \frac{0.20}{10}}$$

= 22.7* pCi/g

* rounded to 3 significant figures

The site-specific guideline levels for each of the contributory radionuclides, when present in the given activity ratios, would then be 9.1 pCi/g (0.40 • 22.7), 9.1 pCi/g (0.40 • 22.7) and 4.5 pCi/g (0.20 • 22.7).

Determining such site-specific guidelines enables an evaluation of site conditions based on analysis for only one of the contributory contaminants, provided the relative ratios of the contaminants does not change.

Exposure Rate Guideline

The exposure rate guideline is independent of the radionuclide source. A site-specific guideline level does not, therefore, have to be developed to account for multiple radionuclides at the site.

APPENDIX B

Statistical Tables
for
Guideline Comparison
and
Sampling Frequency Estimation

TABLE B-1

Factors for Comparison of Survey Data with Guidelines and Determining Additional Data Needs

Degrees of Freedom[a]	$t_{95\%}$	$t_{97.5\%}$
1	6.314	12.706
2	2.920	4.303
3	2.353	3.182
4	2.132	2.776
5	2.015	2.571
6	1.943	2.447
7	1.895	2.365
8	1.860	2.306
9	1.833	2.262
10	1.812	2.228
11	1.796	2.201
12	1.782	2.179
13	1.771	2.160
14	1.761	2.145
15	1.753	2.131
16	1.746	2.120
17	1.740	2.110
18	1.734	2.101
19	1.729	2.093
20	1.725	2.086
21	1.721	2.080
22	1.717	2.074
23	1.714	2.069
24	1.711	2.064

TABLE B-1 (continued)

Factors for Comparison of Survey Data with Guidelines and Determining Additional Data Needs

Degrees of Freedom[a]	$t_{95\%}$	97.5%
25	1.708	2.060
26	1.706	2.056
27	1.703	2.052
28	1.701	2.048
29	1.699	2.045
30	1.697	2.042
40	1.684	2.021
60	1.671	2.000
120	1.658	1.980
400	1.649	1.966
infinite	1.645	1.960

[a]Degree of freedom is the number of items of data minus 1; for values of degrees of freedom not in table, interpolate between values listed.

Reference (Gilbert 1987)

TABLE B-2

Factors for Estimating the Number of Sampling Locations for Guideline Comparison

$\frac{C_G - \bar{X}}{s}$	n
0.05	**3,422**
0.10	**856**
0.15	**380**
0.20	**214**
0.25	**137**
0.30	**95**
0.35	**70**
0.40	**53**
0.45	**42**
0.50	**34**
0.55	**28**
0.60	**24**
0.65	**20**
0.70	**17**
0.75	**15**
0.80	**13**
0.85	**12**
0.90	**11**
0.95	**9**
1.00	**9**

C_g = Concentration or activity guideline authorized by NRC

x = Mean concentration or activity determined for the survey unit.

s = standard deviation of the concentration for the survey unit.

n = number of samples to demonstrate meeting the cleanup guideline, assuming a desired false positive rate of 5% and a false negative rate of 10%, i.e. [$Z_{.95}$ $Z_{.90}$].

Reference (EPA 1989)

APPENDIX C

Survey Plan
For Determining
The Final Radiological Status
Of
The Reference Uranium Fuel
Fabrication Plant

C-ii

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<u>Preface</u>

An example of a final status survey plan for a reference uranium fuel fabrication plant is provided in this Appendix.

The major features used in the site description, such as plant design, radionuclides used, operations conducted, waste-disposal practices, levels of radionuclides remaining, etc., were taken from reports prepared for the NRC for the purpose of evaluating the technology, safety, and costs of decommissioning. The specific source documents were: *NUREG/CR-1266, Technology, Safety, and Costs of Decommissioning a Reference Uranium Fuel Fabrication Plant, and NUREG/CR-2241, Technology and Cost of Termination Surveys Associated with Decommissioning of Nuclear Facilities.*

Some alterations of and/or additions to information from these documents have been made, however, to demonstrate principles and procedures given in this manual. Care has been taken to ensure that these additions represent typical conditions that could be expected at the reference facility. To enhance readability, the term "reference" has been used as though it were the name of the facility; e.g., Reference Uranium Fuel Fabrication (RFF) Plant. Also, a fictitious company, e.g., General Nuclear Corporation, has been named as the owner and operator of the plant, and fictitious personal names have been included to present a more realistic example of a termination survey plan. Fictitious names and titles are shown in italics.

1.0 Background Information

The *Reference Uranium Fuel Fabrication Plant (RFF)* in Yorktown, Pennsylvania was built between 1960 and 1964 and was operated from 1964 until mid 1985 by the *General Nuclear Corporation*. Operating under NRC License XXX-100, Docket No. 00-000, the plant converted natural and enriched uranium hexafluoride (UF_6) to uranium oxide (UO_2), formed the UO_2 into pellets, and incorporated pellets into fuel rods and bundles. Auxiliary facilities were used to recover uranium from scrap and waste materials. The primary method involved the hydrolysis of UF_6 to ammonium diuranate (ADU), which was then reduced and calcined to produce dry UO_2 powder; the secondary process was the conversion of UF_6 to U_3O_8 in a flame conversion reactor, followed by reduction to UO_2 provider in a reduction-calciner. Two processes were used for the UF_6 to UO_2 conversion.

In 1985 the plant was shut down and nuclear materials were removed and shipped to Department of Energy facilities in Idaho Falls, Idaho. The plant remained in the shut-down state until 1986, when decommissioning efforts were initiated. Process equipment, fixtures, piping, etc., were removed and disposed of as radioactive waste. Buildings and adjacent grounds were characterized and those areas exceeding NRC guidelines for license termination were decontaminated; these efforts were completed in late 1990. This document describes the plan for conducting the final status survey of the site. Supporting information is presented in the Site Decommissioning Plan, prepared and submitted to the NRC in May 1986, and in the Characterization Survey Report, submitted in February 1988.

2.0 Site Information

2.1 Site Description

The *Reference Uranium Fuel Fabrication Plant* is located on a total land area of approximately 470 hectares (1160 acres); there is a moderate size stream (Wandering River) running through one corner of the site (Figure 1). Actual plant processing facilities are on a much smaller, restricted, fenced-in area of approximately 30,000 m^2 (3 hectares). The plant area occupies a low bluff that forms a bank of the river, and several flat alluvial terraces comprise the main topographical features of the property. These terraces lie at average elevations of 280 to 284 m above sea level and slope away from the river at grades of 2 to 3 percent. The river is used for disposal of acceptable liquid effluents from the on-site liquid waste systems.

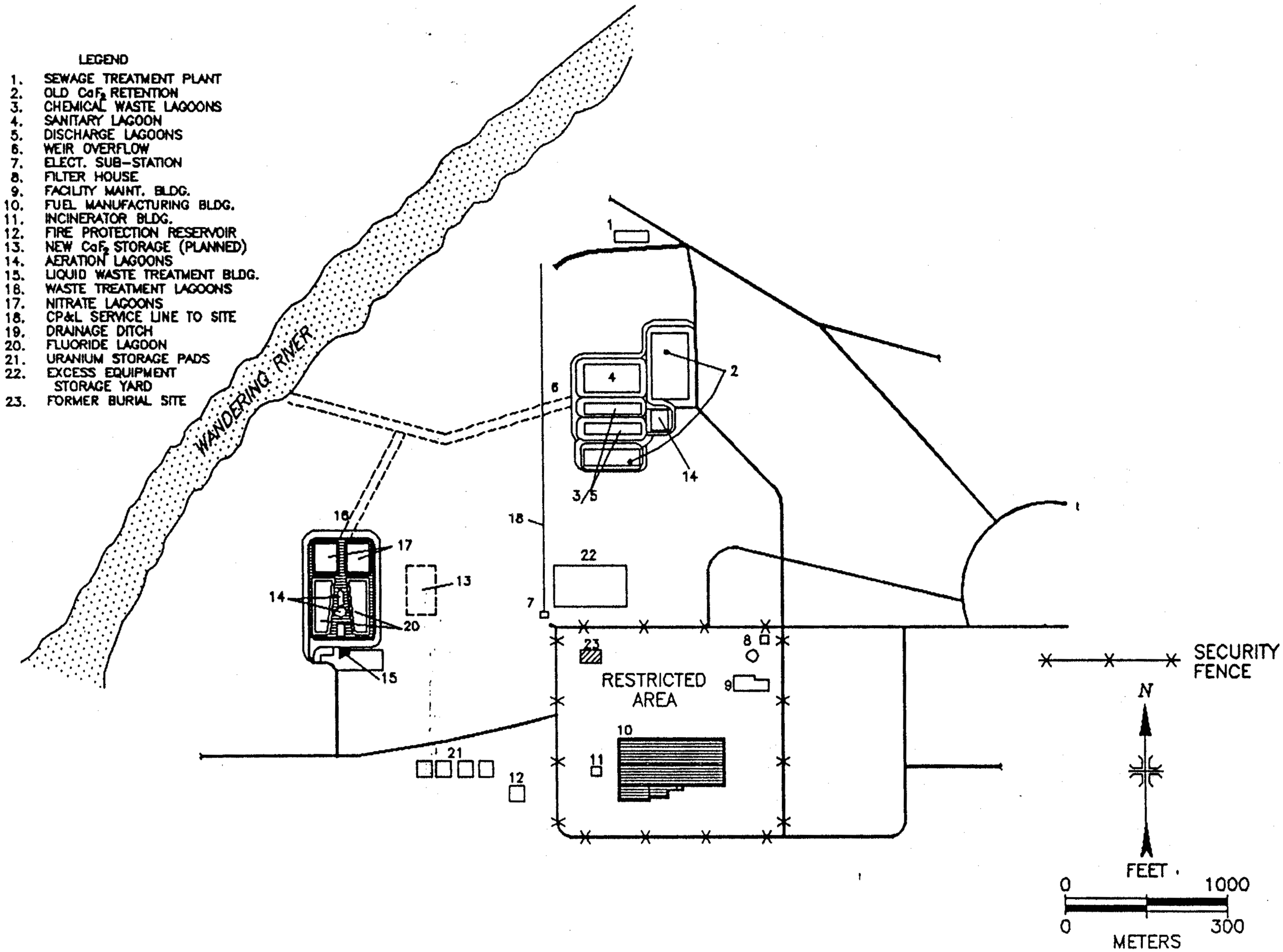


FIGURE 1: Map of the Reference Uranium Fuel Fabrication Plant Site

The major structures in the restricted processing area include the main building (with inter-connected chemical/metal laboratory and uranium scrap recovery and powder warehouse rooms), an incinerator building, a maintenance building, and a filter house (Figures 2A & 2B).

Auxiliary facilities are located outside the fenced area. These include a boiler house, a fluoride and nitrate waste treatment plant and associated lagoons, liquid chemical waste treatment lagoons, a sewage treatment plant and sanitary lagoon, and concrete uranium storage pads. The auxiliary facilities were used to recover uranium from scrap and waste materials and to recover valuable chemicals from gaseous and liquid wastes.

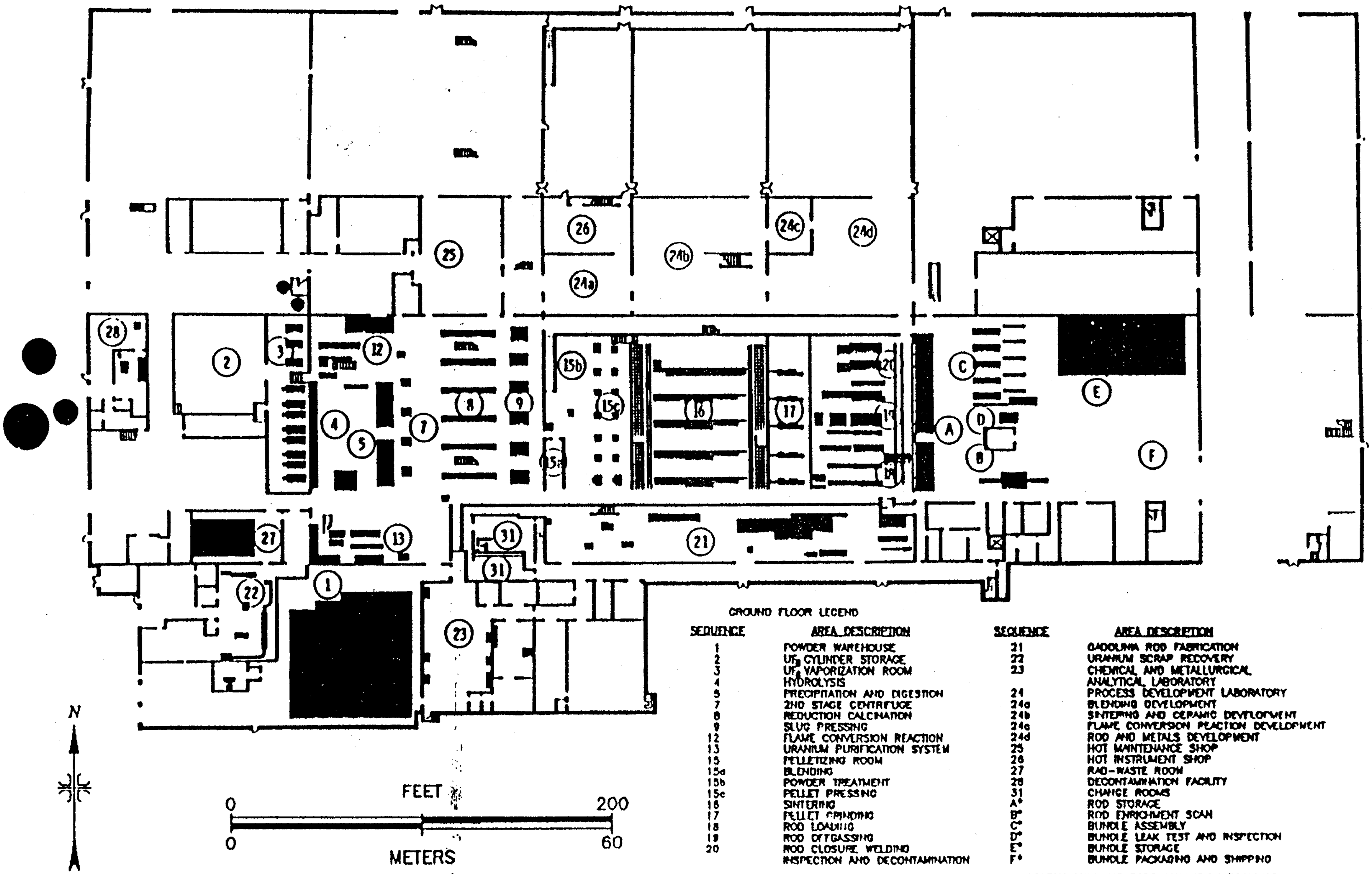
During the plant's 21 years of operation, an estimated total of 0.2 Ci of radioactivity was released into the atmosphere and subsequently deposited on the site. The property also contained one small, shallow land burial area for low-level radioactive waste. This area was operated in accordance with 10 CFR 20.304 between 1966 and 1970, receiving an estimated total activity of 0.3 Ci of uranium. This waste was excavated and disposed of at an authorized burial site as part of the decommissioning process. Although the site has been shut down for five years, total uranium radioactivity would change very little from shutdown due to the dominance of long-lived radionuclides.

2.2 Site Conditions at Time of Final Survey

In the opinion of the licensee the Plant site has been decontaminated to a level which satisfies the current NRC guidelines and is ready for a termination survey. As part of the decommissioning activities, process equipment and supporting fixtures were removed from radioactive materials areas and cleaned and released or disposed of as radioactive waste. Potentially contaminated structural surfaces have been stripped of coatings by grit blasting or use of chemical agents. Contaminated surfaces identified by the characterization survey have been cleaned or removed.

The on-site shallow land burial was excavated. Facilities used for processing of potentially contaminated effluents such as the lagoons and sewage treatment plant have been characterized, and, where necessary, decontamination has been performed. Soil contamination in the vicinity of process building was identified and removed to depths ranging from 5 cm to 1.5 m.

GROUND FLOOR



GROUND FLOOR LEGEND

SEQUENCE	AREA DESCRIPTION	SEQUENCE	AREA DESCRIPTION
1	POWDER WAREHOUSE	21	GADOLINIA ROD FABRICATION
2	UF_6 CYLINDER STORAGE	22	URANIUM SCRAP RECOVERY
3	UF_6 VAPORIZATION ROOM	23	CHEMICAL AND METALLURGICAL ANALYTICAL LABORATORY
4	HYDROLYSIS		
5	PRECIPITATION AND DIGESTION	24	PROCESS DEVELOPMENT LABORATORY
7	2ND STAGE CENTRIFUGE	24a	BLENDING DEVELOPMENT
8	REDUCTION CALCINATION	24b	SINTERING AND CERAMIC DEVELOPMENT
9	SLUG PRESSING	24c	FLAME CONVERSION REACTION DEVELOPMENT
12	FLAME CONVERSION REACTION	24d	ROD AND METALS DEVELOPMENT
13	URANIUM PURIFICATION SYSTEM	25	HOT MAINTENANCE SHOP
15	PELLETIZING ROOM	26	HOT INSTRUMENT SHOP
15a	BLENDING	27	RAD-WASTE ROOM
15b	POWDER TREATMENT	28	DECONTAMINATION FACILITY
15c	PELLET PRESSING	31	CHANGE ROOMS
16	SINTERING	A*	ROD STORAGE
17	PELLET GRINDING	B*	ROD ENRICHMENT SCAN
18	ROD LOADING	C*	BUNDLE ASSEMBLY
19	ROD OFFGASSING	D*	BUNDLE LEAK TEST AND INSPECTION
20	ROD CLOSURE WELDING	E*	BUNDLE STORAGE
	INSPECTION AND DECONTAMINATION	F*	BUNDLE PACKAGING AND SHIPPING

*CLEAN AREA, NO DECONTAMINATION REQUIRED

FIGURE 2A: Process Building Layout, Indicating Those Areas Used for Licer d Activities

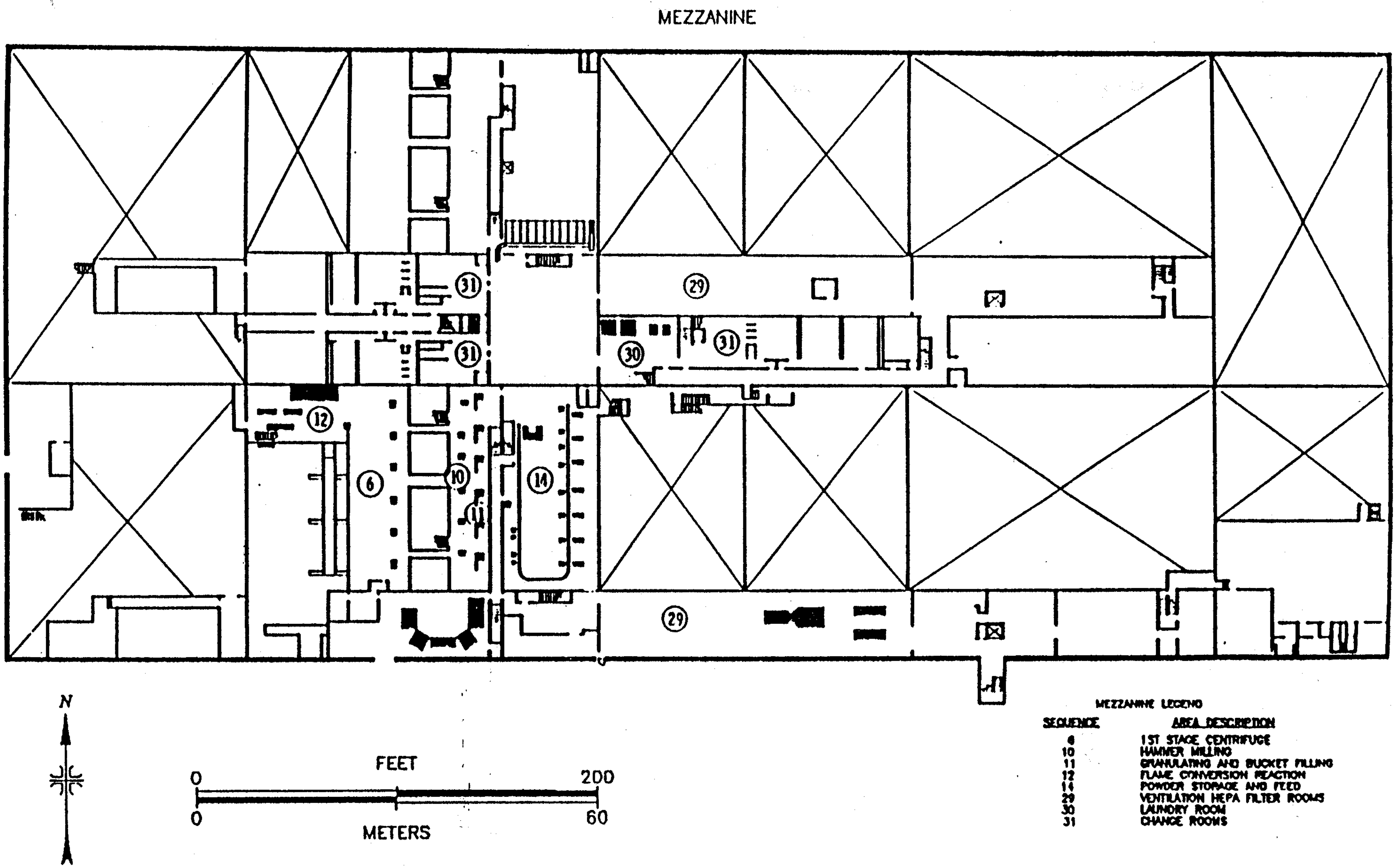


FIGURE 2B: Process Building Layout, Indicating Those Areas Used for Licensed Activities

Details regarding the decontamination actions will be presented in the Final Site Decommissioning Report, currently in preparation.

3.0 Final Status Survey Overview

3.1 Survey Objectives

The purpose of the final status survey is to demonstrate that the radiological conditions at the *Reference Uranium Fuel Fabrication Plant* satisfy the NRC guidelines and that the plant site can, therefore, be released from licensing restrictions for future use without radiological controls. The specific objectives of the survey are to show that:

A. Surface Activity of Buildings and Structures

1. Average surface contamination levels for each survey unit are within the authorized values.

2. Small, areas of residual activity, known as "hot-spots" do not exceed three times the average value. The hot-spot limit applies to areas of up to 100 cm^2. The average activity level within the 1 m^2 area containing a hot-spot must be within the guideline.

3. Reasonable efforts have been made to clean up removable activity and removable activity does not exceed 20% of the average surface activity guidelines.

4. Exposure rates in occupiable locations are less than 5 μR/h above background. Exposure levels are measured at 1 m from floor/lower wall surfaces and are averaged over floor areas, not to exceed the size of a small office, i.e. about 10 m^2.

B. Volume Activity of Soil and Building Materials

1. Average radionuclide concentrations are within the authorized value. Averaging is based on a 100 m^2 grid area.

2. Reasonable efforts have been made to identify and remove hot-spots that may exceed the average guideline by greater than a factor of $(100/A)^{1/2}$, where A is the area (in m^2) of the hot spot.

3. Exposure rates do not exceed 5 μR/h above background at 1 m above the surface. Exposure rates may be averaged over a 100 m^2 grid areas. Maximum exposure rates over any discrete area of <100 m^2 may not exceed 10 μR/h above background.

The above conditions will be demonstrated at a 95% confidence level for each survey unit as a whole.

Finally, the survey data will be used to calculate the total inventory of residual activity from licensed site operations.

3.2 Identity of Contaminants

Based on the knowledge of site operations and the results of the preliminary assessment and characterization survey the significant radiological contaminants have been determined to be isotopes of uranium. The uranium is enriched in U-234 and U-235 above naturally occurring levels; the average activity ratios of the uranium isotopes is:

U-234	81.4%
U-238	15.5%
U-235	3.1%

On the basis of this combination of contaminants the surface contamination guidelines for the site are:

________ dpm/100 cm^2, average over 1 m^2
________ dpm/100 cm^2, maximum over 100 cm^2
________ dpm/200 cm^2, removable

The soil contamination guidelines are ______ pCi/g, average total uranium.

In addition to the radiological contaminants the site contains soil areas of nitrate and fluoride contamination. These areas will be addressed in accordance with requirements of the Commonwealth of Pennsylvania and the U.S. Environmental Protection Agency.

3.3 Organization and Responsibilities

The survey will be performed by a team composed of qualified personnel currently employed by the *RFF Plant* and *General Nuclear Corporation.* This is the same organizational structure which conducted the characterization survey activities. Figure 3 is an organizational chart for the survey activities.

The team will operate under the supervision of *Dr. Allen Babcock*, Nuclear Engineer for *General Nuclear Corporation. Dr. Babcock* will have the authority to make appropriate changes to the survey plan (subject to the established QA/QC program) as deemed necessary as the survey progresses.

Field measurements of radiological parameters and sample collection will be under the direction of *Mr. Raymond Metter* of the *General Nuclear Corporation's Environmental Measurements Section. Mr. Metter* will also oversee the activities of field subcontracts.

Mr. John Scott of the *RFF Plant Analytical Services Group* will direct laboratory activities for both in-house analyses and the contractor laboratory services of *Analytical Operations,Inc.*

QA/QC responsibilities will be handled by a QA officer whose work responsibilities are otherwise separate from those on the termination survey team. *Mr. John Perkins* from the Plant's Quality Assurance/Quality Control Office will serve as the QA officer and will, in that capacity, coordinate all interface requirements during the survey process and name members of the QA/QC team as needed. QA/QC procedures will be adopted from the ANSI/ASTM NQA-1, *Quality Assurance Program Requirements for Nuclear Facilities* (ANSI 1989) and where applicable, Reg. Guide 4.15, *Quality Assurance for Radiological Monitoring Programs--Effluent Streams and the Environment* (NRC-1979). Any changes or alterations to these procedures will be handled in the same manner as changes to survey procedures, except that approval will be required at a higher level of management. All changes from procedures will be documented and will become a part of the final report submitted to NRC.

Mr. Al Hillman will provide expertise on Health and Safety issues for the survey process. *Mr. Hillman* currently serves as a Health and Safety officer in *General Nuclear's Environmental Safety Division.* Health and safety considerations for workers and for the general public are incorporated into the survey plan. The *General Nuclear Corporation Health and Safety Procedures Manual* will be used as procedural guidelines, since this manual is both based on industry standard and already encompasses specific plant areas and conditions.

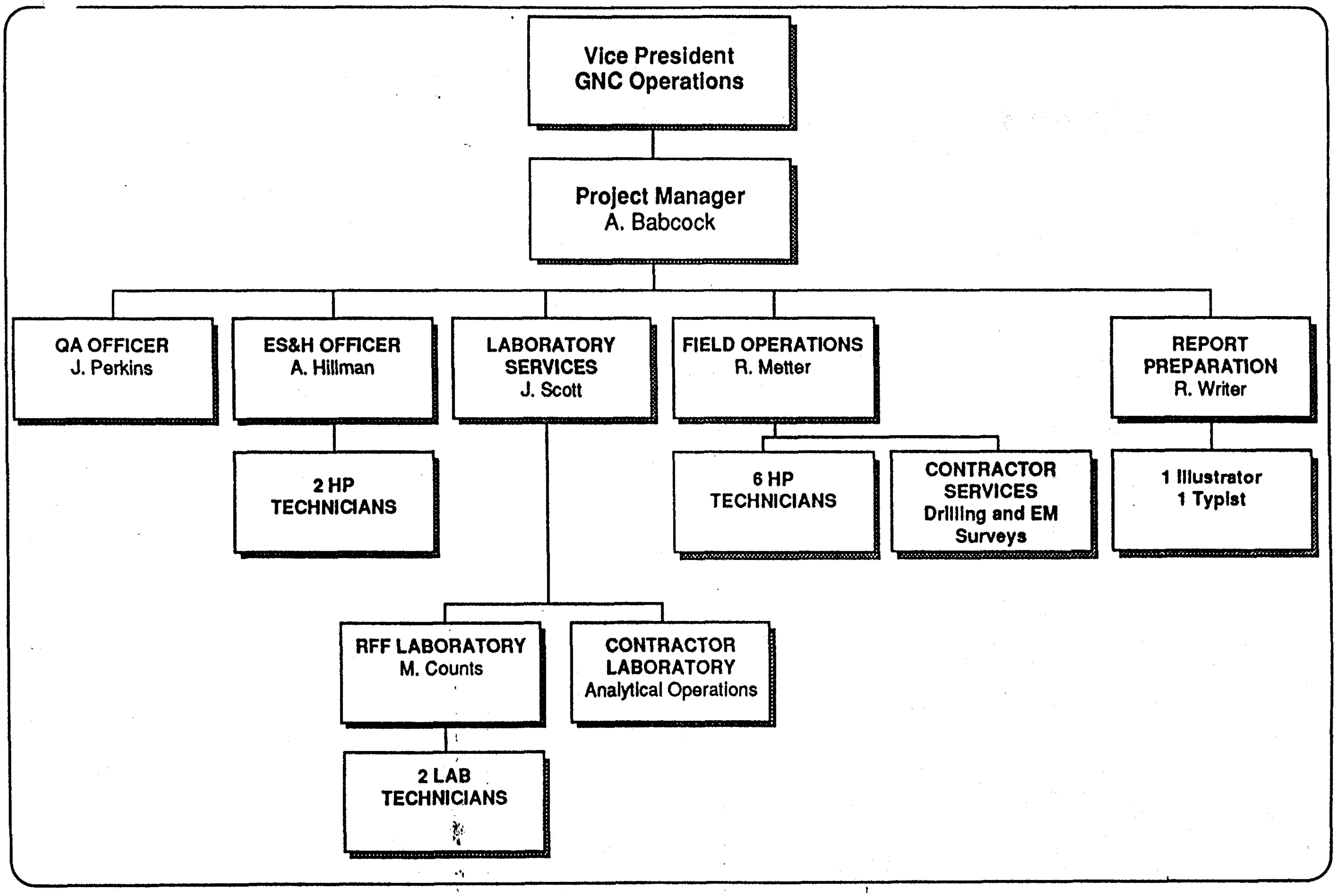


FIGURE 3: Organization Chart for Final Status Survey Activities

Qualifications of each key team member were presented in Attachment 1 of the decommissioning plan and the characterization survey report, previously provided to the NRC.

3.4 Training

The *Reference Uranium Fuel Fabrication Plant* provides continuing training for its health physics personnel and other workers who may be exposed to radioactive materials. Training varies according to potential exposure and the nature of the employee's job duties. In addition to the regular training, special training will be provided on equipment, special techniques, and practices relative to the survey activities for those employees who will be involved in taking radiological measurements and samples. All members of the final status survey team will attend an in-house training session reviewing radiation protection, survey procedures, and quality assurance activities. Documentation of training participation and results of testing to demonstrate knowledge and skills will be retained in the *General Nuclear Corporation* training files.

3.5 Laboratory Services

Analytical services for gross alpha/beta levels on smears, air, and water samples will be performed by the Plant Analytical Services Laboratory in accordance with standard Plant procedures, "Laboratory Analyses of Environmental Samples" procedures GNC/RFF-HP 3.1, 3.2, 3.4, and 3.7 (1988). Samples of soil and other special samples, requiring gamma spectrometry or wet chemistry analyses will be conducted by a contract laboratory, *Analytical Operations*, Inc. QA/QC programs for both in-house and contractor laboratory services will be monitored by the QA coordinator of the termination survey team.

3.6 General Survey Plan

This survey plan consists systematic processes and procedures that have been deemed acceptable by industry standards and the NRC. Activities (organized units of work needed to complete a function) have been defined and tasks (specific work assignments within a specific activity) have been delegated to the appropriate team members. Table 1 provides a breakdown of activities and tasks that are currently a part of the termination survey plan.

TABLE 1

OVERVIEW OF MAJOR ACTIVITIES AND TASKS

ACTIVITIES		TASKS
Evaluate contamination potential	1.	Review operating history with respect to facility use, spills, releases etc.
	2.	Review radiological data from scoping and characterization surveys.
	3.	Identify radionuclides of concern and determine guidelines.
	4.	Classify areas as to "affected" and "unaffected".
Establish grid reference system	1.	Install grids.
	2.	Prepare facility survey maps.
Determine background levels	1.	Measure indoor exposure rates and ambient beta-gamma levels.
	2.	Measure outdoor exposure rates.
	3.	Collect background soil samples.
Perform direct measurements	1.	Conduct surface scans.
	2.	Determine frequency and locations of measurements to meet criteria.
	3.	Conduct surface activity measurements.
	4.	Measure exposure rates.
Collect Samples	1.	Determine frequency and locations of sampling to meet criteria.
	2.	Conduct electromagnetic scans of subsurface sampling areas.
	3.	Collect systematic and special samples.
Analyze samples	1.	Count smears and swabs.
	2.	Analyze soil, paint, residue and other solid samples for uranium activity.
Interpret data	1.	Convert data to standard units.
	2.	Calculate average levels.
	3.	Compare data with criteria.
	4.	Compute total residue activity inventory.
Prepare report	1.	Construct data tables.
	2.	Develop graphics.
	3.	Prepare text.
	4.	Submit report to NRC.

Tasks will be performed in accordance with guidelines stated in the *Manual for Conducting Radiological Survey in Support of License Termination, NUREG/CR-5849.*

- Section 4.0 - Planning and Designing the Final Status Survey
- Section 5.0 - Radiological Instrumentation
- Section 6.0 - Survey Techniques
- Section 7.0 - Samples Analysis
- Section 8.0 - Interpretation of Survey Results

3.7 Tentative Schedule

The termination survey is scheduled to begin in February 1991 and completed by the end of September 1991. A milestone chart showing tentative dates for performing the major termination survey activities is shown in Figure 4.

3.8 Survey Report

A report, describing the survey procedures and findings, will be prepared and submitted to the NRC. Report format and content will follow the recommendations contained in *Manual for Conducting Radiological Surveys in Support of License Termination*, NUREG/CR-5849.

4.0 Survey Plan and Procedures

4.1 General

Due to the nature of the operations and the estimated extent of airborne contamination, both main plant and auxiliary facilities must be surveyed as well as any potentially contaminated surrounding land areas. The number of sample taken per area in the total facility will be stratified based on the potential for residual radioactivity. Contamination potential has been based on a review of site history and the results of the preliminary assessment and characterization survey. Additional information on classifications is provided in Section 4.3.1 of this plan. To the extent that locations of measurements or sampling in support of characterization, remedial action control, or other previous surveys have not been disturbed since those earlier surveys and the radiological status would therefore unchanged, that data will be utilized in support of the termination survey.

ACTIVITY / MONTH 1991	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Evaluate Contamination Potential	<------->					
Establish Grid		<-------------->				
Determine Background	<---->					
Perform Direct Measurements		<-------	----------------	-----------------	---------->	
Collect Samples				<----------	-------------->	
Analyze Samples				<----------	---------------->	
Interpret Data				<----	-----------------	-------->
Prepare Report					<---------	--------------->

FIGURE 4. MILESTONE CHART FOR TERMINATION SURVEY ACTIVITIES

4.2 Instrumentation

Table 2 lists the instrumentation to be used for the survey activities, along with typical parameters and detection sensitivities for the instrumentation and survey technique. The combination of instrumentation and technique were chosen to provide a detection sensitivity of 25% or less of the guideline levels.

The basic equation for determining field instrument detection limits is:

$$MDA = \frac{2.71 + 4.65\sqrt{Background}}{counting\ time \bullet efficiency \bullet \frac{probe\ area}{100}}$$

Sensitivities for scanning techniques are based on movement of the detector over the surface at 1 detector width per second and use of audible indicators to sense changes in instrument count rate. Experience documented in comparing training files demonstrates that qualified surveyors can detect the levels listed in Table 2 with a 90% confidence level. All instruments will be calibrated a minimum of once every 3 months, using NIST-traceable standards. Calibration will be for the specific uranium radiation energies expected to be present at the site. Operation' and background checks will be performed at least once each 4 hours c instrument use.

4.3 Survey Plan

4.3.1 Area Classification

For purposes of establishing the sampling and measurement frequency and pattern, the site has been divided into affected and unaffected areas. The bases for these classifications are:

- **affected areas:** Areas that have potential radioactive contamination (based on plant operating history) or known radioactive contamination (based on past of preliminary radiological surveillance). This includes areas where radioactive materials were used and stored, where records indicate spills or other unusual occurrences that could have resulted in spread of contamination, and where radioactive materials were buried. Areas immediately surrounding or adjacent to locations where radioactive materials were used or stored, spilled, or buried were included in this classification because of the potential for inadvertent spread of contamination.

- **unaffected areas:** All areas not classified as affected. These areas are not expected to contain residual radioactivity, based on a knowledge of site history and previous survey information.

Table 3 lists the various site areas in each classification category.

4.3.2 Reference Grids

Grids will be established for the purpose of referencing locations of samples and measurements, relative to building and other site features. The gridding intervals are based on the potential for residual contamination in the various plant areas. (See Table 3). All affected building area floor and lower wall (up to 2 m) surfaces will be gridded at 1 m intervals; upper walls and ceilings of affected areas will also be gridded at 1 m intervals, if residual activity above 25% of the guideline is known or suspected. Building surfaces in unaffected areas or those upper surfaces in affected areas that have not been contaminated as a result of prior activities will not be gridded; measurements will be referenced to other grid systems or to prominent building features. Affected outside areas will be gridded at 10 m intervals; unaffected areas will not be gridded. This grid system is identical to the one used during the characterization survey and the remedial action activities; where necessary the earlier grid will be reestablished, expanded, or subdivided.

The facility will be divided into "survey units" having common history, contamination potential, or that are naturally distinguishable from other sites areas. These survey units will be sized to assure a minimum of 30 measurement locations each for floors and lower walls, other vertical surfaces, and other horizontal surfaces.

Areas identified by scans or direct measurements or as exceeding guidelines will be reclassified as affected areas and will be gridded and resurveyed accordingly.

TABLE 2

INSTRUMENTATION FOR RADIOLOGICAL SURVEYS

Type of Measurement	Instrumentation Detector	Instrumentation Meter	Bkgd.[1]	4 π[1] Eff. (%)	Detection Sensitivity
Surface scans - alpha	large area gas prop., AB Co., Model 100	Countrate meter[2], AB Co., Model 1000	20 cpm	25	70 dpm/100 cm^2
Surface scans - alpha	scintillation, XYZ Inc. Model 10	Countrate meter[2], AB Co., Model 1000	2 cpm	18	100 dpm/100 cm^2
Surface scans - beta	large area gas prop., AB Co.,Model 100	Countrate meter[2], AB Co., Model 1000	1500 cpm	30	1500 dpm/100 cm^2
Surface scans - beta-gamma	pancake GM, XYZ Inc., Model 20	Countrate meter[2], XYZ Inc., Model 120	40 cpm	20	3500 dpm/100 cm^2
Surface scans - gamma	NaI scintillation, N Products, Model X	Countrate meter[2], XYZ Inc., Model 120	3500 cpm	N/A	2 μR/h
Surface activity - alpha	gas prop., AB Co.,Model 200	Digital scaler[3], N Prod., Model Y-1	5 cpm	25	60 dpm/100 cm^2
Surface activity - alpha	scintillation, XYZ Inc., Model 10	Digital scaler[3], N. Prod., Model Y-1	2 cpm	18	100 dpm/100 cm^2
Surface activity - beta	gas prop., AB Co.,Model 200	Digital scaler[3], N. Prod., Model Y-1	350 cpm	30	300 dpm/100 cm^2
Surface activity - beta-gamma	pancake GM, XYZ Inc., Model 20	Digital scaler[3], N. Prod., Model Y-1	40 cpm	20	1100 dpm/100 cm^2
Exposure rates	pressurized ionization, R. Co., Model 1111	(same as detector)			<1 μR/h
Gross α/β on smears	gas prop., T&C Co., Model 5000	(same as detector)	0.2 cpm α 1.5 cpm β	35 40	10 dpm 20 dpm

[1]Nominal Values.
[2]Monitoring audible signal.
[3]1 minute integrated count.

TABLE 3

CLASSIFICATION OF RFF PLANT SURFACES
AND AREAS ACCORDING TO CONTAMINATION POTENTIAL

Plant Area	Bldg. or Facility	Room or Area	Classification of Contamination Potential	Remarks
Restricted	Process Bldg.	Powder Warehouse	Affected	
		UF_6 Cyl. Storage	Affected	
		UF_6 Vapor. Rm.	Affected	
		Hydrolysis	Affected	
		Precip. & Digestion	Affected	
		2nd Stage Centrifuge	Affected	
		Reduction Calculation	Affected	
		Slug Pressing	Affected	
		Flame Conv. Reaction	Affected	
		Uranium Purif. System	Affected	
		Pelletizing Room	Affected	
		Blending	Affected	
		Powder Treatment	Affected	
		Pellet Pressing	Affected	
		Sintering	Affected	
		Pellet Grinding	Affected	
		Rod Loading	Affected	
		Rod Offgassing	Affected	

TABLE 3 (Cont'd)

CLASSIFICATION OF RFF PLANT SURFACES
AND AREAS ACCORDING TO CONTAMINATION POTENTIAL

Plant Area	Bldg. or Facility	Room or Area	Classification of Contamination Potential	Remarks
Restricted	Process Bldg.	Rod Closure Welding Inspection & Decon.	Affected	
		Gadolinia Rod Fab.	Affected	
		Uran. Scrap Recovery	Affected	
		Chem & Metallurgical Anal. Laboratory	Affected	
		Process Devel. Lab.	Affected	
		Blending Development	Affected	
		Sint. & Cer. Develop.	Affected	
		Flame Con. Reac. Dev.	Affected	
		Rod & Metal Develop.	Affected	
		Hot Maint. Shop	Affected	
		Hot Inst. Shop	Affected	
		Rad-Waste Rm.	Affected	
		Decon. Facility	Affected	
		Change Rooms	Affected	
		1st Stage Centri.	Affected	
		Hammer Milling	Affected	

Table 3 (Cont'd)

CLASSIFICATION OF RFF PLANT SURFACES
AND AREAS ACCORDING TO CONTAMINATION POTENTIAL

Plant Area	Bldg. or Facility	Room or Area	Classification of Contamination Potential	Remarks
Restricted	Process Bldg.	Gran. & Bucket Fill	Affected	
		Flame Conv. Reaction	Affected	
		Powd. Storage & Feed	Affected	
		Vent. Hepa Filt. Rm.	Affected	
		Laundry Room	Affected	
		Rod Storage	Affected	Upper surfaces not affected.
		Rod Enrichment Scan	Affected	Upper surfaces not affected.
		Bundle Assembly	Affected	Upper surfaces not affected.
		Bundle Leak Test & Inspection	Affected	Upper surfaces not affected.
		Bundle Storage	Affected	Upper surfaces not affected.
		Bundle Packaging & Shipping	Affected	Upper surfaces not affected.
		Office and Admin. Areas	Unaffected	Upper surfaces not affected.

TABLE 3 (Cont'd)

CLASSIFICATION OF RFF PLANT SURFACES
AND AREAS ACCORDING TO CONTAMINATION POTENTIAL

Plant Area	Bldg. or Facility	Room or Area	Classification of Contamination Potential	Remarks
Restricted	Filter House	Entire Interior	Affected	
		Roof	Affected	
	Former Waste Burial Site	-----	Affected	
	Grounds Adj. to Proc. Areas	-----	Affected	
	Liquid Waste Transfer Line	-----	Affected	
		Soil	Affected	Upper surfaces not affected.
		Paved Areas	Affected	Upper surfaces not affected.
Unrestricted	Other Buildings	Entire Interior	Unaffected	Upper surfaces not affected.
	Roofs		Unaffected	Upper surfaces not affected.
	Sewage Trmt. Plant	Entire Interior	Affected	Upper surfaces not affected.
		Roof	Unaffected	Upper surfaces not affected.
	Grounds	Entire Unrestricted Plant Area	Unaffected	Upper surfaces not affected.

4.3.3 Surface Scans

Scanning of surfaces to identify locations of residual surface and near-surface activity will be performed according to the following schedule:

Affected Area Surfaces - 100% of surface

Non-contaminated upper surfaces in affected areas - scans in immediate vicinity of measurement

Unaffected Area Surfaces - 10% of lower surface

Building interior surface scans will be conducted for alpha, beta, and gamma radiations. Scans of exterior building and paved surfaces will be for beta and gamma radiations. Soil surfaces will be scanned for gamma radiations only.

Instrumentation for scanning is listed in Table 2. The instruments having the lowest detection sensitivity will be used for the scans, wherever physical surface conditions and measurement locations permit.

Scanning speeds will be no greater than 1 detector width per second for alpha and beta detection instruments and 0.5 m per second for gamma instruments. Audible indicators (headphones) will be used to identify locations, having elevated (1.5 to 3 times ambient) levels of direct radiation. All scanning results will be noted on standard field record forms; locations of elevated radiation will be identified for later investigation.

4.3.4 Surface Activity Measurements

<u>Direct Measurements</u>

Direct measurements of alpha, beta, and/or beta-gamma surface activity will be performed at selected locations using instrumentation described in Table 2. Unless precluded by surface conditions or physical parameters, the most sensitive of the instruments listed for surface measurements (Table 2) will be used. Measurements will be conducted by integrating counts over a 1 minute period.

Because scanning techniques are capable of detecting residual uranium activity at <25% of the guideline level, direct surface activity measurements will be systematically performed at 2 m intervals on floors and lower walls of affected areas and at the same intervals on upper surfaces that may have residual activities in excess of 25% of the guidelines.

On upper surfaces of affected areas which are not inspected of residual activity, measurements will be performed at a minimum of 30 locations each on vertical and horizontal surfaces. These locations will include surfaces where radioactive material would likely settle, and sufficient additional locations to provide coverage at a minimum average of 1 location per 20 m^2 of surface area.

On surfaces of unaffected areas, a minimum of 30 random measurements or an average measurement of 1 per 50 m^2 of building surface area, whichever is greater, will be performed for each survey unit. These locations will include all building surfaces.

Removable Contamination Measurements

A smear for removable contamination will be performed at each measurement location.

4.3.5 Exposure Rate Measurements

Gamma exposure rates will be measured at 1 m above ground or floor surfaces, using a pressurized ionization chamber or a gamma scintillation instrument, calibrated for low enrichment uranium energies. Measurements will be uniformly spaced according to the following pattern:

Building Interiors

Affected Areas: 1 measurement per 4 m^2.
Unaffected Areas: 1 measurement per 200 m^2.

Grounds

Affected Areas: 5 measurements per 100 m^2 grid block.
Unaffected Areas: 50 measurements at randomly selected locations.

4.3.6 Soil/Sediment Sampling

Surface

Samples (about 500 grams each) of surface soil (0-15 cm) will be systematically collected from the center and 4 points midway between the center and the block corners for each 10 m x 10 m grid in affected areas. Fifty samples will be obtained from random locations in unaffected areas, outside the restricted plant site. Samples will be collected at 10 m intervals along the drainage ditches from the former waste processing facilities to the *Wandering River* and from other natural surface drainage pathways to the River. At each surface sampling location, contact gamma levels before and after sampling will be monitored to determine whether subsurface contamination may be present.

Sediment (about 500 grams) samples will be obtained at the outfall of drainage ditches to the *Wandering River* and from 25 to 50 m upstream and downstream of the outfall. Sampling will be from the River center and near both banks.

Subsurface

Subsurface investigations will be performed at the locations of the former burial site, liquid waste lagoons, and previously excavated underground piping between the processing areas and the waste ponds. These locations will be scanned by a commercial contractor using electromagnetic sensors (ground penetrating radar) to verify that no buried objects remain and to guide placement of subsurface sampling locations. Subsurface samples will be obtained by a commercial contractor, using the split-barrel method. Sampling will be at the surface (0-15 cm) and at 1 m intervals to a depth of 7 m at the former burial site and liquid waste lagoon areas; along the path of the previously excavated liquid waste transfer piping, sampling will be at 1 m intervals to a depth of 3 m. Ten, uniformly spaced sampling locations will be selected in the former burial site and twenty uniformly spaced locations will be selected in the area of the lagoons. In addition, two sampling locations will be selected on each side around the perimeter of these facilities, to confirm absence of subsurface migration. Subsurface samples will be obtained at approximately 6 locations along the former waste transfer piping system.

Following sampling, a gamma scintillation probe will be inserted into the borehole and relative count rates determined at approximately 50 cm intervals between the surface and the hole bottom. This data will assist in evaluating the presence of residual radioactive material in vicinity of the sampling location. If results are positive, additional subsurface sampling will be conducted to define the area of residual contamination.

4.3.7 Special Measurements and Samples

Building Interiors

Samples of paint will be obtained from 100 cm^2 areas on lower walls in former liquid and powder processing rooms. One paint sample per 10 m^2 will be obtained from these surfaces. Paint samples will also be collected from surfaces where direct and removable activity measurements suggest contamination may have been painted over.

Trenches where contaminated drain piping was excavated in the Analytical Laboratory, Rad Waste Decontamination, and Change Room facilities will be sampled at locations of elevated direct radiation and at approximately 3 m intervals along the excavations. (Conversion, powder handling, and other product processing facilities did not have subfloor piping.) Other remaining drains and piping in affected areas will be accessed, direct alpha and beta-gamma scans and measurements performed at all access points, and a large-area swab obtained from the piping, using a plumbers "snake" and piece of cloth.

Remaining ducts, electrical boxes, conduit, or other interior surfaces in affected areas, which may contain residual contamination, will be accessed at random and measurements of direct and removable activity performed. Swabs will be obtained from insides of wall and floor penetrations, anchor bolt holes, and floor cracks or expansion joints.

Floor cores will be removed from 10 locations in the areas where conversion was performed; gamma scans of subfloor soil will be performed and soil samples from the floor/soil interface and 0.5 m below the interface will be collected at each coring location. Additional floor coring and subfloor sampling will be conducted, if surface scans and measurements suggest subfloor contamination.

Building Exteriors

Measurements of direct and removable activity will be performed on exterior and interior surfaces of air exhaust equipment and at representative locations on roof drains. Samples of roofing material will be obtained where direct measurements suggest possible entrained contamination.

Grounds

Cores will be removed at 6 locations on the uranium storage pads and samples of subpad soil collected. Coring and soil sampling will also be performed on other paved outside surfaces, where scans or direct measurements suggest possible contamination beneath the paving. The number and location of these cores will be determined on the basis of findings as the survey progresses.

4.4 Background Level Determinations

Background exposure rates will be determined for the building interior by taking a minimum of 8-10 pressurized ionization chamber measurements at locations of similar construction but without a history of radioactive materials use. Also, 8-10 locations for area background measurement and sampling will be selected within a 0.5 to 10 km radius of the site. Exposure rate measurements will be performed using a pressurized ionization chamber. A background soil sample will be collected from each location of external background measurement. Results of background exposure rate and uranium soil concentrations will be evaluated to assure that the averages determined are representative of the true averages, using procedures described in NUREG/CR-5849. Additional sampling or measurements will be performed if necessary to satisfy criteria.

4.5 Sample Analysis

Smears and swabs for removable contamination will be analyzed for gross alpha, gross beta activity. Soil, sediment, gravel, roofing material, and other large volume samples will be analyzed for U-235 and U-238 by gamma spectrometry; total uranium will be calculated on the basis of previously determined (Section 3.2) isotopic activity ratios for this site. Samples of paint, residue, and other samples of small volume will be analyzed for uranium by wet chemical separation and alpha spectroscopy.

Laboratory chain-of-custody procedures (GNC/RFF-HP 3.6-1988) will be observed for all sample analyses.

5.0 Data Interpretation

Measurement data will be converted to units of dpm/100 cm^2 (surface activity), μR/h (exposure rates) and pCi/g (soil concentrations) for comparison with guidelines. Values will be adjusted for contributions from natural background. Individual measurements and soil levels will be compared with "hot-spot" criteria. Average values for survey units will be determined and compared with guideline levels. Data for each survey unit will be tested against the confidence level objective, using guidance and procedures described in NUREG/CR-5849.

Additional remediation and/or further sampling and measurements will be performed where guidelines are not met or cannot be demonstrated to the specified level c confidence. Computations and comparisons will be repeated, as necessary.

The average levels will be used to estimate the total residual inventory of uranium at the site.

6.0 Report

A report, describing the procedures and findings of the final status survey will be prepared and submitted to the NRC. Data will be summarized in tables. Measurement and sampling locations will be shown on scale drawings.

All field and analytical data will be archived by *General Nuclear Corporation* until such time as the NRC authorizes disposal.

APPENDIX D

Final Radiological Status Report
for
The Reference Uranium Fuel
Fabrication Plant

D-ii

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Preface

An example of a final status survey report for a reference uranium fuel fabrication plant is provided in this Appendix. This sample report duplicates some of the background, site description, and other general information presented in the survey plan for this same reference facility (see Appendix C); it is repeated here for thoroughness and to provide the Manual user with a more complete pattern to follow during report preparation.

The major features used in the site description, such as plant design, radionuclides used, operations conducted, waste-disposal practices, levels of radionuclides remaining, etc., were taken from reports prepared for the NRC for the purpose of evaluating the technology, safety, and costs of decommissioning. The specific source documents were: *NUREG/CR-1266, Technology, Safety, and Costs of Decommissioning a Reference Uranium Fuel Fabrication Plant*, and *NUREG/CR-2241, Technology and Cost of Termination Surveys Associated with Decommissioning of Nuclear Facilities.*

Some alterations of and/or additions to information from these documents have been made, however, to demonstrate principles and procedures given in this manual. Care has been taken to ensure that these additions represent typical conditions that could be expected at the reference facility. To enhance readability, the term "reference" has been used as though it were the name of the facility; e.g., Reference Uranium Fuel Fabrication (RFF) Plant. Also, a fictitious company, e.g., General Nuclear Corporation, has been named as the owner and operator of the plant.

1.0 Background Information

The *Reference Uranium Fuel Fabrication Plant (RFF)* in Yorktown, Pennsylvania was built between 1960 and 1964 and was operated from 1964 until mid 1985 by the *General Nuclear Corporation*. Operating under NRC License XXX-100, Docket No. 00-000, the plant converted natural and enriched uranium hexafluoride (UF_6) to uranium oxide (UO_2), formed the UO_2 into pellets, and incorporated pellets into fuel rods and bundles. Auxiliary facilities were used to recover uranium from scrap and waste materials. Two processes were used for the UF_6 to UO_2 conversion. The primary method involved the hydrolysis of UF_6 to ammonium diuranate (ADU), which was then reduced and calcined to produce dry UO_2 powder; the secondary process was the conversion of UF_6 to U_3O_8 in a flame conversion reactor, followed by reduction to UO_2 powder in a reduction-calciner.

In 1985 the plant was shut down and nuclear materials were removed and shipped to Department of Energy facilities in Idaho Falls, Idaho. The plant remained in the shut-down state until 1986, when decommissioning efforts were initiated. Process equipment, fixtures, piping, etc., were removed and disposed of as radioactive waste. Buildings and adjacent grounds were characterized and those areas exceeding NRC guidelines for license termination were decontaminated; these efforts were completed in late 1990. This document describes the plan for conducting the final status survey of the site. Supporting information is presented in the Site Decommissioning Plan, prepared and submitted to the NRC in May 1986, and in the Characterization Survey Report, submitted in February 1988.

Beginning in April 1991, a survey to determine the final radiological status was performed. The survey was performed in accordance with a survey plan, reviewed and approved by the NRC. This report describes the results of that survey and demonstrates that the facility now satisfies the NRC guidelines, established for release of formerly licensed sites to unrestricted use. Supporting information is presented in the Site Decommissioning Plan, prepared and submitted to the NRC in May 1986, the Characterization Survey Report, submitted in February and the Final Site Decommissioning Report, submitted in January 1992.

2.0 Site Information

2.1 Site Description

The *Reference Uranium Fuel Fabrication Plant* is located on a total land area of approximately 470 hectares (1160 acres); there is a moderate size stream (Wandering River) running through one corner of the site (Figure 1). Actual plant processing facilities were on a much smaller, restricted, fenced-in area of

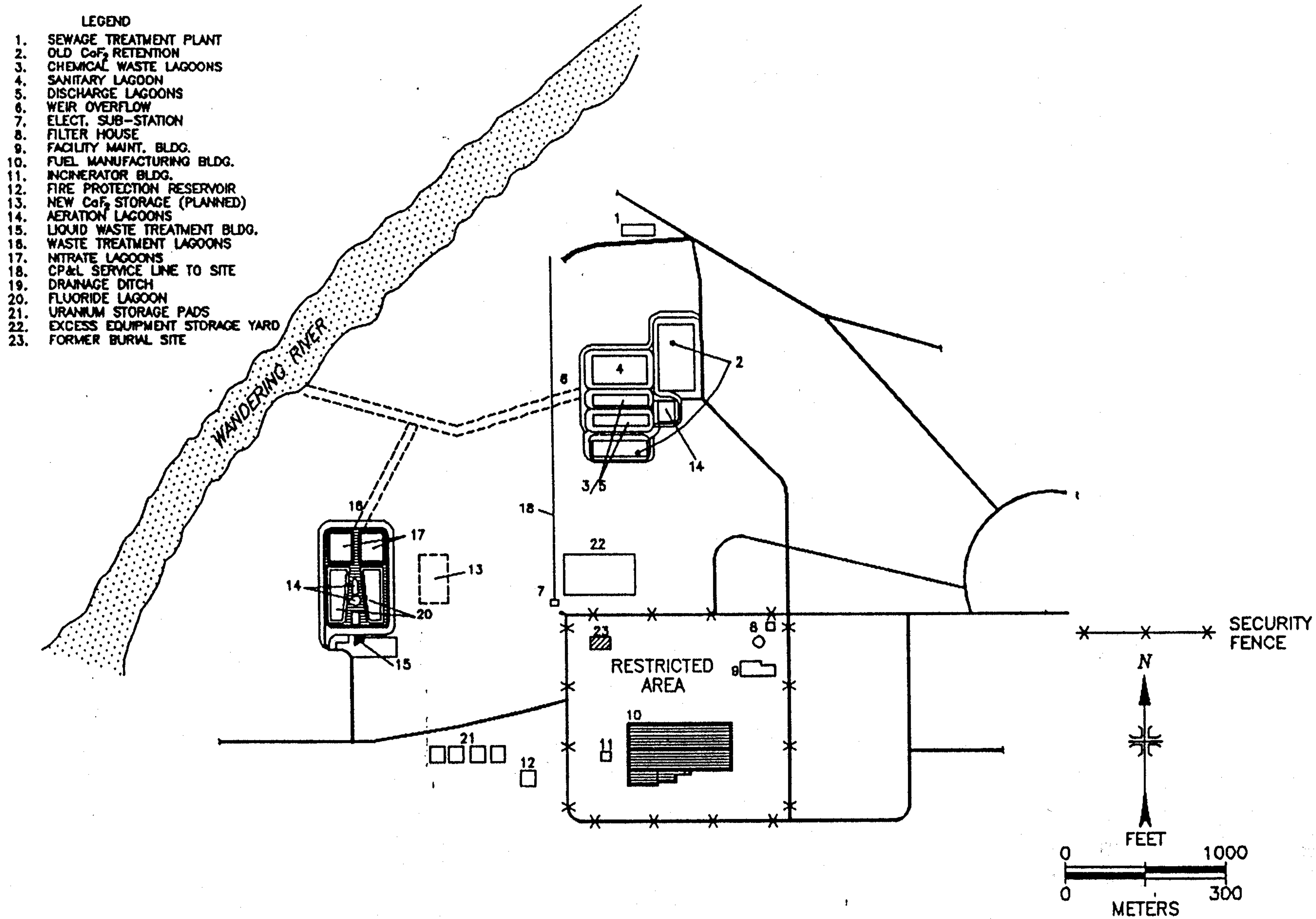
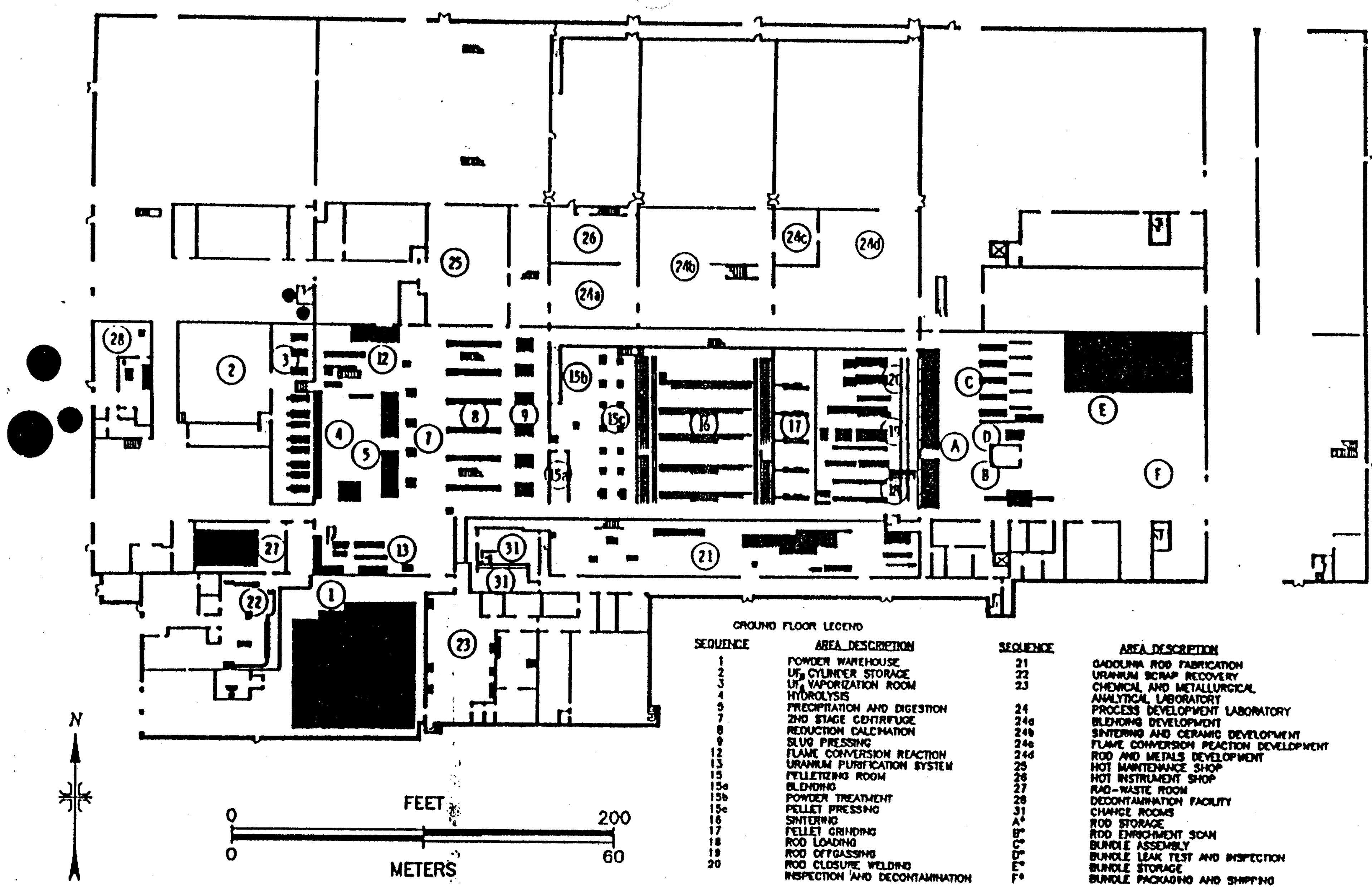


FIGURE 1: Map of the Reference Uranium Fuel Fabrication Plant Site

GROU LOOR



GROUND FLOOR LEGEND

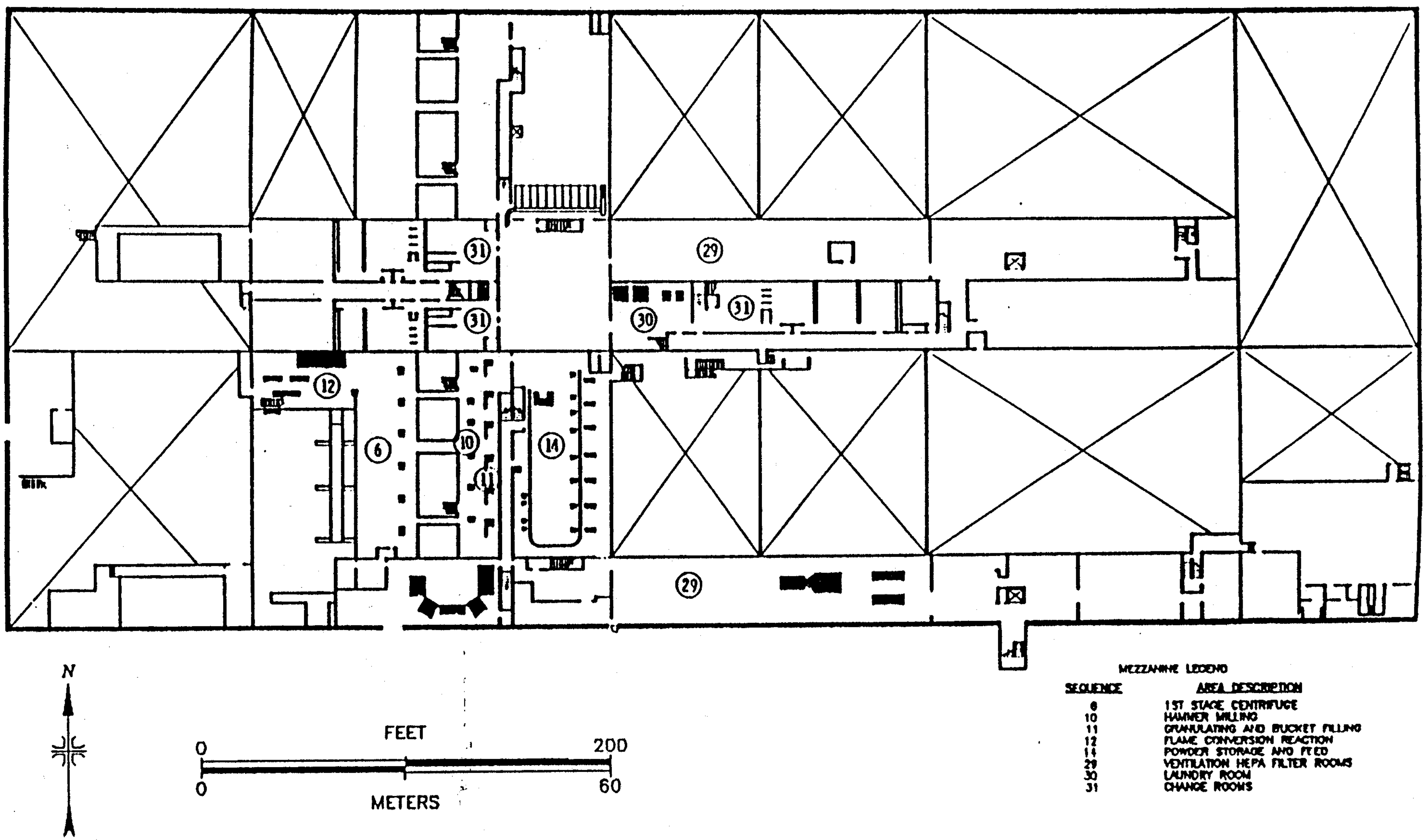
SEQUENCE	AREA DESCRIPTION
1	POWDER WAREHOUSE
2	UF_6 CYLINDER STORAGE
3	UF_6 VAPORIZATION ROOM
4	HYDROLYSIS
5	PRECIPITATION AND DIGESTION
7	2ND STAGE CENTRIFUGE
8	REDUCTION CALCINATION
9	SLUG PRESSING
12	FLAME CONVERSION REACTION
13	URANIUM PURIFICATION SYSTEM
15	PELLETIZING ROOM
15a	BLENDING
15b	POWDER TREATMENT
15c	PELLET PRESSING
16	SINTERING
17	PELLET GRINDING
18	ROD LOADING
19	ROD OFFGASSING
20	ROD CLOSURE WELDING
	INSPECTION AND DECONTAMINATION

SEQUENCE	AREA DESCRIPTION
21	GADOLINIA ROD FABRICATION
22	URANIUM SCRAP RECOVERY
23	CHEMICAL AND METALLURGICAL ANALYTICAL LABORATORY
24	PROCESS DEVELOPMENT LABORATORY
24a	BLENDING DEVELOPMENT
24b	SINTERING AND CERAMIC DEVELOPMENT
24c	FLAME CONVERSION REACTION DEVELOPMENT
24d	ROD AND METALS DEVELOPMENT
25	HOT MAINTENANCE SHOP
26	HOT INSTRUMENT SHOP
27	RAD-WASTE ROOM
28	DECONTAMINATION FACILITY
31	CHANGE ROOMS
A*	ROD STORAGE
B*	ROD ENRICHMENT SCAN
C*	BUNDLE ASSEMBLY
D*	BUNDLE LEAK TEST AND INSPECTION
E*	BUNDLE STORAGE
F*	BUNDLE PACKAGING AND SHIPPING

*CLEAN AREA, NO DECONTAMINATION REQUIRED

FIGURE 2A: Process Building Layout, Indicating Those Areas Used for Licensed Activities

MEZZANINE



MEZZANINE LEGEND

SEQUENCE	AREA DESCRIPTION
6	1ST STAGE CENTRIFUGE
10	HAMMER MILLING
11	GRANULATING AND BUCKET FILLING
12	FLAME CONVERSION REACTION
14	POWDER STORAGE AND FEED
29	VENTILATION HEPA FILTER ROOMS
30	LAUNDRY ROOM
31	CHANGE ROOMS

FIGURE 2B: Process Building Layout, Indicating Those Areas Used for Licensed Activities

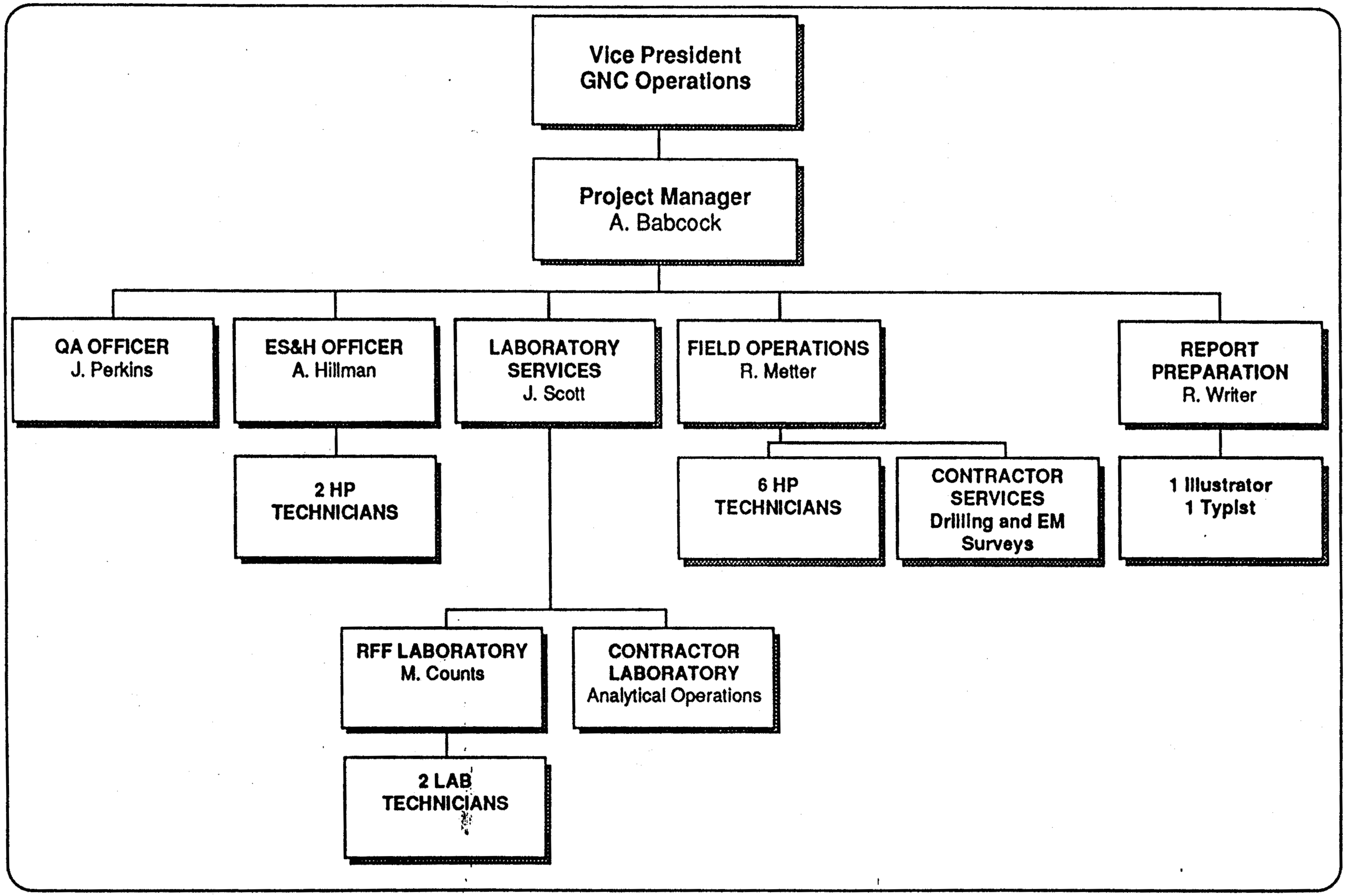


FIGURE 3: Organization Chart for Final Status Survey Activities

approximately 30,000 m^2 (3 hectares). The plant area occupies a low bluff that forms a bank of the river, and several flat alluvial terraces comprise the main topographical features of the property. These terraces lie at average elevations of 280 to 284 m above sea level and slope away from the river at grades of 2 to 3 percent. The river was used for disposal of acceptable liquid effluents from the on-site liquid waste systems.

The major structures in the formerly restricted processing area include the main building (with inter-connected chemical/metal laboratory and uranium scrap recovery and powder warehouse rooms), an incinerator building, a maintenance building, and a filter house (Figures 2A & 2B).

Auxiliary facilities are located outside the fenced area. These include a boiler house, a fluoride and nitrate waste treatment plant and associated lagoons, liquid chemical waste treatment lagoons, a sewage treatment plant and sanitary lagoon, and concrete uranium storage pads. The auxiliary facilities were used to recover uranium from scrap and waste materials and to recover valuable chemicals from gaseous and liquid wastes.

During the plant's 21 years of operation, an estimated total of 0.2 Ci of radioactivity was released into the atmosphere and subsequently deposited on the site. The property also contained one small, shallow land burial area for low-level radioactive waste. This area was operated in accordance with 10 CFR 20.304 between 1966 and 1970, receiving an estimated total activity of 0.3 Ci of uranium. This waste was excavated and disposed of at an authorized burial site as part of the decommissioning process.

2.2 Site Conditions at Time of Final Survey

As part of the decommissioning activities, process equipment and supporting fixtures were removed from radioactive materials areas and cleaned and released or disposed of as radioactive waste. Potentially contaminated structural surfaces were stripped of coatings by grit blasting or use of chemical agents. Contaminated surfaces identified by the characterization survey were cleaned or removed.

The on-site shallow land burial was excavated. Facilities used for processing of potentially contaminated effluents such as the lagoons and sewage treatment plant were characterized, and, where necessary, decontamination was performed. Soil contamination in the vicinity of process building was identified and removed to depths ranging from 5 cm to 1.5 m.

Details regarding the decontamination actions are presented in the Final Site Decommissioning Report.

2.3 Identity of Potential Contaminants and Release Guidelines

Based on the knowledge of site operations and the results of the preliminary assessment and characterization survey the significant radiological contaminants were determined to be isotopes of uranium. The uranium is enriched in U-234 and U-235 above naturally occurring levels; the average activity ratios of the uranium isotopes is:

U-234	81.4%
U-238	15.5%
U-235	3.1%

On the basis of this combination of contaminants the surface contamination guideline values for the site are:

5000 dpm/100 cm^2, average over 1 m^2*
150000 dpm/100 cm^2, maximum over 100 cm^2 *
1000 dpm/200 cm^2, removable*

*Hypothetical values, chosen for the purpose of demonstrating survey design and data evaluation.

The soil contamination guideline value is 30 pCi/g, total uranium.

3.0 Final Status Survey Overview

3.1 Survey Objectives

The purpose of the final status survey was to demonstrate that the radiological conditions at the *Reference Uranium Fuel Fabrication Plant* satisfy the NRC guidelines and that the plant site can, therefore, be released from licensing restrictions for future use without radiological controls. The specific objectives of the survey were to show that:

A. Surface Activity of Buildings and Structures

- Average surface activity levels (total of fixed and removable activity) are at or below guideline values established as acceptable by NRC.

- Reasonable efforts have been made to identify, evaluate, and remove, if necessary, areas of residual activity exceeding the guideline value, known as elevated areas, may be acceptable, provided the activity levels are less than three times the guideline values, when averaged over a surface region of 100 cm^2, and provided the average level within a 1 m^2 area containing the elevated area is within the guideline value.

- Reasonable efforts have been made to clean up removable activity and removable activity in any 100 cm^2 area does not exceed 20% of the average surface activity values.

B. Volume Activity of Soil and Building Materials

- Average radionuclide concentrations are at or below guideline values, established as acceptable by the NRC. For your land areas, averaging is based on a 100 m^2 (10 m x 10 m) grid area.

- Reasonable efforts have been made to identify, evaluate, and remove, if necessary, areas of residual activity exceeding the guideline values. Areas of residual activity exceeding the guideline value, known as elevated areas, may be acceptable, provided they do not exceed the guideline value by greater than a factor of $(100/A)^{1/2}$, where A is the area of residual activity in m^2, and provided the activity level at any location does not exceed three times the guideline value.

C. Exposure Rate

- Exposure rates do not exceed 5 μR/h above background at 1 m above the surface. Exposure rates may be averaged over a 100 m^2 grid area. Maximum exposure rates over any discrete area may not exceed 10 μR/h above background.

The objective of the survey was to demonstrate at a 95% minimum level of confidence, that the above conditions have been met. For the purpose of this demonstration, each survey unit independently evaluated.

3.2 Organization and Responsibilities

The survey was performed by a team composed of qualified personnel of the *RFF Plant* and *General Nuclear Corporation.* This is the same organizational structure which conducted the characterization survey activities; the Survey Plan contains further details on this organization.

Analytical services for gross alpha/beta levels on smears, air, and water samples were performed by the Plant Analytical Services Laboratory in accordance with standard Plant procedures, "Laboratory Analyses of Environmental Samples" procedures GNC/RFF-HP 3.1, 3.2, 3.4, and 3.7 (1988). Samples of soil and other special samples, requiring gamma spectrometry or wet chemistry analyses were conducted by a contract laboratory, *Analytical Operations, Inc.* QA/QC programs for both in-house and contractor laboratory services were monitored by the QA coordinator of the final status survey team.

3.3 Instrumentation

Table 1 lists the instrumentation used for the survey activities, along with parameters and detection sensitivities for the instrumentation and survey technique. The combination of instrumentation and technique were chosen to provide a detection sensitivity of 25% or less of the guideline levels. All instruments were calibrated a minimum of once every 3 months, using NIST-traceable standards. Calibration was for the specific uranium radiation energies expected to be present at the site. Operational and background checks were performed at least once each 4 hours of instrument use.

3.4 Survey Procedures

Survey planning and procedures were in accordance with the *Manual for Conducting Radiological Surveys in Support of License Termination, NUREG/CR-5849.* Procedures are briefly described in this section; further detail on procedures is presented in Appendix A.

3.4.1 Area Classification

For purposes of establishing the sampling and measurement frequency and pattern, the site was divided into affected and unaffected areas. The bases for these classifications are:

- **affected areas:** Areas that have potential radioactive contamination (based on plant operating history) or known radioactive contamination (based on past or preliminary radiological surveillance). This includes areas where radioactive materials were used and stored, where records indicate spills or other unusual occurrences that could have resulted in spread of contamination, and where radioactive materials were buried. Areas immediately surrounding or adjacent to locations where radioactive materials were used or stored, spilled, or buried were included in this classification because of the potential for inadvertent spread of contamination.

- **unaffected areas:** All areas not classified as affected. These areas are not expected to contain residual radioactivity, based on a knowledge of site history and previous survey information.

Table 2 lists the various site areas in each classification category.

TABLE 1
INSTRUMENTATION FOR RADIOLOGICAL SURVEYS

Type of Measurement	ID	Instrumentation Detector	Instrumentation Meter	Bkgd.[1]	4 π[1] Eff. (%)	Detection Sensitivity
Surface scans - alpha	1	large area gas prop., AB Co., Model 100	Countrate meter[2], AB Co., Model 1000	20 cpm	25	70 dpm/100 cm^2
Surface scans - alpha	2	scintillation, XYZ Inc. Model 10	Countrate meter[2], AB Co., Model 1000	2 cpm	18	100 dpm/100 cm^2
Surface scans - beta	3	large area gas prop., AB Co.,Model 100	Countrate meter[2], AB Co., Model 1000	1500 cpm	30	1500 dpm/100 cm^2
Surface scans - beta-gamma	4	pancake GM, XYZ Inc., Model 20	Countrate meter[2], XYZ Inc., Model 120	40 cpm	20	3500 dpm/100 cm^2
Surface scans - gamma	5	NaI scintillation, N Products, Model X	Countrate meter[2], XYZ Inc., Model 120	3500 cpm	N/A	2 μR/h
Surface activity - alpha	6	gas prop., AB Co.,Model 200	Digital scaler[3], N Prod., Model Y-1	5 cpm	25	60 dpm/100 cm^2
Surface activity - alpha	7	scintillation, XYZ Inc., Model 10	Digital scaler[3], N. Prod., Model Y-1	2 cpm	18	100 dpm/100 cm^2
Surface activity - beta	8	gas prop., AB Co.,Model 200	Digital scaler[3], N. Prod., Model Y-1	350 cpm	30	300 dpm/100 cm^2
Surface activity - beta-gamma	9	pancake GM, XYZ Inc., Model 20	Digital scaler[3], N. Prod., Model Y-1	40 cpm	20	1100 dpm/100 cm^2
Exposure rates	10	pressurized ionization, R. Co., Model 1111	(same as detector)			<1 μR/h
Gross α/β on smears	11	gas prop., T&C Co., Model 5000	(same as detector)	0.2 cpm α 1.5 cpm β	35 40	10 dpm 20 dpm

[1]Nominal Values.
[2]Monitoring audible signal.
[3]1 minute integrated count.

3.4.2 Reference Grids

Grids were established for the purpose of referencing locations of samples and measurements, relative to buildings and other site features. The gridding intervals were based on the potential for residual contamination in the various plant areas. (See Table 2). All affected building area floor and lower wall (up to 2 m_2) surfaces were gridded at 1 m intervals; upper walls and ceilings of affected areas were also gridded at 1 m intervals, if residual activity above 25% of the guideline was known or suspected. Building surfaces in unaffected areas or those upper surfaces in affected areas that were not contaminated as a result of prior activities were not gridded; measurements were referenced to other grid systems or to prominent building features. Affected outside areas were gridded at 10 m intervals; unaffected areas were not gridded. This grid system is identical to the one used during the characterization survey and the remedial action activities; where necessary the earlier grid was reestablished, expanded, or subdivided.

The facility was divided into "survey units" having common history, contamination potential, or that are naturally distinguishable from other sites areas. These survey units were sized to assure a minimum of 30 measurement locations each for floor and lower walls, other vertical surfaces, and other horizontal surfaces. Areas of building surface survey units, classified as affected, were limited to a maximum of 100 m^2. A total of 48 affected area survey units and 5 unaffected areas survey units were established.

During the survey, two small soil areas on the unrestricted plant site and one office area, adjacent to the processing facility, were found to contain residual activity exceeding 75% of the guideline levels. These areas were reclassified from unaffected to affected areas and surveyed by a more intensive procedure than initially planned.

3.4.3 Surface Scans

Scanning of surfaces to identify locations of residual surface and near-surface activity was performed according to the following schedule:

Affected Area Surfaces - 100% of surface

Non-contaminated upper surfaces in affected areas - in immediate vicinity of measurement

Unaffected Area Surfaces - 10% of lower surface

TABLE 2

CLASSIFICATION OF RFF PLANT SURFACES
AND AREAS ACCORDING TO CONTAMINATION POTENTIAL

Plant Area	Bldg. or Facility	Room or Area	Classification of Contamination Potential	Remarks
Restricted	Process Bldg.	Powder Warehouse	Affected	
		UF_6 Cyl. Storage	Affected	
		UF_6 Vapor. Rm.	Affected	
		Hydrolysis	Affected	
		Precip. & Digestion	Affected	
		2nd Stage Centrifuge	Affected	
		Reduction Calcination	Affected	
		Slug Pressing	Affected	
		Flame Conv. Reaction	Affected	
		Uranium Purif. System	Affected	
		Pelletizing Room	Affected	
		Blending	Affected	
		Powder Treatment	Affected	
		Pellet Pressing	Affected	
		Sintering	Affected	
		Pellet Grinding	Affected	
		Rod Loading	Affected	
		Rod Offgassing	Affected	

TABLE 2 (Cont'd)

CLASSIFICATION OF RFF PLANT SURFACES
AND AREAS ACCORDING TO CONTAMINATION POTENTIAL

Plant Area	Bldg. or Facility	Room or Area	Classification of Contamination Potential	Remarks
Restricted	Process Bldg.	Rod Closure Welding Inspection & Decon.	Affected	
		Gadolinia Rod Fab.	Affected	
		Uran. Scrap Recovery	Affected	
		Chem & Metallurgical Anal. Laboratory	Affected	
		Process Devel. Lab.	Affected	
		Blending Development	Affected	
		Sint. & Cer. Develop.	Affected	
		Flame Con. Reac. Dev.	Affected	
		Rod & Metal Develop.	Affected	
		Hot Maint. Shop	Affected	
		Hot Inst. Shop	Affected	
		Rad-Waste Rm.	Affected	
		Decon. Facility	Affected	
		Change Rooms	Affected	
		1st Stage Centri.	Affected	
		Hammer Milling	Affected	

TABLE 2 (Cont'd)

CLASSIFICATION OF RFF PLANT SURFACES AND AREAS ACCORDING TO CONTAMINATION POTENTIAL

Plant Area	Bldg. or Facility	Room or Area	Classification of Contamination Potential	Remarks
Restricted	Process Bldg.	Gran. & Bucket Fill	Affected	
		Flame Conv. Reaction	Affected	
		Powd. Storage & Feed	Affected	
		Vent. Hepa Filt. Rm.	Affected	
		Laundry Room	Affected	
		Rod Storage	Affected	Upper surfaces not affected.
		Rod Enrichment Scan	Affected	Upper surfaces not affected.
		Bundle Assembly	Affected	Upper surfaces not affected.
		Bundle Leak Test & Inspection	Affected	Upper surfaces not affected.
		Bundle Storage	Affected	Upper surfaces not affected.
		Bundle Packaging & Shipping	Affected	Upper surfaces not affected.
		Office and Admin. Areas	Unaffected	Upper surfaces not affected.

TABLE 2 (Cont'd)

CLASSIFICATION OF RFF PLANT SURFACES AND AREAS ACCORDING TO CONTAMINATION POTENTIAL

Plant Area	Bldg. or Facility	Room or Area	Classification of Contamination Potential	Remarks
Restricted	Filter House	Entire Interior	Affected	
		Roof	Affected	
	Former Waste Burial Site	-----	Affected	
	Grounds Adj. to Proc. Areas	-----	Affected	
	Liquid Waste Transfer Line	-----	Affected	
		Soil	Affected	
		Paved Areas	Affected	
Unrestricted	Other Buildings	Entire Interior	Unaffected	Upper surfaces not affected.
	Roofs		Unaffected	
	Sewage Trmt. Plant	Entire Interior	Affected	Upper surfaces not affected.
		Roof	Unaffected	
	Grounds	Entire Unrestricted Plant Area	Unaffected	

Building interior surface scans were conducted for alpha, beta, and gamma radiations. Scans of exterior building and paved surfaces were for beta and gamma radiations. Soil surfaces were scanned for gamma radiations only.

Instrumentation for scanning is listed in Table 1. The instruments having the lowest detection sensitivity were used for the scans, wherever physical surface conditions and measurement locations permitted.

Scanning speeds were 1 detector width per second for alpha and beta detection instruments and 0.5 m per second for gamma instruments. Audible indicators (headphones) were used to identify locations, having elevated (>1.5 to 3 times ambient) levels of direct radiation. These locations were noted for further investigation.

3.4.4 Surface Activity Measurements

Direct Measurements

Direct measurements of alpha, beta, and/or beta-gamma surface activity were performed at selected locations using instrumentation described in Table 1. Unless precluded by surface conditions or physical parameters, the most sensitive of the instruments listed for surface measurements (Table 1) were used. Measurements were conducted by integrating counts over a 1 minute period. Appendix B contains facility drawings showing the locations of measurements.

Measurement spacings/frequencies were as follows:

Floors and lower walls
- Affected Areas - 2 m intervals
- Unaffected Areas - 1 per 50 m^2 of surface

Other Surfaces
- Affected Areas - 2 m intervals if residual activity expected to exceed 25% of guideline; otherwise 1 per 20 m^2 of surface.
- Unaffected Areas - 1 per 50 m^2 of surface

Removable Contamination Measurements

A smear for removable contamination was performed at each direct measurement location.

3.4.5 Exposure Rate Measurements

Gamma exposure rates were measured at 1 m above ground or floor surfaces, using a pressurized ionization chamber or a gamma scintillation instrument, calibrated for low enrichment uranium energies. Measurements were uniformly spaced according to the following pattern:

Building Interiors

Affected Areas: 1 measurement per 4 m^2.
Unaffected Areas: 1 measurement per 200 m^2.

Grounds

Affected Areas: 5 measurements per 100 m^2 grid block.
Unaffected Areas: 50 measurements at randomly selected locations.

3.4.6 Soil/Sediment Sampling

<u>Surface</u>

Samples (about 500 grams each) of surface soil (0-15 cm) were systematically collected from the center and 4 points midway between the center and the block corners for each 10 m x 10 m grid in affected areas. Sixty samples were obtained from random locations in unaffected areas, outside the restricted plant site. Samples were collected at 10 m intervals along the drainage ditches from the former waste processing facilities to the *Wandering River* and from other natural surface drainage pathways to the River. At each surface sampling location, contact gamma levels before and after sampling were monitored to determine whether subsurface contamination may be present.

Sediment (about 500 grams) samples were obtained at the outfall of drainage ditches to the *Wandering River* and from 25 to 50 m upstream and downstream of the outfall. Sampling was from the River center and near both banks. Locations of surface soil sampling are indicated on facility drawings in Appendix B.

<u>Subsurface</u>

Subsurface investigations were performed at the locations of the former burial site, liquid waste lagoons, and previously excavated underground piping between the processing areas and the waste ponds. These locations were scanned by a commercial contractor using electromagnetic sensors (ground penetrating radar) to verify that no buried objects remain and to guide placement of subsurface sampling locations. Results of that survey are included as Appendix C of this report. Subsurface samples were obtained by a commercial contractor, using the split-barrel method. Sampling was at the surface (0-15 cm) and at 1 m intervals to a depth of 10 m at the former burial site and liquid waste lagoon areas; along the path of the previously excavated liquid waste transfer piping, sampling was at 1 m intervals to a depth of 3 m. Fifteen, uniformly spaced sampling locations were selected in the former burial site and twenty-five uniformly spaced locations were selected in the area of the lagoons. In addition, two sampling locations were selected on each side around the perimeter of these facilities, to confirm absence of subsurface migration. Subsurface samples were obtained at approximately 5 locations along the former waste transfer piping system.

Following sampling, a gamma scintillation probe was inserted into the borehole and relative count rates determined at approximately 50 cm intervals between the surface and the hole bottom. If results were positive, additional subsurface sampling was conducted to define the area of residual contamination.

Locations of subsurface soil sampling are indicated on drawings in Appendix B.

3.4.7 Special Measurements and Samples

Building Interiors

Samples of paint were obtained from 100 cm^2 areas on lower walls in former liquid and powder processing rooms. One paint sample per 10 m^2 was obtained from these surfaces. Paint samples were also collected from surfaces where direct and removable activity measurements suggested contamination may have been painted over.

Trenches where contaminated drain piping was excavated in the Analytical Laboratory, Rad Waste Decontamination, and Change Room facilities were sampled at locations of elevated direct radiation and at approximately 3 m intervals along the excavations. Other remaining drains and piping in affected areas were accessed, direct alpha and beta-gamma scans and measurements performed at all access points, and a large-area swab obtained from the piping, using a plumbers "snake" and piece of cloth.

Remaining ducts, electrical boxes, conduit, or other interior surfaces in affected areas, which may contained residual contamination, were accessed at random and measurements of direct and removable activity performed. Swabs were obtained from insides of wall and floor penetrations, anchor bolt holes, and floor cracks or expansion joints.

Floor cores were removed from 17 locations in the areas where conversion was performed; gamma scans of subfloor soil were performed and soil samples from the floor/soil interface and 0.5 m below the interface were collected at each coring location.

Building Exteriors

Measurements of direct and removable activity were performed on exterior and interior surfaces of air exhaust equipment and at representative locations on roof drains. Samples of roofing material were obtained where direct measurements suggested possible entrained contamination.

Grounds

Cores were removed at 5 locations on the uranium storage pads and samples of subpad soil collected. Coring and soil sampling was also performed on three other paved outside surfaces, where scans or direct measurements suggest possible contamination beneath the paving.

Locations of special samples are shown on Figures in Appendix B.

3.5 Background Level Determinations

Background exposure rates were determined for the building interior by taking of 8 pressurized ionization chamber measurements at locations of similar construction but without a history of radioactive materials use. Also, 8 locations for area background measurement and sampling will be selected within a 0.5 to 10 km radius of the site. Exposure rate measurements were performed using a pressurized ionization chamber. A background soil sample was collected from each location of external background measurement. Results of background exposure rate and uranium soil concentrations were evaluated to assure that the averages determined were representative of the true averages, using procedures described in NUREG/CR-5849. Based on this evaluation, an additional 6 samples were obtained for determining the uranium average background concentrations in soil. Figures B-97 and B-98 in Appendix B indicate the locations of background measurements and samples.

3.6 Sample Analysis

Smears and swabs for removable contamination were analyzed for gross alpha, gross beta activity. Soil, sediment, gravel, roofing material, and other large volume samples were analyzed for U-235 and U-238 by gamma spectrometry; total uranium was calculated on the basis of previously determined isotopic activity ratios for this site. Samples of paint, residue, and other samples of small volume were analyzed for uranium by wet chemical separation and alpha spectroscopy.

3.7 Data Interpretation

Data conversions and evaluations were performed, following the guidance in NUREG/CR-5849. Calibrational methods and sample calculations are provided in Appendix D. Measurement data were converted to units of dpm/100 cm^2 (surface activity), μR/h (exposure rates) and pCi/g (soil concentrations) for comparison with guidelines. Values were adjusted for contributions from natural background. Individual measurements and soil radionuclide concentration levels were compared with "hot-spot" criteria. Average values for survey units were determined and compared with guideline levels. Data for each survey unit were tested against the confidence level objective.

Additional remediation and/or further sampling and measurements were performed where guidelines were not met or could not be demonstrated to the specified level of confidence. Computations and comparisons were repeated, as necessary.

The average activity levels were used to estimate the total residual inventory of uranium at the site.

3.8 Records

All samples and original survey data have been archived at the General Nuclear Corporation main offices and will be held until such time as authorized by the NRC for disposal.

4.0 Survey Findings and Results

Appendix E contains tables of data, affected during the survey. Data are summarized in tables of Appendix F; Appendix F also contains results of data interpretations and comparisons with guidelines and conditions established as survey objectives.

4.1 Background Levels (Table E-1)

Background exposure rates for interior and exterior areas averaged 9.3 and 10.1 μR/h respectively. Concentrations of uranium in area soil averaged 1.1 ± 0.3 pCi/g, U-234; 0.1 ± 0.1 pCi/g, U-235; and 1.2 ± 0.3 pCi/g, U-238.

4.2 Building Surveys

Scans

Scans of surfaces (Table E-2) identified approximately 50 small isolated areas of residual contamination and 1 larger area, adjacent to the lower conversion operation. The area adjacent to the conversion operation was reclassified from "unaffected" to "affected" for purposes of surface activity surveys. All other locations identified by scans were evaluated to determine status relative to guidelines and, if necessary, remediated and resurveyed (refer to Tables E-4 and E-5).

Surface Activity Measurement

Table E-3 present the results of surface activity measurements. All individual measurements were within guideline levels, with many of the measurement being below the sensitivity levels of the procedures.

Sampling

Table E-6 and E-7 contain results of paint samples from building interior surfaces and soil samples from below floors of several former process areas. No evidence of sample activity exceeding guidelines was noted. Gamma scans at subfloor sampling locations did not indicate potential residual activity.

Exposure Rates

Exposure rates inside structures ranged from 8 to 12 μR/h (Table E-8). These rates were within the guideline levels of 5 μR/h above background.

4.3 Grounds Surveys

Scans

Scans identified 11 locations of elevated contact gamma radiation, suggesting residual soil activity (See Table E-9). Two of these locations were reclassified as affected areas for further survey; the remainder of the locations were remediated by removal of small areas of surface soil.

Exposure Rates

Exposure rate measurements are presented in Table E-10. Rates ranged between 9 and 13 μR/h; all locations satisfied the guidelines.

Uranium Concentrations in Soil

Tables E-10 and E-11 summarize the results of surface and subsurface soil sampling. Fifteen individual surface soil samples exceeded the guideline level; the maximum was approximately 5 times the guideline. Further sampling at the locations of the hot-spots indicated that in each case the area of residual activity was 1 m^2 or less in area and averaging conditions for the grid containing these sampling locations were satisfied. No subsurface samples contained in excess of the uranium guideline. Borehole gamma logging did not identify any locations of elevated subsurface gamma radiation.

4.4 Data Evaluation

Tables F-1, F-2, and F-3 summarize the average levels in the different survey units for building and grounds surveys. Comparisons of averages with guidelines indicated the guidelines were satisfied for all survey units, at the 95% confidence level conditions.

4.5 Residual Activity Inventory

Calculations indicate that residual activity above the average background on building surfaces and in soil is approximately 4.3×10^8 and pCi and 2.7×10^6, respectively.

5.0 Summary

Between April and September 1991, surveys of the Reference Uranium Fuel Fabrication Plant were conducted. Results of the survey demonstrate that the decontamination actions were effective in reducing residual activity at the site meet the NRC limits for release for unrestricted use.

SAMPLE

TABLE E-1

BACKGROUND EXPOSURE RATES AND SOIL CONCENTRATIONS REFERENCE URANIUM FUEL FABRICATION PLANT

Location[a]	Exposure Rate μR/h	Uranium Concentrations (pCi/g)								
		U-234			U-235			U-238		
		Conc.	Uncert[b]	MDA	Conc.	Uncert.	MDA	Conc.	Uncert.	MDA
Bldg. Interior										
1	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
-	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
-	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Exterior										
1	10	1.3	0.2	0.2	0.1	0.1	0.1	1.5	0.3	0.2
2	9	0.9	0.2	0.1	0.1	0.1	0.1	1.1	0.2	0.2
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-

[a]Refer to Figures 97 and 98.
[b]Uncertainties represent the 95% confidence level, based on counting statistics.

SAMPLE

TABLE E-2

RESULTS OF SURFACE SCANS
REFERENCE URANIUM FUEL FABRICATION PLANT

Building/ Area and Surface	Figure	Scan Results						Areas of Residual Activity Identified
		Alpha		Beta-Gamma		Gamma		
		Instrument*	c/m	Instrument	c/m	Instrument	c/m	
Conversion								
floor	7	#1	40-460	#3	320-5000	#5	3.0 K - 3.5 K	2 (See Figure 7)
lower wall	7	#1	30-300	#3	280-450	#5	2.8 K - 3.2 K	0

*Refer to Table 1 for instrument type.

SAMPLE

TABLE E-3

SURFACE ACTIVITY MEASUREMENTS
BUILDING INTERIORS
REFERENCE URANIUM FUEL FABRICATION PLANT

Building/ Area and Surface	Measurement Location	Figure	Activity (dpm/100 cm^2)											
			Total						Removable					
			Alpha			Beta-Gamma			Alpha			Beta		
			Act.	Uncert.[a]	MDA	Act.	Uncert.	MDA	Act.	Uncert.	MDA	Act.	Conf. Lev.	MDA
<u>Conversion</u>														
floor	C,0	7	850	220	150	2200	460	460	4	4	7	15	5	9
	C,2	7	2100	430	150	4500	510	470	-2	5	7	10	4	9
	C,4	7	-50	120	150	200	500	470	0	3	7	-2	5	9
	D,0	7	-	-	-	-	-	-	-	-	-	-	-	-
upper walls	1	9	-	-	-	-	-	-	-	-	-	-	-	-
	2	9	-	-	-	-	-	-	-	-	-	-	-	-
	3	9	-	-	-	-	-	-	-	-	-	-	-	-
	4	9	-	-	-	-	-	-	-	-	-	-	-	-

[a]Uncertainties represent the 95% confidence level, based on counting statistics.

SAMPLE

TABLE E-4

LOCATION OF ELEVATED DIRECT RADIATION IDENTIFIED BY SCANS
REFERENCE URANIUM FUEL FABRICATION PLANT

Building/Area and Surface	Location	Figure	Area Involved (cm^2)	Total Activity (dpm/100 cm^2)		Exceed Guidelines		Resolution
				Alpha	Beta	Hot Spot	Average	
Conversion floor	1H	7	20	27000	39000	yes	no	remediated
	2H	7	300	3800	4200	no	no	more required

SAMPLE

TABLE E-5

LOCATIONS OF RESIDUAL CONTAMINATION IDENTIFIED BY SCANS AND ACTIVITY MEASUREMENTS FOLLOWING REMEDIATION REFERENCE URANIUM FUEL FABRICATION PLANT

Building/ Area and Surface	Measurement Location	Figure	Activity (dpm/100 cm^2)											
			Total						Removable					
			Alpha			Beta-Gamma			Alpha			Beta		
			Act.	Uncert.[a]	MDA	Act.	Uncert.	MDA	Act.	Uncert.	MDA	Act.	Conf. Lev.	MDA
<u>Conversion</u> floor	D + .5, 3.7 (1H)	7	700	150	150	1900	600	470	1	4	7	10	5	9

[a]Uncertainties represent the 95% confidence level, based on counting statistics.

SAMPLE

TABLE E-6

ACTIVITY IN PLANT AND RESIDUE SAMPLES
REFERENCE URANIUM FUEL FABRICATION PLANT

Building/Area and Surface	Sample Location	Sample Type	Figure	Uranium Activity Content (pCi/100 cm^2)		
				Activity	Uncertainty	MDA
Conversion Lower Wall	4P	Paint	10	100	40	10

SAMPLE

TABLE E-7

URANIUM CONCENTRATIONS IN SUBFLOOR SOIL
REFERENCE URANIUM FUEL FABRICATION PLANT

Building/ Area and Surface	Sample Location	Depth (cm)	Figure	Uranium Concentration (pCi/g)					
				U-238			U-235		
				Act.	Uncert.	MDA	Act.	Uncert.	MDA
Process 1 Floor	3B	30	11	1.8	0.7	1.0	0.1	0.1	0.1

SAMPLE

TABLE E-8

EXPOSURE RATES INSIDE BUILDINGS
REFERENCE URANIUM FUEL FABRICATION PLANT

Building/Area	Location	Figure	Exposure Rate at 1 m Above Surface (μR/h)
<u>Conversion</u>	1E	12	9.0
	2E	12	10.2

SAMPLE

TABLE E-9

AREAS OF ELEVATED GAMMA RADIATION IDENTIFIED BY SCANS
REFERENCE URANIUM FUEL FABRICATION PLANT

Location	Figure	Maximum Contact Gamma Level (c/m)	Resolution
1G	99	55,000	remediated
2G	30	70,000	remediated
3G	10	10,000	area reclassified

SAMPLE

TABLE E-10

EXPOSURE RATES AND
SURFACE SOIL CONCENTRATIONS
REFERENCE URANIUM FUEL FABRICATION PLANT

Location[a]	Exposure Rate μR/h	Uranium Concentrations (pCi/g)					
		U-235			U-238		
		Conc.	Uncert.[b]	MDA	Conc.	Uncert.	MDA
Cylinder Storage							
13 N, 27 E	10	0.2	0.2	0.1	2.3	0.7	0.8
18 N, 32 E	12	0.1	0.2	0.2	1.2	0.6	0.7

[a]Refer to Figures _____.
[b]Uncertainties represent the 95% confidence level, based on counting statistics.

SAMPLE

TABLE E-11

SUBSURFACE SOIL CONCENTRATIONS
REFERENCE URANIUM FUEL FABRICATION PLANT

Location[a]	Small Depth (m)	Uranium Concentrations (pCi/g)					
		U-235			U-238		
		Conc.	Uncert.[b]	MDA	Conc.	Uncert.	MDA
Cylinder Storage 1 BH	Surface	0.1	0.2	0.2	1.3	0.6	0.7
	0.5	0.3	0.2	0.2	1.8	0.7	0.8
	1.0	0.2	0.2	0.2	0.9	0.5	0.7

[a]Refer to Figures _____.
[b]Uncertainties represent the 95% confidence level, based on counting statistics.

SAMPLE

TABLE F-1

SUMMARY OF BUILDING SURFACE ACTIVITY RESULTS
REFERENCE URANIUM FUEL FABRICATION PLANT

Building/ Area and Surface	Surface Area (m²)	Average Total Activity (dpm/100 cm²)						$\mu_{\alpha(5)}$	$n_{1(4),(5)}$	Guidelines/ Conditions Satisfied
		Alpha			Beta-Gamma					
		n[1]	$\bar{x}$ [2]	s[3]	n	$\bar{x}$	s			
<u>Conversion</u> floor and lower walls	440	445	1280	620	445	2940	820	4120*	280*	yes/yes
ceiling	270	30	130	100	30	480	200	590*	24*	yes/yes
upper walls	220	35	190	95	35	480	230	630*	19*	yes/yes

[1]n = number of measurements

[2] $\bar{x}$ = average

[3]s = standard deviation

[4]n = number of data points to demonstrate 95% confidence level

[5] = based on beta-gamma level

* = numbers are hypothetical (not actual calculations)

SAMPLE

TABLE F-2

SUMMARY OF SOIL SAMPLING RESULTS
REFERENCE URANIUM FUEL FABRICATION PLANT

Survey Unit	# of Samples (n)	Total Uranium Activity (pCi/g) (Includes Background)		μ_{α}[c]	n_1[d]	Guidelines/Conditions Satisfied
		$\bar{x}$[a]	s[b]			
Former Burial Site	95	6.2	3.1	13.4	55	yes/yes

[a] $\bar{x}$ = average

[b] s = standard deviation

[c] μ_d = comparison value (hypothetical)

[d] n_1 = total # of samples for 95% confidence level (hypothetical)

SAMPLE

TABLE F-3
SUMMARY OF EXPOSURE RATE MEASUREMENTS
REFERENCE URANIUM FUEL FABRICATION PLANT

Survey Unit	# of Measurements (n)	Exposure Rate (μR/h)		μ_{α} [c]	n_1 [d]	Guidelines/Conditions Satisfied
		$\bar{x}$ [a]	s [b]			
Building Group #7	26	11.3	1.5	13.2	21	yes/yes
Former Burial Site	39	12.0	1.7	14.0	35	yes/yes

[a] $\bar{x}$ = average

[b] s = standard deviation

[c] μ_d = comparison value (hypothetical)

[d] n_1 = total # of samples for 95% confidence level (hypothetical)

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11. ABSTRACT (200 words or less)

This document describes a process for conducting radiological surveys during decommissioning, to demonstrate that residual radioactive material satisfies criteria established by the U.S. Nuclear Regulatory Commission (NRC) for termination of a license. The manual describes procedures for design and conduct of surveys in a manner which will provide a high degree of assurance that NRC guidelines and conditions have been satisfied. The manual also describes methods for documenting the survey findings in a final report to the NRC. This manual updates information contained in NUREG/CR-2082, *Monitoring for Compliance With Decommissioning Termination Survey Criteria*, (ORNL 1981). It incorporates statistical approaches to survey design and data interpretation used by the Environmental Protection Agency for evaluation of hazardous materials sites under Superfund (CERCLA). Quality assurance is emphasized throughout.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

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