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Lecture 12.1

Completion of Decommissioning: Monitoring for Site Release and License Termination

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Scope

This lecture covers post-decommissioning surveys of a facility for site release and ultimately license termination. Topics include:

- Post decommissioning radiological surveys
- Verification of achieving release criteria for the project
- Regulatory interactions for license termination.

The material contained in this lecture is drawn from:

- Decommissioning project experiences
- Technical references on this topic
- Regulatory references on this topic.

This lecture draws heavily upon the approach used by the U. S. Nuclear Regulatory Commission (NRC) to perform license site termination surveys and independent verification surveys of sites.

Completion of Decommissioning: Monitoring the Site for Release and License Termination

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1. INTRODUCTION

To request termination of a license upon completion of dismantling or decommissioning activities, documenting any residual radioactivity to show that the levels are environmentally acceptable will be necessary. When the regulators approve the decommissioning plan, they establish what the release criteria for the decommissioned site will be at the time of the site release and license termination.

The criteria are numeric guidelines for direct radiation in soils and on surfaces. If the regulatory body finds that the measured on-site values are below the guidelines, the site will be acceptable for unrestricted release (no radiological controls or future use). If areas are found above those values, more decontamination or cleanup of these areas may be required unless the regulatory body grants an exemption.

2. GENERAL DISCUSSION

Several factors will influence the complexity of completing the license termination process (including the final survey) for a given site/facility. These include:

- Type and number of buildings
- Type of facility and its use
- Type and variety of radioisotopes present from operations
- Extent of facility decontamination before D&D

Often, the regulatory body requires a formal written request for license termination when the licensee decides not to renew the operating license. In most cases, a copy of the D&D Plan must accompany the termination request. The licensee then:

- Ends the use of the licensed material
- Removes radioactive contamination from the facility
- Properly packages and disposes of the removed materials
- Conducts a radiological survey to document conditions
- Submits a final survey report to show compliance with the release criteria.

The regulator will then evaluate the information, perform an independent verification of site conditions (at their discretion) and make a determination on termination of the license.

3. DECOMMISSIONING CRITERIA/GUIDELINES

The regulatory body's concern will be to ensure that any future user of a formerly licensed facility/site is not exposed to unacceptable levels of radiation or radioactive materials. Establishing an acceptable radiation dose to a potentially exposed individual is based on risk and scientific data related to risk. By running a number of analyses of various pathways through which exposure could occur some guideline values are established for:

- direct radiation levels
- surface activity levels
- volume concentration limits for soil and materials
- site inventory limits.

These levels are above normal background levels. The following units are typically used:

• direct radiation levels	exposure rates
• surface activity levels	activity/surface area
• volume concentration guideline values	activity/unit mass
• site inventory limits	units of activity

Due to differences in behavior of certain radionuclides, the sum effects from all sources over time must be considered.

The regulatory body may allow some select areas within a surface region to exceed the guideline values if the values do *not* exceed a limited fraction of the values.

An earlier lecture (4.1) covered radiological surveys for characterization and included sections on instrumentation and survey techniques.

4. PLANNING THE FINAL RADIOLOGICAL SURVEY

The purpose of the final radiological survey is to show that the licensee has met the established release criteria for the facility/site as specified in the decommissioning plan. To show compliance with these criteria, information on surface activity levels, direct exposure rates, and radionuclide concentration in soil must be collected. Additional information may be required by the regulatory body depending on specific concerns they may have. This may include groundwater radionuclide concentrations and total site inventory of radioactive material, etc. To have a technically sound and definable basis for this survey, a statistically based detailed survey plan should be prepared. The plan should address:

- Types, numbers, and locations of measurements to be made and samples to be collected
- Equipment and techniques to be used for data collection and analysis
- Methods to be used to interpret and evaluate the collected survey data
- Quality control procedures

4.1 Quality Assurance

A quality assurance program consistent with the regulator's requirement should be developed. The regulator should be able to provide some guidance on an acceptable QA program for radiological monitoring. This program can often be applied to the final survey activity.

Suitably trained personnel should do surveys using written procedures and appropriate instruments for the suspected contaminants. Additionally, the instruments must be properly calibrated before and periodically (if needed) during the work. Data collected should be kept in an orderly and verifiable form.

All records and associated paperwork must be maintained in an auditable manner.

The detailed final survey plan should specify the organizational structures under which the final survey will be done. Designating an individual as a QA Coordinator for the survey may be appropriate, but this is dependent upon the size of the overall survey effort. Otherwise, this could probably be covered through a central QA organization.

4.1.1 Documentation

All aspects of the survey should be documented in detail. Standard industry-wide procedures should be adopted where available for field or laboratory activities. These procedures and others unique to the project should be approved by the project manager with the effective date clearly shown. Any change to these procedures requires proper documentation.

4.1.2 Training

All personnel should be properly qualified in the procedures being performed. Records of the training should be maintained and be in an auditable form.

4.1.3 Equipment Maintenance and Calibration

Survey equipment should be maintained, calibrated, and tested to assure validity of the survey data. Calibration procedures, schedules, and responsibilities should be documented as well. Maintenance information and use limitations should be referred to in vendor documentation. All equipment should be calibrated to traceable standards.

Measuring equipment should be tested at least once a day when the equipment is used in the field. The test results should be recorded daily and compared with the acceptable performance range for the equipment.

4.1.4 Data Management

A consistent method of data generation, handling, evaluation, and reporting should be maintained as a part of the survey plan. Data is normally maintained in either bound log books or on a standard data collection form. Data should be entered neatly and legibly.

Data review and validation should be done regularly at the level of which the data is being collected or reviewed by the appropriate persons. All records should be maintained in a location protected from loss or destruction.

Handling and tracking procedures for samples collected for analysis (soil, water, scrapings, etc.) should be developed and followed to help ensure that sample integrity is maintained. This will ensure that the sample is not tampered in transit and is actually the sample collected from the facility.

4.1.5 Audits

Routine audits should be done to verify that the survey activities comply with the QA program.

4.2 Health and Safety

The final radiological status survey should not require any radiation protection controls. The primary health and safety concerns are the industrial hazards presented by the site. These could include electrical, enclosed space, excavations, and tripping hazards. The survey plan should address the means of mitigation of such hazards.

4.3 Physical Characteristics of Site

This aspect of the site survey could have major impacts on the schedule, cost, and complexity in executing the survey.

4.4 Interior Surveys

The design of the building and the condition of the interior surfaces can have a major impact on the effort required to survey these areas. High ceilings, ductwork, and piping are typical obstructions. Often lifting devices such as manlifts or scaffolding may be required.

Floor coverings like tiles and linoleum may have been placed over these surfaces. Contamination may be present under these at their seams or joint lines. Painting over surfaces to fix radioactive contamination is another common problem.

The surface conditions after decommissioning may pose problems as well. After scabbling concrete surfaces or jack hammering spots of deep contamination, maintaining a proper set-off from the surface being surveyed to alleviate attenuation concerns may not be possible. Wheeled monitoring equipment may also be difficult to use on these areas and also hazardous to the Mylar detector head covering.

Anchor bolts, stress cracks, or recessed items in the floor allow contamination to become hidden to the detectors used in surveys. These areas require careful evaluation before starting work in the area. Another troublesome class of items is those that allow no access to survey easily - pipes, tanks, and sumps, etc. Often process history and operations personnel interviews may help with evaluating the need for further evaluation.

4.5 Exterior Surveys

Normally, exterior surface surveys have a low potential for residual contamination. However, this should not imply that they do not warrant spot-checks. Locations that should be considered for checking are:

- Roof exhausts and roofing surfaces should be checked because layers of roofing materials are common and have been known to fix contaminants. Roof drainage discharge areas should also be checked.
- Wall areas where penetrations for process systems pass through are potential sources of contaminants.
- Exit areas from former contamination control areas.

4.6 Grounds

As a minimum, those areas immediately adjacent to a facility or area where radioactive materials were handled should be surveyed. Other open land areas to be considered include:

- Downwind areas of stack discharge points
- Storage areas
- Liquid waste collection areas
- Surface drainage pathways
- Roadways used for transport of radioactive or contaminated materials

Certain areas of the site may require sub surface soil sampling:

- Septic leach fields
- Buried tanks/piping areas
- Areas of former spills

Use of coring or split spoon sampling equipment should be anticipated for these areas.

5. DESIGNING THE SURVEY

Since all areas of the site will not have the same potential for residual contamination, they do not require the same level of confidence to ensure compliance with the release criteria. Therefore, areas for the survey should be broken down into two classifications:

- Affected areas are defined as those areas with the potential to have radioactive contamination <u>or</u> known RA contamination. This includes areas where radioactive materials were used, stored, or buried. Affected areas are also areas where spills or contamination incidents occurred. Areas immediately surrounding or next to locations where radioactive materials were used, stored, spilled, or buried, are also included in this classification due to the potential for spread of contamination.

- Unaffected areas are defined as all areas not classified as "affected areas." These areas are not expected to contain residual radioactivity based on site history and previous survey records.

The regulator should require the licensee to substantiate how areas were determined to be considered affected or unaffected.

5.1 Establishing the Reference Grid System

Grid systems are used to:

- Facilitate selection of measuring/sampling points
- Provide a means for referencing the location where a particular sample or measurement was taken or read
- Provide a means of determining average activity levels

A grid consists of a system of intersecting lines, referenced to a fixed point or a bench mark. In a typical arrangement, the grid lines run in a perpendicular pattern dividing the plot to be surveyed into squares of equal area.

Surveys on horizontal surfaces are identified numerically on one axis and alphabetically on the other. Grid patterns on vertical surfaces include a third identifier that shows a position relative to the floor or ground level.

The basic grid system for affected areas of structures is 1 meter. Gridding may be limited to the floor and the lower 2 meters of wall surface, unless a known potential for upper wall or ceiling contamination exists. As indicated above, the survey locations are referenced back to the grid system; ungridded surfaces are referenced to the floor grid or to a prominent building feature. A 10-meter grid is generally used on grounds and other open land areas classified as affected areas.

Generally, unaffected areas do not require a grid for the purposes of establishing measurement or sampling locations. Larger spacing grid systems such as 5 to 10 meters for large structural surfaces and 20 to 50 meters for land areas may be useful for the licensee to use to simplify its linkage to a common site reference system.

Certain areas may be divided into smaller units of common operational history or other characteristic.

5.2 Selecting Measurement/Sampling Locations

When designing the survey, the objective is to collect quality radiological data from a sufficient number of representative locations so that a statistically sound conclusion as to the radiological status of the site can be reached. Having a statistically based plan for the selection of the sampling and measuring locations will be necessary to meet this objective. Any residual contamination can be expected to be in an asymmetrical configuration, with much of the material in small, isolated hot spots. In general, the licensee's actions should have resulted in all locations having below guideline levels of residual activity. The pattern of residual activity will most likely assume a normal distribution. However, this does not eliminate the option of collecting additional samples from areas with unusual localized contamination patterns.

5.2.1 Structure Surveys

Affected Areas

The floors and lower walls of all affected areas should receive 100% scans survey coverage for the radionuclides interest during the final survey. Coverage provided for upper walls and ceilings will be dependent upon the potential for contamination of these surfaces. Surface activity survey measurements should consist of a combination of: surface scans, direct measurements, and removable activity measurements. Residual activity that exceeds three times the guideline value results in external radiation more than twice the guideline value above background at 1 meter from the surface, and should be remediated. Areas should also be remediated when the average activity is above the guideline value in any contiguous 1 square meter.

Once all elevated areas of contamination are remediated, systematic measurements of surface activity should be performed. If the scanning technique has a detection sensitivity for the radionuclides or radiation of interest, less than or equal to 25% of the guideline level, measurements should be taken every 2 meters or less to provide at least 30 data points. If the detection sensitivity does not meet the less than or equal to 25% requirement, systematic measurements should be taken at 1 meter intervals. The number of required data points to be measured to show that the survey meets the 95% objective for a given unit is a function of the data average and variance for that given unit. If the statistics suggest a need for further data, any additional measurements should be made at evenly-spaced intervals within the survey unit.

Ceilings, overhead areas, and upper walls suspected of residual activity greater than 25% of the guideline value (based on earlier surveys and operating history) should be surveyed in the same manner as floors and lower walls. If there is no reason to expect residual activity on surfaces that would exceed the 25% guideline value, a minimum of 30 measurements should be made on vertical and horizontal surfaces where radioactive material could accumulate. Reasonable coverage of these areas would require that an average of 1 measurement location per 20 square meters of surface area be selected. A scan of the immediate area should be made followed by a measurement. If either the scan or measurement exceeds the 25% guideline value, then the area should be considered possibly contaminated and the surfaces then surveyed in the same manner as an affected area.

If gamma emitting radionuclides are potential contaminants, exposure rate measurements should be made at 1 meter from the floor and lower wall surfaces at a frequency of 1 measurement per every 4 square meters. If gamma emitting radionuclides are not of concern, then a minimum spacing of 1 measurement per 10 square meters should be used.

Unaffected Areas

Scans of surfaces designated as unaffected areas should cover a minimum of 10% of the floor and lower wall areas. For removable and total activity, a minimum of 30 randomly selected measurement locations with an average of 1 measurement per 50 square meters of building surface area is recommended - whichever of these is greater. These locations should include all building surfaces. Areas identified that exceed the 25% guideline levels (either by scanning or direct measurements) should be reclassified as affected areas. Testing of the data relative to the confidence level objective is done in the same manner as for an affected area. Other measurements for the area should be randomly selected. Exposure rate measurements at 1 meter from the floor should be taken for each location of a surface activity measurement.

5.2.2 Open Land Surveys

Affected Areas

These areas are handled in the same manner as structural surfaces. Coverage of 100% of affected open land areas is recommended. Open land areas include paved (asphalt) surfaces and soil. Scanning areas to detect elevated activity levels should be followed by sampling and analysis to find the exact activity level and extent of the elevated levels. Once any identified areas are remediated, confirmatory scanning should be performed. Once the guidelines have been satisfied, systematic soil sampling of each affected area grid block should be done at locations equidistant between the center and each of the four grid block corners.

The scanning instrument should be able to detect surface areas with activity levels less than or equal to 75% of guideline values for the radionuclides of interest. If this is not possible, additional sampling may be required to provide an acceptable level of confidence that areas of elevated activity have been identified. A much more aggressive sampling protocol is carried out for these areas.

Sampling of soil and paved areas requires a minimum of 30 data collection locations in areas designated as affected areas. Data collected are tested relative to the guideline values and confidence level objectives. Any additional samples that may be required to satisfy these objectives are obtained at uniformly spaced intervals of the survey unit.

Unaffected Areas

Unaffected open land areas should be scanned for radiation from the radionuclides of interest. A minimum of 10% of the surface area should be scanned with soil samples taken from a minimum of 30 randomly selected locations. Surface activity measurements on paved areas are taken at 30 randomly selected locations. Those locations with activity levels greater than 75% of the guideline values require reclassification of the area as an affected area. Any additional samples are collected at randomly selected locations in the survey unit.

5.2.3 Other Measurement/Sampling Locations

Depending on the specific facility, measurements or samples should be collected from other locations such as equipment, fixtures, drains, ducts, and piping. These items require internal and external evaluation. This is generally performed using a scanning technique with individual measurements used/or samples collected at appropriate locations. As with building surfaces in unaffected areas, other locations should be surveyed at lower frequencies depending upon contamination potential, sensitivity of scanning technique to guideline levels, and findings as the survey progresses.

5.2.4 Subsurface Sampling

The number and location of subsurface samples should follow the same pattern as described in Section 5.2.3. For initial sampling, a sample should be collected at 1 meter interval, starting at the surface and proceeding too at least 1 meter below the suspected or potential region of activity. This shallow sampling can be done by using standard hand-held equipment (posthole diggers or portable hand operated or motorized augers). At depths more than several meters, equipment such as a drill rig with an auger or a core sampler is required. Evaluating the use of electromagnetic sensing techniques to identify likely sampling areas may be useful if items external to the structure(s) are left in place.

Use of a subsurface sampling process that exposes the soil surface will allow for scanning to identify any subsurface activity. It may be necessary to collect subsurface water samples at certain sites, although this normally requires special precautions to ensure representative sampling.

6.0 SURVEY TECHNIQUES

This section covers the general considerations in performing radiological surveys and some specific items to be aware of when performing the final survey after decommissioning.

6.1 General Considerations

6.1.1 Survey plan and procedures

The survey should be performed after all decommissioning is completed and in accord with the approved facility final survey plan and procedures. It is possible that the regulatory authority may elect to review and approve both the survey plan and its implementing procedures. Specific survey techniques should be presented as detailed procedures. The survey plan specifies the objectives, the designs to meet those objectives, and the general survey approach. Only qualified personnel should perform the survey of the facility. The supervisor of the onsite staff doing the survey should be authorized to make any changes to the survey plans and procedures deemed appropriate, however, deviations should be properly documented.

6.1.2 Records

Records of the final survey should be legible, thorough and unambiguous. All records should be kept in indelible ink, signed, and dated, and adequate to enable an independent evaluation of site conditions. All changes should be clearly indicated, correct data entered, and initialed. Standardized forms should be used for the data and a bound log book for that which forms are not appropriate. The survey records should be protected from loss or damage and stored in a proper record repository for the period required by the regulatory authority.

6.1.3 Worker Health and Safety

Since most if not all areas will be free of any radiation or contamination, this matter should be of minor concern. Prudent standard work place practices and measures for preventing potential cross contamination should be in place to mitigate any concerns. It is a good practice to use gloves where hand contamination is possible and good personal hygiene should be practiced. Instruments and equipment should be routinely checked for contaminants. Eating, drinking, and smoking should not be allowed in the work areas.

6.2 Instrument Selection

Instruments selected should be reliable, environmentally and physically suited for use at the particular site being surveyed, and for the radiation and radionuclides of interest. The MDA for the instrumentation selected should be less than 25% of the guideline value for structural surveys and less than 75% of the guideline value for open land surveys. Having the latter value as low as 10% of the guideline value is preferable. The instrumentation must be properly calibrated for the site of concern and traceable to an accepted standard. Routine operational checks must be done to ensure that the instrument is maintained within acceptable ranges.

Background radiation levels for the particular site being surveyed must be established to allow for comparison of the measured values to the acceptable guideline values.

6.3 The Surveying Process - Buildings

Typical preparations needed to begin the survey process include:

- Assessment of surfaces of interest in the facility including sealed floors, ducts, drains, sumps (an initial scan of the area should be done at this time).
- Establishment of a survey reference grid based on the contamination potential. Grids can be marked with paint, chalk, or markers at grid block corners.
- Preparation of scale drawings of the survey areas for mapping features and superimposing the grid.

6.4 Scanning

Surface scanning should be done to identify the presence of any elevated direct radiation. This is based on the operating history and all radiations potentially present at the facility. The scanning detector should be kept as close as possible (about 2 centimeters) from the surface and moved at a slow speed. For alpha contaminants a distance of about 1 centimeter should be used and for the low energy alpha and beta radiations the scan speed should not exceed one detector width per second. For gamma radiation the scanning speed may be greater, but typically a rate of about 0.5 meters per second should be used and the instrument moved in a serpentine motion.

Audible instrumentation output and analog meter readings should be monitored to optimize detector sensitivity and to note changes in instrument response. Those areas with discernible direct radiation levels above the ambient level should be marked on the facility maps and noted for further measurement and sampling. The sensitivity of the scanning technique should be noted in the final status report.

6.5 Direct Measurements

Instruments with the required detection sensitivity should be used for direct measurements. Generally, a 1 minute integrated count using a 100 square centimeters area detector provides adequate detector sensitivities for most guideline levels. All potential radiations should be measured. Care should be taken to ensure that any dirt or dust that could possibly hide alpha radiation is removed before surveying. This is a requirement to ensure that there are no residual levels of either alpha or beta.

The direct surface activity measurements are made at systematically and randomly selected locations and at locations that exhibited elevated levels of direct radiation from scanning. If an area exhibits deviated levels above action guidelines, the area should be remediated and scanned again to ensure that a proper cleanup has been performed.

Areas exhibiting elevated radiation levels from the area gamma scans should have gamma exposure rate measurements conducted at 1 meter above the floor at systematically and randomly selected points.

6.6 Removable Contaminants Measurements

Smears for removable surface activity are obtained by wiping an area of about 100 square centimeters using a dry filter paper (Whatman 50) with moderate pressure on the smear paper. A 47 mm diameter filter is typically used except whenever low-energy beta emitters are a concern. In the latter case smaller sized papers may be used due to their ability to fit into a liquid scintillation counting vial. For tritium contamination, Styrofoam pieces may be used. A smear sample is collected at each location of a direct surface activity measurement.

Cotton swabs can be used to smear cracks or anchor bolts with the swabs then placed into individual envelopes to prevent cross contamination. The swabs are then sent to an analytical laboratory for analysis.

6.7 Samples

The extent to which sampling is required should be based upon the specific facility conditions and upon the results of scans and direct measurements. Residues can be collected from drain lines using a piece of cloth attached to a piece of wire. Special attention should be given to "low points" or "traps" of drain lines since these are likely accumulation points for activity. Any further sampling should be based upon the results of this first sampling series.

Checking for activity below floor slabs will require access (if possible) to the crawl space beneath the floor. If this is not possible, then removal of a section of floor will be required. Coring is normally used to sample the sub floor soil. Tools for this operation are commercially available.

Cores are generally from several centimeters in diameter up to 20 centimeters in diameter. Direct monitoring of the underlying soil can be performed and samples of soil collected.

Collecting samples of construction material that may contain activity or be activated may be necessary. Roofing materials should not be overlooked as a possible "trap" for contaminants in the layers built-up over the years. Analyzing the cores can determine the distribution and radionuclide content.

In many older facilities painted surfaces may conceal that the surface underlying the coating and the paint itself may be contaminated. Usually, removing a sample (~100 square centimeters) from a known or potentially contaminated area is necessary. This is typically done with a surface abrading device. The removed coating is analyzed for activity content and compared with the relevant guidelines for surface activity. Direct measurements of the underlying surface can be made after removal of the coating.

6.8 Ground Surveys

6.8.1 Preparations

Refer to Section 4.4 on preparations for interior building surveys. The same steps should be taken in preparing for surveys of site grounds. Any equipment or materials that restrict access should be moved and any heavy ground cover removed. The reference grid should be established as appropriate based on the contamination potential for the areas. Usually wooden survey sticks mark grid line intersections or (where this is not possible) marked using spray paint. As mentioned earlier, scale drawings of the survey areas should be made indicating facility features and the site grid.

6.8.2 Scanning

Surfaces should first be scanned to identify any hot spots of activity. This should be done with the most sensitive detection system available. The detector is moved back and forth as it is kept as close as possible to the surface. The speed of the surface scan should be about 0.5 meters per second. Instrument response is monitored both audibly and visually on the meter. Those areas with direct radiation levels above the ambient level are noted for further measurements and/or sampling.

In addition to gamma scanning, paved areas should be scanned for alpha/beta in a manner similar to the scans of building surfaces.

6.8.3 Direct Measurements

The same process should be used for surface activity level measurements of the ground survey as used for the building surfaces.

Exposure rate measurements should be conducted at 1 meter above the ground at both systematic and random locations and at those areas showing elevated gamma levels based on area scanning. If the radionuclides of concern are high energy gamma emitters, this may be all that is necessary. However, some limited sampling should be done to identify and show that any residual activity is distributed in the surface layer of the soil. Alpha and beta measurements of outdoor ground are normally not recommended.

6.8.4 Removable Activity Measurements

As with direct measurements for alpha and beta radiations, it is very unlikely that any ground areas exposed to rain and wind should have significant levels of removable activity.

6.8.5 Soil Sampling

Surface soil samples should be collected from the top 15 centimeters of soil or locations established earlier. If gamma spectrometry is to be done, a sample size of about 1 kilogram is required. Wet chemistry analysis requires a sample size of about 100 grams or less. Sampling can normally be done with simple hand tools like a shovel or trowel. Compositing of samples may be possible.

If paved surfaces have been or potentially could be contaminated, the surface should be removed and the underlying soil sampled in the same manner as the surface soils.

Any foreign matter, such as grass rocks, sticks, should be removed from soil samples (to the extent possible) before submitting the sample for analysis.

Locations of known or suspected subsurface activity should be sampled using the same grid pattern used for surface areas. Subsurface soil sampling should be done with portable manual equipment or for depths greater than a few meters, heavier truck mounted rigs should be used. A post hole digger, shovel, or motorized auger should be used for shallow sub-surface sampling. Loose soil should be removed and the samples collected over the next 15 to 30 centimeters. For deeper sampling split-barrel samples can be used which are typically advanced through hollow-stem augers. The entire core can then be retained, monitored and/or specific areas sampled for analysis. Typically, 1 meter increment samples are collected using this technique until the core extends below the area of suspected contamination. Sampling the subsurface water to assist in evaluation of the water table for activity may be necessary.

Boreholes should be logged to identify the process of any gamma-emitting radionuclides/deposits. Count rates should be taken at 0.3 - 0.5 meter intervals using a sensitive gamma detector such as a NaI gamma scintillation probe. Sensitivity and specificity can be enhanced by using a shielded collimator or the probe.

Buried piping, tanks, etc., can be found using electromagnetic sensing techniques.

7. RADIOLOGICAL INSTRUMENTATION

The selection and proper use of instrumentation used for decommissioning surveys is critical to determine the site status accurately. Survey instrumentation for decommissioning includes direct field measurements using portable instruments and sample analyses using fixed laboratory equipment or systems. The selection and proper use of these are the most critical factors in assuring an accurate determination of a site radiological condition. Two components - a detector and power source/display unit - are used for surveys.

7.1 Instrument Types

7.1.1 Radiation Detectors

There are three general types based on the detector material that radiation interacts with to produce a measured event. These three types are:

- Gas-filled detectors - where radiation interacts with the filling gas producing ion pairs collected by charged electrodes. Typical types of gas-filled detectors are ionization, proportional, or Geiger-Muller (G.M.).

- Scintillation detectors - where radiation interacts with a solid or liquid medium and results in a small flash of light (scintillation) which is converted to an electrical signal by a photomultiplier tube.

- Solid-state detectors - where the radiation interacts with a germanium or silicon semiconductor to create ion pairs collected by a charged electrode.

The design and operating conditions will determine which types of radiation can be measured with a particular detector. Therefore, the capabilities of a detector to a given radiation type will determine its potential for use in a license termination survey.

7.1.2 Display and Recording Equipment

The radiation detector must be connected to some type of electronic device to provide proper power for the detector to operate with and enable measurement of the number of radiation interactions in the detector. The most common type of recording and display equipment is a rate meter that provides an analog meter display of the number of interactions per unit time.

Another kind of recording and display equipment is the digital scaling device that gives a definite value of detections per unit time rather than a rate meter where more operator interpretation of results may be required.

A specialized electronic device called a pulse height analyzer can be used to measure and record events in a single range or multiple ranges of energy. In the former case, the detector is called a single channel spectrometer and in the latter case a multichannel analyzer or spectrometer.

7.2 Instrument Detection Sensitivity

Detection sensitivity of a measurement system refers to the statistically determined quantity of radiation or radioactive material that can be measured or detected at a preselected confidence level. This sensitivity is a factor of both the procedure used to perform the count and the instrument used. Generally, a detection sensitivity of 5% probability that radioactivity will be reported as present when it is really absent (Type I error) or vice verse (Type II error) is used.

The minimum detectable activity is an estimate of the minimum activity level that is practically measurable with a specific instrument and measurement or sampling technique. (The reader is referred to a text or reference similar to Knoll, 1979 for additional discussion on this topic.)

The basic relationship for estimating the MDA is:

$$MDA = K(2.71 + 4.65\ s_b)$$

where

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

s_b = the standard deviation of the background count.

7.2.1 Surface Activity Measurement

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

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

where

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

The MDA of a rate meter 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.

$$MDA = \frac{4.65\sqrt{B_R/2t_c}}{E \cdot \frac{A}{100}}$$

where

MDA	=	activity level in disintegrations/minute/100 square centimeters
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 square centimeters

7.2.2 Scanning

Identification of a small area of slightly elevated radiation during surface scanning is primarily dependent upon the surveyors skill in recognizing an increase in audible output of the detection instrument. Experience has shown that in background levels of several thousand counts per minute this change is most readily recognizable. However, at levels of several counts per minute this change is nearly impossible to recognize. Other factors can influence the sensitivity of scanning are detector speed, size of elevated region, and detector offset from a surface. An approximation of the MDA can be calculated by using the equation above and substituting audibly discernable increase in count rates for the numerator.

7.2.3 Laboratory Analyses

Additional factors may be introduced into the calculation for estimating detection sensitivies 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:

$$MDA = \frac{2.71 + 4.65\sqrt{B_R \cdot t}}{t \cdot E \cdot S \cdot Y \cdot 2.22}$$

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.

7.2.4 General Considerations

The sel[illegible]ystem should be able to measure levels below 75% and preferably at or below 10% of the established guideline value. The reader should be advised that often the standard health physics instrumentation used in the operational phase at a facility is not a good choice for demonstrating compliance with guideline values for license termination at the time of decommissioning.

Detection sensitivities can be lowered (i.e., improved) by: selecting an instrument with a higher efficiency or lower background; increasing the counting time; increasing chemical recovery; or increasing the size of the sample or the effective probe area.

7.3 Instrument Selection and Use

It is unlikely that any single instrument (detector and read out combination) could measure all radiological parameters of interest adequately enough to demonstrate compliance with the criteria for unrestricted release or license termination. Therefore, multiple instruments will be needed to perform the variety of measurements required.

Instrument selection may be influenced by several factors or conditions. The instruments must be stable and reliable under the anticipated working conditions and be able to detect the type of radiation of interest at levels less than the guideline values.

All instrumentation described in this lecture are available from many commercial firms.

This section addresses field radiological measurements for license termination surveys. Another section in this lecture addresses laboratory applications.

Two basic questions must be answered when conducting a final status survey:

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

2. Do small localized areas of residual activity greater than the average guideline value, satisfy the established conditions?

The latter question has generally posed the more difficult issue than the former. For this reason a survey technique called scanning is used to find areas that are above ambient or general site levels before actual measurements are conducted. Therefore, the scanning technique should use the most sensitive instrument available for the survey team.

In performing gamma scanning, a scintillation detector rate meter combination is the usual instrument of choice. For alpha and beta radiations, a large proportional detector with rate meter is recommended; if conditions do not permit this, an alpha scintillation or thin window GM detector for beta may be used. Scanning is performed within 1 centimeter of the surface and moved at a slow speed.

When attempting to detect certain radionuclides, because of their types, energies, and abundancies, it will be essentially impossible to measure them at guideline values in the field using state of the art measurements and techniques. Typical radionuclides in this group include H-3, Ni-63 (both beta emitters) and Fe-55, and I-125 (both low energy gamma emitters). Pure alpha emitters in soil or covered with some absorbing layer may not be detectable because of the inability of alpha particles to penetrate the layer. In such circumstances, sampling and laboratory analysis should be used to determine residual activity levels.

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(T1) scintillation detectors with countrate meters, cross calibrated to a PIC or calibrated for the energy of interest.

Additional information on performing such measurements is covered in later sections of this lecture.

7.4 Instrument Calibration

Each instrument must be calibrated to enable the measurement counts to be expressed and compared to guideline values. In general, industry-recognized organization standards should be used. Often the major instrument manufacturers or health physics service organization will provide this service.

Some instruments will have responses which are dependent on the energies of the radiation. Therefore, calibrations should be performed with the radionuclide of concern or the appropriate conversion factors used for the mix of radionuclides present. If using a gamma scintillation instrument with an energy dependent response for measuring low-level gamma exposure rates, it may be necessary to separate/calibrate the instrument for each location.

Field instruments should be calibrated semi-annually and after any maintenance is performed. Calibration of pressurized ionization chambers for gamma exposure rate is recommended at an interval of every two years.

Periodic checks of instrument response should be made to ensure that the calibration and background have not changed. There is a generally established range of acceptable levels. For analog readout, +/- 20% is usually acceptable. For digital readout, an acceptable range is +/- 2σ or 3σ is desirable.

Once a day (at a minimum), the instrument response should be tested and recorded, typically at the start of the work day. If response is deemed unsatisfactory the instrument should be removed from use, checked by maintenance personnel, recalibrated, and made available for use.

8. Sample Analysis

8.1 Introduction

Samples collected during the survey should be submitted to a well-established laboratory for analysis. Analysis should be done by appropriately trained individuals with appropriate equipment and procedures. An established QA/QC program should be in place that assures the validity of all analytical results.

Radiation detection measuring equipment was described in an earlier lecture. The same types of equipment should be used for laboratory analysis, however, these are usually used in a more controlled condition that provide lower levels of detection and more specificity to radionuclides. The remainder of this section describes laboratory methods available to most types of radiological surveys and license termination activities.

8.2 Prior Considerations

It is imperative that the leader of the survey team realizes that adequate lead time should be made for the laboratory to receive, analyze, and report the analytical results. For example, specific radionuclide analysis in soil samples for very low levels of detection require more time to complete then do gross gamma spectrometry on samples. Based on earlier site characterization activities substituting certain gross measurements for specific costly radionuclide-specific analysis may be possible.

Liquid scintillation counting for gross alpha and beta counts of smears and water samples or soil gamma spectrometry, can usually be performed using existing in-house laboratory capabilities. Most labor intensive procedures should be submitted to an outside laboratory for analysis.

Laboratory analytical methods should be able to detect levels below the established release guidelines. A typical detection sensitivity of 10-25% of the guideline values is a good target. Remember that detection limits are often based on ideal situations, not actual measurement conditions that are subject to variation from sample to sample, instrument to instrument, and procedure to procedure. Other variables include counting times, geometry, background, and self-absorption among others.

8.3 Sample Preparation

Varying degrees of preparation of the collected samples may be required before direct measurement with wet chemistry procedures. The only treatment for smears is to allow for short-lived naturally occurring radon to decay to negligible levels before gross alpha/beta counting. Typically this can be achieved in a period of from 4 to 72 hours. For liquid scintillation samples, smears may need to cut into smaller pieces to fit into vials to reduce the chances of attenuation of the smears by the paper itself.

Generally, soil sample preparations should include removal of sticks, rocks, and vegetation, which exceed 0.25 inch in diameter. Certain volatile radionuclides (H-3, Tc-99, iodides) may need to be separated from samples before drying for nonvolatile analysis. Dried samples should be homogenized using mortar and pestle or other available grinding techniques then sieved to obtain a uniform sample. For wet chemistry procedures, a sieve size of 35 to 200 mesh is typical. If samples are to be chemically separated, ashing in a furnace should be done to remove organic material. To reduce the number of samples requiring analysis, multiple samples can be composited from the same region and an average value obtained for the region. Traceability of the components of a composite sample must be maintained. Archive specimens of all individual and composite samples should be maintained in case additional follow-up or analyses are needed.

Water samples should be filtered using a 0.45 micrometer filter and acidified with either nitric or hydrochloric acid to a pH of 2 or less. This allows for the analysis of the suspended and dissolved fractions and prevents the loss of any plated out contaminants on the container surfaces.

8.4 Analytical Procedures

Once the medium has been prepared for analysis, the samples should be submitted to an analytical laboratory. These analytical results should be used to determine the residual activity at the site. Since the release guidelines will be radionuclide-specific, it is vital that the analyses are accurate and are performed for the radionuclides of concern.

Normally, information on a variety of topics in this technical area can be found in equipment vendor catalogs and instrument manuals.

8.4.1 Smear (filter paper) analysis

After collection of all smear samples, it is prudent to first scan them individually with a gamma spectrometer or gross GM counter. At this time, smears should be left in their protective envelopes to prevent any possibility of cross-contamination.

Gross Alpha/Gross Beta

The most common smear analysis method for these contaminants is to count the samples on a low-background proportional counting system. Automatic and manual systems are available. These systems have low backgrounds, good sensitivity, and can process large quantities of smears in a relatively short time.

Several minute count times are routinely used and sensitivities are typically less than 10 dpm alpha and 20 dpm beta. Standard filter instrumentation (alpha scintillation and beta end-window-GM) can be used but sensitivities are higher - less than 20 dpm alpha and 100 dpm beta for a 5 minute count. This field approach is labor intensive.

Liquid Scintillation

Low - energy beta emitters (H-3, C-14, Ni-63) are detected by placing smears in a scintillation cocktail for counting in a liquid scintillation spectrometer. Counting efficiencies may be reduced but with today's technology, this technique allows specific radionuclides to be identified by the analyst. Quenching is a common problem with this analytical technique. It requires the use of a spiked sample to determine the counter's efficiency, such that the efficiency of the counter can then be determined and the proper multiplier applied to the counting results. This then provides the analyst the "true dpm" on the smear paper.

8.4.2 Soil/Sediment Analysis

After collection of all soil/sediment samples, the samples should be separately analyzed for gamma and alpha contaminants. The analyses performed should be specific to the radionuclide of interest for a particular facility being decommissioned.

Gamma Spectrometry

The sample can be analyzed for gamma emitters using gamma spectrometry. This is a nondestructive analytical technique that can identify and quantify multiple gamma-emitting nuclides of interest. It is prudent to select and subject at least several soil samples to the gamma spectroscopic analysis to verify that contaminants do not exist. Both solid state detectors and sodium iodide (NaI) scintillation detectors can be used. Solid state detectors have better resolution, while NaI detectors have high counting efficiencies.

Although detection systems with computer-based spectrum analysis capabilities are available, it is critical that the resulting gamma spectrums are carefully reviewed and analyzed. This is especially true due to the very low concentrations typically encountered in post-decommissioning surveys. Gamma emitters with difficult to resolve photopeaks and secondary or daughter photopeaks should be given special attention.

Typically, soil/sediment analysis by gamma spectrometry can be performed using large samples and favorable counting geometries such as 0.5 Marinelli Beakers and 100 to 400 ml cans or jars. Counting times of 30 minutes or less are typical; measurement sensitivities of several pCi/gram are possible when using such favorable geometries.

Alpha Spectrometry

Wet chemistry separation followed by counting to quantify specific alpha energies present is recommended for those samples that are primarily alpha emitters. After sample dissolution using standard analytical laboratory procedures, the alpha emitting specimens are separated out onto filter paper for counting. Typically, counting is performed using a solid state detector and alpha spectrometer. Lower levels of detection are less than 1 pCi/g using standard alpha spectrometry methods. Sample sizes are typically a few grams or less.

Liquid Scintillation

When decommissioning a facility where tritium is a concern, the tritium is separated by distilling the sample after adding a known spike of low-tritium water. An aliquot from the collected moisture is then placed in a scintillation cocktail and counted using the beta spectrometer. Typical detection sensitivities below 1 pCi/gram can be obtained with this method.

Other Procedures

Analysis of soil/sediment samples for most pure beta emitters require wet chemistry separation followed by counting with liquid scintillation or beta proportional instruments. Each beta emitter to be analyzed for requires a specific procedure; the reader is advised to consult with a technical specialist. Detection limits of less than 1 pCi/gram are achievable using standard methods.

8.4.3 Water Sample Analysis

The same equipment used for counting gamma emitters in soil/sediment can be used for water sample analysis. Typically, the guideline values for unrestricted use should be much lower for water then for soil. Therefore, larger sample volumes (1 to 3.5 liters) and longer count times (12 to 16 hours) may be necessary.

Gross alpha and beta analyses can be used 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. Sensitivities of 1 pCi/l can be obtained; self-absorption may be a problem due to substantial sample thickness. Typically, samples containing more than 15 pCi/l gross alpha or 50 pCi/l gross beta should be analyzed for specific radionuclides.

Special handling is required when volatile radionuclides may be contained in the samples. In this case, direct analyses by liquid scintillation or a combination of wet chemistry and liquid scintillation may be required.

9. SURVEY DOCUMENTATION

The final survey documentation must provide a complete and detailed record of the facility status relative to the license to termination guidelines. The data and information should be adequate to allow for an independent evaluation of the data later. The final survey report consists of many elements from previously prepared documents for the decommissioning project plus the survey data and its analysis to verify that the cleanup is complete.

Appendix A provides a basic outline for the reports; more complex sites may require more detail and less complex sites may require less detail.

(Note: The regulator may specify specific required contents for this report.)

APPENDIX A

Final Survey Report Outline

Background
- Reason for Decommissioning
- Approach to Decommissioning

Site Description
- Type and Location of Facility
- Ownership of Facility

Facility Description
- Buildings
- Grounds

Operating History
- Licensing and Operations
- Processes Performed
- Waste Disposal Practices

Decommissioning Activities
- Objectives
- Previous Survey Results
- Decommissioning Procedures (overview)

Final Survey Procedures
- Sampling Parameters
- Background/Baseline Levels
- Major Contaminants
- Guidelines Established
- Equipment and Procedures
- Instruments/Equipment Used
- Techniques Used
- Procedures Used
- Credentials of Survey Team

Survey Findings
- Techniques for Data Evaluation
- Statistical Evaluation
- Comparison of Results with Guideline Values

Summary

APPENDIX B

Suggested Reading

Suggested reading is from NUREG/CR-5849 listing.

ANSI 1978 Radiation Protection Instrumentation Test and Calibration, ANSI N323-1978, Institute of Electrical and Electronic Engineers, Inc., September 1978.

ANSI 1989 Quality Assurance Program Requirements for Nuclear Facilities, ANSI/ASME NQA-1, American Society of Mechanical Engineers, 1989.

EPA 1980 Upgrading Environmental Radiation Data, EPA 520/1-80-012, U.S. Environmental Protection Agency, August 1980.

EPA 1989 Methods for Evaluating the Attainment of Cleanup Standards, Volume 1: Soils and Solid Media, EPA 230/02-89-042, U.S. Environmental Protection Agency, February 1989.

GILBERT 1987 Statistical Methods for Environmental Pollution Monitoring, R.O. Gilbert, Van Nostrand Reinhold, 1987.

KNOLL 1979 Radiation Detection and Measurement, G.F. Knoll, J. Wiley & Sons, 1979.

NCRP 1978 Instrumentation and Monitoring Methods for Radiation Protection, NCRP Report 57, National Council on Radiation Protection and Measurements, May 1978.

NCRP 1985 A Handbook of Radioactivity Measurement Procedures, NCRP Report 58, National Council on Radiation Protection and Measurements, 2nd Edition, February, 1985.

NRC 1974 Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors, U.S. Nuclear Regulatory Commission, June 1974.

NRC 1979 Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Programs - Effluent Streams and the Environment, U.S. Nuclear Regulatory Commission, February 1979.

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ORNL 1981 Monitoring for Compliance with Decommissioning Termination Survey Criteria, Oak Ridge National Laboratory, U.S. Nuclear Regulatory Commission, NUREG/CR-2082, June 1981.

PNL 1990 Residual Radioactive Contamination from Decommissioning, Pacific Northwest Laboratory, U.S. Nuclear Regulatory Commission, NUREG/CR-5512, January 1990 (Draft).

Survey Design

Preparation of Soil Sampling Protocol: Techniques and Strategies, EPA-600/4-83-020, U.S. Environmental Protection Agency, May 1983.

Data Quality Objectives for Remedial Response Activities - Example Scenario: RI/FS Activities at a Site with Contaminated Soils and Ground Water, PB90-272634, U.S. Environmental Protection Agency, May 1987.

M.G. Barnes, *Statistics and the Statistician in Nuclear Site Decontamination and Decommissioning*, PNL-SA-9486, Pacific Northwest Laboratory, April 1981.

R.O. Gilbert and J.C. Simpson, *Statistical Methods for Evaluating the Attainment of Cleanup Standards, Volume 3: Background Based Standards for Soils and Solid Media*, PNL-XXXX (Draft), Pacific Northwest Laboratory, May 1990.

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W.J. Price, *Nuclear Radiation Detection*, McGraw-Hill, 1964.

H. Cember, *Introduction to Health Physics*, Pergamon Press, 1983.

J.P. Corley, et al., *A Guide for: Environmental Radiation Surveillance at U.S. Department of Energy Installations*, DOE/EP-0023, U.S. Department of Energy, 1981.

Radiation Instrumentation (cont'd)

A Guide for Radiological Characterization and Measurements for Decommissioning of U.S. Department of Energy Surplus Facilities, DOE/EP-0100, U.S. Department of Energy, August 1983.

Survey Procedures

A Compendium of Superfund Field Operations Methods, EPA/540/P-87/001, U.S. Environmental Protection Agency, December 1987.

Procedure Manual for the ORNL Radiation Survey Activities Program, ORNL/TM-8600, Oak Ridge National Laboratory, April 1987.

Environmental Radiation Measurements, NCRP Report 50, National Council on Radiation Protection and Measurements, December 1976.

Monitoring for Compliance with Criteria for Unrestricted Release Related to Decommissioning of Nuclear Facilities, Draft IAEA Report 4/1990-08-08, International Atomic Energy Agency, August 1990.

A Guide for Radiological Characterization and Measurements for Decommissioning of U.S. Department of Energy Surplus Facilities, DOE/EP-0100, U.S. Department of Energy, August 1983.

Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A), EPA/540/1-89/002, U.S. Environmental Protection Agency, December 1989.

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Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, U.S. Environmental Protection Agency, March 1979.

Analytical Chemistry Branch Procedures Manual, IDO-12096, U.S. Department of Energy - Idaho Operations Office, 1982.

EML Procedures Manual, HASL-300 Ed. 25, U.S. Department of Energy, 1982.

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