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# Radiological Characterization of a Uranium Processing Facility

C. A. England
*University of Tennessee - Knoxville*

To the Graduate Council:

I am submitting herewith a thesis written by C. A. England entitled "Radiological Characterization of a Uranium Processing Facility." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

James E. Turner, Major Professor

We have read this thesis and recommend its acceptance:

Peter Groer, Larry F. Miller

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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# RADIOLOGICAL CHARACTERIZATION OF A URANIUM PROCESSING FACILITY

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

C. A. England

May 1996

## ACKNOWLEDGMENTS

This project has been an experience that I will not soon forget. It would also be difficult to forget those who have been so helpful and supportive throughout this entire task. I would first like to thank James E. Turner. Words cannot express the gratitude I owe him. Thanks also go to James C. Ashley, James S. Bogard, Peter Groer, Robert N. Hamm and Larry F. Miller. Their encouragement and support have been a tremendous help. Thanks go to James H. Barker for the opportunity to work on this project, and for all the helpful advice during times of confusion. My thanks go out also to Kathy Brown. I don't know how I could have finished this without her help. Special thanks go to the members of my work group: Gwen T. Eagle, Bruce R. Fortune, Gary R. Galloway, Jr., J. David Gass, and Raymond H. Ortiz. To my parents Charles and Jean England and my brother Allen England, the successes I have enjoyed are a direct result of their love and encouragement.

I owe a great debt of gratitude to my wife Page and to my children Lauren, Mary, and Lacey for their constant support, and for the encouragement when there seemed to be no end in sight. I would not have completed this if it were not for them. Finally, to God I give the recognition for this and all else that may be accomplished through my life.

## ABSTRACT

This document describes the plan that was developed and is being carried out at the Oak Ridge Y-12 Plant to provide data needed for radiological characterization of the site in anticipation of new posting regulations provided in Title 10, Code of Federal Regulations, Part 835, as codified from Volume 58, Number 238 of the Federal Register. The characterization plan addresses the entire site in terms of three categories: 1) Outdoor paved surfaces, 2) buildings, and 3) outdoor nonpaved surfaces. Instruments chosen for use in this project are described, as well as survey techniques and the data management scheme. A quantitative assessment of the effectiveness and adequacy of the survey plan for paved surfaces is also provided.

**TABLE OF CONTENTS**

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF PLATES

## ACRONYMS

| | |
|---|---|
| 10CFR835 | Title 10, Code of Federal Regulations, Part 835 |
| ALARA | as low as reasonably achievable |
| CEDE | committed effective dose equivalent |
| DAC | derived air concentration |
| DOE | Department of Energy |
| DRF | dose-rate factor |
| EA | Exclusion Area |
| GM | Geiger-Mueller |
| HPAM-5 | Health Physics Area Monitoring-5 |
| LA | Limited Area |
| NCRP | National Council on Radiation Protection and Measurements |
| NRC | Nuclear Regulatory Commission |
| ORISE | Oak Ridge Institute for Science and Education |
| ORNL | Oak Ridge National Laboratory |
| PPA | Property Protection Area |
| PSPC | position-sensitive proportional counter |
| R | roentgen |
| RADCON | Radiological Control |
| RCT | radiological control technician |
| RWP | Radiological Work Permit |
| SBIR | Small Business Innovative Research |
| SRA | Shonka Research Associates |
| ST | source term |
| $\mu$Ci | microcurie |
| USACXRP | U.S. Advisory Committee on X-Ray and Radium Protection |

# CHAPTER 1

# INTRODUCTION

On January 1, 1996 new requirements for operations at Department of Energy (DOE) sites regarding "Posting and Labeling for Radiological Control" take effect in Title 10, Code of Federal Regulations, Part 835 (10CFR835), as codified from Volume 58, Number 238 of the Federal Register (OC93). The new posting provisions become a part of the general program for protection of individuals from ionizing radiation as a result of DOE activities. Some operations, such as activities conducted under the authority of the Director of the Naval Nuclear Propulsion Program, are excluded from the new law. The DOE plants in Oak Ridge have made plans and taken steps to assure that they will be in compliance with 10CFR835 by the January 1 deadline.

This thesis describes the plan that was developed and carried out at the Oak Ridge Y-12 Plant to provide data needed for characterization of the site and implementation of the new posting regulations. The author was a senior member of the team charged with responsibility for design and enactment of the detailed plan as presented in the following chapters. In addition to overall involvement with all phases of the project, his specific contributions included initial design of the protocols for the pavement and building surveys, selection and maintenance of instrumentation, scheduling and supervision of the survey crews and analysis of the results. He was also instrumental in the development of the documentation necessary to establish compliance with 10CFR835. This project and the results obtained are

described in the following chapters.

A foldout map of the Oak Ridge Y-12 Plant is provided in Plate 1.1 (In Pocket). The Y-12 Plant was built during World War II in the early 1940s. The Plant Controlled Area encompasses approximately 800 acres of land in the city of Oak Ridge. Included in this area are approximately 600 buildings and other structures, roads, streets, parking areas, grassy fields, woods, and streams. The principal mission of Y-12 today involves the handling of large quantities of depleted and enriched uranium. Virtually all types of industrial operations with uranium are carried out, including casting, chemical processing, machining, storing, and shipping the metal. The site has inherited legacy contamination from its early days, when radiation protection and environmental controls were far less stringent than today.

Although radioactive materials other than uranium have been present at the Y-12 site, activities involving these materials occur on a far smaller scale than those for uranium. The other materials have been limited to various known areas, and appropriate precautions have been taken to limit their release. The resulting contamination is relatively minor compared with that from uranium. For this reason, contamination within the Y-12 Plant is generally considered to be enriched or depleted uranium unless laboratory analysis indicates otherwise.

The profession of health physics did not exist before World War II. It was born early within the Manhattan District of the U.S. Army Corps of Engineers, where it was recognized that the development of the atomic bomb would create new and enormous quantities of radioactive materials and radiation sources. The first group of eight "health physicists" was formed at the University of Chicago by mid-1943 to study and control these radiation hazards (M067, KZ80). At that time the principal source for recommended radiation exposure limits

in the United States was the U.S. Advisory Committee on X-Ray and Radium Protection (USACXRP), which was formed in 1929. This body was the forerunner of the present National Council on Radiation Protection and Measurements (NCRP). The USACXRP first recommended a human exposure limit of 0.2 R/day in a 1931 publication, and then lower limits of 0.1 R/day in 1936 and 0.02 R/day in 1941. They also proposed a maximum body burden of 0.1 $\mu$Ci for radium.

The field of radiation protection as we know it today thus began to evolve out of the early days of protection from X-rays and radium as a part of the Manhattan District activities. Many new concepts were introduced, such as the rem unit and maximum permissible concentrations for inhalation of radioactive materials. Instrumentation and monitoring controls were developed. Procedures for physical and administrative controls were introduced.

The practice of radiation protection has changed steadily and enormously from its wartime beginnings to the present day. Detailed requirements such as those described in 10CFR835 are the norm today for control of radiation exposure of workers and the public. At a facility like the Y-12 Plant, which was built in the war years and carries a legacy of contamination from an era of different concerns and different practices, the new posting requirements entail an array of potential problems to be dealt with. This thesis presents the site characterization plan and its implementation to acquire the technical data needed to comply with the site posting requirements of 10CFR835.

# CHAPTER 2

# SITE CHARACTERIZATION PLAN

As mentioned in the Introduction (Chapter 1), the Oak Ridge Y-12 Plant Controlled Area contains approximately 800 acres of land with a variety of structures and surface coverings. The Controlled Area consists of three sections, which are physically separated for security reasons, and require different levels of security clearance for entry. The three sections are referred to as:

- the Property Protection Area (PPA), in which no clearance is required for unescorted access. This area includes the BCTTA, PPA, and large section of Limited Area (LA), as shown on Plate 1.1;
- the Limited Area (LA), in which a DOE "L" or higher clearance is required for unescorted access. This includes a small section of the LA shown on Plate 1.1; and
- the Exclusion Area (EA), in which a DOE "Q" clearance is required for unescorted access. This includes the Protected Area and EA shown on Plate 1.1.

The Y-12 process/production activities are all primarily associated with uranium, both enriched and depleted.

In the spring of 1995 a team was formed to develop a site characterization plan for the Y-12 Plant in anticipation of the requirements of 10CFR835. The plan would detail the

actions necessary to survey the site, document the findings, and provide possible posting options or recommendations. Under 10CFR835 the deadline for completion of this project was specified as December 31, 1995. The characterization team members were J. C. Ashley, J. S. Bogard, C. A. England, R. N. Hamm, and J. E. Turner.

The sheer magnitude of the project and the time constraints presented formidable problems. Also, the work had to be performed without unreasonable expenditures. Success depended upon a well thought out and workable characterization plan.

The characterization team decided to begin making radiological surveys and collecting data as soon as possible. Because there was not available manpower on the site, radiological control technicians (RCTs) were contracted from outside the Plant. This circumstance introduced several complications. First, the outside RCTs would not be available until May 1995, and thus would begin work with only eight months to complete the necessary surveys. Second, they would not have DOE security clearances and would require escorts in all areas except the PPA. Third, street and road surveys would require that RCTs be utilized as flagmen, thus decreasing the number available to actually perform surveys. In addition, a large part of the instrumentation needed for the surveys would not be available until mid-June of 1995. The team realized early that the project scope must be limited without compromising the overall outcome.

The characterization plan addressed the entire site in terms of the following three categories:

1. outdoor paved surfaces, including streets, sidewalks, and parking areas;
2. buildings, principally interiors and roofs; and

3. outdoor unpaved surfaces, such as grassy fields, wooded areas, and graveled areas.

This breakdown provided a logical organization of the work to be performed. Each category would have its own survey protocol. Outdoor paved surfaces were easily accessible, allowing surveys to begin immediately in the PPA. Building surveys could be performed on days when weather conditions precluded outdoor survey work. Building surveys also required special preparations, such as reviews of existing survey data, acquiring Building Manager approval, and planning for limitations associated with uncleared RCTs. Outdoor nonpaved areas were unique, requiring different instrumentation and special survey techniques. Contaminated nonpaved surfaces also required different posting in some situations.

At the time of this writing, major portions of the survey work for the outdoor paved surfaces and the buildings have been completed. Work on the unpaved areas has not yet been undertaken. This thesis thus presents results from only the first two of the above three categories of site characterization work.

## 2.1 Outdoor Paved Surfaces

Outdoor paved surfaces within the Controlled Area consist of roads, parking lots, sidewalks, equipment pads, docks and other features. There are more than 200 acres of paved surfaces within the Y-12 Controlled Area. Roughly 35% of the paved area is located in the PPA, 15% is in the LA, and 50% is in the EA. These surfaces are generally flat, smooth and easily surveyed. Paved surfaces were deemed to be a priority item by the Y-12 Radiological Control Manager. Surveying began on outdoor paved surfaces located within the PPA, then

moved successively into the LA and EA.

As described in Appendix A, the DOE Radiological Control (RADCON) Manual specifies limiting values separately for removable and total (fixed-plus-removable) contamination. Distinguishing between these two types of contamination is a key factor in the radiological characterization of the site. Surveys were required not only to locate areas in which radioactive contamination was present, but also determine whether it was fixed on the surface. Fixed contamination is defined in the RADCON Manual as radioactive material that cannot be readily removed from surfaces by nondestructive means such as casual contact, wiping, brushing, or washing. As described in Chapters 4 and 5, removable contamination had to be dealt with immediately when found.

There is considerable evidence to suggest that contamination, both on paved surfaces and generally within the Y-12 Controlled Area, is indeed fixed. The Y-12 Radiological Control Department manages programs in which shoes of personnel are periodically surveyed for radioactive contamination. All entrance and exit portals to the site are also routinely surveyed. Results of the ongoing surveillance give no indication that radioactive contamination is moving about the site. Nevertheless, it was decided to periodically perform "dry scrubs" (see Chapter 4) of areas found with elevated contamination levels during the site-characterization surveys. This process was to be the deciding factor in determining whether or not contamination is indeed fixed. The detailed plan for surveying the paved surfaces is presented in Chapter 4, together with some detailed survey results.

## 2.2 Buildings

There are approximately 600 buildings of various types in the Y-12 Controlled Area. These consist of process buildings, office buildings, trailers, cooling towers, guard shacks, pumphouses, and a variety of other structures. Approximately 20% of the buildings are located in the PPA, 20% in the LA, and 60% in the EA. A number of the buildings on the site did not have to be considered for inclusion in the Y-12 site characterization. These included buildings managed by Oak Ridge National Laboratory (ORNL) or other prime contractors within the Y-12 Controlled Area as well as buildings in which Y-12 RADCON Field Operations provided direct support. The latter are already under the jurisdiction of Y-12 Field Operations groups, who are responsible for characterizing and posting the buildings they directly support. Approximately 121 buildings were thus eliminated from within the Controlled Area.

While developing a characterization plan for buildings, it was important to utilize all existing survey data. Many Y-12 buildings have undergone extensive surveys in past years. One such survey was performed by ORNL in 1992-1993. The Y-12 Plant contracted ORNL to characterize all Y-12 buildings, but the work was not completed due to funding problems. Many buildings were characterized by ORNL, however, and those survey data were utilized for this project. The detailed building survey plan is described in Chapter 5. The buildings to be characterized were separated into three categories, and survey plans were developed for each category. Category 1 included buildings, characterized by ORNL, in which contamination levels existed which were equal to or greater than the RADCON Manual Table 2.2 release limits. Category 2 included buildings which were not surveyed by ORNL.

Category 3 included buildings, characterized by ORNL, in which no contamination levels equal to or greater than the RADCON Manual Table 2.2 release limits were found.

## 2.3 Posting Options

Upon completion of area and building characterizations, and based upon the findings, appropriate posting options for them were to be analyzed. Implementation of 10CFR835 will require some combination of the following generic responses:

1. Post at entrance to Controlled Area for fixed contamination on paved surfaces.
2. Post individual locations of fixed contamination on paved surfaces.
3. Post at entrances to Controlled Area for fixed contamination inside buildings.
4. Post individual building entrances for fixed contamination.
5. Post specific locations of fixed contamination inside buildings.

## 2.4 Pilot Survey of Paved Surfaces

After a preliminary plan was drawn up to accomplish the surveying of paved surfaces, a pilot study was made to gain actual field experience to assist in further development of the plan. The pilot study consisted of the one-day survey of paved surfaces adjacent to Building 9212, an enriched uranium processing facility with several docks utilized for the transfer of radioactive materials (see Figure 2.1). This area was chosen due to its presumed high likelihood of surface contamination. However, very little contamination was actually found. A computer-generated map of the survey area was produced beforehand showing building

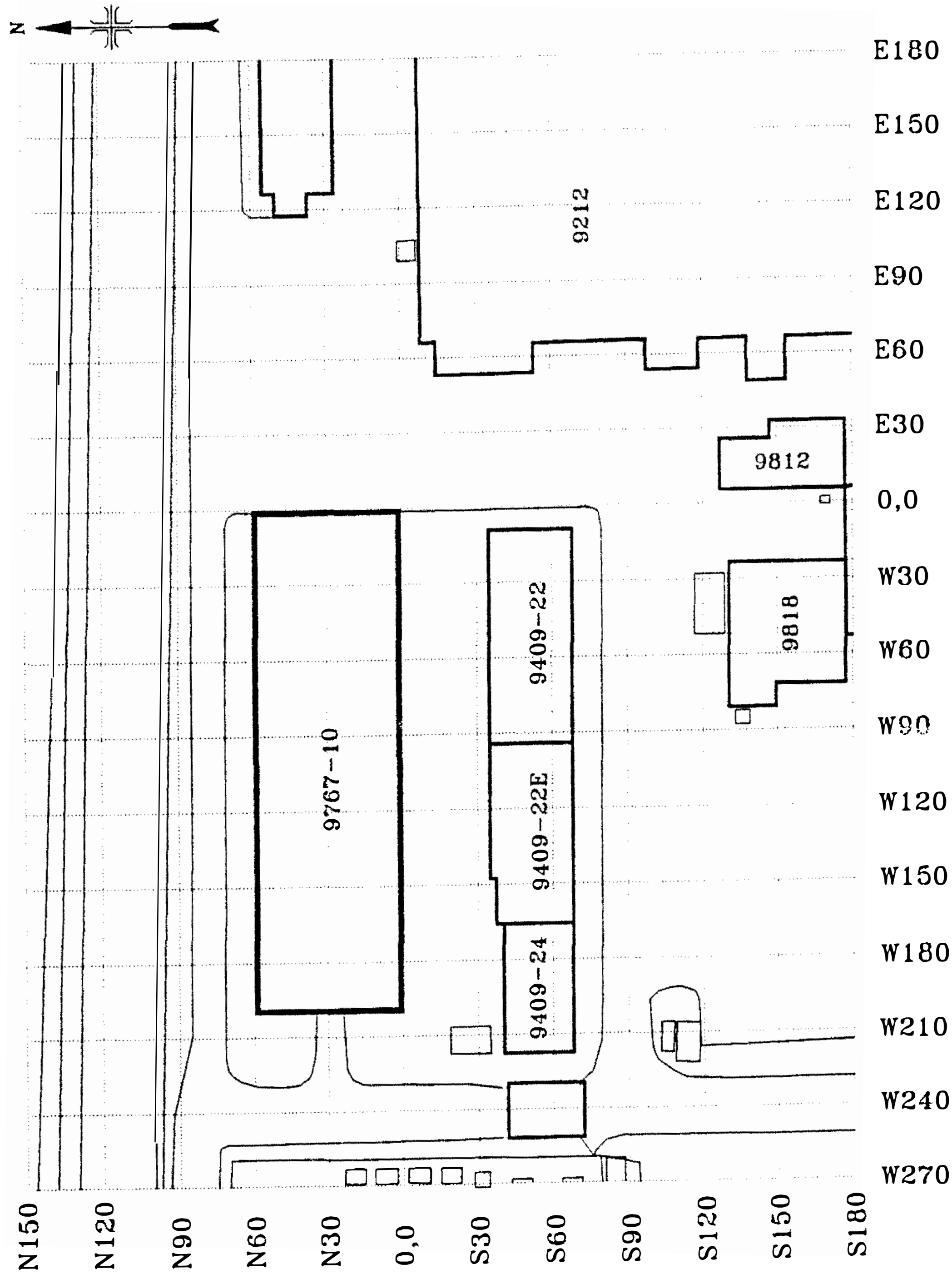


Figure 2.1. Area surrounding Building 9212 at the Oak Ridge Y-12 Plant Site.

locations, streets and other structures. The map was overlaid with 30' × 30' square gridlines. The corner of Building 9767-10 was the origin with coordinates (0,0). A 100% survey was performed–that is, 100% of the surface was surveyed.

Results from the pilot study were somewhat different than anticipated. The form used to record survey data is shown in Figure 2.2, and results are shown in Table 2.1. Although the entire area was expected to have elevated levels of contamination, the survey proved otherwise. There was no contamination detected on new blacktop (2-3 years old). This result suggests that contamination control techniques, now utilized within the Y-12 Plant, are working. Contamination was detected on old pavement (older than 2-3 years) directly adjacent to a contaminated dock. The levels of contamination decreased as distance from the dock increased. Locations such as holes and cracks in the road were found to be likely spots for contamination. Also, old pavement/new pavement interfaces proved to be likely locations for contamination. Other contaminated items included the foundation of a cooling tower, drain spouts and other runoff points.

The pilot study showed that there are specific areas and locations in which there is a high likelihood that contamination is present. For the purposes of this project, such an area was identified as a source term (ST), defined as an area from which radioactive contamination may be transferred to generally accessible paved surfaces. It represents, therefore, a point of origin for uncontrolled migration of surface contamination.

Potential STs included (but were not necessarily restricted to) the following:

- areas without adequate contamination control, but with known levels of contamination above background;

Form-HPAM-5
Revised: 09/29/95

## RADIOLOGICAL CONTROL ORGANIZATION
## MONITORING AND SURVEY RESULTS

| BUILDING: | ROOM/AREA | AREA CODE | |
|---|---|---|---|
| TYPE OF SURVEY<br>☐ AREA ☐ MATERIAL/EQUIPMENT | DESCRIPTION OF MATERIAL/EQUIPMENT/AREA: | DATE. | TIME: |

| Sample Number | DESCRIPTION* | CONTAMINATION READINGS (1) | | | | RADIATION READINGS (2) | | |
|---|---|---|---|---|---|---|---|---|
| | | ALPHA (dpm/100 cm2) | | BETA/GAMMA (dpm/100 cm2) | | | | |
| | | Max. Fixed Plus Removable | Removable | Max. Fixed Plus Removable | Removable | Gamma mrem/hr | Beta mrem/hr | Neutron mrem/hr |
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RadCon Instrument Used (I.D.) ALPHA ____________ BETA/GAMMA ____________ NEUTRON ____________

RADCON TECHNICIAN SIGNATURE: ____________ BADGE: ____________

RADCON TECHNICIAN PRINTED NAME: ____________

Y-12 SITE URANIUM SURFACE RADIOACTIVITY GUIDES IN dpm/100 cm2:

| ALPHA | | BETA/GAMMA | | |
|---|---|---|---|---|
| Removable | Max Fixed Plus Removable | Removable | Max Fixed Plus Removable | |
| ≤ 1,000 | ≤5,000 | ≤1,000 | ≤5,000 | Classified as uncontaminated. |
| >1,000 | >5,000 | >1,000 | >5,000 | Classified as contaminated. |

***SEE MAP ON REVERSE SIDE FOR SURVEY LOCATIONS**

1. The minimum detectable limit is approximately 250 dpm/100 cm2 alpha and 600 dpm/100 cm2 beta/gamma fixed plus removable. For radioactivity guidelines, other than uranium, refer to Procedure Y70-101.
2. Readings are taken at a distance of 30 cm unless otherwise noted.

DISTRIBUTION:
Operations Supervisor
RCT Supervisor

REVIEW AND APPROVAL

____________ RCT Supervisor ____________ Date

Reference:
Y70-101
Y70-117

Figure 2.2. HPAM-5 Form for recording survey data.

**Table 2.1. Pilot Study Results**

| Description | ALPHA (dpm/100 cm$^2$) | | BETA/GAMMA (dpm/100 cm$^2$) | |
|---|---|---|---|---|
| | Max. Fixed Plus Removable | Removable | Max. Fixed Plus Removable | Removable |
| SCAFFOLD RUNOFF | 6400 | <250 | 1500 | <120 |
| FOOT OF STEPS | 4000 | <250 | 6000 | <120 |
| DOCK EDGE STREET LEVEL | 32000 | <250 | 3000 | <120 |
| 8' FROM DOCK | 4000 | <250 | 30000 | <120 |
| WEST EDGE OF DUMPSTER | 8000 | <250 | 4500 | <120 |
| RIGHT OF STEPS | 2500 | <250 | 15000 | <120 |
| LEFT OF STEPS | 4000 | <250 | 9000 | <120 |
| E717 TANK MAN HOLE COVER NORTH OF | 12400 | <250 | 1500 | <120 |
| NE CORNER OF TANK TRANSFER PAD | <250 | <250 | 45000 | <120 |
| Dock Base-78 | 40,000 | N/A | 9,000 | N/A |
| -78,35 | 400 | N/A | <600 | N/A |
| -78,40 | 4,000 | N/A | 6,000 | N/A |
| -78,45 | 4,000 | N/A | 6,000 | N/A |
| -73,30 | <250 | N/A | <600 | N/A |
| -73,35 | <250 | N/A | <600 | N/A |
| -73,40 | 1,000 | N/A | 1,500 | N/A |
| -73,45 | 4,000 | N/A | 3,000 | N/A |
| Dock Base-73 | 4,000 | N/A | 6,000 | N/A |
| -68,30 | <250 | N/A | <1,000 | N/A |
| -68,35 | 400 | N/A | <600 | N/A |
| -68.40 | 4.000 | N/A | 1.500 | N/A |

**Table 2.1 (continued)**

| Description | ALPHA (dpm/100 cm²) | | BETA/GAMMA (dpm/100 cm²) | |
|---|---|---|---|---|
| | Max. Fixed Plus Removable | Removable | Max. Fixed Plus Removable | Removable |
| -68,45 | 8,000 | N/A | 9,000 | N/A |
| Dock Base-68 | 4,000 | N/A | 9,000 | N/A |
| -63,30 | 400 | N/A | <600 | N/A |
| -63,35 | 400 | N/A | <600 | N/A |
| -63,39 | 400 | N/A | 1,500 | N/A |
| -58,30 | 400 | N/A | <600 | N/A |
| -58,35 | 400 | N/A | <600 | N/A |
| -58,40 | 400 | N/A | 1,500 | N/A |
| -58,45 | 800 | N/A | 9,000 | N/A |
| -58,47 | 400 | N/A | 9,000 | N/A |
| -53,35 | 800 | N/A | <600 | N/A |
| -53,40 | 800 | N/A | <600 | N/A |
| -53,45 | 8,000 | N/A | 12,000 | N/A |
| -53,47.5 | 800 | N/A | 16,000 | N/A |
| -48,35 | 400 | N/A | <600 | N/A |
| -48,40 | 400 | N/A | <600 | N/A |
| -48,42 | 400 | N/A | 1,500 | N/A |
| -43,35 | 400 | N/A | <600 | N/A |
| -43,40 | 400 | N/A | <600 | N/A |
| -43,42.5 | 400 | N/A | <600 | N/A |
| -38,35 | 400 | N/A | <600 | N/A |
| -38,40 | 400 | N/A | <600 | N/A |
| -38,42.5 | 400 | N/A | <600 | N/A |
| -33,40 | <250 | N/A | <600 | N/A |
| -33,42.5 | <250 | N/A | <600 | N/A |

- all interfaces (docks, portals) between paved surfaces and areas where unsealed radioactive materials are, or have been, processed, handled, or stored;
- street intersections, sidewalk intersections, crosswalks, and outside pedestrian and vehicular portals between plant security zones;
- low spots or uneven surfaces where runoff water pools or channels;
- ventilation intake/exhaust grilles; and
- eddy points where dust and blown trash tend to collect.

Ideally, professional judgement and experience would be used to identify all potential STs in the plant prior to the start of survey activities. All such identified areas were to be separated into four categories listed in order of priority.

Priority 1: STs with known or suspected levels of contamination in excess of RADCON Table 2.2 limits.

Priority 2: STs with known or suspected levels of contamination elevated above background, but not in excess of RADCON Table 2.2 limits.

Priority 3: Potential STs with no known or suspected contamination.

Priority 4: Paved surfaces not included as part of Priority 1, Priority 2, or Priority 3.

Following the pilot study, actual site characterization surveys began in an area identified as a Priority 1. The garage area at the east end of the Y-12 Controlled Area was selected for the initial characterization survey (see Figure 2.3). It contains garages, gasoline stations, a vehicle wash, workshops, and vehicle parking and storage areas. To gain additional

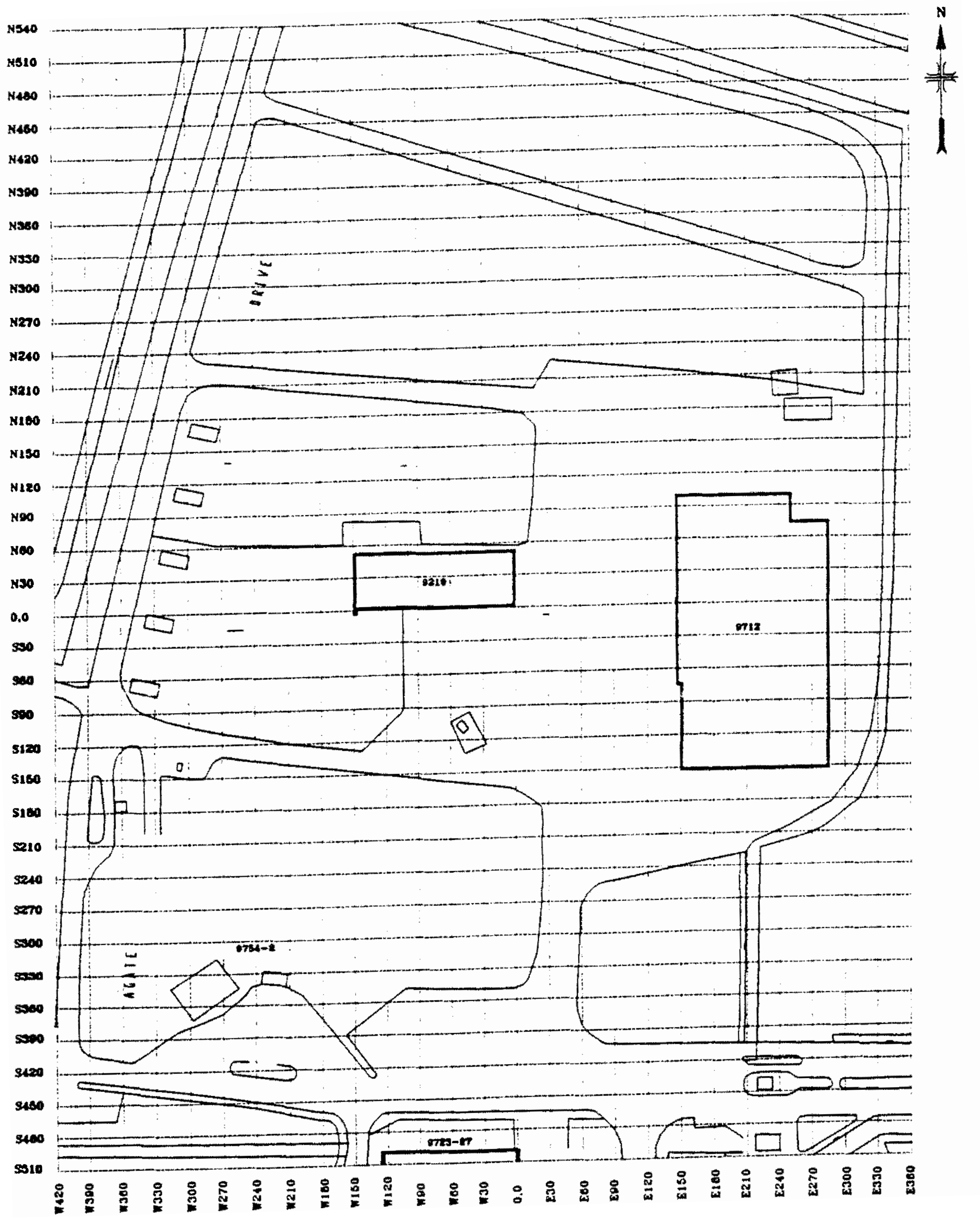


Figure 2.3. Garage area.

experience, 100% of this area was monitored. With the completion date of December 31, 1995, such a 100% survey of all paved areas in the Y-12 Plant was impractical, although this method provided excellent data. The actual plan, as it was developed and implemented for paved surfaces, is described in Chapter 4. Its development was guided by the primary purpose for surveying the Y-12 Plant: to determine posting requirements and subsequently post areas with regard to radioactive contamination per the requirements of 10CFR835. The success of the plan is evaluated in the last chapter by applying it to this garage area and comparing the implied posting requirements with those based on the known, 100% characterization.

# CHAPTER 3

# RELATIONSHIP BETWEEN SURFACE CONTAMINATION LIMITS AND DOSE-EQUIVALENT RATES

Surface contamination limits, such as those specified in Table 2-2 of the DOE RADCON Manual (see Table A-1) or others in use for radiological control can be analyzed by means of dosimetric-model calculations. The contamination limits are then seen as embodying added, conservative factors of safety. Models are idealizations, but they do provide a well-defined set of technical conditions and assumptions that relate contamination levels to specific estimates of organ and effective dose equivalents in an individual. The methodology of performing such calculations is reviewed in this chapter. Results obtained for uranium and its daughters are then used to compare with RADCON Table 2-2.

## 3.1 Statement of Problem

Consider a plane contaminated with a uniform surface density of a radionuclide (e.g., Bq $m^{-2}$, $\mu$Ci $cm^{-2}$). For the time-dependent concentration density C(t) on the surface, the dose equivalent $H_T$ ($\tau$) over time $\tau$ in an organ or tissue T of a person above the surface from external radiation can be expressed by writing

$$H_T(\tau) = h_T \int_0^{\tau} C(t)\, dt \quad . \tag{3.1}$$

Here $h_T$, which is independent of the time $\tau$, is called the dose coefficient for external exposure. It is the dose-equivalent in tissue T per unit time-integrated exposure. Alternatively, writing

$$h_T = \frac{H_T(\tau)}{\int_0^{\tau} C(t)\, dt} \quad , \tag{3.2}$$

one can regard the dose coefficient as giving the instantaneous dose-equivalent rate in tissue T per unit activity concentration on the surface. Its units are illustrated, for example, by writing

$$1 \; \frac{\text{Sv s}^{-1}}{\text{Bq m}^{-2}} = 2.22 \times 10^{15} \; \frac{\text{mrem min}^{-1}}{\mu\text{Ci cm}^{-2}} \tag{3.3}$$

Having determined the $h_T$, one can evaluate the coefficient $h_E$ for the effective dose equivalent, given by

$$h_E = \sum_T w_T \, h_T \quad . \tag{3.4}$$

The $w_T$ are the tissue weighting factors (NC87), and the sum goes over all organs and tissues of the body T. With $h_E$ one has directly the effective dose-equivalent rate $\dot{H}_E$ per unit activity density on the surface. For comparison, the annual occupational limit on the effective dose equivalent $H_E$ of an individual is 5 rem. Extensive recent tables of $h_T$ and $h_E$ for virtually all important radionuclides and a number of organs have been published (ER93).

The foregoing formalism can be applied in a straightforward manner to estimate external dose rates from surface contamination. If the surface contamination is not fixed, it can, in principle, become airborne and present a hazard as an internal emitter after inhalation. Resuspension factors for removable contamination have been investigated. Using such an assumed factor, one can compare the implied air concentration with the derived air concentration (DAC). The DAC is related to the 50-y committed effective dose equivalent (CEDE), defined as

$$H_{50,E} = \int_0^{50\,y} \dot{H}_E(t)\,dt \quad . \tag{3.5}$$

Occupational exposure at the DAC for one year results either in a CEDE of $H_{50,E}$ = 5 rem or an organ committed dose equivalent $H_{50,T}$ = 50 rem, whichever is the more restrictive. These derived limits are equal to the annual ones for stochastic and nonstochastic effects, respectively. One can thus relate a given density of removable surface contamination to these derived quantities.

In the next two sections it is shown how this methodology can be used for uranium as a basis to compare the limits given in RADCON Table 2-2 for removable and total, or fixed-plus-removable, contamination with the basic annual occupational limits on dose equivalent.

### 3.2 Fixed Contamination - External Dosimetry

Consider a point Q in a uniform, homogeneous medium exposed to an isotropic point

source of gamma rays from a radionuclide at a point P, located at a position $\vec{r}$ with respect to Q (see Figure 3.1). The specific absorbed fraction Φ (r,E) is defined as the fraction of gamma-ray energy (E in MeV) emitted at P and absorbed per unit mass in grams of material at Q. If the source activity A(t) at time t is expressed in Bq, then the dose rate in Gy $s^{-1}$ at Q is given by

$$\dot{D}(r,t) = 1.6 \times 10^{-10} A(t) E \Phi(r,E) \quad . \tag{3.6}$$

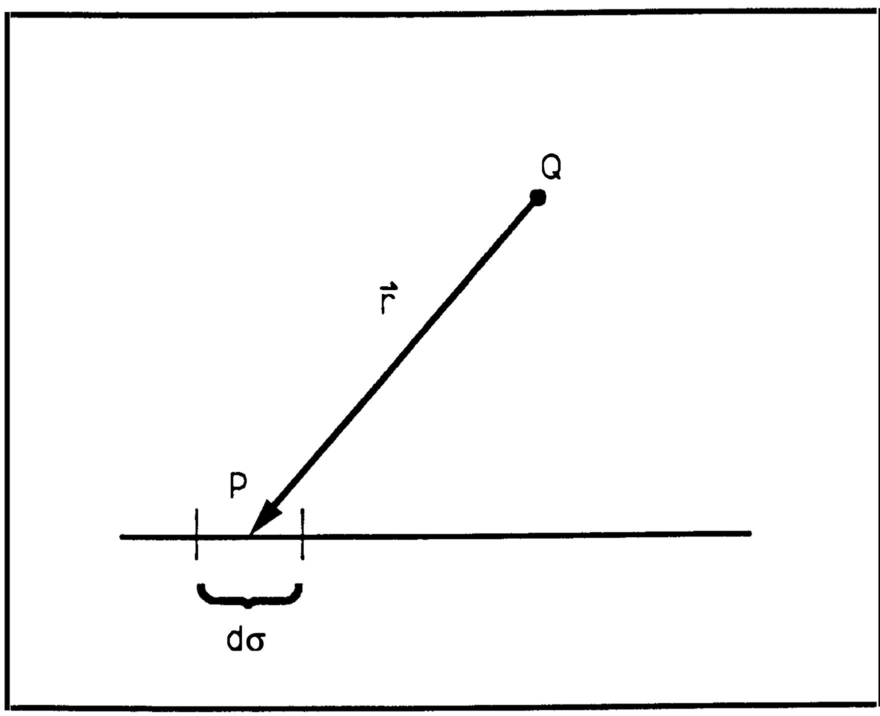


Figure 3.1. Dose rate at Q from isotropic point source of gamma photons at P is given by Eq. (3.6).

The numerical factor in front converts units. Since $E\,\Phi\,(r,E)$ is in MeV $g^{-1}$, one has

$$(1 \text{ MeV g}^{-1}) \times (1.6 \times 10^{-13} \text{ J MeV}^{-1}) \times (10^{3} \text{ g kg}^{-1})$$
$$= 1.6 \times 10^{-10} \text{ J kg}^{-1} = 1.6 \times 10^{-10} \text{ Gy} \quad . \qquad (3.7)$$

If the source emits several gamma photons with energies $E_i$ and frequencies $f_i$ per disintegration, then the dose rate at Q is

$$\dot{D}\,(r,t) = 1.6 \times 10^{-10} A(t) \sum_i E_i f_i \Phi(r,E_i) \quad , \qquad (3.8)$$

where the summation extends over the entire gamma energy spectrum.

Instead of a point source at P, consider next a plane with surface contamination described by a density function $C(\vec{r}, t)$ in Bq $cm^{-2}$. The contribution to the dose rate at Q from the activity in an element of surface area $d\sigma$ around P is given by replacing A(t) in Eq. (3.8) by $C(\vec{r}, t)d\sigma$. Integrating over the entire surface $\sigma$, one has for the dose rate in Gy $s^{-1}$ at Q

$$\dot{D}(t) = 1.6 \times 10^{-10} \sum_i E_i f_i \int_\sigma C(\vec{r}, t) \Phi(r,E_i) d\sigma \quad . \qquad (3.9)$$

The dose over time $\tau$ is given by

$$D(\tau) = \int_0^\tau \dot{D}(t)\,dt \quad . \qquad (3.10)$$

If the surface contamination is uniform, the dependence of the concentration on $\vec{r}$ drops out. One can then combine Eqs. (3.10) and (3.9) to write

$$D(\tau) = DRF \int_0^{\tau} C(t)dt \quad , \tag{3.11}$$

where DRF, the dose-rate factor, gives the dose rate per unit activity density on the surface (KO83).

Comparison with Eq. (3.1) shows that the DRF is formally related to $h_T$. (The quality factor for gamma rays is unity.) Whereas $H_T(\tau)$ is the dose equivalent in tissue T, $D(\tau)$ is the dose in air, from which the tissue dose is then calculated (KO83).

In principle, organ doses in an anthropomorphic phantom above a plane surface with a uniformly distributed gamma emitter can be calculated by Monte Carlo techniques. However, this process can be inefficient, even with the application of sophisticated variance-reduction techniques. To avert these complexities, the problem of dose calculation can be carried out in two steps. First, the radiation field incident on a closed surface surrounding the phantom is computed. Second, the organ dose is calculated from the resulting surface source. This method has been used by Eckerman and Ryman to determine organ dose-equivalent and effective dose equivalent conversion factors for a number of radionuclides distributed uniformly on a surface (ER93).

The dose coefficients defined by Eqs. (3.2) and (3.4) are given in Table III.3 of (ER93). They enable one to compute external effective dose-equivalent rates for an infinite plane surface contaminated uniformly with depleted or enriched uranium at the RADCON limits (Table A-1). Contamination with depleted uranium results in gamma rays emitted by $^{238}U$ in secular equilibrium with its short-lived daughters, $^{234}Th$ and $^{234m}Pa$. The following dose

coefficients given in (ER93) enable one to compute the effective dose equivalent for depleted uranium:

| **Nuclide** | **$h_E$ (Sv $s^{-1}$/Bq $m^{-2}$)** |
|---|---|
| $^{238}U$ | $5.51 \times 10^{-19}$ |
| $^{234}Th$ | $8.32 \times 10^{-18}$ |
| $^{234m}Pa$ | $1.53 \times 10^{-17}$ |
| Total | $2.42 \times 10^{-17}$ |

In more convenient units,

$$h_E = 2.42 \times 10^{-17} \frac{\text{Sv s}^{-1}}{\text{Bq m}^{-2}} \times 10^5 \frac{\text{mrem}}{\text{Sv}} \times 10^4 \frac{\text{cm}^2}{\text{m}^2} \times 3600 \frac{\text{s}}{\text{h}} \tag{3.12}$$

$$= 8.71 \times 10^{-5} \frac{\text{mrem h}^{-1}}{\text{Bq cm}^{-2}} \ . \tag{3.13}$$

The RADCON limits are specified in terms of dpm/100 $cm^2$ alpha, which comes only from the $^{238}U$. Thus,

$$h_E = 8.71 \times 10^{-5} \frac{\text{mrem h}^{-1}}{\text{Bq cm}^{-2}} \times \frac{1 \text{ Bq}}{60 \text{ dpm}} \tag{3.14}$$

$$= 1.45 \times 10^{-6} \frac{\text{mrem h}^{-1}}{\text{dpm cm}^{-2}} \quad . \tag{3.15}$$

At the RADCON release limit of 5,000 dpm/100 cm$^2$ alpha for total (fixed-plus-removable) contamination, the effective dose equivalent rate is

$$h_E = 1.45 \times 10^{-6} \frac{\text{mrem h}^{-1}}{\text{dpm cm}^{-2}} \times \frac{5{,}000 \text{ dpm}}{100 \text{ cm}^2} \tag{3.16}$$

$$= 7.3 \times 10^{-5} \text{ mrem h}^{-1} \quad . \tag{3.17}$$

Based on this model analysis, the RADCON limit implies an external dose-equivalent rate for depleted uranium that is well below the average occupational limiting rate of 2.5 mrem h$^{-1}$ (for an annual dose equivalent of 5 rem). It is also considerably below the time-averaged nonoccupational (general public) limiting rate of $1.1 \times 10^{-2}$ mrem h$^{-1}$ (for an annual dose equivalent of 100 mrem).

For enriched uranium, a common form is Oralloy, consisting approximately of 93% $^{235}$U, 6% $^{238}$U, and 1% $^{234}$U. The latter is in secular equilibrium with $^{238}$U in uranium ore and closely follows $^{235}$U in the cascade process. Although present only at the 1% level, $^{234}$U contributes about 97% of the activity, because of its short half-life. For $^{235}$U, only the daughter $^{231}$Th contributes significantly to the effective dose equivalent. The details of the calculations for Oralloy are similar to those just described for depleted uranium and hence will not be given. The result, $3.3 \times 10^{-5}$ mrem h$^{-1}$, for enriched uranium is comparable to that for

the depleted isotope (see Eq. 3.17).

### 3.3 Removable Contamination - Internal Dosimetry

It is recognized that there is no well-defined relationship between surface contamination and internal dose to workers. Nevertheless, it is important to establish a technical link between the RADCON limits for removable surface contamination and the internal exposure that might result under certain assumptions.

To help establish this link, the concept of a resuspension factor R is useful. It is defined as the ratio of the airborne concentration $C_A$ (e.g., Bq $m^{-3}$) and the surface contamination $C_S$ (e.g., Bq $m^{-2}$) of a radionuclide:

$$R = \frac{C_A}{C_S} \quad . \tag{3.18}$$

The dimensions of R are those of inverse length (e.g., $m^{-1}$). Resuspension factors have been measured under a variety of conditions and typically range from $10^{-3}$ $m^{-1}$ to $10^{-7}$ $m^{-1}$. The value $R = 10^{-6}$ $m^{-1}$ has been considered as an appropriate factor "for average work situations and general surface contamination and routine work conditions" (RH88, p. 5-44).

With this value of R, Eq. (3.18) can be used to estimate the surface-contamination density $C_S$ for a given airborne concentration $C_A$. The most restrictive value of the occupational DAC for $^{238}U$ given in 10 CFR 20 (ST94) applies to a class-Y aerosol:

$$DAC = 2 \times 10^{-11} \frac{\mu\text{Ci}}{\text{cm}^3} \times 3.7 \times 10^4 \frac{\text{Bq}}{\mu\text{Ci}}$$
$$= 7.4 \times 10^{-7} \frac{\text{Bq}}{\text{cm}^3} \quad . \tag{3.19}$$

With R = $10^{-7}$ $m^{-1}$ and $C_A$ = DAC in Eq. (3.18), one finds

$$C_S = \frac{C_A}{R} = \frac{7.4 \times 10^{-7} \text{ Bq cm}^{-3}}{10^{-6} \text{ m}^{-1} \times 0.01 \text{ m cm}^{-1}}$$
$$= 74 \text{ Bq cm}^{-2} \tag{3.20}$$

$$= 74 \frac{\text{Bq}}{\text{cm}^2} \times 60 \frac{\text{dpm}}{\text{Bq}} \times \frac{100}{100}$$
$$= 444{,}000 \frac{\text{dpm}}{100 \text{ cm}^2} \quad . \tag{3.21}$$

This value can be compared with the earlier derived limit of 220,000 dpm/100 $cm^2$, recommended by the International Atomic Energy Agency (IA76) and the British National Radiological Protection Board (WL79). As for the dose-equivalent rate for external radiation at the RADCON limit for total surface contamination, that implied for removable contamination under conservative assumptions is far below the basic and derived occupational limits for internal exposure.

# CHAPTER 4

# SURVEY PLAN FOR PAVED SURFACES

## 4.1 Radiological Characterization of Y-12 Streets and Sidewalks

This plan describes a methodology for determining the extent of radiological contamination on paved surfaces (streets, parking lots, and sidewalks) within the Y-12 Plant Controlled Area. It provides guidance in (1) establishing the sequence in which surveys are conducted, (2) choosing appropriate survey techniques, and (3) establishing a coordinate system to locate surveyed areas precisely. The study was designed to determine whether, and if so, the degree to which paved areas within Y-12 exceed surface contamination and posting limits of 10CFR835, as reflected in Table 2-2 of the DOE RADCON Manual (see Table A-1).

## 4.2 Survey Locations and Sequence

Surveys were conducted by a RADCON survey team and began in the east end of the Y-12 Plant, moving westward toward the EA. The east end of Y-12 is the part of the Plant to which the public has greatest access. No large quantities of radioactive materials are routinely handled or stored here, but there is a historic and continuing movement of vehicles and materials from process areas to facilities in the east end.

Characterization activities focused primarily on those paved areas which were considered to have the greatest probability of radiological contamination (suspect areas):

- Paved areas in the immediate vicinity of docks and portals;

- Vehicle parking areas;
- Materials storage areas (unless fenced);
- Street intersections, sidewalk intersections, crosswalks, and outside pedestrian and vehicular portals between plant security zones;
- Low spots or uneven surfaces where runoff water pools or channels;
- Areas around ventilation intake/exhaust grilles, and
- Eddy points where dust and blown trash tend to collect.

Areas which were considered to have a low probability for radiological contamination were partially surveyed if no contamination was found in the higher-probability areas.

All paved areas in the Controlled Area were subdivided into 30-ft grids for ease in recording the location of contamination. A complete survey of a 30-ft grid square was not warranted if contamination equal to or greater than the RADCON Manual Table 2.2 limits was found anywhere within the square; however, a survey adequate to determine the extent of contamination was performed. This usually resulted in a 100% survey of the grid. The contaminated area was thus identified, and survey activities continued with the next grid square. Nearby grids, those located directly adjacent to grids in which contamination was found, underwent an extensive survey as well. Generally this resulted in a 75% survey of the total surface area. Remote grids with no identified suspect areas, no detected contamination, and which were not positioned adjacent to contaminated grids underwent a 10% surface area survey. Figure 4.1 outlines the primary steps involved in the performance of paved surface characterizations.

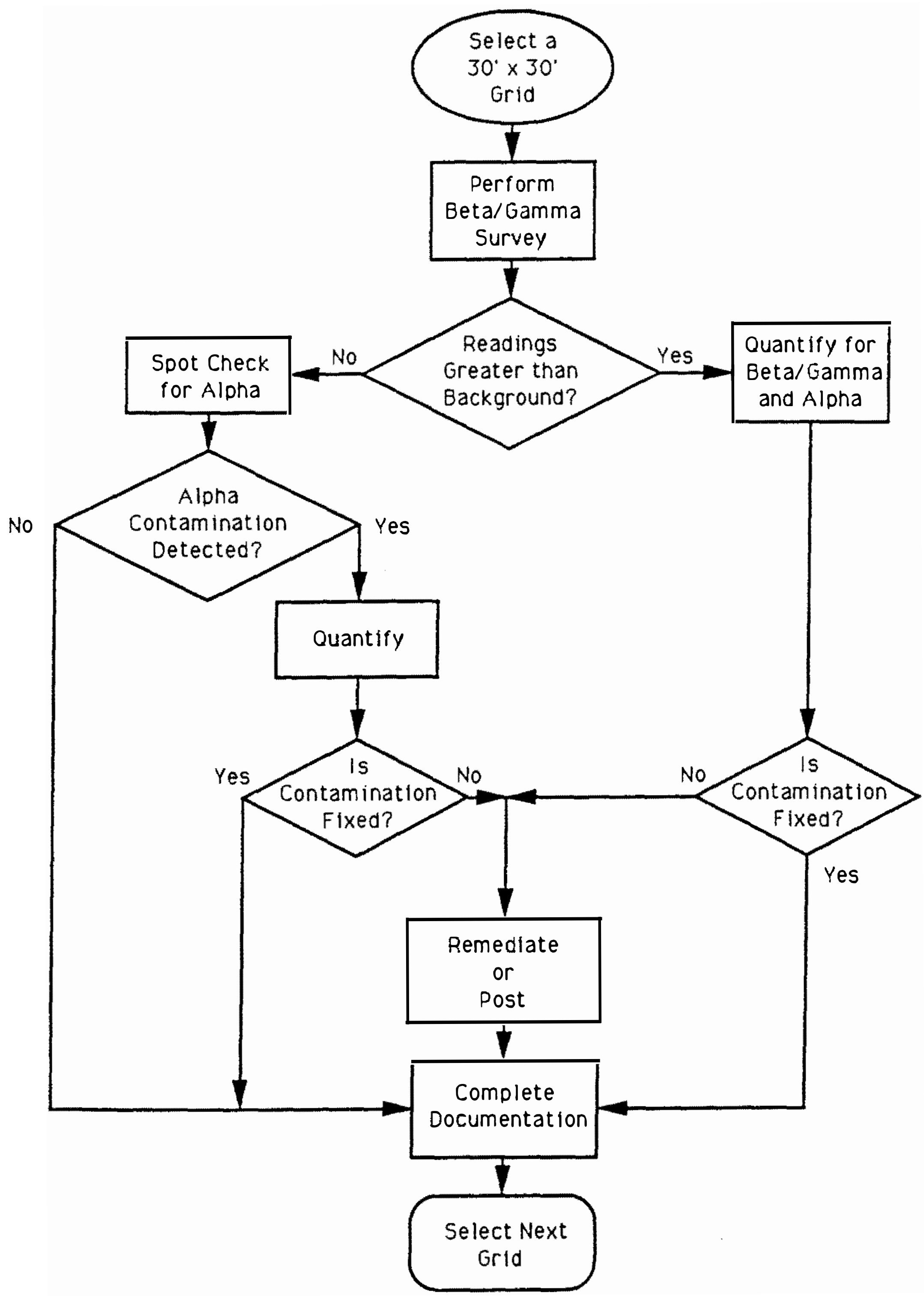


Figure 4.1. Flowchart for characterization of paved surfaces.

## 4.3 Survey Methods and Instrumentation

### 4.3.1 Instrumentation

Instruments used in the survey included "floor monitors" with wide-area ionization (gas-flow proportional counter) detectors for identifying areas of contamination above background ("elevated activity"), hand-held survey instruments calibrated for quantitative determination of surface alpha (scintillation detector) and beta-gamma (G-M tube) activity, and "μR" meters for determining external penetrating dose rates. The latter is a tissue-equivalent rate instrument that reads in μrem per unit time, i.e., dose equivalent per unit time. Each floor monitor was configured in one of two ways: (1) to respond to α particles alone or (2) to respond primarily to β particles and photons. Further details are given in Appendix B. Radioactivity on swipes was analyzed with a 2π proportional counter for gross alpha and beta-gamma activity and an α-particle spectrometer for isotopic analysis.

### 4.3.2 Survey Techniques

The area of the survey consisted of all paved surfaces within the controlled area of the Y-12 Plant. Paved surfaces were surveyed first, using floor monitors set for optimal response to β-γ radiation. Earphones were used in high noise areas, in conjunction with visual observation of the meter readout, for improved discrimination of contamination levels elevated above background. Floor monitors were moved at a linear velocity not exceeding approximately one detector width per second in performing α-contamination surveys, and not exceeding approximately two detector widths per second for β-γ surveys.

Hand-held survey instruments calibrated for quantitative determination of alpha and beta-gamma contamination levels were used to characterize representative areas not

accessible to the floor monitor. They were also used to monitor areas of elevated radioactivity identified by the floor monitors, irregular surfaces not suited to the use of floor monitors, and areas such as driplines under building eaves, gutter downspout discharge points, storm sewer drains, and depressions where contamination might concentrate or accumulate. Surveys were conducted in accordance with specifications set forth in Y-12 Plant Procedures. Wide-area contamination (contamination distributed in an area exceeding 100 $cm^2$) was averaged as specified in Section 4.6, Contamination Averaging, when maximum total (fixed + removable) contamination levels were between 1 and 3 times the RADCON Manual Table 2.2 limits. Survey results were recorded using a standard Y-12 radiological survey data sheet, Health Physics Area Monitoring-5 (HPAM-5), revised 09/29/95, "Radiological Control Organization Monitoring and Survey Results," (see Figure 2.2). The location (see Mapping Requirements, Section 4.4) of each surveyed area was noted on the data sheet in the column labeled "Description." Dose-rate measurements were made 30 cm from surfaces having beta-gamma levels which exceeded 75,000 dpm/100 $cm^2$.

Swipe samples were taken, in accordance with specifications set forth in Y-12 Plant Procedures, at each location of elevated radioactivity confirmed by hand-held survey instruments. Swipes were screened for radioactivity by using the hand-held survey instruments, and then stored in glassine or paper envelopes. Each swipe was marked with the location (see Mapping Requirements, Section 4.4) at which the swipe was taken. Swipes were analyzed for gross alpha and beta-gamma contamination with a $2\pi$ proportional counter and then retained until the completion of the characterization study, so that possible later isotopic analysis could be performed if needed. Swipes from locations with measurable removable

contamination exceeding 500 dpm/100 $cm^2$ were submitted for isotopic analysis when uncertainty existed about the isotopes expected in the area, or when experience showed that unusual isotopic mixtures might be expected.

"Dry-scrub swipes" were taken in addition to the standard swipe samples as defined in Y-12 Plant Procedures at locations of elevated radioactivity which exceeded 500 dpm/100 $cm^2$. Analysis and disposition of dry-scrub swipes were the same as for standard dry swipes described above. A procedure for taking dry-scrub swipes is included as Section 4.7 entitled Dry-Scrub Swipe Method.

## 4.4 Mapping Requirements

Observations, samples, and measurements were recorded with information sufficient to plot results on a Y-12 site map. Maps of areas to be surveyed were supplied by the characterization team to the RADCON survey team for their use in identifying landmarks. The maps included a superimposed 30' × 30' grid system, with coordinates at grid intersections, to assist in determining coordinates for regions of recordable activity. A point used to record a measurement, sample, or observation was identified by two coordinates and a reference point. A point which is shown on the map as the intersection of two structural boundaries, such as the corner of a building, was required as a reference point. The two coordinates were then reported as the distances in feet north/south and east/west of the reference point, using the grid orientation of the map to determine compass directions.

Spot contamination covering an area not exceeding 100 $cm^2$ was located by using coordinates for a single point. Wide-area contamination was mapped by drawing the boundary

of the contamination on a grid representing the 30' × 30' square within which the contamination is located.

## 4.5 Follow-up Actions

Removable contamination, equal to or greater than the RADCON Manual Table 2.2 limits, determined either by screening swipes with hand-held instruments or by analysis of swipes using a $2\pi$ proportional counter, was posted immediately by the RADCON survey team and reported to Field Operations Supervision. Areas for which dry-scrub swipe results exceeded 20 dpm/100 $cm^2$ were identified and reported to the characterization team. Copies of data sheets containing survey results, a summary report which included any unusual findings or circumstances, and the locations of areas which required posting as specified in the RADCON Manual were forwarded to the characterization team by the RADCON survey team within a week of the survey. The characterization team had the responsibility to compile and analyze the survey data.

Areas for which dry-scrub swipe results exceeded 20 dpm/100 $cm^2$ were considered by the characterization team for further evaluation, such as isotopic analysis or remedial action.

Remedial actions to be considered for areas which cannot be cleaned below the RADCON Manual Table 2.2 levels include posting, periodic monitoring of "fixed" contamination exceeding removable contamination limits, application of fixative, and removal/resurfacing.

## 4.6 Contamination Averaging Method

The RADCON Manual allows averaging of total (fixed + removable) contamination over 1 square meter, provided the maximum activity in any area of 100 $cm^2$ is less than three times the surface contamination guide values in RADCON Manual Table 2.2. This procedure provides a method for determining when contamination averaging is appropriate and for taking measurements with which to estimate the average contamination levels in a 1-$m^2$ area.

Guide values are exceeded for any square meter of surface if either of two conditions is met. First, the total activity $S_i$ over any 100-$cm^2$ section exceeds three times the guideline value G:

$$S_i > 3G \quad . \tag{4.1}$$

Second, for a representative number $n$ of sections, having activity $S_i$ (dpm/100 $cm^2$), within the square meter of surface, the average reading exceeds the guideline value:

$$\frac{1}{n}\sum_{i=1}^{n} S_i \geq G \quad . \tag{4.2}$$

The following procedure is then carried out:

1. Determine the boundaries of a contaminated area when elevated radioactivity levels are detected with either floor monitors or with hand-held survey instruments.
2. Subdivide the contaminated area with circles having a radius of 22 inches

(approximately half the length of the cable connecting a hand-held survey instrument package with its probe). (The area of a circle having this radius is approximately 1 $m^2$.)

3. Record all elevated contamination levels $S_i$ (dpm/100 $cm^2$) of all isolated spots or particles in any 100-$cm^2$ area within each circle.

4. Compare contamination levels in each 1-$m^2$ area with RADCON Manual Table 2.2 guide values.

   A. Use condition (4.1) to determine whether any single 100-$cm^2$ area exceeds RADCON Manual guidance.

   B. Use condition (4.2) if more than one 100-$cm^2$ area of contamination is found in a 1-$m^2$ area and no individual 100-$cm^2$ area exceeds the criterion (4.1).

5. Immediately post and notify Field Operations, or take other appropriate remedial action, if either of the conditions (4.1) or (4.2) is met.

6. Report contamination levels and locations on Form HPAM-5, Revised 09/29/95, "Radiological Control Organization Monitoring and Survey Results" (see Figure 2.2).

### 4.7 Dry-Scrub Swipe Method

"Dry-scrub swipes" provide assurance that radioactive material cannot be readily

removed from surfaces by nondestructive means such as casual contact, wiping, or brushing.[1] Dry-scrub swipes were taken (in addition to swipe samples as defined in Y-12 Plant Procedures) at randomly selected locations of elevated radioactivity (fixed + removable) which exceeded 500 dpm/100 cm$^2$. Swipes were stored in glassine or paper envelopes, and each swipe was marked with the location (see Section 4.4) at which the swipe was taken. Swipes were retained after analysis of gross $\alpha$ and $\beta$-$\gamma$ contamination until the completion of the characterization study, so that possible later isotopic analysis could be performed. The characterization team will consider gross results which exceed 20 dpm/100 cm$^2$ for further evaluation (e.g., isotopic analysis) or for remedial action. Isotopic analysis of swipes having measurable removable contamination from these locations will be requested when uncertainty exists about the isotopes expected in the area, or when experience shows that unusual isotopic mixtures might be expected.

Procedure

1. Complete all direct monitoring and dry-swipe sampling as defined in Y-12 Plant Procedures.
2. Label the back of a swipe consisting of absorbent material with the location of the contaminated area using nonwater-soluble ink.
3. Scrub[2] 100 cm$^2$ of the contaminated area, using moderate pressure, by applying three strokes forward and backward in one direction and then three

[1]The existence of contamination on outside exposed surfaces is considered to be evidence that washing (by rain) has not occurred.

[2]Use a Palmyra fiber scrub brush, Consolidated Stores Catalog no. 08-020-0560.

strokes forward and backward in a direction at right angles to the first.

4. Discard contaminated brushes which cannot be cleaned as contaminated waste.

5. Obtain a swipe sample as specified in Y-12 Plant Procedures.

6. Store the swipe in an appropriately labeled paper or glassine envelope.

### 4.8 Shonka Study

Shonka Research Associates (SRA) under Small Business Innovative Research (SBIR) funding from the Nuclear Regulatory Commission (NRC) developed a new and unique floor monitor which was field-tested as part of the Y-12 Site Characterization Project. The field test involved surveys of designated areas within the Y-12 Controlled Area. The surveys were performed with staff from the Oak Ridge Institute for Science and Education (ORISE) under the direction of the characterization team. As well as providing an operations assessment of the floor monitor, the field test provided an opportunity for work performed by the RADCON survey team to be evaluated with regard to detail and accuracy. Two locations, previously characterized by the RADCON survey team, were chosen for the field test.

The Y-12 garage (a vehicle service building) parking area was chosen as the first field test location (Area-1). During the previous Y-12 survey of this area, numerous spots exceeding the RADCON Manual Table 2.2 limits were detected. Utilizing this area ensured the presence of radiological contamination for the field test. This area was also chosen because the previous characterization involved a 100% survey of all paved surfaces, thus

providing a known sample. In addition to providing an operational assessment of the floor monitor, the field test provided the opportunity for an independent check of the work performed by the RADCON survey team. Excellent agreement was found between the two methods of surveying in this limited study.

A second field test location (Area-2) was chosen to assess the Outdoor Paved Surfaces Characterization Plan. Area-2 consisted of paved surfaces surrounding the Y-12 Maintenance Shop. This area was monitored by the RADCON survey team per the characterization plan. The characterization plan describes a partial survey focusing primarily on those paved areas considered to have the greatest probability of radiological contamination. Areas considered to have a low probability for radiological contamination required only a spot-check if no contamination was found in the higher probability areas. The 100% survey to be performed by SRA would provide a standard by which to appraise the characterization plan logic. However, SRA did not complete a full survey of Area-2 due to minor instrumentation problems. Thus, an appraisal of the characterization plan logic based on SRA data was not possible.

The SRA floor monitor consists of a computer-controlled, position-sensitive proportional counter (PSPC) which records the count rate from every 25 square centimeters of surface area (DE95). The detector is 137 cm long with a 132 cm long by 13 cm wide aluminized mylar window. The detector is instrumented with preamplifier modules which amplify the electronic signal from each end of the anode wire. Position information is obtained by using the inherent resistance of the anode wire as a voltage divider, with the pulse height from each end used to calculate the position. For a given event, the difference between the

pulse heights from each end of the PSPC divided by the sum of the pulse heights is the relative position. The sum of the two pulse heights is the energy of the event, which is the information obtained from traditional, nonposition-sensitive proportional counters. The detector and its associated electronics are capable of position resolutions of better than 0.1% of the effective length (which is a small fraction of a centimeter). Normally, the output from the detector is summed into 5-centimeter lengths across the detector, referred to as bins. As the detector is rolled across the ground, position information is used to establish the count and time for each 5-cm bin in 5-cm increments; i.e., distance traversed. Thus, raw count rate is established for each 25-$cm^2$ area of ground surface (roughly the field view of an industry standard pancake GM detector held 1/2 inch from a surface). Data is logged into an electronic binary file, along with information to correct for dead time. Counts are summed into square areas 10 cm on a side. This provides contamination per 100 $cm^2$, as is commonly specified in regulatory requirements.

An on-board data management system provides a method of maintaining multiple surveys and includes a high performance numeric computation and visualization package. The surveys may be stored on magnetic media or output to paper.

# CHAPTER 5

# SURVEY PLAN FOR BUILDINGS

## 5.1 Radiological Characterization of Y-12 Buildings

This plan describes the methodology for determining the extent of radiological contamination inside buildings within the Y-12 Plant Controlled Areas. The plan provided guidance in (1) establishing the sequence in which surveys were to be conducted, (2) choosing appropriate survey techniques, and (3) establishing a coordinate system to locate surveyed areas precisely. The study was designed to determine whether (and, if so, the degree to which) buildings within Y-12 exceeded surface contamination and posting limits of 10CFR835, as reflected in the DOE RADCON Manual Table 2.2.

## 5.2 Survey Locations and Sequence

A radiological characterization is required for all buildings within the Y-12 Plant. Some buildings, however, are excluded from this characterization plan because they are outside the administrative control of Y-12. Other buildings, which have the greatest potential for contamination, are already under fulltime Y-12 radiological control and need not be included in the plan. The building characterization plan thus applies to structures that are not generally used for radiological work and do not pose nearly as great a threat as those buildings under fulltime radiological control.

Extensive use has been made of records from a subcontracted ORNL survey of five

years ago which encompassed 126 of the 600 Y-12 structures. The ORNL surveys found that 74 buildings had some contaminated surfaces while 52 buildings were determined to be clean. This information was used to separate buildings subject to this plan into three categories:

1. Buildings which were previously characterized by ORNL, and radiological contamination equal to or greater than Table 2.2 limits was detected.
2. Buildings that were not characterized by ORNL.
3. Buildings which were previously characterized by ORNL, and radiological contamination equal to or greater than Table 2.2 limits was not detected.

Surveys conducted by the RADCON survey team began with Category 1 buildings, which will be completed prior to starting Category 2 and then Category 3.

Characterization activities will focus primarily on those areas which are considered to have the greatest probability of radiological contamination. The Building History Review Checklist (see Figure 5.1) will be used to identify these areas. The following items are potential survey points and should be considered during the characterization of each area:

- floors
- lower walls;
- stationary equipment;
- door knobs;
- door kickplates;
- drains;
- vents; and
- floor material interfaces.

**BUILDING HISTORY REVIEW CHECKLIST**

Building:________________ Building Manager:____________

Form Originator:______________ RADCON Supervisor:__________

| Checklist Item | Yes | No | NN* |
|---|---|---|---|
| Has this building ever been associated with radioactive material processing, handling, storage and/or transportation? | | ** | |
| Radiological survey reports reviewed? | | | |
| Radioactive material acquisition, transfer, and disposal records reviewed? | | | |
| Incident/occurrence reports reviewed? | | | |
| Operational procedures reviewed? | | | |
| Building manager interview performed? | | | |
| RADCON Field Operations Representative interview performed? | | | |
| Facility drawings reviewed? | | | |
| Process information reviewed? | | | |

* Deemed to be Not Necessary.

** If no is checked, the remainder of this checklist may be left blank.

REQUIRED INFORMATION:

1. List specific radionuclides that can be associated with this building.
2. What chemical/physical forms and quantities of radionuclides can be associated with this building?
3. Identify methods and locations of processing, storage, transportation, and disposal of radioactive materials.
4. Have there been incidents such as spills or fires that may have resulted in the release/spread of radioactive contamination throughout this building?
5. List areas and equipment that are potentially contaminated and the possible extent of contamination.

Form Originator's Signature:____________________ Date:________

Peer Reviewer's Signature:____________________ Date:________

Figure 5.1. Building history review checklist.

Areas which are considered to have a low probability for radiological contamination will be spot-checked if no contamination is found in the higher-probability areas. Larger areas may be subdivided into 10' × 10' grids for ease of recording the survey results. Figure 5.2 outlines the primary steps involved in the performance of building characterizations.

### 5.3 Building History Investigation

A building history investigation will be conducted as part of the characterization for each building included in this study. The purpose of the investigation is to provide a radiological history of each building. Particular attention should be given to all factors that could assist in identifying areas of potential radiological concern. The needed information includes:

- specific radionuclides used and locations;
- methods and locations of processing, storage, transportation, and disposal of radioactive materials;
- chemical and physical forms and quantities of radionuclides used;
- areas and equipment that are potentially contaminated and the possible extent of contamination; and
- incidents such as spills and fires, that could have resulted in the release and/or spread of radioactive material (GA93).

The Building History Review Checklist (Figure 5.1) was developed to aid in this process. One checklist will be completed for each building characterized during this study.

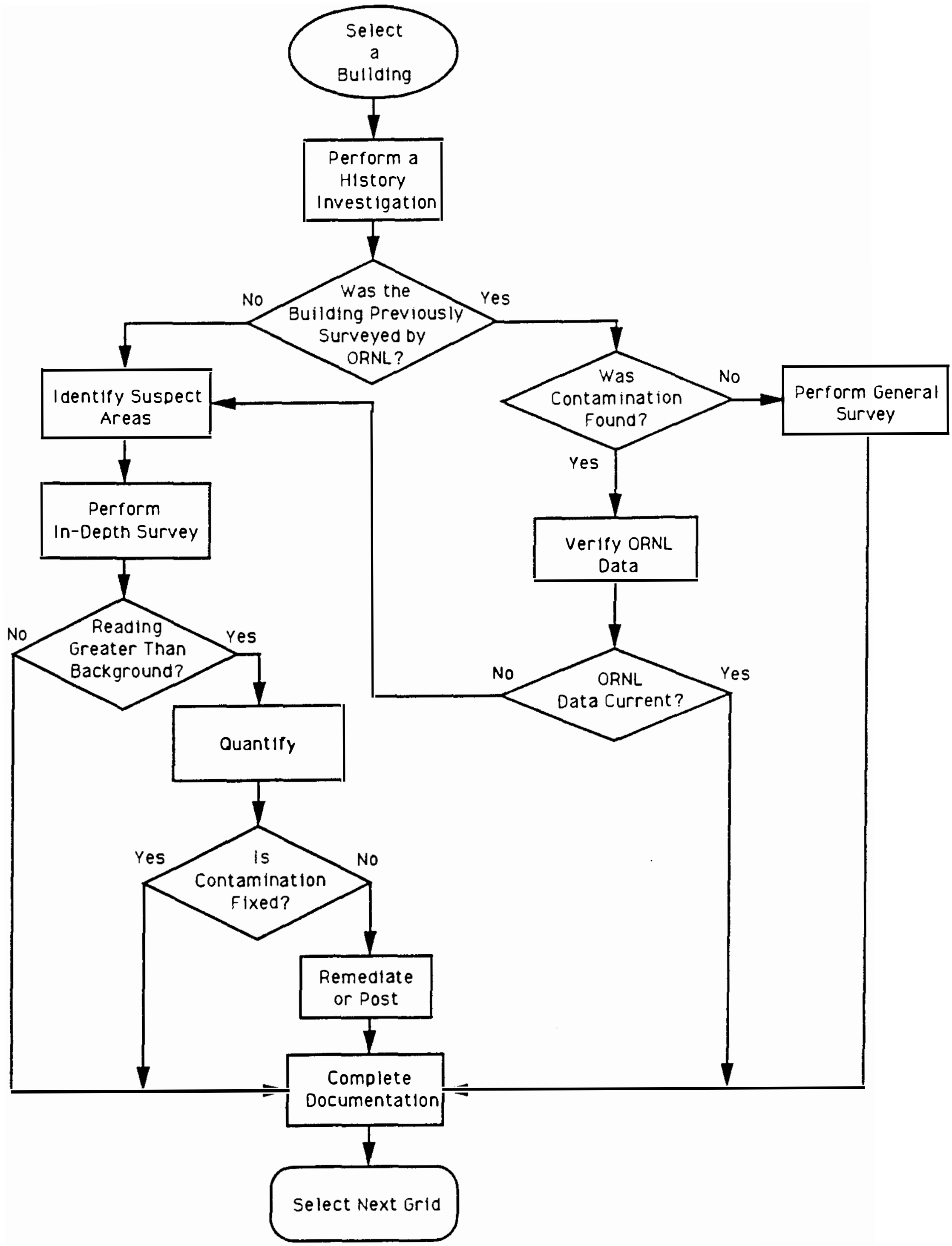


Figure 5.2. Flowchart for characterization of buildings.

## 5.4 Survey Methods and Instrumentation

### 5.4.1 Instrumentation

Instruments used in the survey will include floor monitors, with wide-area ionization (gas-flow proportional counter) detectors for identifying areas of contamination above background ("elevated activity"), hand-held survey instruments calibrated for quantitative determination of surface alpha (scintillation detector) and beta-gamma (GM tube) activity, and μR meters for determining external penetrating dose rates. The latter is a tissue-equivalent rate instrument that reads in μrem per unit time, i.e., dose equivalent per unit time. As for the surveys of paved surfaces (Section 4.3.1), each floor monitor will be configured in one of two ways:

1. to respond to alpha particles alone or
2. to respond primarily to beta particles and photons.

Radioactivity on swipes will be analyzed with a 2π proportional counter for gross alpha and beta-gamma quantification and an alpha-particle spectrometer for isotope analysis.

### 5.4.2 Survey Techniques

The area of survey will consist of all buildings within the Y-12 Controlled Area that are managed by the Y-12 Plant and that do not have direct support by a RADCON Field Operations Office.

Surfaces will be surveyed first by using floor monitors, where feasible, set for optimal response to: (1) alpha radiation and (2) beta-gamma radiation. Earphones will be used in high noise areas, in conjunction with visual observation of the meter readout, for improved discrimination of contamination levels elevated above background. Floor monitors will be

moved at a linear velocity not exceeding approximately one detector-width per second in performing alpha-contamination surveys, and not exceeding approximately two detector-widths per second for beta-gamma surveys.

Hand-held survey instruments calibrated for quantitative determination of alpha and beta-gamma contamination levels will be used to characterize representative areas not accessible to the floor monitor, and areas of elevated radioactivity identified by the floor monitors. Surveys will be conducted in accordance with specifications set forth in Y-12 Plant Procedures. Wide-area contamination (contamination distributed in an area exceeding 100 $cm^2$) may be averaged as specified in Section 4.6 when maximum total (fixed + removable) contamination levels are between 1 and 3 times the RADCON Manual Table 2.2 limits. Survey results will be recorded using a standard Y-12 radiological survey data sheet (Form HPAM-5, Revised (9-29-95), "Radiological Control Organization Monitoring and Survey Results," see Figure 2.2). The location (see Section 4.4, Mapping Requirements) of each surveyed area will be noted on the data sheet in the column labeled "Description."

Hand-held survey instruments will also be used to monitor irregular surfaces not suited to the use of floor monitors, as well as areas such as floor edges, lower walls, stationary equipment, door knobs, door kickplates, drains, vents, and depressions where contamination might concentrate or accumulate. Dose-rate measurements will be made 30 cm from surfaces having beta-gamma levels which exceeded 75,000 dpm/100 $cm^2$.

Swipe samples will be taken in accordance with specifications set forth in Y-12 Plant Procedures, at each location of elevated radioactivity confirmed by hand-held survey instruments. Swipes will be screened for radioactivity using the hand-held survey instruments,

and will then be stored in glassine or paper envelopes. Each swipe will be marked with the location (see Section 5.5, Mapping Requirements) at which the swipe was taken. Swipes will be analyzed for gross alpha and beta-gamma contamination using a $2\pi$ proportional counter, and then retained until the completion of the characterization study so that possible later isotopic analysis can be performed if needed. Isotopic analysis will be requested of swipes from locations having measurable removable contamination exceeding 20 dpm/100 $cm^2$ when uncertainty exists about the isotopes expected in the area, or when experience shows that unusual isotopic mixtures might be expected.

Large area swipes will be performed with masslin cloths. All suitable floor surfaces, such as tile, concrete, and wood, will be subjected to large area swipes. Floor surfaces such as carpeted areas do not require large area swipes. Upon completion of a large area swipe, the masslin cloth will be monitored for radioactivity using the hand-held survey instruments. If an evaluation indicates that a swiped area is contaminated, a thorough contamination swipe survey will be performed.

## 5.5 Mapping Requirements

Observations, samples, and measurements will be recorded with information sufficient to plot results on building floor plans when available. Floor plans of buildings to be surveyed will be supplied by the characterization team to the RADCON survey team.

Floor plans of larger areas, such as roofs, machine shops, foundries, process areas, and storage areas, require that a grid system be used to identify regions of recordable activity. An example of a typical indoor grid system is provided in Figure 5.3. In such cases a 10' × 10'

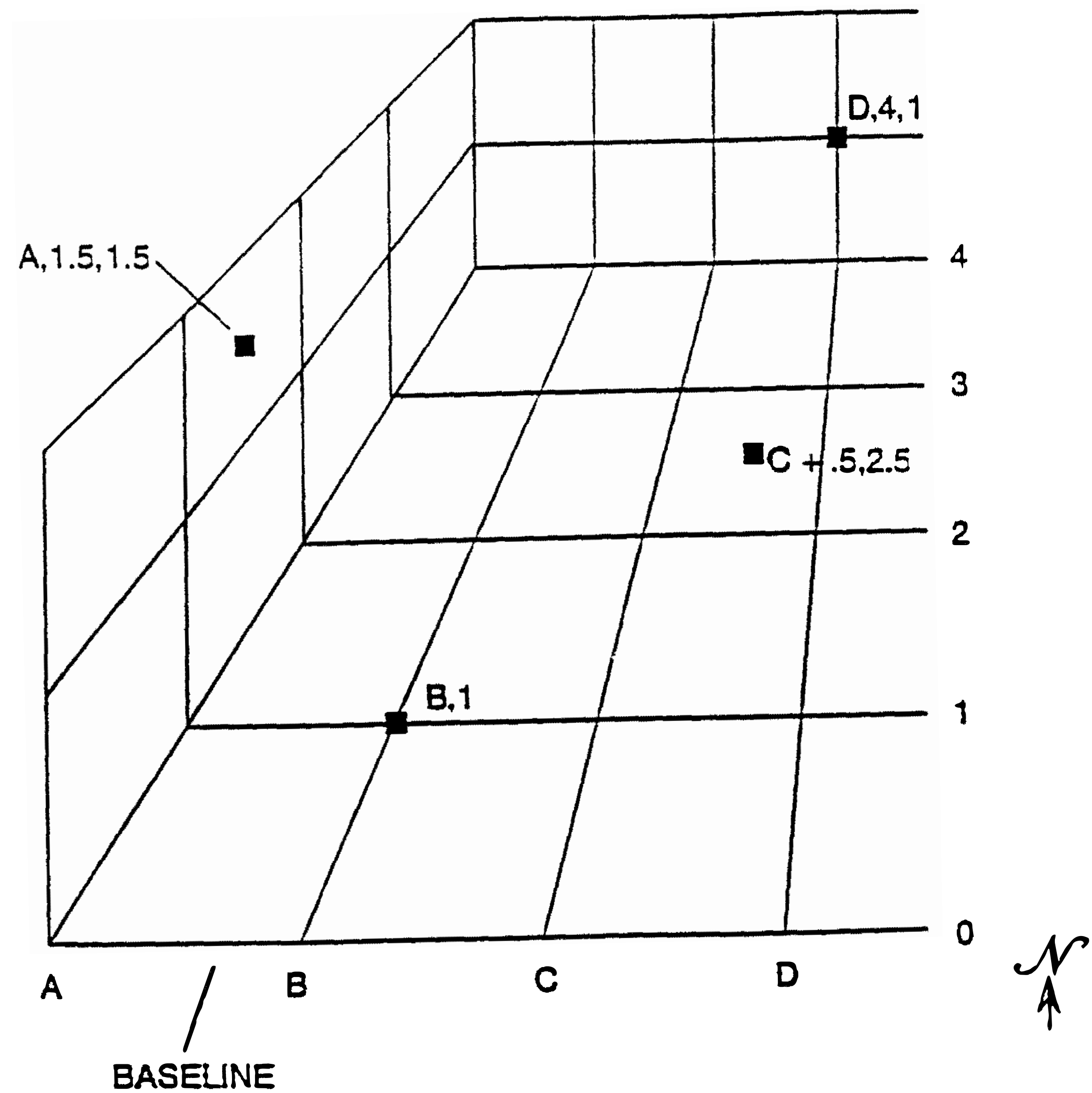


Figure 5.3. Typical indoor grid system (GA93).

grid will be superimposed over building floor plans, with coordinates at grid intersections. A point used to record an observation, sample, or measurement is identified by two coordinates and a reference point. A point which is shown on the map as the intersection of two main walls (the corner of a room, for instance) is required as a reference point. The two coordinates are then reported as the distance in feet north/south and the distance east/west of the reference point. Smaller rooms such as offices, laboratories, and closets, do not require that a grid system be used if surveyed areas can be accurately identified using stationary objects such as doors, windows, vents, and wall corners.

Buildings/areas of buildings in which floor plans are not available will require that hand-drawn floor plans be developed by the RADCON survey team. An example of a typical building room drawing is provided in Figure 5.4. Hand-drawn floor plans will include a grid system when necessitated by the size of the room being surveyed. Hand-drawn floor plans will in all cases be neatly drawn, reference stationary objects, and include room dimensions.

### 5.6 Follow-up Actions

Removable contamination which exceeds the RADCON Manual Table 2.2 limits (see Table A-1), determined either by screening swipes using hand-held instruments, or by analysis of swipes using a $2\pi$ proportional counter, and total (fixed or removable) contamination which results in a dose equivalent rate at 30 cm exceeding 5 mrem/h will be immediately posted by the RADCON survey team and reported to Field Operations Supervision. Copies of data sheets containing survey results, a summary report which includes any unusual findings or circumstances, and the locations of areas which require posting as specified in the

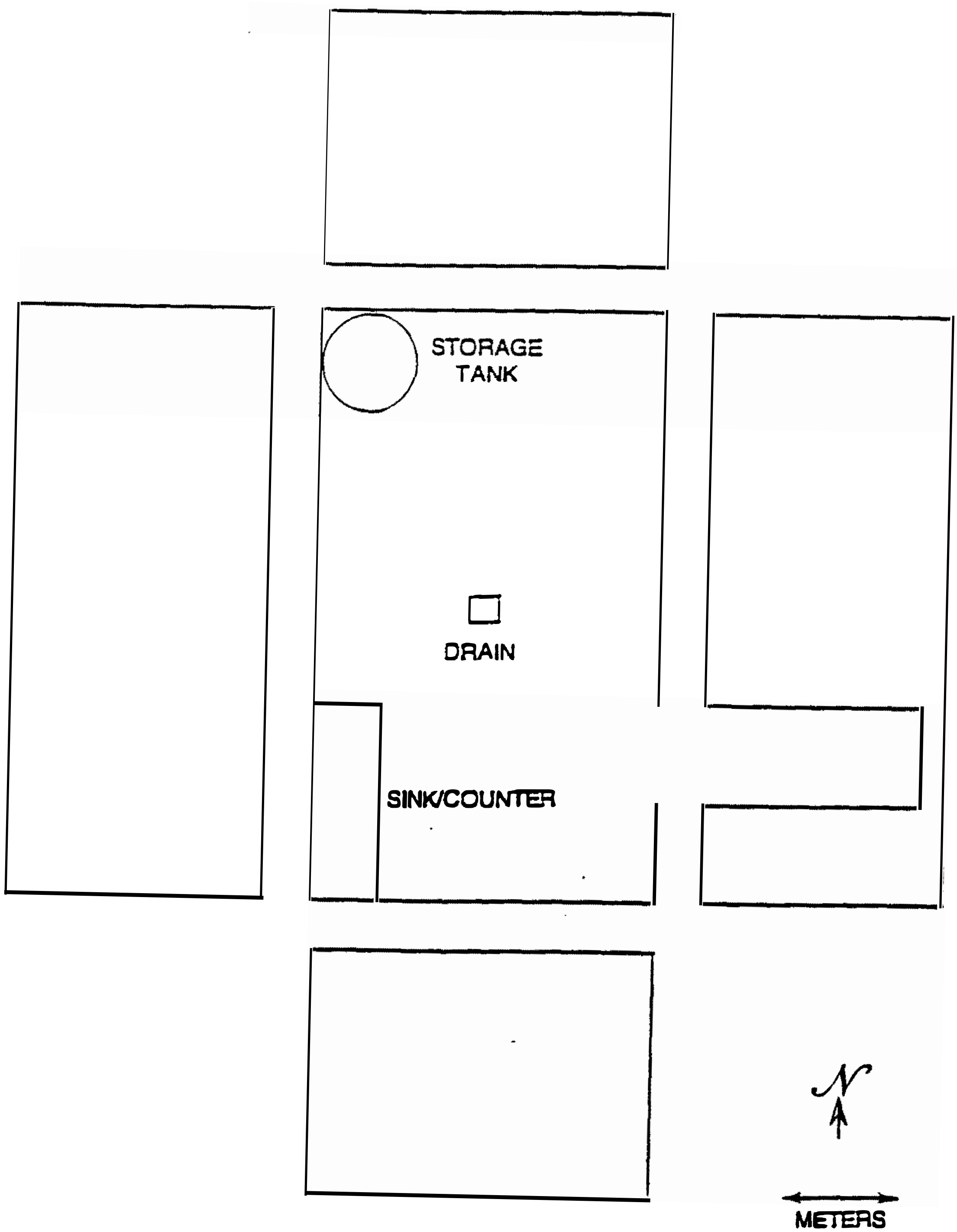


Figure 5.4. Typical room drawing (GA93).

RADCON Manual will be forwarded by the RADCON survey team within a week of the survey to the characterization team. The characterization team will compile and analyze the survey data. Remedial actions which should be considered for areas which cannot be cleared below the RADCON Manual Table 2.2 limits include posting, periodic monitoring of "fixed" contamination exceeding removable contamination limits, application of fixative, and removal/resurfacing.

### 5.7 Required Survey Activities

1. Perform building history investigation using the Building History Review Checklist (see Figure 5.1).
2. Determine if the building has been previously characterized by ORNL (1992-1993 survey).
    a. If building was not characterized by ORNL, perform characterization per the steps specified in Section 5.7.1, Buildings That Have Not Been Previously Characterized
    b. If building was characterized by ORNL, determine if ORNL data indicate radiological contamination levels equal to or greater than RADCON Manual Table 2.2 limits.
        1. If ORNL data do not indicate radiological contamination levels equal to or greater than RADCON Manual Table 2.2 limits, perform characterization per the steps specified in Section 5.7.2, Characterization of Buildings ORNL Surveys Show To Be Clean.

2. If ORNL data indicate radiological contamination levels equal to or greater than RADCON Manual 2.2, determine, using building history investigation, if building has been decontaminated.

   a. If building has not been decontaminated, perform characterization per the steps specified in Section 5.7.3, Characterization of Buildings ORNL Surveys Show To Be Contaminated That Have Not Been Decontaminated.

   b. If building has been decontaminated, perform characterization per the steps specified in Section 5.7.4, Characterization of Buildings ORNL Surveys Show To Be Contaminated But Have Since Been Decontaminated.

5.7.1 Buildings That Have Not Been Previously Characterized

1. Review building history investigation.
2. Identify areas with the greatest potential for radiological contamination (suspect areas) using information provided from the building history investigation.
3. Perform a complete survey in all suspect areas.
4. Perform a complete survey of building access points (entrances) and docks.
5. Perform partial survey of halls by making 1-2 passes down each hall using floor monitors and masslins.
6. Perform partial survey of rooms focusing on potential survey points listed in Section 5.2, Survey Locations and Sequence, and spot check other areas.

7. Perform further surveys, as deemed necessary by the RCT, to ensure building has been accurately characterized.

NOTE: If contamination equal to or greater than Radcon Manual Table 2.2 limits is detected, a complete survey of the room/area is required.

5.7.2 Characterization of Buildings That ORNL Surveys Show To Be Clean

1. Review building history investigation.
2. Compare ORNL survey data to other information acquired from the building history investigation.
3. Perform a complete survey of areas with the greatest potential for radiological contamination, such as suspect areas. (Circumstances such as conflicts existing between ORNL data and other building history information or incidents involving spills/releases of radioactive material since the ORNL survey may indicate suspect areas.)
4. Perform survey of building access points (entrances) and docks.
5. Perform further surveys, as deemed necessary by the RCT, to ensure building has been accurately characterized.

NOTE: If ORNL data are found to be no longer current, then the building shall be characterized per Section 5.7.1, Buildings That Have Not Been Previously Characterized.

5.7.3 Characterization of Buildings ORNL Surveys Show To Be Contaminated That Have Not Been Decontaminated

1. Review building history investigation.
2. Compare ORNL survey data to other information acquired from the building

history investigation.

3. Perform a complete survey of areas with the greatest potential for radiological contamination, such as suspect areas. (Circumstances such as conflicts existing between ORNL data and other building history information or incidents involving spills/releases of radioactive material since the ORNL survey may indicate suspect areas.)

4. Perform survey of all access areas (entrances) and docks.

5. Perform surveys, as deemed necessary by the RCT, to verify ORNL data.

   - An adequate number of ORNL data points shall be verified.
   - An adequate number of locations throughout the building shall be verified.

6. Perform further surveys, as deemed necessary by the RCT, to ensure building has been accurately characterized.

NOTE: If ORNL data are found to be no longer current, then the building shall be characterized per Section 5.7.1, Buildings That Have Not Been Previously Characterized.

5.7.4 Characterization of Buildings ORNL Surveys Show To Be Contaminated But Have Since Been Decontaminated

1. Review building history investigation.

2. Ensure documentation regarding decontamination activities, if available, is included in building history investigation file.

3. Compare ORNL survey data to other information acquired from the building history investigation.

4. Perform a complete survey of areas with the greatest potential for radiological contamination, such as suspect areas. (Circumstances such as conflicts existing between ORNL data and other building history information or incidents involving spills/releases of radioactive material since the ORNL survey may indicate suspect areas.)

5. Perform survey of all locations in which ORNL data shows contamination levels equal to or greater than the RADCON Manual Table 2.2 limits.

6. Compare current survey data with ORNL survey data and determine if results are consistent with building history investigation.

NOTE: If results are not consistent with building history investigation, a complete building survey as described in Section 5.7.1, Buildings That Have Not Been Previously Characterized, is required.

7. Perform survey of building access points (entrances) and docks.

8. Perform further surveys, as deemed necessary by the RCT, to ensure building has been accurately characterized.

NOTE: If radiological contamination is detected, in areas not documented in ORNL survey data, equal to or greater than the RADCON Table 2.2 limits, a complete building survey as described in Section 5.7.1, Buildings That Have Not Been Previously Characterized, is required.

# CHAPTER 6

# SURVEY RESULTS AND ASSESSMENT OF PLAN

At the time of this writing, the Y-12 Site characterization is ongoing. A large portion of the project has been completed, but there is still more to do. Although the posting requirements of 10CFR835 will be met, further surveys and a more complete characterization of the Y-12 Controlled Area will continue into 1996.

Survey results thus far confirm that there is much legacy contamination present on both outdoor paved surfaces and building interior/exterior surfaces. The majority of radiological contamination detected has been depleted uranium. Virtually all areas identified as being contaminated are expected to meet the Fixed Contamination Area criteria. Anticipated posting options have been developed. Figure 6.1 is an example of a posting sign for a Fixed Contamination Area. Figure 6.2 is an example of a posting sign for a Contamination Area. The signs are yellow with magenta lettering and symbols.

This chapter summarizes the Y-12 Site Characterization survey results obtained thus far, and presents the apparent posting options available to meet 10CFR835 on January 1, 1996. A quantitative assessment of the effectiveness and adequacy of the survey plan for paved surfaces is also given.

## 6.1 Outdoor Paved-Surface Surveys

Surveys of outdoor paved surfaces within the PPA and LA have been completed.

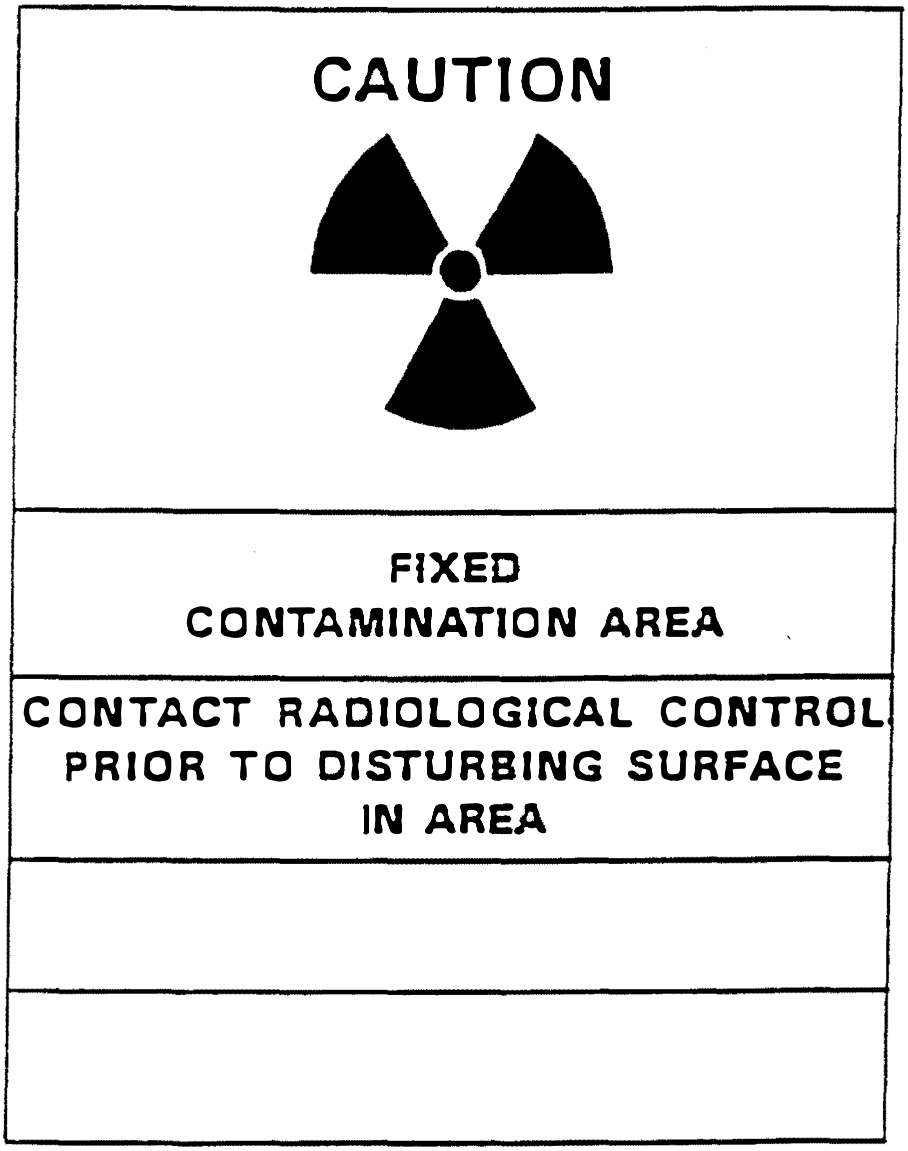


Figure 6.1. Example of a posting sign for a Fixed Contamination Area.

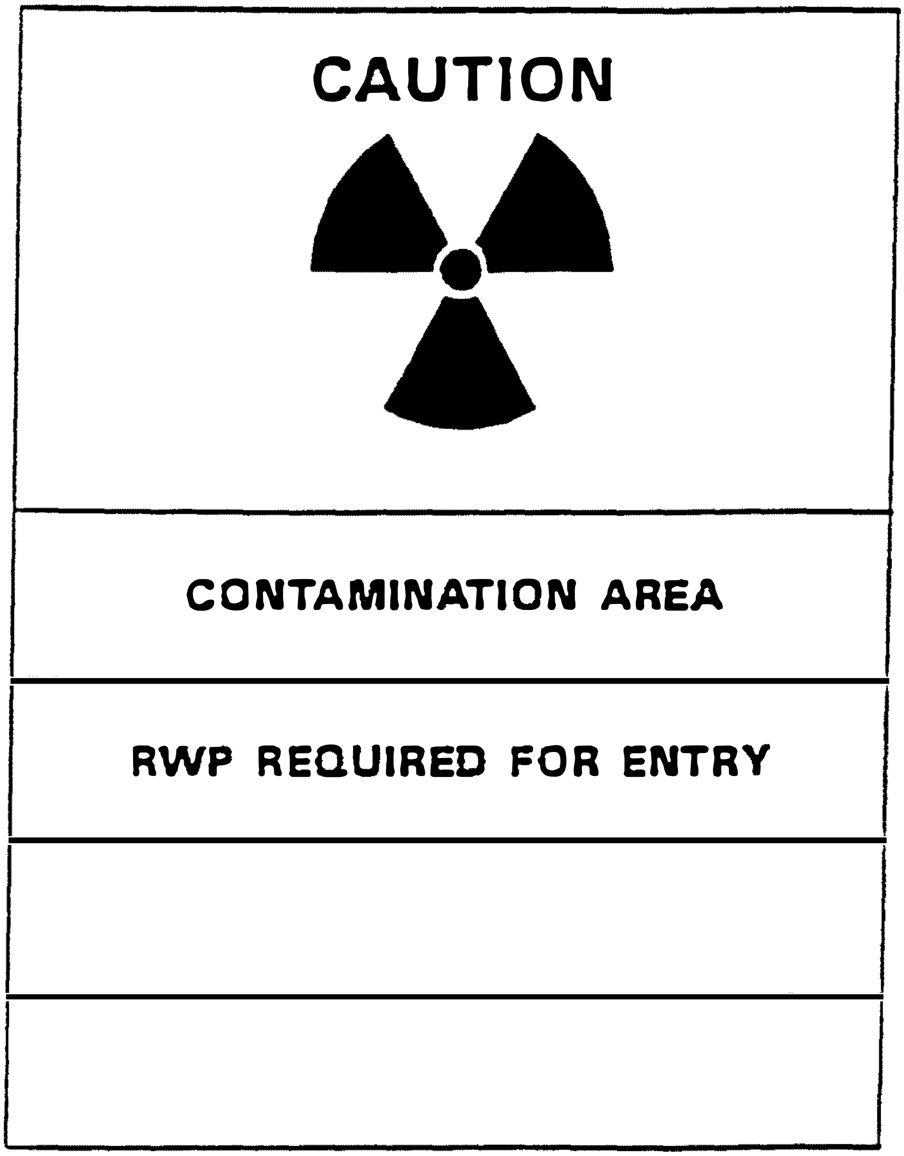


Figure 6.2. Example of a posting sign for a Contamination Area.

Approximately 7% of the outdoor paved surface surveys within the EA are complete. A total of 273 locations have been identified as candidates for Fixed Contamination Area postings based on direct readings and swipes. Four locations have been posted as Contamination Areas.

The mean contamination levels, for those locations exceeding the RADCON Manual Table 2.2 limits, were 52,500 dpm/100 $cm^2$ beta-gamma and 22,000 dpm/100 $cm^2$ alpha. The maximum contamination levels detected were 1,500,000 dpm/100 $cm^2$ beta-gamma and 60,000 dpm/100 $cm^2$ alpha. The major contaminant on paved surfaces was depleted uranium, which accounted for more than 99% of the contaminated areas identified.

As indicated by the pilot study, radiological contamination was detected primarily on old pavement. The contamination was usually concentrated in holes and cracks. However, a surprising number of contaminated spots were discovered in open areas. Several of these open-area spots were located in the parking areas surrounding Building 9712, which serves as the Y-12 Plant garage. In past years, many contaminated vehicles have been parked or stored for long periods of time in the areas surrounding this building. It is likely that these vehicles are the means by which contamination was transferred to this particular area. Contaminated spots in other open areas of the Plant are not as easily explained.

Surveys of outdoor paved surfaces within the EA are expected to be completed by December 31, 1995.

### 6.2 Building Surveys

To date, 43 buildings have been partially characterized. Characterization work associated with these buildings has been carried out simultaneously with the development of

the building characterization plan. Much of the information provided in the building plan has resulted from these preliminary building survey experiences. For instance, many areas found by ORNL to have contamination exceeding the RADCON Manual Tabie 2.2 limits have since been decontaminated. Documentation to this effect is not readily available to the RADCON survey team. This, among other things, impressed upon the characterization team the need for a building history investigation. With the completed characterization plan, partially characterized buildings will now be completed.

Each of the partially characterized buildings was chosen because ORNL survey data indicated that radiological contamination exceeding the RADCON Manual Table 2.2 limits was present. Characterization efforts thus far have consisted of surveys to verify the ORNL data. Of the buildings partially characterized, 22 appear to have been decontaminated or partially decontaminated. Confirmation of this cleanup is pending the completion of building history investigations. Currently no building history investigations have been performed.

The mean contamination levels, for those locations exceeding the RADCON Manual Table 2.2 limits, is currently 58,600 dpm/100 $cm^2$ beta-gamma and 19,300 dpm/100 $cm^2$ alpha. The maximum contamination levels detected thus far are 1,500,000 dpm/100 $cm^2$ beta-gamma and 32,000 dpm/100 $cm^2$ alpha. The major contaminant in buildings so far has been depleted uranium, which accounted for 100% of the contaminated spots identified.

### 6.3 Assessment of Survey Plan for the Paved Surfaces

As described in Chapter 2, 100% of the paved surfaces of the garage area was surveyed early in the project, both to gain experience, and to provide a known baseline for

critical evaluation of the paved-surfaces plan itself. This paved area of 5.3 acres is located at the east end of the Plant (see Plate 1.1 In Pocket). Obtaining data sufficient for meeting the posting requirements of 10CFR835 was the primary underlying objective of the survey plan. How well the plan achieved this objective for paved surfaces is discussed next. In addition, it is important to assess how well the survey plan enabled the survey team to locate the actual contamination present on the site. Realizing as much savings as feasible in personnel time required for carrying out the surveys is also an important consideration.

As noted in the survey plan, paved surfaces were divided into 30' x 30' grids. At least 10% of the area in each and every grid was surveyed. At a minimum, each grid was traversed twice by a floor monitor, thus covering one-tenth of its area. Surveys focused primarily on those grids which were considered to have the greatest potential for contamination. Such suspect grids were ones associated with docks, vehicle parking, ventilation orifices, eddy points, and those having other characteristics described in Section 4.2. All suspect areas within a suspect grid were surveyed completely (100% coverage). Generally this resulted in a 100% survey of the suspect grid. If there was contamination in a suspect area, then the probability of finding it was considered to be unity.

Nearby grids which were not suspect, but were adjacent to suspect grids, were extensively surveyed. The actual extent of surveying was determined by the survey team members. Estimates from the team members indicated overall that a contaminated spot in a nearby grid would be found about three out of four times. All other grids, which were designated as remote, comprised the remainder of the entire area. None of these were adjacent to a contaminated suspect grid. According to the plan as described above, a

minimum of one-tenth of the area of each remote grid was surveyed. Therefore, if a remote grid had a contaminated spot, the probability of finding it was, conservatively, 0.10. Generally, contamination of any remote grid would be found with at least this probability.

Figure 6.3 shows the detailed results for the location of contaminated areas found by the complete survey of the garage area. A total of 257 grids, 30 ft x 30 ft, were laid out to cover the entire surface. The total area surveyed was thus 257 x 900 = $2.31 \times 10^5$ $ft^2$. The suspect grids are identified in the figure by a shaded area. It is seen that most, but not all, suspect grids were found to have contamination. In all cases except one, only fixed contamination was found on the garage site. The area in which removable contamination was found was immediately posted as a Contamination Area. The vehicle parking area between Buildings 9219 and 9712, which the plan designated as a suspect location, was found to have contaminated spots, as did areas immediately adjacent to the buildings.The grid (E240, N180) contains a facility used for washing vehicles. A filling station, no longer in use, is located in the lower left of the figure, in grid (W180, S450). Both of these grids contain suspect areas which would be surveyed 100% in the site characterization plan.

Nine of the nearby grids were found to have contamination. As can be inferred from the figure, a number of the nearby grids were found to be clean by the complete survey. Seven remote grids were found to be contaminated, principally in localized regions. Five of these had single spots, one had two spots, and the remaining remote grid had four spots.

To test the overall adequacy of the site characterization plan for paved surfaces, one can apply it directly to the garage area and compare the results with the known situation. The resulting data are summarized in Table 6.1. As described earlier in this section, if a grid

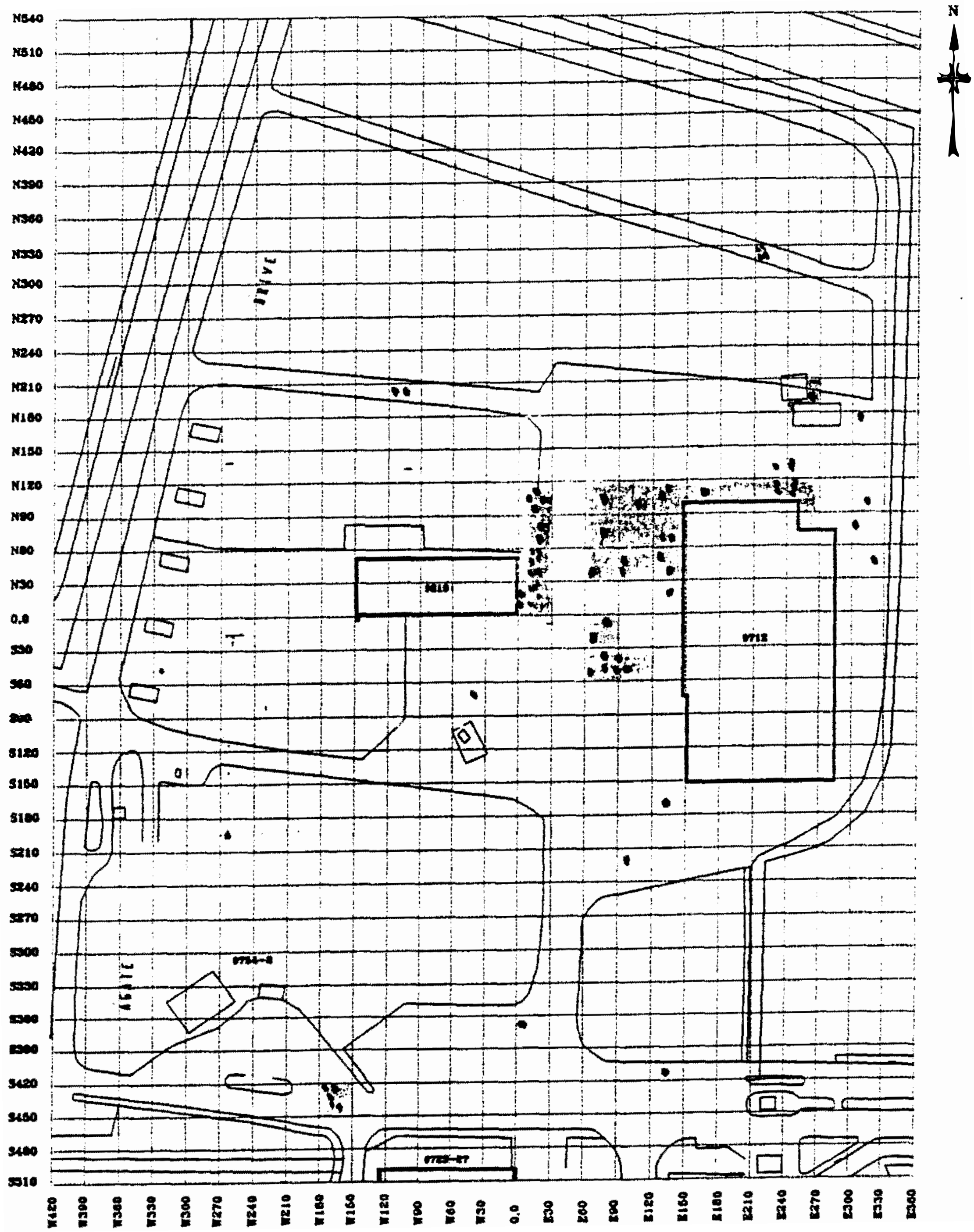


Figure 6.3. Locations of contaminated areas at the garage area.

**Table 6.1. Comparison of Findings - 100% Survey Versus Survey Plan**

| Types of Grids | Total Number of Grids Surveyed | Number of Contaminated Grids Identified from Total Survey | Probability | Expected Number of Grids Identified Using Survey Plan |
|---|---|---|---|---|
| Suspects | 20 | 18 | 1.0 | 18 |
| Nearbys | 40 | 9 | 0.75 | 6.8 |
| Remotes | 197 | 7 | | 1.1 |
| 1 spot | | 5 | 0.10 | 0.5 |
| 2 spots | | 1 | 0.20 | 0.2 |
| 4 spots | | 1 | 0.40 | 0.4 |
| Total | 257 | 34 | | 25.9 |

designated as suspect does have contamination, one would expect always to find it, since the entire area of such a grid is generally surveyed. The 18 contaminated suspect grids identified from the survey would have been found also by using the characterization plan. By the surveyors' estimate, if there is contamination in a nearby grid, the probability of finding it by using the plan is about 75%. As Table 6.1 indicates, the number of contaminated nearby grids expected to be found by using the plan is 6.8 out of the total of nine present.

The expected number of remote grids found by using the plan, among the five having single hot spots and 10% of their area surveyed, is 0.5. With two and four spots in the other two grids, the probabilities of finding the contamination are assumed to be 0.20 and 0.40, respectively; thus, the expected number of contaminated remote grids as found by the survey plan is 1.1 out of the seven present.

Overall, if the site characterization plan alone had been used on the garage area, about 26 of the total of 34 contaminated grids could be expected to be found. The sampling used for the remote grids might well have picked up one or more of the seven contaminated ones

in the garage area. For the Y-12 Site overall, a number of remote grids with contamination have turned up in the large number of such grids surveyed. Many of these are candidates for future remediation.

An estimate can also be made for the fraction of the total garage paved area actually surveyed by the plan. There was a total of 20 suspect grids. These would generally be completely surveyed, their total area being 20 x 900 = 18,000 $ft^2$. The nearby grids, 40 in number, would undergo a 75% survey, amounting to 40 x 900 x 0.75 = 27,000 $ft^2$. The amount of area surveyed in the remaining 197 remote grids would be 197 x 900 x 0.10 = 17,730 $ft^2$. From the total garage paved area of $2.31 \times 10^5$ $ft^2$, the plan would thus actually survey an area of 62,730 $ft^2$, or about 27%. The plan is judged successful in providing a reasonable assessment of the actual contamination picture, as summarized in Table 6.1, with the actual surveying of about one-fourth of the surface area. There appears to be a reasonable balance between the amount of hard data obtained and the expenditure of manpower. Based on this test case, four times the amount of effort called for in the survey plan would be needed to obtain the data in the third column of the table in place of the last column.

As the basis for posting, the plan is deemed to be very good. If the garage area were an isolated site faced with a posting decision, then the data in the last column of Table 6.1 would suggest that the entire site be posted as one with fixed contamination on paved surfaces. Alternatively, it might be desirable to post the perimeter around the individual contamination areas rather than the entire complex. However, before this could be justified, one would have to carry out additional sampling of the nearby and, especially, the remote grids. As the remote contamination spots were found, they could either be posted as such or

remediated.

### 6.4 Model Analysis of Survey Plan for Remote Grids

In this section, a statistical analysis is made to evaluate the effectiveness of the survey protocol in assessing the extent of contamination in the large number of remote grids that cover the paved surfaces. As stated in Section 6.3, one would expect to find 100% of all suspect grids that have radiological contamination. Contaminated spots located within nearby grids would be discovered with about a 75% success rate. Contaminated remote grids, having generally only 10% of their surface surveyed, are the most likely of these three categories to escape contamination detection. For this reason, a statistical analysis of remote-grid survey plans was carried out in an idealized model to assess the significance of the results found. To perform this analysis, data from the garage area 100% survey were used as a guide.

There are $N_0 = 197$ remote grids among the total of 257 grids in the garage area. The fraction of the grids that are remote thus is 0.77. Of the $N_0 = 197$ remote grids, $N_C = 7$ were contaminated. Therefore, the probability that a given remote grid in the garage area is contaminated is $p = N_C/N_0 = 0.0355$. The remaining paved surfaces throughout the plant encompass roughly 160 acres, or 7,740 total grids. Assuming the same proportion of remote grids as in the garage area implies that there are about 6,000 remote grids in the total paved areas of the Plant.

The following model is considered for analysis. The site consists of a set of remote grids, any number of which might be contaminated. A "trial" consists of surveying a given remote grid for contamination. If contamination is found, the result of the trial is called a

"success." The following numbers are assigned:

- There are $N_0 = 6{,}000$ remote grids, each measuring 30' × 30'.
- A contaminated remote grid contains exactly one contaminated point.
- Probability of success (contamination found) is $p = 0.036$ for all grids.
- Sample size = $N = 600$ grids, or 10% of $N_0$.
- The N grids are surveyed 100%.

Given the model, one can perform an in-depth evaluation, considering questions such as the following:

1. What is the probability that no contaminated grids would be identified?
2. What is the average number of contaminated grids one would expect to find?
3. What is the minimum number of contaminated grids one would expect to find with a given degree of confidence?

The probability of finding a given number of contaminated grids in this model will follow the binomial distribution. This distribution results from a Bernoulli process, which is characterized by four conditions. Related to the sampling procedure with the model, these are:

1. The sample consists of N trials (i.e., N grids are sampled, each potentially contaminated).
2. Each trial has a binary outcome: success or failure (contaminated or not contaminated).
3. The probability of success (finding contamination) is the same from trial to trial.

4. The trials are independent (the result of a given trial is independent of the others).

The number of successes k from N trials is a discrete random variable, which obeys the binomial distribution. Since the probability of success is defined as p = 0.036, the probability of failure is q = 1-p = 0.964. The probability distribution for the number k of successes, P(k), from N trials is given by the binomial distribution,

$$P(k) = \frac{N!}{(N-k)!k!} p^{k} q^{N-k} \quad . \tag{6.1}$$

For the model, the mean number of contaminated grids is $\mu$ = pN = 0.036 (600) = 21.6, and the standard deviation is $\sigma = (Npq)^{1/2} = 4.56$. It is important for the survey to determine the reliability for finding at least a certain number of contaminated grids. The distribution (6.1) can be used to perform this computation. However, the individual factors in (6.1) become unwieldy. Fortunately, the binomial distribution is approximated extremely well by the Poisson distribution when $p \ll 1$ and $N \gg 1$, as is the case in this model. The Poisson distribution for exactly k successes when the mean number is $\mu$ is:

$$P_k = \frac{\mu^k e^{-\mu}}{k!} \quad . \tag{6.2}$$

(With parameter $\mu$ = 21.6, for example, the Poisson standard deviation is $\sqrt{\mu} = 4.65$, compared with the binomial 4.56.) Furthermore, with a mean value of about 20 or more, both the binomial and Poisson distributions are approximated well by a normal distribution for a continuous variable x. One can write

$$f(x) = \frac{1}{\sqrt{2\pi}\ \sigma}\ e^{-\frac{(x-\mu)^2}{2\sigma^2}} \ , \tag{6.3}$$

where the mean $\mu$ and standard deviation $\sigma$ are independent parameters. This distribution can be transformed into the universal standard normal distribution, having zero mean and unit standard deviation.

Tabulated areas between boundaries under the standard normal distribution provide the needed information to answer the questions posed above. For example, the probability of finding a number of contaminated grids less than 1.645 standard deviations below the mean is the one-tail area 0.0500. In this model, $1.645\sigma = 1.645 \times 4.56 = 7.50$; and so $\mu - 1.645\sigma = 21.6 - 7.5 = 14.1$. Thus, the model survey is expected to find at least 14 contaminated remote grids with 95% confidence. Table 6.2 shows results for other levels of confidence, truncated to next lower integer, I, for the number of contaminated remote grids. In the extreme, one would expect to find at least five contaminated grids with the survey plan with 99.98% probability. The probability that one would randomly select 600 grids and find none to be contaminated is, from Eq. (6.1),

$$\begin{aligned} P(0) &= \frac{600!}{600!0!}\ (0.036)^0\ (0.964)^{600} \\ &= 2.79 \times 10^{-10} \ . \end{aligned} \tag{6.4}$$

For comparison, the approximate Poisson result, (6.2), is $P(0) = e^{-21.6} = 4.16 \times 10^{-10}$.

**Table 6.2. Results for Contaminated Remote Grids**

| One-tail area | $k_\alpha$ | $k_\alpha\sigma$ | $\mu$-$k_\alpha\sigma$ | Integral number, I | Probability of finding at least I contaminated grids |
|---|---|---|---|---|---|
| 0.100 | 1.282 | 5.85 | 15.8 | 15 | 90% |
| 0.050 | 1.645 | 7.50 | 14.1 | 14 | 95% |
| 0.025 | 1.960 | 8.94 | 12.7 | 12 | 97.5% |
| 0.010 | 2.326 | 10.6 | 11.0 | 11 | 99% |
| 0.005 | 2.576 | 11.7 | 9.90 | 9 | 99.5% |
| 0.0002 | 3.500 | 16.0 | 5.60 | 5 | 99.98% |

Using a different sampling protocol, one might consider surveying 10% of all 6,000 remote grids (as was done for the actual site characterization). For this situation the probability of success (finding contamination in a given grid) is $p^* = 0.10p = 0.0036$, and the probability of failure is $q^* = 1 - p^* = 0.9964$. A given grid might thus show no contamination because it either has none or else its contaminated spot is not in the 10% of its area surveyed. The sample size is now $N^* = 6{,}000$. The probability distribution is given by Eq. (6.1) with p and q replaced, respectively, by $p^*$ and $q^*$. The expected value of the number of contaminated remote grids found is

$$\mu^* = p^* N^* = 21.6 \quad , \qquad (6.5)$$

the same as $\mu$ in the previous protocol. This equality is to be expected, since the total area surveyed by both protocols is the same (100% of 600 grids and 10% of 6,000 grids). The

standard deviation for the second protocol is slightly larger: $\sigma^* = (N^*p^*q^*)^{1/2} = 4.64$, as compared with 4.56 before. The ratio is $\sigma^*/\sigma = (q^*/q)^{1/2}$. In the Poisson approximation the standard deviations would be the same, since $\mu^* = \mu$.

Based on the experience with the garage area and the analysis of this model, the 10% sampling for the remote grids in the actual survey plan appears reasonable. Taking a much smaller sample would be unacceptable. For example, if 100% of only 60 grids were surveyed, then like Eq. (6.4), the probability of finding none contaminated would be

$$\mathcal{P}(0) = (0.964)^{60} = 0.111 \quad . \tag{6.6}$$

(With $\mu = 2.16$, the Poisson approximation gives $e^{-2.16} = 0.115$). There would thus be more than a 12% chance that the existence of any contaminated remote grids would be missed.

In another version of the model, one can specify that there are (unknown to the surveyors) exactly C contaminated remote grids from among the total of $N_0$. The probability of success can then change with each trial, depending on the results of the previous trials. This circumstance violates conditions 3 and 4, given before Eq. (6.1), for a Bernoulli process. If the survey of Y-12 is regarded as an experiment, repeated over and over by different survey teams, with C out of $N_0$ grids contaminated, then the number of successes (contaminated grids discovered) would follow a hypergeometric distribution. The number of ways that exactly k contaminated grids can be selected from among the C available is:

$$h(k;\, N_0,\, N,\, C) = \frac{\binom{C}{k}\binom{N_0-C}{N-k}}{\binom{N_0}{N}} \quad . \tag{6.7}$$

The numerator represents the total number of favorable samples among the total number of samples, given by the denominator, all samples being taken without regard to order. For large $N_0$, as in the present model, the change in the success probability from trial to trial is small. Therefore, the binomial and hypergeometric distributions are practically the same.

If this scenario was reversed, that is, if the same team surveyed many different Y-12 Sites, and each site had remote grids with a probability of being contaminated $p = 0.036$, then the number of successes would again follow the binomial distribution.

### 6.5 Present Status

The Y-12 Site Characterization Project has thus far been a success. Characterization plans for both outdoor paved surfaces and buildings have been developed and implemented. At this writing, more than half of the surveys of outdoor paved surfaces have been carried out, and the rest are nearing completion. Building characterizations are underway, and many will be completed by the year's end. It will not be feasible to perform extensive surveys of the unpaved surfaces within the Controlled Area by year's end. However, since many of these regions are wooded, inaccessible, and virtually never occupied by personnel, they are considered to be a lower priority than the paved surfaces and buildings. Some preliminary measurements have been initiated.

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# APPENDICES

# APPENDIX A

## REGULATORY REQUIREMENTS APPLICABLE TO THE Y-12 SITE CHARACTERIZATION PROJECT

Radiological control activities at DOE facilities are conducted in accordance with provisions of the following two regulatory documents entitled:

- *Code of Federal Regulations*, Title 10, Part 835, "Occupational Radiation Protection" (10CFR835) (OC93); and
- "U.S. Department of Energy Radiological Control Manual," DOE/EH-0256T (RADCON Manual) (RA94).

Although requirement units within 10CFR835 and the RADCON Manual are similar, and in many cases identical, the two documents are separate and have different purposes. Radiological work at DOE facilities must be conducted in compliance with the requirements of 10CFR835. Failure to comply may result in civil and/or criminal penalties. The RADCON Manual is a technical standard which provides a detailed outline for the implementation of a quality radiological control program.

The RADCON Manual states in Article 551.1 that radiological monitoring of radiation exposure levels, contamination and airborne radioactivity shall be conducted to characterize workplace conditions, to verify the effectiveness of physical design features and engineering and administrative controls, and to identify areas requiring posting. This requirement unit provides the basis for the Y-12 Site Characterization Project.

The remaining pages of this appendix provide a detailed list of 10CFR835 and RADCON Manual requirement units directly applicable to the Y-12 Site Characterization Project.

## 2.1 Requirements of 10 CFR 835

10 CFR 835.401 addresses general requirements. 10 CFR 835.401(a) states that monitoring of individuals and areas shall be performed to:

1. Demonstrate compliance with the regulations in this part.
2. Document radiological conditions in the workplace.
3. Detect changes in radiological conditions.
4. Detect the gradual buildup of radioactive material in the workplace.
5. Verify the effectiveness of engineering and process controls in containing radioactive material and reducing radiation exposure.

10 CFR 835.401(b) specifies that area monitoring in the workplace shall be routinely performed, as necessary, to identify and control potential sources of personnel exposure to radiation and/or radioactive material.

10 CFR 835.404(b) addresses radioactive contamination control and monitoring in the workplace. It requires that appropriate controls shall be maintained and verified which prevent the inadvertent transfer of removable contamination to locations outside of radiological areas under normal operating conditions. 10 CFR 835.404(c) states that any area in which contamination levels exceed the values specified in Appendix D of this part shall be:

1. Posted in accordance with 835.603.

2. Controlled in a manner commensurate with the physical and chemical characteristics of the contaminant, the radionuclides present, and the fixed and removable contamination levels.

However, special criteria are specified for areas having fixed contamination.

10 CFR 835.404(d) states that areas with fixed contamination exceeding the total radioactivity values specified in Appendix D of this part may be located outside of radiological areas, provided the following criteria are met:

1. Removable contamination levels are below the levels specified in Appendix D of this part.
2. Unrestricted access to the area is not likely to cause any individual to receive a total effective dose equivalent in excess of 0.1 rem (0.001 sievert) in a year.
3. The area is routinely monitored.
4. The area is clearly marked to alert personnel of the contaminated status.
5. Appropriate administrative procedures are established and exercised to maintain control of these areas.
6. Dose rates do not exceed levels which would require posting in accordance with 10 CFR 835.603.

10 CFR 835.404(e) states that entry control pursuant to 10 CFR 835.501 and posting pursuant to 10 CFR 835.603 are not required for areas with fixed contamination meeting the conditions of 10 CFR 835.404(d).

10 CFR 835.501 applies to personnel entry control in radiological areas. 10 CFR 835.501(a) requires personnel entry control to be maintained for each radiological area. 10

CFR 835.501(b) states the degree of control shall be commensurate with existing and potential radiological hazards within the area. 10 CFR 835.501(c) specifies that one or more of the following methods shall be used to ensure control:

1. Signs and barricades.
2. Control devices on entrances.
3. Conspicuous visual and/or audible alarm.
4. Locked entrance ways.
5. Administrative controls.

10 CFR 835.601 addresses posting and labeling. 10 CFR 835.601(e) states that the posting requirements in this section may be modified to reflect the special considerations of DOE activities conducted at private residences. Such modifications shall provide the same level of protection to individuals as the existing provisions in this section.

10 CFR 835.603 deals with posting of radiological areas. It states that each access point to a radiological area (as defined in 835.2) shall be posted with conspicuous signs bearing the wording provided in this section.

10 CFR 835.603(a) Radiation Area. The words "Caution, Radiation Area" shall be posted at any area accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent to excess of 0.005 rem (0.05 millisievert) in 1 hour at 30 centimeters from the source or from any surface that the radiation penetrates.

10 CFR 835.603(b) High Radiation Area. The words "Danger, High Radiation Area" shall be posted at any area accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent to excess of 0.1 rem (0.001 sievert) in 1 hour

at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

10 CFR 835.603(c) Very High Radiation Area. The words "Grave Danger, Very High Radiation Area" shall be posted at any area accessible to individuals in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads (5 gray) in one hour at 1 meter from the radiation source or from any surface that the radiation penetrates.

10 CFR 835.603(d) Airborne Radioactivity Area. The words "Caution, Airborne Radioactivity Area" shall be posted for any occupied area in which airborne radioactivity levels exceed, or are likely to exceed, 10 percent of the derived air concentration (DAC) value listed in Appendix A or Appendix C of this part.

10 CFR 835.603(e) Contamination Area. The words "Caution, Contamination Area" shall be posted where contamination levels exceed values listed in Appendix D of this part, but are less than or equal to 100 times those values.

10 CFR 835.603(f) High Contamination Area. The words "Danger, High Contamination Area" shall be posted where contamination levels are greater than 100 times the values listed in Appendix D of this part.

10 CFR 835.703 addresses monitoring and workplace records. The following information shall be documented and maintained:

(a) Results of surveys for radiation and radioactive material in the workplace as required by 835.401, 835.403 and 835.404.

Appendix D is identical to Table 2-2 of the RADCON Manual (see Table A-1).

**Table A-1. RADCON Manual Table 2-2, Summary of Contamination Values**

| NUCLIDE (See Note 1) | REMOVABLE (dpm/100 $cm^2$) (See Note 2) | TOTAL (FIXED + REMOVABLE) (dpm/100 $cm^2$) (See Note 3) |
|---|---|---|
| U-natural, U-235, U-238 and associated decay products | 1,000 alpha | 5,000 alpha |
| Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-129 | 20 | 500 |
| Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-125, I-126, I-131, I-133 | 200 | 1,000 |
| Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above. Includes mixed fission products containing Sr-90 | 1,000 beta-gamma | 5,000 beta-gamma |
| Tritium organic compounds, surfaces contaminated by HT, HTO and metal tritide aerosols | 10,000 | 10,000 |

*Notes*:

1. The values in this Table apply to radioactive contamination deposited on, but not incorporated into the interior of the contaminated item. Where contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for the alpha- and beta-gamma-emitting nuclides apply independently.

2. The amount of removable radioactive material per 100 $cm^2$ of surface area should be determined by swiping the area with dry filter or soft absorbent paper while applying moderate pressure, and then assessing the amount of radioactive material on the swipe with an appropriate instrument of known efficiency. For objects with a surface area less than 100 $cm^2$, the entire surface should be swiped, and the activity per unit area should be based on the actual surface area. Except for transuranics, Ra-228, Ac-227, Th-228, Th-230, Pa-231 and alpha emitters, it is not necessary to use swiping techniques to measure removable contamination levels if direct scan surveys indicate that the total residual contamination levels are below the values for removable contamination.

3. The levels may be averaged over 1 square meter provided the maximum activity in any area of 100 $cm^2$ is less than three times the values in Table 2-2.

*Source:* "U.S. Department of Energy Radiological Control Manual," DOE/EH-0256T.

## 2.2 RADCON Manual Requirements

Article 551 of the RADCON Manual specifies radiological monitoring and survey requirements for the workplace. These are as follows:

1. Radiological monitoring of radiation exposure levels, contamination and airborne radioactivity shall be conducted to characterize workplace conditions, to verify the effectiveness of physical design features and engineering and administrative controls, and to identify areas requiring postings.
2. Monitoring shall be performed only by trained and qualified personnel using instruments that are properly calibrated and routinely tested for operability.
3. Surveys for radiation, contamination and airborne radioactive materials shall be performed as specified in Technical Work Documents and Radiological Work Permits.
4. The Radiological Control Organization shall perform and document a review of the adequacy of sampling and monitoring systems as part of any facility or operational changes affecting radiological control. In the absence of such changes, a review should be conducted annually.
5. Instruments used to perform radiation surveys shall be readily available and response-checked daily or prior to operation. When response checks are not within ±20 percent of the expected value, the instrument should be taken out of service. When response checks are not feasible, such as with instruments used to measure neutrons or tritium, compensatory actions should be

established to ensure proper instrument performance.

6. Assessment of radiological conditions should include a sufficient number of survey points to characterize the radiation present and to verify boundaries.

7. Surveys should be performed before, during and at the completion of work that has the potential for causing changes in levels of radiation and radioactivity.

8. Survey frequencies should be established based on potential radiological conditions, probability of change in conditions and area occupancy factors.

9. Monitoring results should be reviewed by the cognizant radiological supervisor. The review should ensure that all required surveys have been performed and that the documentation is accurate and complete.

10. Results of current surveys or survey maps should be conspicuously posted to inform personnel of the radiological conditions.

11. Monitoring results should be made available to line management, and used in support of pre- and post-job evaluations, As Low As Reasonably Achievable (ALARA) preplanning, contamination control and management of radiological control operations.

12. Monitoring data in each building or area should be compiled and reviewed at least quarterly. Changes or trends should be noted and corrective actions assigned.

Article 554 of the RADCON Manual addresses Contamination Surveys. It sets forth the following provisions:

1. In addition to the requirements of Article 551, routine contamination surveys should be conducted in Radiological Buffer Areas established for the control of contamination and other areas with the potential for spread of contamination as follows:

   a. Prior to transfer of equipment and material from one Radiological Buffer Area to another;

   b. Prior to transfer of equipment and material from highly contaminated areas within Radiological Buffer Areas unless precautions such as bagging or wrapping are taken prior to transfer;

   c. Daily, at contamination area control points, change areas, or step-off pads when in use, or per shift in high use situations;

   d. Daily, in office space located in Radiological Buffer Areas;

   e. Daily, in lunch rooms or eating areas near Radiological Buffer Areas;

   f. Weekly, in routinely occupied Radiological Buffer Areas;

   g. Weekly, or upon entry if entries are less frequent, in areas where radioactive materials are handled or stored;

   h. Weekly, or upon entry if entries are less frequent, where contamination boundaries or postings are located;

   i. During initial entry into a known or suspected contamination area, periodically during work, at completion of job, or as specified in a Radiological Work Permit;

   j. After a leak or spill of radioactive materials.

2. Surveys for the release of materials shall be conducted in accordance with Articles 421 and 422.

3. Contamination surveys should incorporate techniques to detect both removable and fixed contamination.

4. Items with inaccessible surfaces which were located in known or suspected contamination areas and had the potential to become contaminated at levels likely to exceed Table 2-2 values shall be treated as potentially contaminated and subject to administrative controls unless the items are dismantled and monitored or special survey techniques are used to survey all surfaces.

5. The requirements for assessing representative samples of bulk material, such as sand, sweeping compounds or plate steel, which are not suitable for normal loose and fixed contamination-level assessment techniques, are specified in DOE 5400.5.

6. Swipe surveys for removable contamination shall be reported in units of disintegrations per minute per 100 $cm^2$ (dpm/100 $cm^2$). For swipe surveys of small items covering less than 100 $cm^2$, the results shall be reported in units of dpm per area swiped.

7. Large area wipes are encouraged and should be used to supplement standard swipe techniques in areas generally assumed not to be contaminated, such as entrances to Radiological Buffer Areas. If an evaluation indicates that an area wiped is contaminated, a thorough contamination swipe survey should be performed.

8. Areas identified as either contaminated with, or having the potential for being contaminated with, highly radioactive particles ("hot particles") should be surveyed weekly. These areas should be surveyed at least daily during periods of work that may result in the generation of hot particles. Special swipe techniques to collect hot particles, such as tape and large area wipes, should be used.

RADCON Manual Article 222-1 states that a surface shall be considered contaminated if either the removable or total radioactivity is detected above the levels in Table 2-2 of that document (see Table A-1). If an area cannot be decontaminated promptly, then it shall be posted as specified in Article 235 "Posting Contamination, High Contamination and Airborne Radioactivity Areas." However, special criteria are specified for areas having fixed contamination.

Article 221-2 states that surfaces exceeding the values of RADCON Table 2-2 (see Table A-1) for total contamination may be covered with a fixative coating to prevent the spread of contamination. However, reasonable efforts should be made to decontaminate an area before a coating is applied. A fixative coating shall not be applied without the approval of the Radiological Control Manager.

Article 221-3 states that, in addition to the posting criteria in Article 235, the conditions for establishing and maintaining Fixed Contamination Areas include all of the following:

a. Radiological surveys shall be performed to detect contamination that may become removable over time;

b. A formal inventory shall be maintained of Fixed Contamination Areas;

c. Markings shall be kept legible;

d. Removable contamination shall not exceed RADCON Manual Table 2-2 values, and should be reduced as far below Table 2-2 as is reasonably achievable before a fixative coating is applied;

e. Fixed contamination should be covered with two layers of fixative coatings having different colors;

f. Markings should include the standard radiation symbol, be clearly visible from all directions and contrast with the colors of the surface coatings;

g. Additional coating should be applied when the bottom color appears;

h. A plan for identifying and adding to the inventory of existing areas of fixed contamination not included in the initial inventory should be developed.

Article 221-4 states that a Fixed Contamination Area may be located outside Controlled Areas unless unrestricted access is likely to result in a dose equivalent to any person greater than 100 mrem in a year.

Article 221-5 states that A Fixed Contamination Area is exempt from the general posting requirements of Article 231, and entry and exit requirements of Chapter 3. Article 221-6 states that, for contaminated soil that is not releasable in accordance with DOE 5400.5, a Soil Contamination Area shall be established that:

a. Is posted as specific in Article 235. Posting should include instruction or special warning to the worker, such as "Consult With Radiological Control Organization Before Digging" or "Subsurface Contamination Exists;"

b. Meets the requirements of Article 231.1 through 231.8.

Article 221-7 states that Soil Contamination Areas may be located outside a Radiological Buffer Area.

Article 235 addresses posting of Contamination, High Contamination and Airborne Radioactivity Areas. Article 235, Item 1 states that areas shall be posted to alert personnel to contamination in accordance with Table 2-4 of the RADCON Manual (see Table A-2) and Article 231.

Article 235, Item 4 states that areas meeting the criteria for Fixed Contamination Areas specified in RADCON Table 2-4 (see Table A-2) and Article 222.3 do not have to be posted as Contamination or High Contamination Areas.

Article 231 addresses posting requirements. It states that:

1. Radiological posting shall be used to alert personnel to the presence of radiation and radioactive materials and to aid them in minimizing exposures and preventing the spread of contamination.
2. Signs shall contain the standard radiation symbol colored magenta or black on a yellow background. Lettering shall be either magenta or black. Magenta is the preferred color over black. Standard signs, as described in the standardized core training, shall be used where practicable.
3. Signs shall be conspicuously posted, clearly worded, and, where appropriate, may include radiological control instructions. Radiological postings should be displayed only to signify actual or potential radiological conditions. Signs used for training should be clearly marked, such as "For Training Purposes Only."

4. Posted areas should be as small as practicable for efficiency.

5. Postings should be maintained in a legible condition and updated based upon the results of the most recent surveys.

6. If more than one radiological condition (such as contamination and high radiation) exists in the same area, each condition should be identified.

7. In areas of ongoing work activities, the dose rate and contamination level or range of each should be included on or in conjunction with each posting as applicable.

8. Entrance points to areas of ongoing work activities controlled for radiological purposes should state basic entry requirements, such as dosimetry, Radiological Work Permit (RWP) and respirator required.

9. Rope, tape, chain and similar barriers used to designate the boundaries of posted areas should be yellow and magenta in color.

10. Physical barriers should be placed so that they are clearly visible from all directions and at various elevations. They should not be easily walked over or under, except at identified access points. These barriers shall be set up such that they do not impede the intended use of emergency exits or evacuation routes.

11. Posting of doors should be such that the postings remain visible when doors are open or closed.

12. A radiological posting that signifies the presence of an intermittent radiological condition should include a statement specifying when the

**Table A-2. RADCON Manual Table 2-4, Criteria for Posting Contamination, High Contamination and Airborne Radioactivity Areas**

| AREA | CRITERIA | POSTING |
|---|---|---|
| Contamination | Contamination levels (dpm/100 $cm^2$) > 1 time but ≤ 100 times Table 2-2 values | "CAUTION, CONTAMINATION AREA" |
| High Contamination | Contamination levels (dpm/100 $cm^2$) > 100 times Table 2-2 values | "DANGER, HIGH CONTAMINATION AREA"<br>"RWP Required for Entry" |
| Fixed Contamination | Removable contamination levels < Table 2-2 removable values and total contamination levels > Table 2-2 total values | "CAUTION, FIXED CONTAMINATION" |
| Soil Contamination | Contaminated soil not releasable in accordance with DOE 5400.5 | "CAUTION, SOIL CONTAMINATION AREA" |
| Airborne Radioactivity | Concentrations ($\mu$Ci/cc) > 10% of any DAC value | "CAUTION, AIRBORNE RADIOACTIVITY AREA"<br>"RWP Required for Entry" |

*Source:* "U.S. Department of Energy Radiological Control Manual," DOE/EH-0256T.

radiation is present, such as "CAUTION: RADIATION AREA WHEN RED LIGHT IS ON."

# APPENDIX B

## LUDLUM MODEL 239-1F FLOOR MONITOR

The Ludlum Model 239-1F Floor Monitor utilizes the Ludlum Model 43-37 gas-flow proportional detector instrumented by a Model 2221 portable scaler ratemeter. The detector dimensions are 18.250 inches in length, 6.250 inches in width and 0.75 inches in depth. The active area of the detector is 425 $cm^2$. There are five wires, stretching across the length of the detector, electrically connected in parallel as a single anode. The instrument operates within the proportional region with the potential difference ranging from 1100-1300 volts for alpha detection and 1650-1750 volts for beta/gamma detection. Thus, the instrument can be calibrated to respond to alpha particles alone or to respond primarily to beta particles and photons. The instrument response is checked using National Institute of Standards and Technology (NIST) traceable sources. The readout, in counts per minute, is acquired from a digital ratemeter.

The digital ratemeter is based on the analog equivalent of a counting ratemeter. In the analog counting ratemeter each logic pulse deposits a small fixed charge on the storage capacitor. This capacitor is also discharged continuously by a current flowing through a resistor to ground. If the rate of pulses is constant, then eventually an equilibrium will be reached where the rate of charge deposition is equal to the rate of discharge through the resistor. Equilibrium will be reached after several values of the time constant of the circuit (KN89). The digital version used in the Ludlum Model 2221 consists of a register in which

logic pulses are counted for some fixed period of time. At the end of this time, a fixed fraction of the register content is subtracted from the accumulated content. This cycle of accumulation and fixed fraction subtraction is repeated continuously. An equilibrium is exponentially approached in which the rate at which pulses arrive is equal to the rate at which they are subtracted.

Use of this instrument in the Y-12 Site Characterization Project involves a walkover of potentially contaminated surfaces at a forward velocity of 1 or 2 detector widths per second, depending on the intended use of the instrument (alpha detection or beta/gamma detection). Prior to its use the instrument is placed over an area, known to be free of radiological contamination, and a background reading is obtained. As the instrument is rolled across a contaminated surface, one would expect to observe an increase in the count rate. The effective use of the instrument requires some training and familiarity on the part of the user. The user must maintain the instrument's forward velocity at or below the rates specified above and possess the ability to recognize increases in the count rate. The most useful application of this instrument is to detect radiological contamination which exceeds background. When such contamination is observed, the user quantifies the levels using hand-held survey instruments. The instrument has been found to be completely satisfactory for finding radiological contamination at levels near or exceeding the DOE release limits.

# VITA

Charles Anthony England was born in Middlesborough, Kentucky on January 29, 1965. He attended elementary schools in Brownsburg, Indiana, and graduated from Campbellsville High School, located in Campbellsville, Kentucky, in May of 1983. The following September he moved to Jefferson City, Tennessee, where he entered Carson Newman College, and in May, 1988 he received the degree of Bachelor of Arts in Physics. After graduating, he married and entered the work force. In January of 1990 he entered the University of Tennessee, Knoxville, and in May, 1996 received a Master of Science degree in Nuclear Engineering.

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