Distribution Category:
Remedial Action and
Decommissioning Program
(UC-70A)

DOE/EV-0005/48
ANL-OHS/HP-84-104

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

# FORMERLY UTILIZED MED/AEC SITES REMEDIAL ACTION PROGRAM

# RADIOLOGICAL SURVEY OF THE HARSHAW CHEMICAL COMPANY CLEVELAND, OHIO

Prepared by

| | |
|---|---|
| R. A. Wynveen | Associate Division Director, OHS |
| W. H. Smith | Senior Health Physicist |
| C. M. Sholeen | Health Physicist |
| A. L. Justus | Health Physicist |
| K. F. Flynn | Health Physicist |

Radiological Survey Group
Health Physics Section
Occupational Health and Safety Division

April 1984

Work Performed under

Budget Activity DOE KN-03-60-40
and ANL 73706

## PREFACE AND EXECUTIVE SUMMARY

This is one in a series of reports resulting from a program initiated in 1974 by the Atomic Energy Commission (AEC) to determine the condition of sites formerly utilized by the Manhattan Engineer District (MED) and the AEC for work involving the handling of radioactive materials. Since the early 1940s, the control of over 100 sites that were no longer required for nuclear programs has been returned to private industry or the public for unrestricted use. A search of MED and AEC records indicated that for some of these sites, documentation was insufficient to determine whether the decontamination work done at the time nuclear activities ceased is adequate by current guidelines. The Harshaw Chemical Company in Cleveland, Ohio, is one such site. The results of surveys initiated in 1976 and continued intermittently through 1979 to determine the radiological condition of this site are presented in this report.

During the MED/AEC era, the Harshaw Chemical Company processed large quantities of normal uranium to produce both oxide and fluoride compounds. This work was done under contract to MED and its successor, AEC. Records indicated that at the time the AEC contract was terminated, the facility was decontaminated by Harshaw and released from AEC control in 1960. However, a search of AEC records indicated that documentation was insufficient to determine whether the decontamination work was adequate by current guidelines. Hence, a radiological assessment of the site was initiated in 1976. The entire grounds and all buildings were surveyed using surface survey instruments to detect surface contamination and radiation detectors to determine general radiation levels.

Extensive surface contamination was found throughout the site. While the major contamination was found in "Plant C," significant levels of contamination also were found in 16 other buildings and at 32 exterior locations. The contaminating material seemed to be normal uranium exclusively.

Air samples were taken at numerous indoor locations throughout the site, but no elevated levels of radon were detected. This was as expected since normal uranium has been separated from radium and hence radon levels are very low.

Several soil samples were taken from around the site. Analyses of these samples indicated extensive soil contamination, as well as suspected contamination of the river bed in the vicinity of the plant outfall. Scheduled subsurface investigation of the site, as well as of the river bed and sewer system, have not been conducted.

Levels of contamination at this site are significantly above guidelines for release of the site for unrestricted use.

This survey was performed under the auspices of the Health Physics Section of the Occupational Health and Safety Division of Argonne National Laboratory, Argonne, Illinois. The following personnel participated: R. A. Wynveen, W. H. Smith, C. B. Mayes,*, J. D. Thereon, D. W. Reilly, A. E. Lissy and P. C. Gray.**

*Now at Exxon Nuclear Idaho, Inc.
**Retired

TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

# RADIOLOGICAL SURVEY OF THE HARSHAW CHEMICAL COMPANY
# CLEVELAND, OHIO

## INTRODUCTION

During the Manhattan Engineer District/Atomic Energy Commission (MED/AEC) era, work involving radioactive materials was performed at various sites throughout the continental United States. Among those sites was the Harshaw Chemical Company Complex at 1000 Harvard Avenue, Cleveland, Ohio (see Fig. 1). Large quantities of normal uranium were processed at this site, but only a few of the numerous Harshaw Complex buildings were actually involved with the use of radioactive materials. The principal building involved with the uranium processing activities was the refinery building identified as Plant C. This facility began operations under a contract with the Manhattan Engineer District and continued work under a contract with the Atomic Energy Commission. It was used primarily for the refining of yellowcake into uranium orange oxide, although the plant was capable of reducing orange oxide ($UO_3$) to brown oxide ($UO_2$), fluorination of brown oxide to green salt ($UF_4$), and fluorination of green salt to hexafluoride ($UF_6$). The feed materials for this plant came from uranium mills throughout the United States and Canada.

Plant C is located within a fenced area of approximately 1.6 acres of company-owned land within the Harvard-Denison Plant at 1000 Harvard Avenue, Cleveland, Ohio. This company-owned building was built and added to at various times over the period 1945-1949. It is a brick and steel building, with one, two, and three-story sections, concrete floor, and pre-cast concrete slab roof. The total approximate floor areas are as follows: first floor 45,100 $ft^2$, mezzanine 3,700 $ft^2$, second floor 14,590 $ft^2$, third floor 3,200 $ft^2$. This is divided into 50,240 $ft^2$ of operating area and 16,350 $ft^2$ of standby-plant area.

Small U.S. Government-owned buildings used for security and storage functions also were associated with the uranium processing activities. The company furnished 4,200 $ft^2$ for office use outside the Plant C area. While the buildings and land are company-owned, essentially all the equipment used in the Plant C operations was U.S. Government-owned.

This facility was decontaminated by Harshaw and released from AEC control in 1960. However, a search of AEC records indicated that documentation was insufficient to determine whether the decontamination work was adequate by current guidelines. Hence the U.S. Department of Energy (DOE) decided to conduct a radiological characterization and assessment of the present status of the site as a part of a DOE program intended to ensure that residual radioactive material from past MED/AEC operations does not pose undue present or future radiological hazards. The Radiological Survey Group (RSG) of the Occupational Health and Safety Division (OHS) of Argonne National Laboratory (ANL) was assigned responsibility for conducting the radiological survey of the facility.

The Plant C building, at the time of the radiological characterization and assessment survey, was being used as a storage warehouse for small-scale chemical operations, for equipment storage, and for drying of fluorspar ($CaF_2$). The latter operation creates an almost continuous dust coating on surfaces within the building and the immediate exterior peripheral area. A 60 ft x 200 ft addition to the building was constructed after the termination of the MED/AEC contract work. This addition is used for storage of large quantities of fluorspar imported from Spain and Portugal.

The radiological survey of Plant C was initiated during May 1976. Follow-up soil corings were taken during November 1976. As a result of these initial studies, the radiological assessment was extended to the entire Harshaw Complex during October 1978. Information available from the "Formerly Utilized Sites Remedial Action Program" (FUSRAP) concurred with this decision. (This information is summarized in FUSRAP Report ORO-777.) At that time, a building identified as H-3 underwent a complete radiological survey. Building H-3, located southeast of Plant C and northeast of the Foundry building (see Fig. 2), housed an operational chemical process unit, used for processes involving potassium compounds, such as potassium fluoborate ($KBF_4$) and potassium bifluoride (KFHF). The edifice, reportedly constructed in the middle 1800s, is to be razed and the process operations moved to a new facility north of Building H-1. A new facility will then be constructed on this site. The remaining buildings on the site (see Fig. 2) were surveyed during October through December 1978 and during May 1979.

The results of all these radiological surveys are included and described in this report.

## SURVEY AND ANALYTICAL TECHNIQUES

### General

This radiological survey was initiated in May 1976 and continued intermittently through May 1979. The first activity was a survey of the building known as Plant C. The survey indicated normal uranium (i.e., uranium separated from its natural daughters) contamination throughout the building.

During November 1976, soil samples were taken from six locations at the site (see Fig. 2). These samples underwent radiochemical analyses to determine the extent of any contamination in the soil surrounding the building. A fluorspar sample from the kiln located at Plant C, as well as duplicate background soil samples from two distant points (one east and one west) of the Harshaw Complex (see Fig. 1), were taken to establish the applicable background conditions.

In October 1978, the radiological assessment was extended to include the entire Harshaw Complex (see Fig. 2). At that time a building identified as H-3 underwent a complete radiological assessment since Harshaw management had expressed their intent to raze the building and construct a new facility on the site. Preliminary radiological survey measurements at the outfall where effluent from the Harshaw site drains into the Cuyahoga River (see Fig. 2) were also made during this site visit.

Radiological surveys of the remaining site buildings were conducted during October through December 1978, and during May 1979.

The methods used in the survey of this site included performing instrument surveys of radiation levels and collecting and analyzing smears, water, air and soil samples. Procedural details are outlined below.

### Instrumentation

Gas-flow proportional detectors with window areas of 61 $cm^2$ (hand probe) and 325 $cm^2$ (floor monitor) using Eberline PAC-3G electronics were used to monitor for alpha and/or beta-gamma radiation. Eberline beta-gamma

end window (7 mg/cm$^2$) detectors were used to monitor for general radiation levels (mR/h) both on contact (for spots identified as contaminated) and at three feet above the floor to establish ambient radiation levels. These instruments and associated calibration procedures are detailed in Appendices 1 and 2. These appendices are written in a generic manner to identify all survey methods and instruments available for radiological surveys. Not all instruments or procedures were necessarily used during the radiological surveys discussed in this report.

## Smear Surveys

Dry smears were taken at representative locations throughout each building with 4.25-cm-diameter filter paper (Whatman #1). A standard smear sample is obtained by applying moderate pressure with the tips of the first two fingers to the back of the filter paper and wiping the surface over an area of approximately 900 cm$^2$. Smears were taken on original structures and components such as walls, floors, pipes, and vents. A smear of 100 cm$^2$ was taken from any area or object indicated by portable survey instrument to have a higher than normal radiation level. A smear of 100 cm$^2$ was also taken if the surface was extremely dusty.

All smears taken were scanned initially using a Technical Associates Samson meter and subsequently measured using a large-area, 10-wire instrument (see Appendix 1). Because of the volume of smears taken, only every tenth smear and any that showed a positive reading on the Samson meter were counted in the Nuclear Measurements Corporation (NMC) PC-3A 2$\pi$ internal gas-flow counter (see Appendix 1). All smears were counted for both alpha and beta contamination.

## Air Samples

Air-particulate samples were collected using a commercial vacuum cleaner (ANL modified) to pull air through filter media (Hollingsworth-Vose HV-70). A total volume of 26.7 m$^3$ of air was sampled at a flow rate of 40 m$^3$/h. A 10 percent portion (5 cm in diameter) was removed from the filter media after collection and counted for both alpha and beta-gamma activity in an internal-flow proportional counter (see Appendix 1).

Concentrations of radon ($^{222}Rn$) daughter, thoron ($^{220}Rn$) daughter, and the presence of any long-lived airborne radionuclides were determined based on the results of several counts of each sample at specified intervals.

Additional air samplers from the Energy Research and Development Administration Health and Safety Laboratory (now the DOE Environmental Measurements Laboratory) in New York City were used to obtain continuous air samples over week-long periods at Plant C. Six radon flux monitors were used at this site to determine emission rates, and two Working-Level monitors were set up to determine radon Working Levels.

Details of air-sampling techniques and associated calculations are given in Appendix 3.

## Soil Corings

Environmental soil samples (4-in-diamter by 12-in-deep corings) were taken from selected undisturbed locations (see Fig. 2). Duplicate corings were taken at two additional sites some distance from the Harshaw Complex to determine background levels of radionuclides in the soils of the area (see Fig. 1). Uranium and gamma-spectral analyses were conducted on all soil samples.

The samples were collected using a 4-in-diameter, 6-in-long right-circular-cylinder cutting tool, commonly used to cut holes on golf greens. Each soil core was 12-in long and was divided into four segments for analysis. Starting from the surface, three, 2-in segments were cut, bagged, and marked A, B, and C, respectively; the final segment of 6-in was marked D (see Fig. 3).

The segmented coring technique was used to determine if any contaminant migration had occurred; to reduce the dilution of lower-level soil with the upper-level segments with respect to the surface deposition of the contaminants, or vice versa; and to reveal if any overburden or backfill had been added.

## Soil Analyses

Soil samples were prepared at ANL as detailed in Appendix 4 and shipped to a commercial laboratory (LFE Environmental Analysis Laboratories) for

radiochemical and gamma-spectral analysis. Uranium concentrations [in units of micrograms U/gram soil (μg/g)] were determined using uranium fluorometric techniques. Gamma spectral analysis was used to establish the concentration (in pCi/g) of $^{232}Th$ and $^{226}Ra$ decay chain in the soil. The concentration of potassium ($^{40}K$) as found in Building H-3, was also established from these analyses. Details of these analyses are given in Appendix 4.

## ANALYSIS OF SURVEY RESULTS

### General

The nature of the operations being conducted by Harshaw at this site made the survey difficult to perform. Much of the floor area could not be surveyed because of stored material. Floor areas were dirty and covered with water in some places. The walls, overhead pipes, and girders were peeling and corroded. Most overhead structures were coated with a tightly bound layer of dirt.

In spite of these conditions, an extensive survey was performed to provide a representative appraisal of the contamination levels throughout the facility. The surveys of floor areas included direct instrument readings at contact, at two inches, and at three feet. Measurements were also made of walls and overhead features (girders, lighting fixtures, pipes), and smears were taken throughout the buildings. Air samples were taken from the appropriate locations throughout the facility.

Prior to the survey of Plant C, the floor area was divided into a grid system to provide a uniform approach to perform and record the survey results. The grid layouts for Plant C are shown in Figures 4, 5, and 6. The survey team had the assistance of Mr. Lewis Barclay of Harshaw. He was familiar with the operations involving normal uranium that had been conducted in the building and also was involved in the decontamination efforts. He was able to provide a clear identification of the potentially contaminated areas, as well as provide information on building modifications. This constituted valuable information that allowed the survey team to pay special attention to those areas with the highest potential for contamination.

The floor area in the three-story section of the building (designated i-ii in Figure 6) was not surveyed because a fluorspar-drying system was

being operated at this location. This process resulted in the dispersal of a fine powder that covered the entire surrounding floor area, thus obviating alpha-beta survey techniques.

The survey of the other buildings at the site were conducted without the gridding system outlined above since these were smaller buildings and, since the primary activities associated with the MED/AEC operations were conducted at Plant C, the levels of contamination expected were much less.

## Instrument and Smear Surveys

While it cannot be assumed that any location not listed in this report as contaminated is at background level, nevertheless, the survey was sufficiently comprehensive so as to identify general areas of contamination as well as general areas that are free from contamination. When decontamination activities are instituted at the site, detailed surveys concurrent with the decontamination activities will, of course, be necessary in order to finally certify the site as free from radioactive contamination.

### Plant C

Approximately 60 percent of the floor areas in Plant C were surveyed. About 130 measurements were made on the girders, lighting fixtures, pipes and walls. A total of 500 smears were taken throughout the building. Areas with elevated radiation levels on the smears are identified on Figure 4 and tabulated in Table 2. All areas of contamination are designated in Table 1 according to the grid locations on the figures. Certain areas of the building (first floor) had new floors laid over the old floors. These areas are located within grids A-C, 8-13; D-E, 6-7; and F-G, 1-2. (These areas were not entirely resurfaced.). Because of the additional shielding provided by the new flooring, the data in Table 1 for these areas reflects lower radiation levels. Higher levels of radiation were always found at the seams and cracks in the new floor.

Beta-gamma measurements made in the first floor areas where the new flooring had been installed indicated contamination levels up to 20,000

dis/min-100 $cm^2$. The floor areas with original concrete measured up to 1,100,000 dis/min-100 $cm^2$. The highest levels of contamination were found in the areas B-C, 4-6; F, 1-4; F, 15; H, 3-5; and G-H, 10-15. Those areas were reported to have been the primary areas for processing and handling normal uranium. Direct contact readings with the end window beta-gamma probe in those areas ranged from background to 3 mR/h. General readings taken at three feet above the floor level ranged up to 0.1 mR/h.

Levels of alpha contamination on the first floor generally ranged from 300 to 900 dis/min-100 $cm^2$, with the specific locations with the highest levels (H, 13-14) having 15,000 and 21,000 dis/min-100 $cm^2$, respectively.

Beta-gamma measurements made on the second floor (see Fig. 5) also showed areas of contamination ranging up to 1,100,000 dis/min-100 $cm^2$. The area (A-E, 1); is the employee locker room. The floor of this room was reported to have been repainted prior to this survey. Three areas on this floor (D, 6;E, 3; D, 2; and E, 6) had readings in the range of 1,000,000 dis/min-100 $cm^2$.

Direct contact readings on the contaminated areas using the end window probe showed levels ranging from 0.3 to 1.4 mR/h. General readings taken at three feet above the floor level ranged up to 0.07 mR/h.

General levels of alpha contamination on the second floor ranged up to 30,000 dis/min-100 $cm^2$. The maximum reading (30,000 dis/min-100 $cm^2$) was found at one spot in area B-2. About half of the floor area had background levels of radiation.

Survey measurements above the floor level were difficult to make. Access was obtained by the use of a ladder or an improvised basket on the end of a forklift truck. Aisleways were obstructed so a consistent pattern could not be followed. Nevertheless, enough surveys were taken to provide evidence that contamination exists in these areas. Contamination levels (beta-mode) ranged up to 700,000 dis/min-100 $cm^2$. Since

a relatively small fraction (i.e., about 25%) of these "above floor level" areas were surveyed, quantification of the contamination cannot be made.

A comprehensive survey of the roof of this building was also conducted. Contamination was found at 22 locations on the roof ranging up to 300,000 dis/min-100 $cm^2$ beta-gamma and 4,000 dis/min-100 $cm^2$ alpha. Contact readings taken with the end window GM counter ranged up to 1.5 mR/h. The levels of contamination for each area are given in Table 1, and the location of each area is given in Figure 7.

Results of the smear surveys (see Table 2) indicated that most of the contamination in Plant C was "fixed."

- Building H-3

There was no evidence of any uranium contamination remaining from MED/AEC activities.

Approximately 20 percent of the floor area, 5 percent of the wall area and 90 percent of the roof area (see Figs. 31, 32, and 33) in Building H-3 were surveyed. Elevated readings were detected throughout the building. All readings were indicative of beta-gamma activity only, no alpha readings above background were found. Smears of these areas also indicated beta-gamma contamination exclusively. General radiation levels throughout the facility ranged up to 0.1 mR/h.

Samples of residues taken from various locations throughout the building were subjected to gamma-spectral analysis. The contaminant was invariably identified as $^{40}K$. This radionuclide is a naturally occurring radioisotope of potassium that was indigenous to the processing taking place in this facility.

- Remaining Site

To conduct a general survey of the entire Harshaw Complex, the site was

subdivided into eight sections identified alphabetically A through H (see Fig. 8). All buildings within each area, as well as the surface of the ground around the buildings, were systematically surveyed to ascertain the extent of any radioactive contamination. Thirty-two areas of external contamination were identified. Locations of these areas are shown in Figures 9 through 16 and tabulated in Table 3. Surface contamination levels up to 400,000 dis/min-100 $cm^2$ beta-gamma and 2,000 dis/min-100 $cm^2$ alpha were measured.

Locations of contaminated areas inside the buildings are shown in Figures 17 through 57 and tabulated in Table 4. Interior surface contamination levels up to 400,000 dis/min-100 $cm^2$ beta-gamma and up to 150,000 dis/min-100 $cm^2$ alpha were measured.

Results of the smear surveys taken throughout the site are tabulated in Table 5. The location of the smears are also identified in Figures 17 through 57. Smears showed loose contamination measuring up to 1,000 dis/min-100 $cm^2$ beta-gamma and up to 300 dis/min-100 $cm^2$ alpha.

While the source of this contamination cannot be firmly established, since it is primarily normal uranium, it is probably associated with activities performed under MED/AEC operations.

## Air Samples

- Plant C

Four air samples were taken in Plant C using standard ANL techniques. The ANL results are presented in Table 6, and the sampling locations are shown in Figures 4 and 5. The detailed calculations used in evaluating the results are given in Appendix 3. Radon ($^{222}Rn$) concentrations ranged from 0.25 pCi/ℓ to 0.69 pCi/ℓ, corresponding to a range of 0.0025 to 0.0069 radon Working Levels (assuming radon daughter equilibrium). These values are well below the limit of 0.02 WL for average annual concentration as specified in the EPA Standard (40 CFR 192).

Additionally, three types of air monitors supplied by the DOE Health and Safety Laboratory (New York City) were used to obtain continuous air samples over a week-long period. These instruments consisted of radon flux charcoal canisters (six), Working Level monitors (two), and TLD air samplers (two). The locations where these monitors were operated are also included in Figures 4 and 5, and the results, as determined by HASL personnel, are included in Table 6. These values also indicated Working Levels substantially below the limits specified by the EPA Standard (40 CFR 192).

- Building H-3

An air sample was taken on each floor of Building H-3 using the ANL techniques described above. Radon ($^{222}Rn$) concentrations were 0.34 pCi/ℓ and 0.13 pCi/ℓ on the first and second floors, respectively. These values, which are well below the EPA limit (40 CFR 192), are included in Table 6 and the locations are identified in Figures 31 and 32.

- Remaining Site

During the radiological survey of the remaining site, a total of 54 air samples were collected from within the various buildings. The locations of these air samples are identified in Figures 17 through 57. The results are included in Table 6. All measured radon ($^{222}Rn$) daughter concentrations were substantially below the EPA limit (40 CFR 192).

- Particulate Contamination

No significant amount of airborne particulate contamination was found in any air sample.

Soil Corings

Two background soil corings were taken from each of two offsite loca-

tions (see Fig. 1) to ascertain background levels of radionuclides in soil for the Cleveland area. These corings were identified as BP-1, BP-2, MW-1 and MW-2. Additionally, one sample of fluorspar (FL) was obtained from the site to ascertain the contribution, if any, of this natural material to the contamination levels found at the site. Soil corings were taken at six locations on the site. These corings have been identified as PC-1 through PC-6. The location of each coring is shown on Figure 2. All soil corings were sectioned and analyzed for uranium (uranium fluorometric), as well as radium and thorium decay chains (gamma-spectral analysis). Although the radium and thorium decay chains were in the range of natural background, the uranium concentrations ranged as high as 1800 pCi/g. The contribution to these levels by the fluorspar was found to be negligible. These results are included in Table 7. Details of these analysis techniques are included in Appendix 4. The results of these analyses indicated the need for extensive subsurface investigation to determine the extent of the contamination.

### Site Effluent

The Harshaw site effluent drains into the Cuyahoga River as indicated in Figure 2. Surface flow of the river (at the outfall) at the time of the survey was estimated to be about 100 feet per minute. The width of the river at the outfall was 124 ft. It was reported that effluents from the north end of the plant and in particular the Plant C and the Foundry buildings discharged via the outfall into the river. Traces of yellowcake were visible on the river bank just east of Building K-1.

The results of this preliminary assessment indicated the need for an extensive examination of the outfall area, as well as the river bottom both upstream and downstream of the outfall, and the sewer system.

## ESTIMATED EXTENT OF CONTAMINATION

A definitive estimate of the extent of the contamination associated with the subsurface and the river is impossible since the assessment was preliminary in nature. Hence these estimates are limited to the buildings and soil-surface contamination.

Extensive interior contamination exists throughout Plant C as well as in 16 other buildings. Extensive exterior contamination exists at 32 locations, but the amount of subsurface contamination in the soil at these locations is unknown. Since the depth of the contamination is unknown, it is impossible to assess the total volume of contaminated material. Nevertheless, these results indicate that the subsurface contamination extends to a foot or more in depth in some locations.

Additional information regarding estimates of contamination is given in Appendix 7.

## DOSE AND POTENTIAL HAZARD EVALUATION

To assess the potential radiological hazard from external exposure to the radiation sources detected in this survey, a "conservative" (or worst-case) situation was assumed. Since commercial, rather than residential occupancy is involved, it was assumed that an individual would be exposed 40 hours per week to the maximum interior or exterior radiation levels.

The maximum interior radiation level observed was 30 mR/h (contact) and the maximum exterior radiation level observed was 6 mR/h (contact). These contact measurements were made with an end window (2 $mg/cm^2$) GM counter (calibrated with a $^{226}Ra$ standard source) and hence are strongly influenced by the surface beta radiation. While these radiation levels might reflect the "rad" dose to skin in contact with the source of radiation, they would clearly overestimate the radiation dose to the total body. In order to better estimate the ambient penetrating radiation field, a comparison was made, using a flat plate normal uranium standard, between contact radiation levels as measured with the GM counter and the ambient penetrating radiation levels as measured with an Eberline PRM-7 μR meter. The ambient penetrating radiation level was found to be 40 times less than the contact GM radiation level. An estimate of an annual radiation dose based on these measurements would be:

Interior: (30 mR/h ÷ 40) x 40 h/w x 50 w/y x 1 rem/R = 1.5 rem/y

Exterior: (6 mR/h ÷ 40) x 40 h/w x 50 w/y x 1 rem/R = 0.3 rem/y

These doses are based on the contact radiation level and hence overestimate the dose to a person occupying the area. Furthermore, the likelihood of a person's occupying one spot for 40 hours per week is extremely remote. Hence, it is our judgement that the contaminated areas of this site do not constitute an immediate radiological hazard in terms of external exposure, even though this worst-case dose is significantly above the DOE 5480.1 limit of 500 millirem per year for a person non-occupationally exposed (see Appendix 6).

Additional information regarding generic evaluation of radiation exposures are given in Appendix 8 for comparison purposes.

## CONCLUSIONS

The surface contamination throughout the site is extensive, occurring in most of the buildings and in a large number of exterior locations. Although the contamination does not constitute an immediate radiological hazard in terms of external exposure, the levels are above guidelines for release of the site for unrestricted use.

The extent of subsurface contamination on the site, as well as the extent of contamination in the sewer system and in the river bed in the vicinity of the site effluent outfall, remains unknown.

TABLE 1

CONTAMINATED AREAS - INTERIOR, PLANT C

| Location | Location[a] Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (1000 dis/min-100 $cm^2$) Beta-Gamma | Alpha | Contact GM Reading (mR/h) |
|---|---|---|---|---|---|
| Area E/Plant C | | | | | |
| 1st floor (Figure 4) | 1-F | 1000 | 1100 | 0.6 | 3.0 |
| | 1-I | 1000 | 200 | 0.3 | 0.7 |
| | 2-F | 1000 | 700 | 0.3 | 0.2 |
| | 2-G | 1000 | 700 | 0.3 | ND[b] |
| | 2-H | 1000 | 700 | 0.3 | ND |
| | 3-A | 1000 | 200 | 0.4 | ND |
| | 3-B | 1000 | 200 | 0.4 | ND |
| | 3-C | 1000 | 400 | 0.4 | ND |
| | 3-D | 1000 | 10 | 0.3 | ND |
| | 3-F | 1000 | 400 | 0.3 | 0.1 |
| | 3-H | 1000 | 900 | 2 | 0.2 |
| | 4-A | 1000 | 200 | 0.4 | ND |
| | 4-B | 1000 | 800 | 0.4 | ND |
| | 4-E | 1000 | 100 | 0.3 | ND |
| | 4-F | 1000 | 900 | 2 | 0.2 |
| | 4-H | 1000 | 800 | 3 | 0.2 |
| | 5-B | 1000 | 1100 | 0.4 | 1.0 |
| | 5-C | 1000 | 200 | 3 | ND |
| | 5-E | 1000 | 100 | 0.3 | ND |
| | 5-F | 1000 | 600 | 6 | ND |
| | 5-H | 1000 | 1100 | 3 | 0.2 |

TABLE 1
(cont'd.)

| Location | Location[a] Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (1000 dis/min-100 $cm^2$) Beta-Gamma | Alpha | Contact GM Reading (mR/h) |
|---|---|---|---|---|---|
| 1st Floor (cont'd.) | | | | | |
| | 6-B | 1000 | 1100 | 0.4 | ND |
| | 6-C | 1000 | 1100 | 0.4 | 1.5 |
| | 6-E | 1000 | 40 | 0.3 | ND |
| | 6-F | 1000 | 70 | 0.3 | ND |
| | 6-G | 1000 | 70 | 0.3 | ND |
| | 6-H | 1000 | 330 | 2 | ND |
| | 7-A | 1000 | 400 | 0.4 | ND |
| | 7-B | 1000 | 200 | 0.4 | ND |
| | 7-D | 1000 | 40 | 0.3 | ND |
| | 7-E | 1000 | 400 | 0.3 | ND |
| | 7-F | 1000 | 200 | 0.3 | ND |
| | 7-G | 1000 | 300 | 0.3 | ND |
| | 7-H | 1000 | 300 | 0.3 | ND |
| | 8-D | 1000 | 200 | 0.3 | ND |
| | 8-E | 1000 | 100 | 0.3 | ND |
| | 8-F | 1000 | 100 | 0.3 | ND |
| | 8-G | 1000 | 400 | 0.3 | ND |
| | 8-H | 1000 | 400 | 0.3 | ND |
| | 8-I | 1000 | 200 | 0.3 | ND |
| | 9-D | 1000 | 30 | 0.3 | ND |
| | 9-E | 1000 | 100 | 0.3 | ND |
| | 9-F | 1000 | 400 | 0.3 | ND |
| | 9-G | 1000 | 200 | 0.3 | ND |

TABLE 1
(cont'd.)

| Location | Location[a] Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (1000 dis/min-100 $cm^2$) Beta-Gamma | Maximum PAC Reading (1000 dis/min-100 $cm^2$) Alpha | Contact GM Reading (mR/h) |
|---|---|---|---|---|---|
| 1st Floor (cont'd.) | | | | | |
| | 10-D | 1000 | 400 | 0.3 | ND |
| | 10-E | 1000 | 60 | 0.3 | ND |
| | 10-F | 1000 | 200 | 0.3 | ND |
| | 10-G | 1000 | 400 | 0.3 | ND |
| | 10-H | 1000 | 1100 | 6 | 1.0 |
| | 11-D | 1000 | 400 | 0.3 | ND |
| | 11-E | 1000 | 100 | 0.3 | ND |
| | 11-F | 1000 | 200 | 0.3 | ND |
| | 11-G | 1000 | 200 | 0.3 | ND |
| | 11-H | 1000 | 1100 | 3 | 0.7 |
| | 11-J | 1000 | 300 | 0.3 | ND |
| | 12-D | 1000 | 200 | 0.3 | ND |
| | 12-E | 1000 | 100 | 0.3 | ND |
| | 12-F | 1000 | 40 | 0.3 | 0.08 |
| | 12-G | 1000 | 800 | 0.3 | ND |
| | 12-H | 1000 | 1100 | 3 | 1.0 |
| | 13-B | 1000 | 90 | 0.3 | ND |
| | 13-D | 1000 | 200 | 0.3 | ND |
| | 13-E | 1000 | 200 | 0.3 | ND |
| | 13-G | 1000 | 1100 | 0.3 | ND |
| | 13-H | 1000 | 1100 | 15 | 1.0 |
| | 13-I | 1000 | 100 | 0.4 | ND |
| | 14-F | 1000 | 300 | BKGD | ND |
| | 14-G | 1000 | 600 | BKGD | ND |
| | 14-H | 1000 | 1100 | 21 | 0.7 |
| | 14-I | 1000 | 400 | 0.4 | ND |

TABLE 1
(cont'd.)

| Location | Location[a] Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (1000 dis/min-100 $cm^2$) Beta-Gamma | Maximum PAC Reading (1000 dis/min-100 $cm^2$) Alpha | Contact GM Reading (mR/h) |
|---|---|---|---|---|---|
| 1st Floor (cont'd.) | | | | | |
| | 15-F | 1000 | 1100 | BKGD | ND |
| | 15-G | 1000 | 1100 | BKGD | ND |
| | 15-H | 1000 | 1100 | 9.0 | ND |
| | 15-I | 1000 | 600 | 0.4 | ND |
| 2nd Floor (Figure 5) | | | | | |
| | 1-C | 1000 | 700 | BKGD | 0.5 |
| | 2-B | 1000 | 700 | 30 | 0.5 |
| | 2-C | 1000 | 700 | 6 | 1.4 |
| | 2-D | 1000 | 1100 | 12 | 1.2 |
| | 2-E | 1000 | 900 | 9 | ND |
| | 3-D | 1000 | 600 | 4 | 0.3 |
| | 3-E | 1000 | 1100 | 0.6 | 1.0 |
| | 5-E | 1000 | 900 | 3 | 0.5 |
| | 6-D | 1000 | 1100 | 6 | 0.5 |
| | 6-E | 1000 | 900 | 3 | 0.4 |
| Roof[c] (Figure 7) | 28 | 100 | 5 | BKGD | 0.07 |
| | 29 | 100 | 20 | BKGD | 0.6 |
| | 30 | 100 | 10 | BKGD | 0.1 |
| | 31 | 100 | 6 | 0.5 | 0.1 |
| | 32 | 10000 | 20 | 4 | 0.05 |

TABLE 1
(cont'd.)

| Location | Location[a] Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (1000 dis/min-100 $cm^2$) Beta-Gamma | Alpha | Contact GM Reading (mR/h) |
|---|---|---|---|---|---|
| Roof (cont'd.) | | | | | |
| | 33 | 1000 | 10 | 0.5 | 0.2 |
| | 34 | 1000 | 20 | 0.5 | 0.3 |
| | 35 | 1000 | 30 | 0.5 | 0.3 |
| | 36 | 1000 | 5 | 0.5 | 0.1 |
| | 39 | 1000 | 12 | 1 | 0.3 |
| | 41 | 1000 | 300 | BKGD | 1.2 |
| | 42 | 10000 | 10 | 0.5 | 0.1 |
| | 43 | 1000 | 40 | 1 | 0.7 |
| | 44 | 1000 | 20 | BKGD | 0.6 |
| | 45 | 10000 | 20 | 0.5 | 1.5 |
| | 47 | 10000 | 50 | 0.5 | 0.7 |
| | 48 | 1000 | 100 | 1 | 1.1 |
| | 49 | 1000 | 50 | 2 | 0.5 |
| | 50 | 1000 | 40 | 0.5 | ND |
| | 52 | 1000 | 3 | BKGD | 0.03 |
| | 53 | 1000 | 3 | BKGD | 0.02 |
| | 54 | 1000 | 10 | 0.5 | 0.2 |

[a]Location based on coordinated system in Figures 4 and 5.

[b]ND indicates that this value was not determined.

[c]Roof locations are identified precisely.

TABLE 2

LOOSE CONTAMINATION - INTERIOR, PLANT C[a]

| Smear Number | Location Number[b] | Smear Results[a] dis/min-100 $cm^2$ Alpha | Beta-Gamma |
|---|---|---|---|
| 1129 | H-10 | 300 | 2100 |
| 1131 | G-11 | 400 | 1300 |
| 1136 | H-14 | 2500 | 7000 |
| 1150 | H-6 | 350 | 2300 |
| 1162 | H-4 | 600 | 2900 |
| 1172 | H-13 | 400 | 2900 |
| 1174 | H-12 | 350 | 2200 |
| 1177 | H-11 | 350 | 2000 |
| 1179 | G-12 | 400 | 1900 |

[a]Approximately 500 smears were taken on the floor area, on the overhead material, and the walls. All the smears were counted and the results were negative except for the ones listed.

[b]Location number based on coordinate system in Figure 4.

TABLE 3

CONTAMINATED AREAS - EXTERIOR, SITEWIDE

| Area | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) Beta-Gamma | Alpha | Contact GM Reading (mR/h) | Comments |
|---|---|---|---|---|---|---|
| A (Fig. 9) | 677 | 1,000 | 1.5 k | BKGD | 0.04 | Gravel |
| B | 675 | 10,000 | 10 k | BKGD | 0.04 | Could be $^{40}K$ |
| (Fig. 10) | 678 | 1,000 | 2 k | BKGD | 0.04 | Concrete |
| | 679 | 1,000 | 2 k | BKGD | 0.06 | Wall |
| | 680 | 1,000 | 2 k | BKGD | 0.03 | Concrete |
| | 681 | 1,000 | 2 k | BKGD | 0.03 | Soil |
| | 682 | 10,000 | 40 k | BKGD | 0.3 | Soil |
| | 683 | 1,000 | 20 k | BKGD | 0.2 | Vertical surface |
| | 684 | 5,000 | 2 k | BKGD | 0.03 | Brown powder |
| | 685 | 1,000 | 2 k | BKGD | BKGD | Concrete |
| C (Fig. 11) | | (No exterior contamination detected in this area.) | | | | |
| D | 676 | 1,000 | 1 k | BKGD | BKGD | Soil |
| (Fig. 12) | 699 | 1,000 | 10 k | BKGD | 0.04 | Concrete |
| E | 674 | NA | 400 k | 0.5 k | 6.0 | Pipe |
| (Fig. 13) | 695 | 10,000 | 8 k | BKGD | 0.05 | Concrete |
| | 696 | 10,000 | 20 k | 1 k | 0.07 | Soil |
| | 700 | 1,000 | 4 k | BKGD | 0.03 | Soil |
| | 701 | 1,000 | 140 k | BKGD | 1.0 | Concrete |
| | 702 | 1,000 | 10 k | BKGD | BKGD | Concrete |
| | 703 | 40,000 | 4 k | BKGD | 0.2 | Concrete |
| | 704 | 1,000 | 4 k | BKGD | 0.2 | Concrete |
| F | 697 | 1,000 | 120 k | 1 k | 2.0 | Soil |
| (Fig. 14) | 698 | 1,000 | 40 k | BKGD | 0.3 | Soil |

TABLE 3
(cont'd.)

| Area | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) Beta-Gamma | Alpha | Contact GM Reading (mR/h) | Comments |
|---|---|---|---|---|---|---|
| G | 686 | 1,000 | 2 k | BKGD | 0.04 | Concrete |
| (Fig. 15) | 687 | 1,000 | 1 k | BKGD | BKGD | Concrete |
| | 688 | 1,000 | 2 k | BKGD | 0.04 | Concrete |
| | 689 | NA | 1 k | BKGD | 0.3 | Material in crate |
| H | 662 | 10,000 | 30 k | 2 k | 0.09 | Concrete |
| (Fig. 16) | 663 | 10,000 | 10 k | BKGD | 0.06 | Concrete |
| | 664 | 1,000 | 50 k | 1 k | 0.1 | Concrete |
| | 665 | 10,000 | 2 k | 0.5 k | BKGD | Soil |
| | 666 | 1,000 | 1 k | BKGD | BKGD | Concrete |
| | 667 | 1,000 | 1 k | BKGD | 0.05 | Looks like yellow cake (buried) |

TABLE 4

CONTAMINATED AREAS - INTERIOR, SITEWIDE

| Area and Building | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) Beta-Gamma | Maximum PAC Reading (dis/min-100 $cm^2$) Alpha | Contact GM Reading (mR/h) | Smear Results (dis/min-100 $cm^2$) Beta-Gamma | Smear Results (dis/min-100 $cm^2$) Alpha | Comments |
|---|---|---|---|---|---|---|---|---|
| Area A (Figure 9) | | | | | | | | |
| B-1 (Figure 17) | (none) | | | | | | | |
| Gate House (Figure 18) | 200 | 1,000 | 1 k | BKGD | BKGD | NCD | NCD | Floor |
| (Roof) (Figure 19) | 201 | 1,000 | 1 k | BKGD | BKGD | NCD | NCD | Roof |
| Garage (Figure 20) | (none) | | | | | | | |
| Area B (Figure 10) | | | | | | | | |
| C-2 (1st flr) (Figure 21) | 445 | 1,000 | 30 k | 2 k | 0.03 | 100 | 6 | Storage Tank |
| | 446 | 1,000 | 20 k | BKGD | 0.03 | BKGD | 4 | Storage Tank |
| | 447 | 1,000 | 50 k | BKGD | 0.6 | NCD | NCD | Platform |
| (2nd flr) (Figure 22) | 494 | 1,000 | 200 k | 8 k | 3.5 | 200 | 30 | Bulletin Board |
| | 495 | 100 | 100 k | BKGD | 1.5 | NCD | NCD | Motor |
| (Roof) (Figure 23) | (none) | | | | | | | |

TABLE 4
(cont'd.)

| Area and Building | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) Beta-Gamma | Maximum PAC Reading (dis/min-100 $cm^2$) Alpha | Contact GM Reading (mR/h) | Smear Results (dis/min-100 $cm^2$) Beta-gamma | Smear Results (dis/min-100 $cm^2$) Alpha | Comments |
|---|---|---|---|---|---|---|---|---|
| C-1 (1st flr)(none) (Figure 24) | | | | | | | | |
| (Roof) (Figure 25) | (none) | | | | | | | |
| Foundry (Figure 26) | 278 | 10,000 | 16 k | 1 k | 0.4 | NCD | NCD | Floor |
| | 279 | 1,000 | 100 k | 1 k | 0.2 | NCD | NCD | Floor |
| | 280 | 1,000 | 160 k | 4 k | 0.2 | 100 | 10 | Floor |
| | 281 | 1,000 | 100 k | 2 k | 0.1 | NCD | NCD | Floor |
| | 282 | 1,000 | 100 k | 2 k | 0.1 | NCD | NCD | Floor |
| | 283 | 1,000 | 120 k | 1 k | 0.7 | NCD | NCD | Floor |
| | 284 | 10,000 | 40 k | 1 k | 0.1 | NCD | NCD | Platform |
| | 285 | 1,000 | 40 k | 1 k | 0.2 | NCD | NCD | Floor |
| | 286 | 1,000 | 4 k | BKGD | 0.1 | NCD | NCD | Office Floor |
| | 287 | 1,000 | 20 k | BKGD | 0.2 | NCD | NCD | Floor |
| | 288 | 1,000 | 120 k | 2 k | 0.5 | 100 | 10 | Floor |
| | 289 | 1,000 | 20 k | BKGD | 0.1 | NCD | NCD | Floor |
| | 290 | 1,000 | 100 k | BKGD | 0.5 | 50 | 5 | Floor |
| | 291 | 1,000 | 200 k | 1 k | 3 | 500 | 50 | Floor |
| | 292 | 1,000 | 40 k | 1 k | 0.8 | NCD | NCD | Floor |
| | 293 | 1,000 | 16 k | BKGD | 0.1 | NCD | NCD | Wall |
| | 299 | 1,000 | 2 k | BKGD | 0.1 | BKGD | 8 | Cross Brace |
| | 300 | 1,000 | BKGD | BKGD | 0.1 | BKGD | 8 | Cross Brace |
| | 301 | 1,000 | 3 k | BKGD | 0.1 | NCD | NCD | Beam |
| | 302 | 1,000 | 1 k | BKGD | 0.1 | NCD | NCD | Beam |
| | 303 | 1,000 | 4 k | BKGD | 0.1 | BKGD | 8 | Beam |
| | 304 | 1,000 | 6 k | BKGD | 0.03 | NCD | NCD | Beam |
| | 305 | 1,000 | 4 k | BKGD | 0.03 | NCD | NCD | Beam |

TABLE 4
(cont'd.)

| Area and Building | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) Beta-Gamma | Maximum PAC Reading (dis/min-100 $cm^2$) Alpha | Contact GM Reading (mR/h) | Smear Results (dis/min-100 $cm^2$) Beta-gamma | Smear Results (dis/min-100 $cm^2$) Alpha | Comments |
|---|---|---|---|---|---|---|---|---|
| Foundry (cont'd.) (Figure 26) | 306 | 1,000 | 1 k | BKGD | 0.03 | NCD | NCD | Beam |
| | 308 | 1,000 | 1 k | BKGD | 0.03 | NCD | NCD | Beam |
| | 309 | 1,000 | 1 k | BKGD | 0.03 | NCD | NCD | Beam |
| | 317 | 1,000 | 4 k | BKGD | 0.04 | 100 | 10 | Beam |
| | 319 | 1,000 | 40 k | 1 k | 0.1 | 100 | 20 | Beam |
| | 320 | 1,000 | 60 k | 1 k | 0.2 | 300 | 40 | Beam |
| | 321 | 1,000 | 1 k | BKGD | 0.03 | NCD | NCD | Beam |
| | 322 | 1,000 | 2 k | 1 k | 0.03 | NCD | NCD | Floor |
| | 323 | 1,000 | 1 k | 1 k | 0.03 | NCD | NCD | Floor |
| | 325 | 1,000 | 12 k | 1 k | 0.04 | NCD | NCD | Floor |
| | 326 | 1,000 | 2 k | 1 k | 0.05 | NCD | NCD | Floor |
| | 327 | 1,000 | 14 k | 1 k | 0.1 | NCD | NCD | Floor |
| | 328 | 1,000 | 120 k | 1 k | 0.6 | 1000 | 100 | Tank |
| | 329 | 100 | 20 k | BKGD | 2 | NCD | NCD | Motor |
| | 330 | 100 | 100 k | 1 k | 1 | 200 | 40 | Pipe Valve |
| | 331 | 100 | 4 k | BKGD | 0.07 | 200 | 50 | Pipe Valve |
| | 333 | 1,000 | 1 k | BKGD | 0.02 | NCD | NCD | Cross Brace |
| | 334 | 1,000 | 1 k | BKGD | 0.03 | NCD | NCD | Pump Room |
| | 335 | 1,000 | 4 k | BKGD | 0.03 | NCD | NCD | Pump Room |
| | 336 | 1,000 | 400 k | 30 k | 2 | 500 | 100 | Store Room |
| | 339 | 100 | 12 k | 1 k | 0.5 | 100 | 10 | Electric Part |
| | 340 | 100 | 400 k | BKGD | 0.2 | 300 | 30 | Shower Head |
| | 342 | 1,000 | 1 k | BKGD | 0.03 | NCD | NCD | Beam |
| | 343 | 1,000 | 40 k | 2 k | 0.6 | 700 | 70 | Barrel lifter |
| | 344 | 100 | 120 k | 2 k | 0.9 | 300 | 40 | Valve |
| | 345 | 100 | 40 k | 2 k | 0.5 | 600 | 80 | Sprocket |
| | 346 | 100 | 40 k | 6 k | 0.1 | 300 | 30 | Conduit |
| | 347 | 100 | 30 k | 2 k | 0.07 | BKGD | 20 | Wrench |
| | 350 | 100 | BKGD | BKGD | BKGD | 500 | BKGD | Floor |

TABLE 4
(cont'd.)

| Area and Building | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) Beta-Gamma | Maximum PAC Reading (dis/min-100 $cm^2$) Alpha | Contact GM Reading (mR/h) | Smear Results (dis/min-100 $cm^2$) Beta-Gamma | Smear Results (dis/min-100 $cm^2$) Alpha | Comments |
|---|---|---|---|---|---|---|---|---|
| Foundry (Figure 27, Roof) | 15 | 1,000 | 4 k | BKGD | 0.03 | NCD | NCD | Facade |
| | 16 | 1,000 | 8 k | BKGD | 0.03 | NCD | NCD | Roof |
| P-1 (Figure 28, 1st Floor) | 55 | 100 | 8 k | BKGD | 0.03 | NCD | NCD | Window ledge |
| | 56 | 100 | 40 k | BKGD | 0.4 | NCD | NCD | Floor |
| | 57 | 100 | 6 k | BKGD | 0.03 | NCD | NCD | Post at Base |
| | 68 | 100 | 4 k | BKGD | 0.03 | NCD | NCD | Window sill |
| | 69 | 100 | 8 k | BKGD | 0.1 | NCD | NCD | Floor Crack |
| | 88 | 1,000 | 200 k | 20 k | 0.15 | NCD | NCD | Floor |
| | 89 | 1,000 | 200 k | 30 k | 0.7 | NCD | NCD | Floor |
| P-1 (Figure 29, 2nd Floor) | 70 | 100 | 3 k | BKGD | 0.05 | NCD | NCD | Wall |
| | 74 | 100 | 2 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 75 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 76 | 100 | 3 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 77 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 80 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 97 | 1,000 | 10 k | BKGD | 0.2 | NCD | NCD | Floor |
| | 98 | 1,000 | 30 k | BKGD | 0.2 | NCD | NCD | Floor |
| (Figure 30, Roof) | 1 | 100 | 6 k | BKGD | 0.07 | NCD | NCD | Facade |
| | 2 | 100 | 2 k | BKGD | 0.03 | NCD | NCD | Roof |
| | 3 | 1,000 | 1 k | BKGD | 0.03 | NCD | NCD | Green Area |
| H-3 (Figure 31, 1st Floor) | 93 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 94 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |

TABLE 4
(cont'd.)

| Area and Building | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) Beta-Gamma | Alpha | Contact GM Reading (mR/h) | Smear Results (dis/min-100 $cm^2$) Beta-Gamma | Alpha | Comments |
|---|---|---|---|---|---|---|---|---|
| (Figure 32, 2nd Floor) | 71 | 100 | 4 k | BKGD | 0.03 | NCD | NCD | Wall |
| | 82 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 84 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 85 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 99 | 1,000 | 6 k | BKGD | 0.1 | NCD | NCD | Floor |
| (Figure 33, Roof) | 4 | ——— | (White Powder - $^{40}K$) | | | ——— | | |
| | 12 | ——— | (White Powder - $^{40}K$) | | | ——— | | |
| Area C (Figure 11) | | | | | | | | |
| (Figure 34, H-1, 2 & 5) | 376 | 100 | 8 k | BKGD | 0.03 | NCD | NCD | Overhead |
| | 377 | 100 | 2 k | BKGD | 0.03 | NCD | NCD | Overhead |
| (Figure 35) | None | | | | | | | |
| Area D (Figure 12) | | | | | | | | |
| M-1 (Figure 36, 1st Floor) | 114 | 1,000 | 1 k | BKGD | 0.02 | NCD | NCD | Floor |
| | 115 | 1,000 | 3 k | BKGD | 0.05 | NCD | NCD | Floor |
| | 122 | 1,000 | 12 k | BKGD | 0.02 | NCD | NCD | Wall |
| | 123 | 100 | 40 k | BKGD | 0.07 | NCD | NCD | Stairs |
| | 151 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 154 | 100 | 1 k | BKGD | 0.02 | 50 | 5 | Beam |
| (Figure 37, 2nd Floor) | 116 | 1,000 | 50 k | BKGD | 0.5 | NCD | NCD | Floor |
| | 117 | 1,000 | 40 k | BKGD | 0.02 | BKGD | 10 | Floor |
| | 118 | 1,000 | 2 k | BKGD | 0.05 | NCD | NCD | Floor |

TABLE 4
(cont'd.)

| Area and Building | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) | | Contact GM Reading (mR/h) | Smear Results (dis/min-100 $cm^2$) | | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | Beta-Gamma | Alpha | | Beta-Gamma | Alpha | |
| (Figure 37, 2nd floor, cont'd.) | 119 | 100 | 1 k | BKGD | 0.05 | NCD | NCD | Stairwell |
| | 147 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 149 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| | 150 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| (Figure 38, Roof) | 61 | 100 | 4 k | BKGD | 0.02 | NCD | NCD | Roof |
| (Figure 39, R-1, R-2) | 156 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Ledge |
| | 159 | 100 | 20 k | 1 k | 0.1 | NCD | NCD | Wood Cabinet |
| | 162 | 100 | 1 k | BKGD | 0.02 | NCD | NCD | Beam |
| (Figure 40, N-1, 2 & 3 | 163 | 1,000 | 1 k | BKGD | 6.0 | NCD | NCD | Floor |
| | 165 | 100 | 4 k | BKGD | 0.02 | NCD | NCD | Ledge |
| | 166 | 100 | 12 k | BKGD | 0.1 | NCD | NCD | Ledge |
| | 181 | 100 | 8 k | BKGD | 0.1 | 25 | 5 | Valve |
| (Figure 41, Roof) | 65 | 1,000 | 1 k | BKGD | 0.02 | NCD | NCD | Roof |
| Boiler House (Figure 42) | 380 | 1,000 | 150 k | 300 | 3.0 | NCD | NCD | Table |
| (Figure 43) | (none) | | | | | | | |
| Area E (Figure 13) | | | | | | | | |
| (Figures 46 & 47, M-2) | (none) | | | | | | | |

TABLE 4
(cont'd.)

| Area and Building | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) Beta-Gamma | Maximum PAC Reading (dis/min-100 $cm^2$) Alpha | Contact GM Reading (mR/h) | Smear Results (dis/min-100 $cm^2$) Beta-Gamma | Smear Results (dis/min-100 $cm^2$) Alpha | Comments |
|---|---|---|---|---|---|---|---|---|
| (Figure 44, Emergency Building) | 135 | 100 | 10 k | BKGD | 0.02 | NCD | NCD | Wall |
| | 137 | 1,000 | 4 k | BKGD | 0.06 | NCD | NCD | Wall |
| (Figure 45, Dept. 1, office) | 197 | 1,000 | 20 k | BKGD | 0.07 | NCD | NCD | Floor |
| | 198 | 1,000 | 40 k | BKGD | 0.5 | NCD | NCD | Floor |
| | 199 | 1,000 | 40 k | BKGD | 0.2 | NCD | NCD | Floor |
| | 203 | 1,000 | 20 k | BKGD | 0.08 | NCD | NCD | Floor |
| | 204 | 1,000 | 2 k | BKGD | 0.05 | NCD | NCD | Floor |
| Plant C | (See Table 1) | | | | | | | |
| Area F (Figure 14) | (none) | | | | | | | |
| Area G (Figure 15) | | | | | | | | |
| (Figure 49, Warehouse Main Floor) | 388 | 100 | 80 k | BKGD | 0.4 | BKGD | 10 | Lift Truck |
| | 392 | 100 | 400 k | BKGD | 0.8 | BKGD | 10 | Bulletin Board |
| | 396 | 100 | 1 k | BKGD | 0.03 | NCD | NCD | Overhead |
| | 423 | 100 | 6 k | BKGD | 0.04 | NCD | NCD | Clock |
| (Figure 50, Lab & office) | 230 | 1,000 | 2 k | 1 k | 0.05 | NCD | NCD | Floor |
| | 231 | 1,000 | 6 k | 1 k | 0.05 | NCD | NCD | Floor |
| (Figure 51, 2nd Floor) | 241 | 1,000 | 2 k | BKGD | 0.02 | NCD | NCD | Floor |
| (Figure 52, Roof) | 120 | 1,000 | 10 k | BKGD | 0.04 | NCD | NCD | Roof |

TALBE 4
(cont'd.)

| Area and Building | Location Number | Estimated Area of Contamination ($cm^2$) | Maximum PAC Reading (dis/min-100 $cm^2$) | | Contact GM Reading (mR/h) | Smear Results (dis/min-100 $cm^2$) | | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | Beta-Gamma | Alpha | | Beta-Gamma | Alpha | |
| Area H (Figure 16) | | | | | | | | |
| (Figure 53, K-1) | 557 | NA | - | - | 20 | NCD | NCD | $^{226}Ra$ source |
| | 558 | 100 | 80 k | 10 k | 1.5 | 1000 | 200 | Valve |
| | 561 | 100 | 2 k | 1 k | 0.02 | NCD | NCD | Glove |
| | 562 | 100 | 2 k | BKGD | 0.1 | NCD | NCD | Floor Crack |
| | 571 | 100 | 6 k | BKGD | 0.06 | NCD | NCD | Wall |
| | 572 | 100 | 30 k | BKGD | 0.6 | NCD | NCD | Floor |
| | 573 | 100 | 2 k | BKGD | 0.02 | NCD | NCD | Floor |
| | 574 | 100 | 10 k | 1 k | 1.0 | NCD | NCD | Floor |
| | 575 | 100 | 10 k | 1 k | 0.2 | NCD | NCD | Floor |
| | 582 | 1,000 | 6 k | 1 k | 0.02 | NCD | NCD | Floor |
| | 583 | 1,000 | 10 k | 1 k | 0.08 | NCD | NCD | Floor |
| | 584 | 1,000 | 10 k | 1 k | 0.03 | NCD | NCD | Floor |
| (Figure 55, L-1) | 607 | 100 | 6 k | BKGD | 0.06 | NCD | NCD | Grate |
| (Figures 54 & 56) | (none) | | | | | | | |
| Quonset (Figure 48) | (none) | | | | | | | |
| (Figure 57, misc. bldgs.) | 612 | 1,000 | 400 k | 150 k | 30 | 700 | 100 | Chipped concrete |
| | 632 | 100 | 140 k | 4 k | 1 | 1000 | 300 | Graphite |

TABLE 5

LOOSE CONTAMINATION - INTERIOR, SITEWIDE
(except Plant C)

| Smear Number | Location | Smear Results dis/min-100 $cm^2$ Beta-Gamma | Alpha |
|---|---|---|---|
| 117 | Area D - M1-2nd Floor | BKGD | 10 |
| 154 | Area D - M1-1st Floor | 50 | 5 |
| 181 | Area D - N1-1st Floor | 25 | 5 |
| 280 | Area B - Foundry | 100 | 10 |
| 288 | " | 100 | 10 |
| 290 | " | 50 | 5 |
| 291 | " | 500 | 50 |
| 299 | " | BKGD | 8 |
| 300 | " | BKGD | 8 |
| 303 | " | BKGD | 8 |
| 317 | " | 100 | 10 |
| 319 | " | 100 | 20 |
| 320 | " | 300 | 40 |
| 328 | " | 1000 | 100 |
| 330 | " | 200 | 40 |
| 331 | " | 200 | 50 |
| 336 | " | 500 | 100 |
| 339 | " | 100 | 10 |
| 340 | " | 300 | 30 |
| 343 | " | 700 | 70 |
| 344 | " | 300 | 40 |
| 345 | " | 600 | 80 |
| 346 | " | 300 | 30 |
| 347 | " | BKGD | 20 |
| 350 | " | 500 | BKGD |
| 388 | Area G - Warehouse | BKGD | 10 |
| 392 | " | BKGD | 10 |
| 445 | Area B - C Building | 100 | 6 |
| 446 | " | BKGD | 4 |
| 494 | " | 200 | 30 |
| 558 | Area H - K1 | 1000 | 200 |
| 612 | Area H - Miscellaneous | 700 | 100 |
| 632 | " | 1000 | 300 |

TABLE 6

WORKING-LEVEL AND RADON-CONCENTRATION DETERMINATIONS[f]

| Sample Number | Location | Working Level[a] | Radon ($^{222}Rn$) pCi/ℓ | Figure Number |
|---|---|---|---|---|
| Plant C | (See Figures 4, 5, 6) | | | |
| ANL-A | | 0.0069 | 0.69 | 5 |
| ANL-B | | 0.0025 | 0.25 | 4 |
| ANL-C | | 0.0031 | 0.31 | 4 |
| ANL-D | | 0.0062 | 0.62 | 4 |
| HASL-82 | | | $(1 \times 10^{-5})^b$ | 4 |
| HASL-84 | | | $(4 \times 10^{-6})^b$ | 5 |
| HASL-85 | | | $(7 \times 10^{-6})^b$ | 4 |
| HASL-86 | | | $(2 \times 10^{-3})^b$ | 4 |
| HASL-87 | | | $(3 \times 10^{-6})^b$ | 5 |
| HASL-88 | | | $(2 \times 10^{-5})^b$ | 4 |
| HASL-F1[c] | | 0.004 | | |
| HASL-F5[c] | | 0.0013 | | |
| HASL-5N[d] | | | 0.35 | 5 |
| HASL-6N[d] | | | e | 4 |
| Building-H3 | | | | |
| 2 | 1st Floor, southwest | 0.0034 | 0.34 | 31 |
| 3 | 2nd Floor, northeast | 0.0013 | 0.13 | 32 |
| Remainder of Complex | | | | |
| 1 | P-1, 1st Floor | 0.0033 | 0.33 | 28 |
| 4 | P-1, 2nd Floor | 0.0012 | 0.12 | 29 |
| 5 | P-1, Center | 0.0029 | 0.29 | 28 |
| 6 | P-1, 2nd Floor | 0.0029 | 0.29 | 29 |
| 7 | M-1, 1st Floor | 0.0034 | 0.34 | 36 |
| 8 | M-1, 1st Floor | 0.0031 | 0.31 | 36 |
| 9 | M-1, 2nd Floor | 0.0035 | 0.35 | 37 |
| 10 | M-1, 2nd Floor | 0.0028 | 0.28 | 37 |
| 11 | R-1, 2nd Floor | 0.0035 | 0.35 | 39 |
| 12 | N-3, 1st Floor | 0.0013 | 0.13 | 40 |
| 13 | N-1 Dock | 0.0034 | 0.34 | 40 |
| 14 | Dept. Office | 0.0043 | 0.43 | 45 |
| 15 | Garage | 0.0037 | 0.37 | 20 |
| 16 | Administration-Gate House | 0.0043 | 0.43 | 18 |
| 17 | Warehouse-Process Area | 0.0033 | 0.33 | 51 |
| 18 | Warehouse-Instrument Shop | 0.0044 | 0.44 | 51 |

TABLE 6
(cont'd.)

| Sample Number | Location | Working WL[a] | Radon ($^{222}Rn$) pCi/ℓ | Figure Number |
|---|---|---|---|---|
| 19 | Warehouse-Technical Area | 0.0044 | 0.44 | 50 |
| 20 | Warehouse-Analytical | 0.0060 | 0.60 | 50 |
| 21 | Foundry | 0.0038 | 0.38 | 26 |
| 22 | Foundry | 0.0056 | 0.56 | 26 |
| 23 | Foundry-Pump Room | 0.0049 | 0.49 | 26 |
| 24 | Foundry-Maintenance Shop | 0.0042 | 0.42 | 26 |
| 25 | Foundry-Supply Room | 0.0017 | 0.17 | 26 |
| 26 | H-2 | 0.0059 | 0.59 | 34 |
| 27 | H-1 | 0.0050 | 0.50 | 34 |
| 28 | H-1 | 0.0050 | 0.50 | 34 |
| 29 | Boiler House | 0.0047 | 0.47 | 42 |
| 30 | M-2 | 0.0050 | 0.50 | 46 |
| 31 | Warehouse | 0.0058 | 0.58 | 49 |
| 32 | Warehouse | 0.0065 | 0.65 | 49 |
| 33 | Warehouse | 0.0043 | 0.43 | 49 |
| 34 | Warehouse | 0.0041 | 0.41 | 49 |
| 35 | C-4, 1st Floor | 0.0039 | 0.39 | 21 |
| 36 | C-5, 1st Floor | 0.0037 | 0.37 | 21 |
| 37 | C-2, 1st Floor | 0.0037 | 0.37 | 21 |
| 38 | C-7, 1st Floor | 0.0028 | 0.28 | 21 |
| 39 | C-8, 2nd Floor | 0.0020 | 0.20 | 22 |
| 40 | C-2, 2nd Floor | 0.0032 | 0.32 | 22 |
| 41 | C-4, 2nd Floor | 0.0037 | 0.37 | 22 |
| 42 | C-3, 2nd Floor | 0.0027 | 0.27 | 22 |
| 43 | C-4 (Same location as 41) | 0.0057 | 0.57 | 22 |
| 44 | K-1 | 0.0030 | 0.30 | 53 |
| 45 | K-1 | 0.0042 | 0.42 | 53 |
| 46 | K-1 | 0.0008 | 0.08 | 53 |
| 47 | K-1 | 0.0017 | 0.17 | 53 |
| 48 | K-1, Stockroom | 0.0011 | 0.11 | 53 |
| 49 | C-1 | 0.0006 | 0.06 | 24 |
| 50 | K-1, Control Lab | 0.0042 | 0.42 | 53 |
| 51 | K-1, Laboratory SW | 0.0057 | 0.57 | 53 |
| 52 | Quonset Hut | 0.0040 | 0.40 | 48 |
| 53 | L-1, 2nd Level | 0.0027 | 0.27 | 55 |
| 54 | K-3, Shed Storage | 0.0026 | 0.26 | 57 |
| 55 | Shed | 0.0018 | 0.18 | 57 |
| 56 | B-1, Storage | 0.0007 | 0.07 | 17 |

TABLE 6
(cont'd.)

[a]A Working Level (WL) is defined in 10 CFR 712 as any combination of short-lived radon-daughter products in 1 liter of air that will result in the ultimate emission of $1.3 \times 10^5$ MeV of potential alpha energy. The numerical value of the WL is derived from the alpha energy released by the total decay through RaC' of the short-lived radon-daughter products, RaA, RaB, and RaC at radioactive equilibrium with 100 pCi of $^{222}Rn$ per liter of air.

[b]Radon flux (charcoal canisters); units - $pCi/cm^2$-s.

[c]Working Level Monitor

[d]TLD air samplers

[e]TLD chips lost; hence no determination.

[f]No significant airborne particulate contamination was found in any air sample.

TABLE 7

GAMMA SPECTRAL AND URANIUM FLUOROMETRIC ANALYSES OF SOIL SAMPLES

| Sample[b] Number | Gamma Spectra, pCi/g±σ | | | Uranium Fluorometric | |
|---|---|---|---|---|---|
| | $^{137}Cs$ | $^{232}Th$ Decay Chain | $^{226}Ra$ Decay Chain | µg/g±10% | pCi/g[a]±10% |
| FL-1 | <0.06 | <0.06 | 0.6 ±0.1 | 2.1± 0.2 | 1.5± 0.2 |
| BP-1A | 0.78±0.06 | 0.78±0.09 | 0.9 ±0.1 | 3.3± 0.3 | 2.3± 0.2 |
| BP-1B | | | | 3.6± 0.4 | 2.3± 0.2 |
| BP-1C | | | | 8.9± 0.9 | 6.2± 0.6 |
| BP-1D | | | | 5.0± 0.5 | 3.5± 0.4 |
| BP-2A | 1.32±0.08 | 0.9 ±0.1 | 0.7 ±0.1 | 3.5± 0.4 | 2.4± 0.3 |
| BP-2B | | | | 3.4± 0.4 | 2.4± 0.3 |
| BP-2C | | | | 4.6± 0.5 | 3.2± 0.3 |
| BP-2D | | | | 3.3± 0.4 | 2.3± 0.3 |
| MW-1A | 0.63±0.05 | 0.9± 0.2 | 1.20±0.06 | 4.5± 0.5 | 3.1± 0.3 |
| MW-1B | | | | 9.0± 0.9 | 6.3± 0.6 |
| MW-1C | | | | 5.1± 0.5 | 3.6± 0.4 |
| MW-1D | | | | 7.1± 0.7 | 5.0± 0.5 |
| MW-2A | 0.50±0.04 | 1.1 ±0.2 | 1.24±0.06 | 6.8± 0.7 | 4.8± 0.5 |
| MW-2B | | | | 6.5± 0.7 | 4.5± 0.5 |
| MW-2C | | | | 7.4± 0.7 | 5.2± 0.5 |
| MW-2D | | | | 5.5± 0.6 | 3.8± 0.4 |
| PC-1A | <0.07 | 1.00±0.08 | 0.72±0.04 | 44 ± 4 | 31 ± 3 |
| PC-1B | | | | 110 ± 11 | 77 ± 8 |
| PC-1C | | | | 1700 ±170 | 1190 ±120 |
| PC-1D | | | | 220 ± 22 | 150 ± 15 |
| PC-2A | 0.22±0.02 | 0.7 ±0.2 | 0.80±0.05 | 11 ± 1 | 7.7± 0.8 |
| PC-2B | | | | 12 ± 1 | 8.4± 0.8 |
| PC-2C | | | | 11 ± 1 | 7.7± 0.8 |
| PC-2D | | | | 15 ± 2 | 10.5± 1.1 |
| PC-3A | 0.09±0.03 | 0.3 ±0.1 | 0.35±0.03 | 10 ± 1 | 7.0± 0.7 |
| PC-3B | | | | 29 ± 3 | 20 ± 2 |
| PC-3C | | | | 21 ± 2 | 15 ± 2 |
| PC-3D | | | | 13 ± 1 | 9 ± 1 |
| PC-4A | 0.27±0.02 | 0.98±0.06 | 2.3 ±0.1 | 110 ± 11 | 77 ± 8 |
| PC-4B | | | | 1300 ±130 | 910 ± 90 |
| PC-4C | | | | 460 ± 46 | 320 ± 32 |
| PC-4D | | | | 2600 ±260 | 1820 ±180 |

TABLE 7
(cont'd.)

| Sample Number | Gamma Spectra, pCi/g±σ $^{137}Cs$ | Gamma Spectra, pCi/g±σ $^{232}Th$ Decay Chain | Gamma Spectra, pCi/g±σ $^{226}Ra$ Decay Chain | Uranium Fluorometric μg/g±10% | Uranium Fluorometric pCi/g±10% |
|---|---|---|---|---|---|
| PC-5A | 0.23±0.04 | 0.8 ±0.1 | 0.83±0.06 | 17 ± 2 | 12 ± 1 |
| PC-5B | | | | 13 ± 1 | 9 ± 1 |
| PC-5C | | | | 15 ± 2 | 10 ± 1 |
| PC-5D | | | | 13 ± 1 | 9 ± 1 |
| PC-6A | 4.9 ±0.2 | 0.90±0.07 | 1.54±0.08 | 12 ± 1 | 8 ± 1 |
| PC-6B | | | | 10 ± 1 | 7 ± 1 |
| PC-6C | | | | 4 ± 0.4 | 3 ± 0.3 |
| PC-6D | | | | 12 ± 1 | 8 ± 1 |

[a]Conversion factor based on values in Appendix 5.

[b]Each soil core was 12 in long and was divided into four segments for analysis. Starting from the surface, three, 2-in segments were cut and labeled A, B, and C, respectively; the final segment of 6-in was labeled D (see Fig. 3).

ANL-HP DWG. NO. 80-1

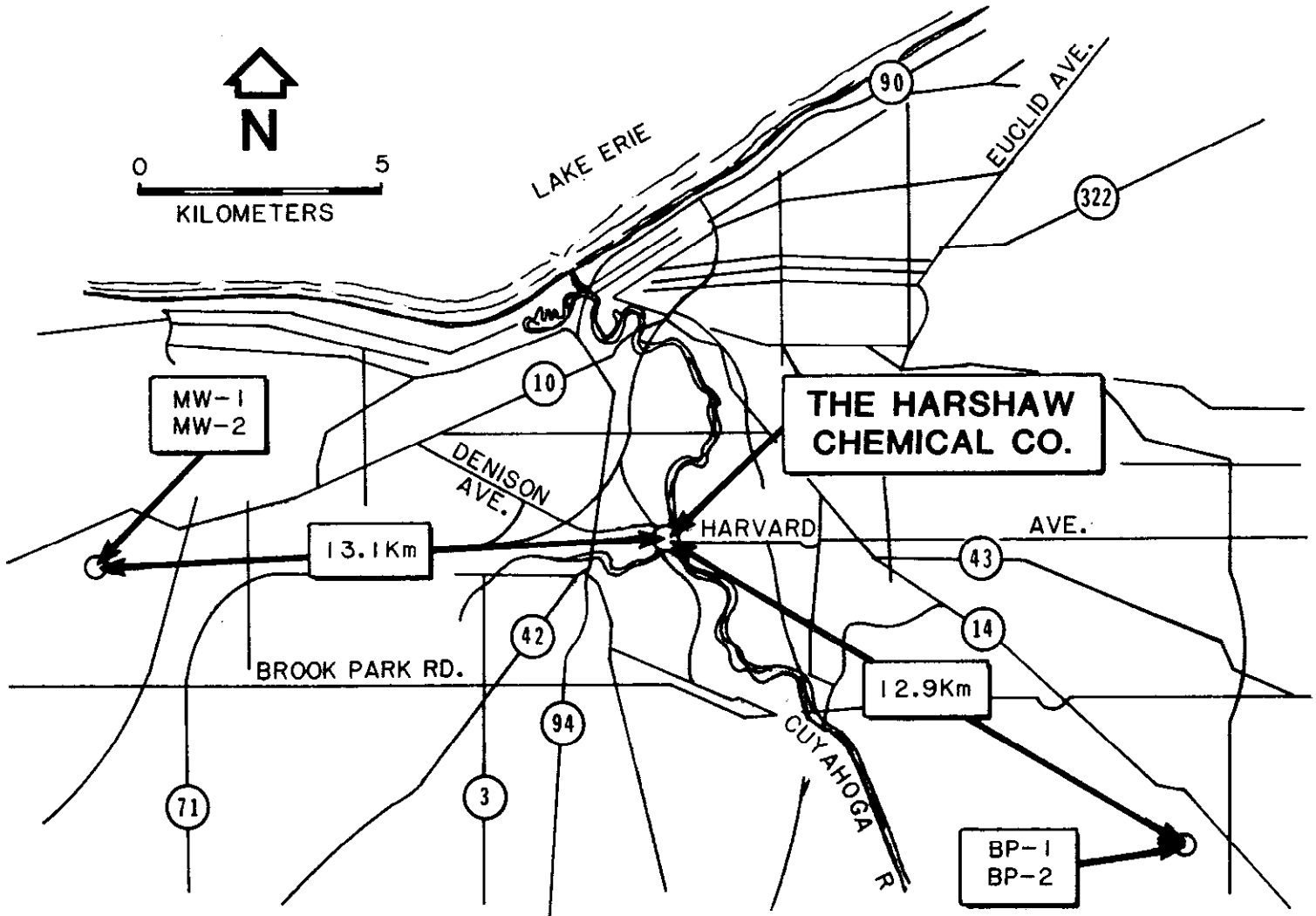



Figure 1. Map of Cleveland Area Showing Location of Harshaw Complex and Background Soil Samples.

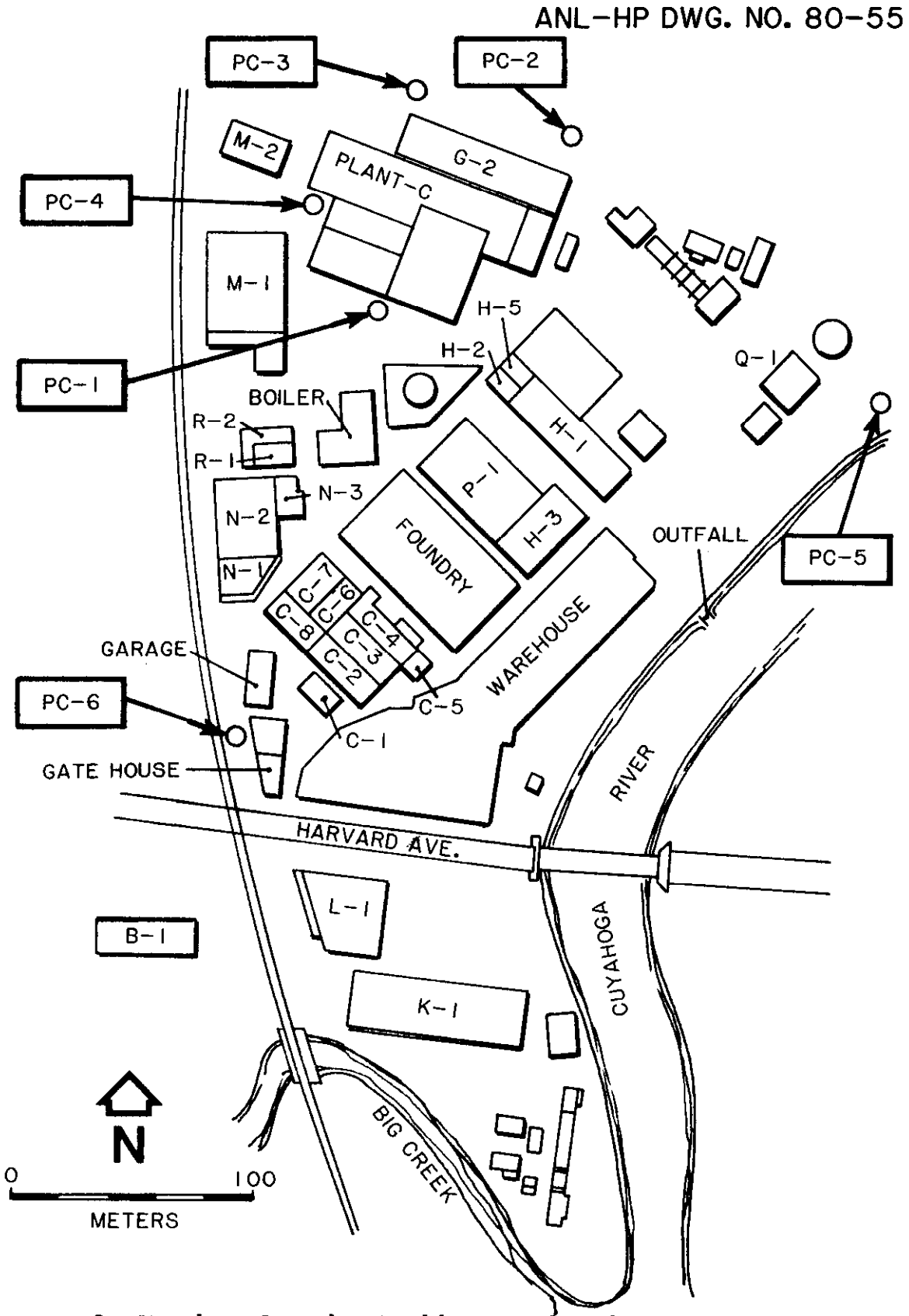



Figure 2. Harshaw Complex Buildings and Soil Sample Locations.

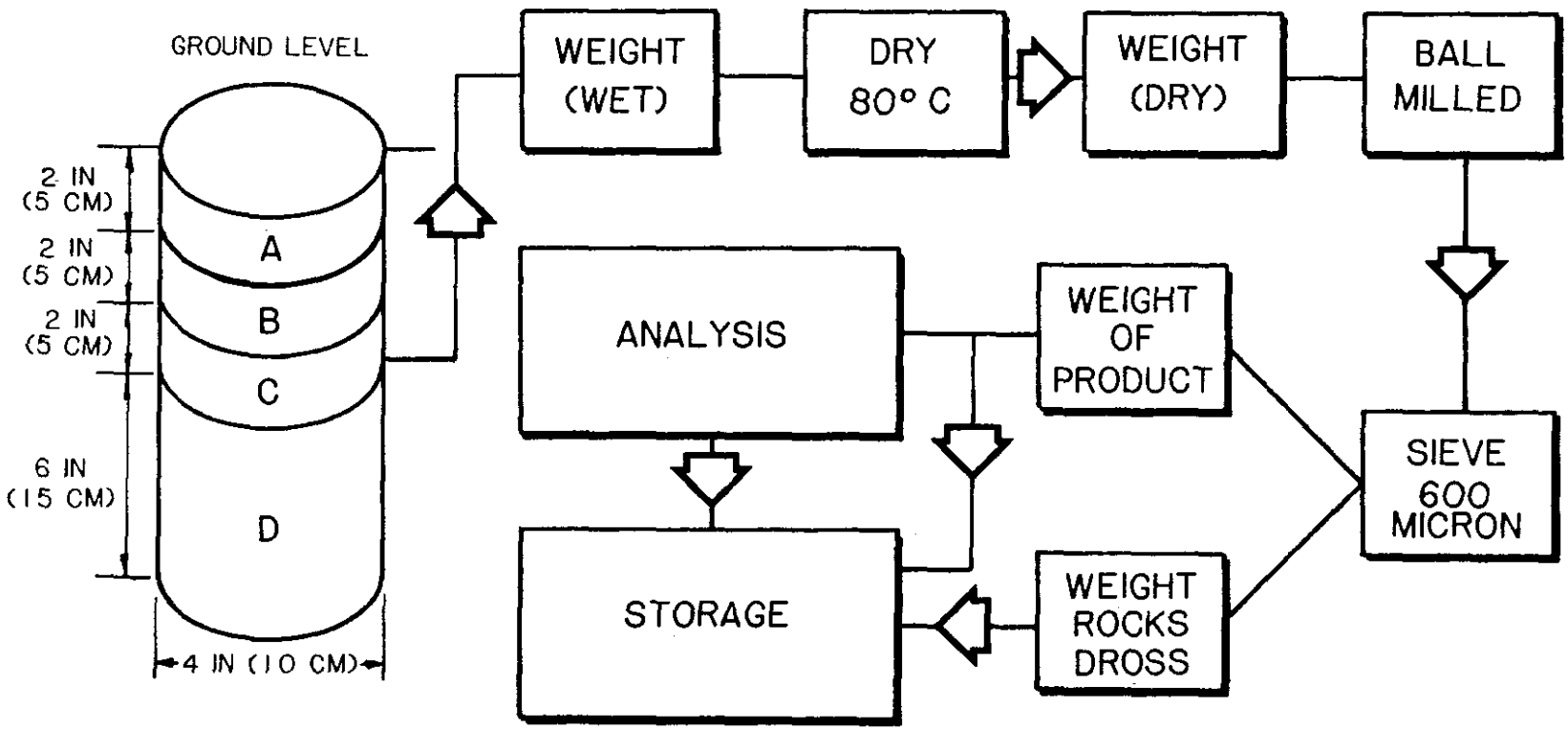



Figure 3. Soil and Sewer Sludge Sample Processing.

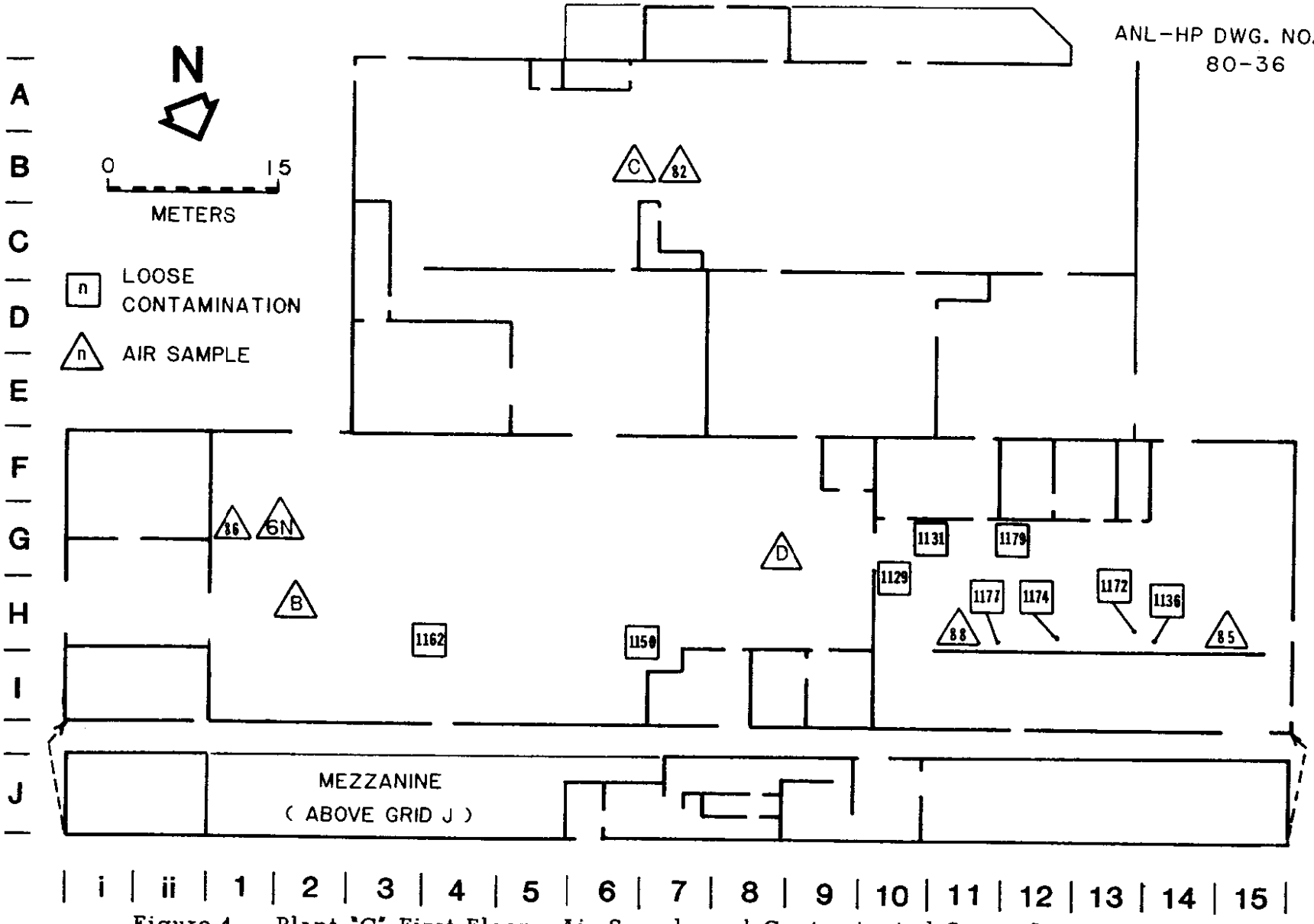



Figure 4. Plant "C" First Floor. Air Sample and Contaminated Smear Locations.

ANL-HP DWG. NO. 80-37

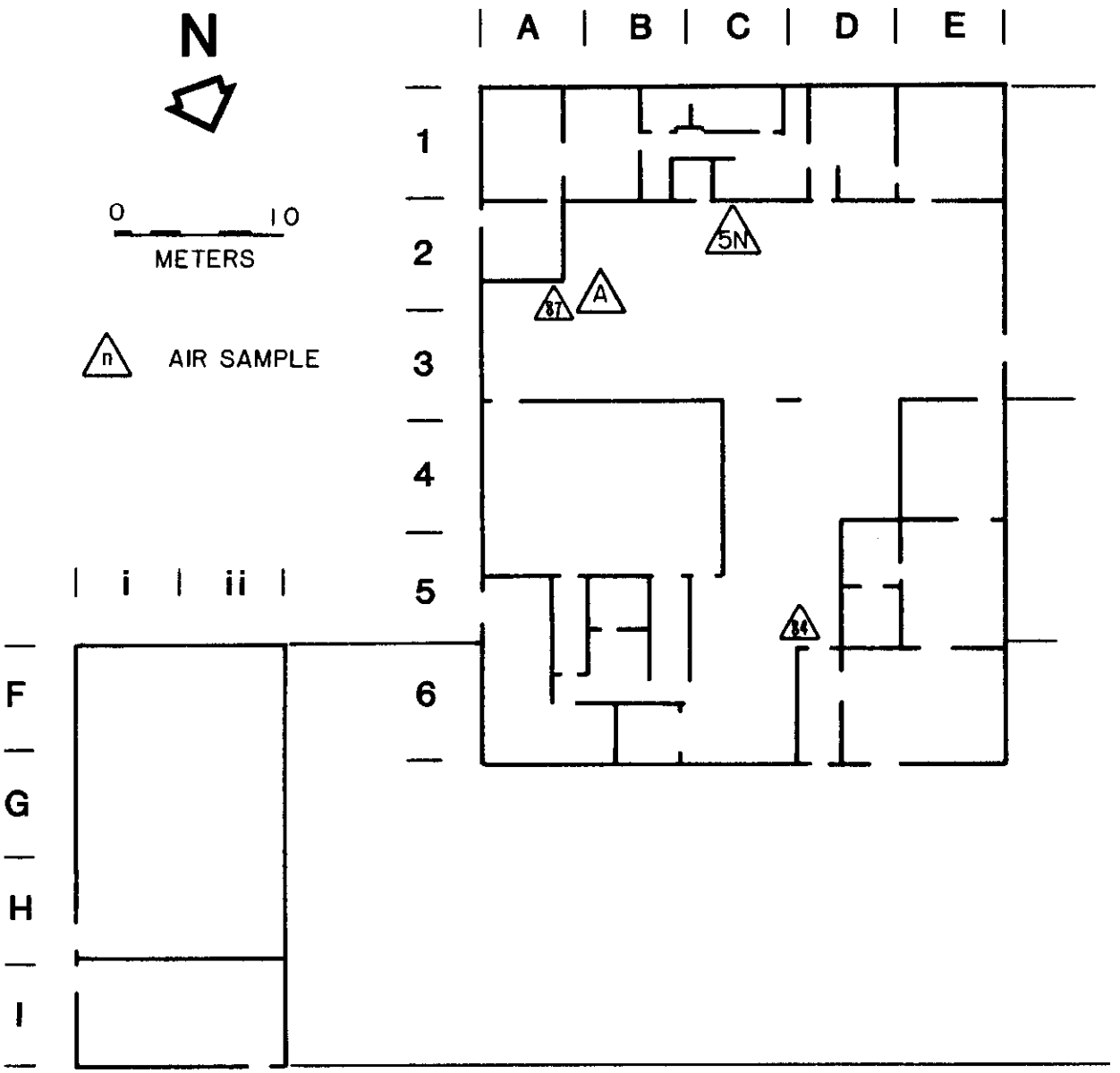



Figure 5. Plant "C" Second Floor Air Sample Locations.

ANL-HP DWG. NO. 80-39

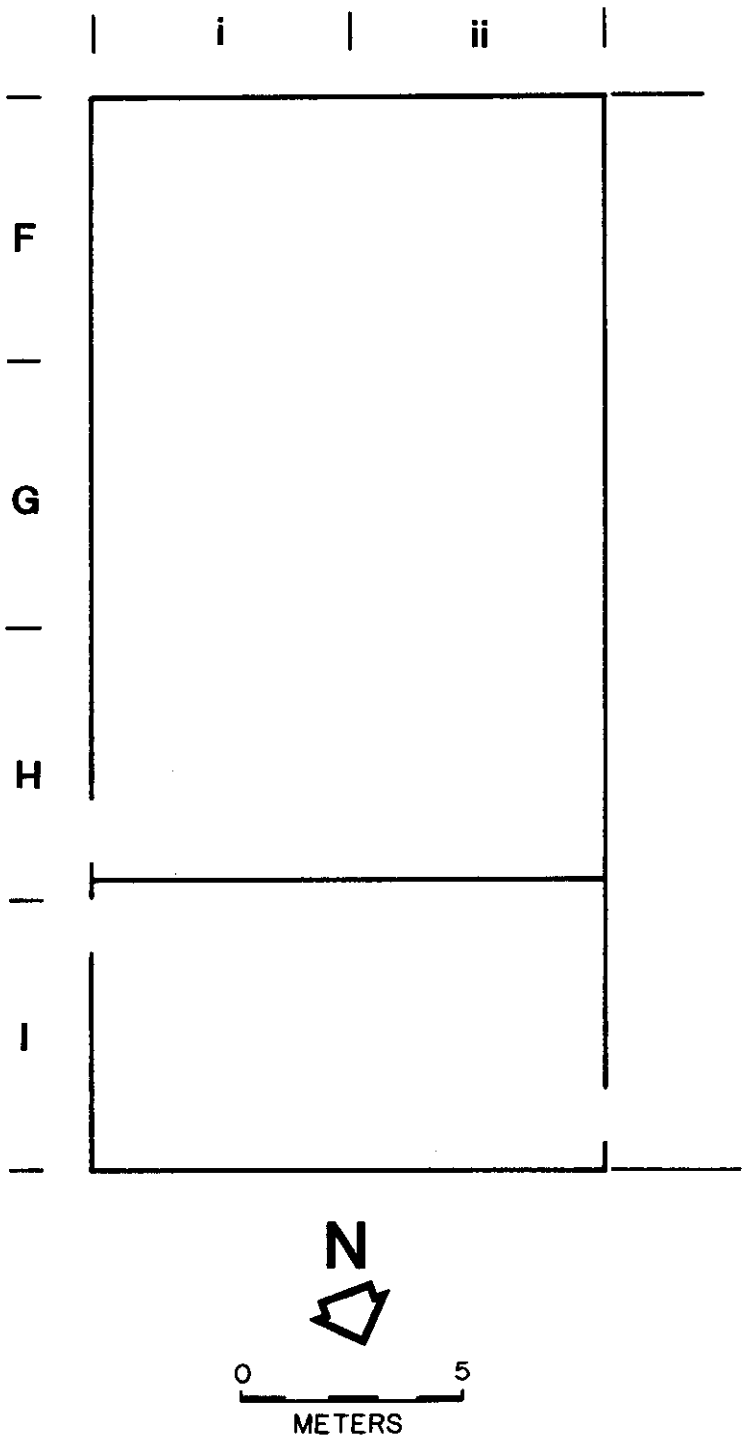



Figure 6. Plant "C" Third Floor.

ANL-HP DWG. NO. 80-40

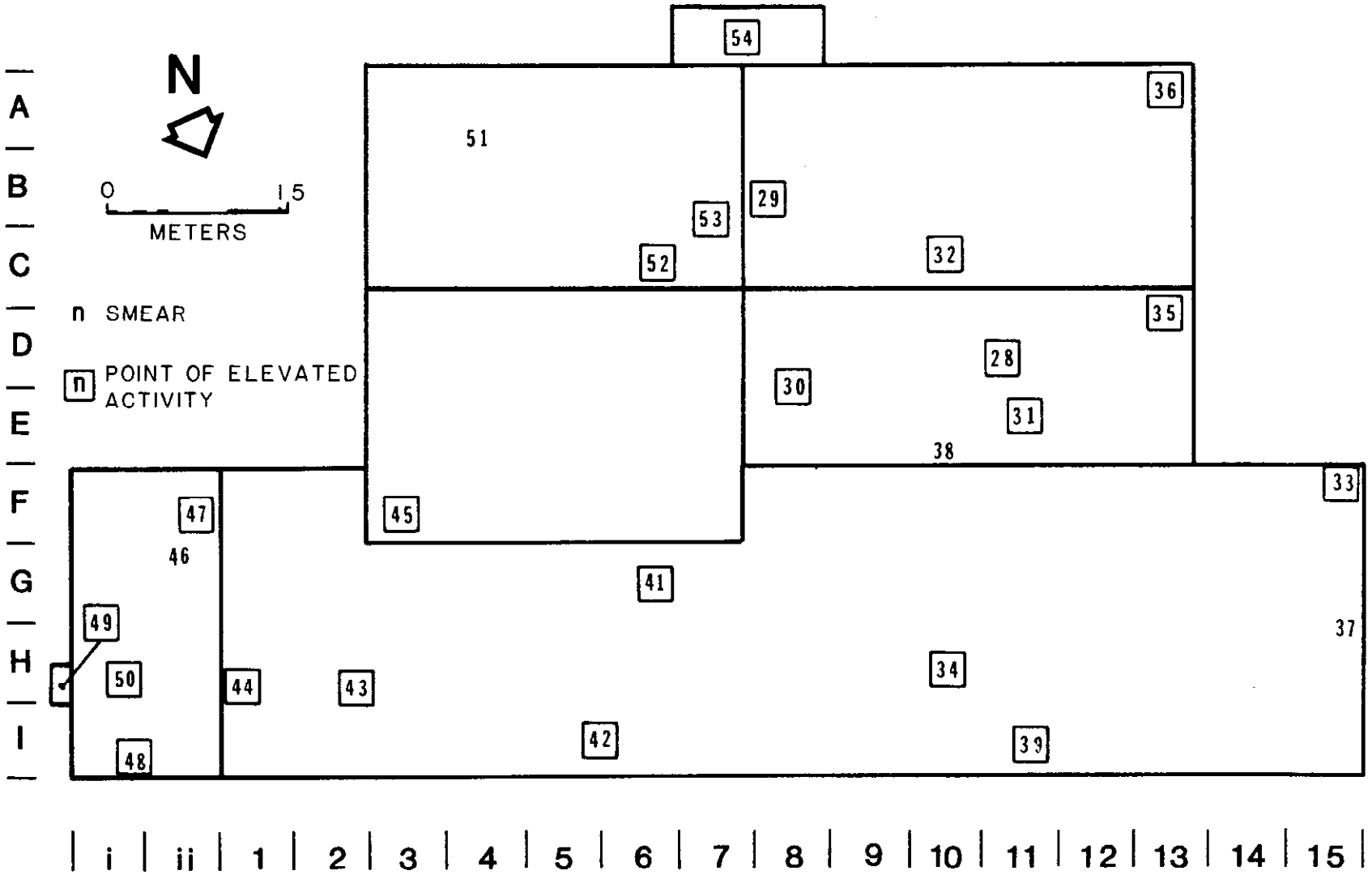



Figure 7. Plant "C" Roof Survey Locations.

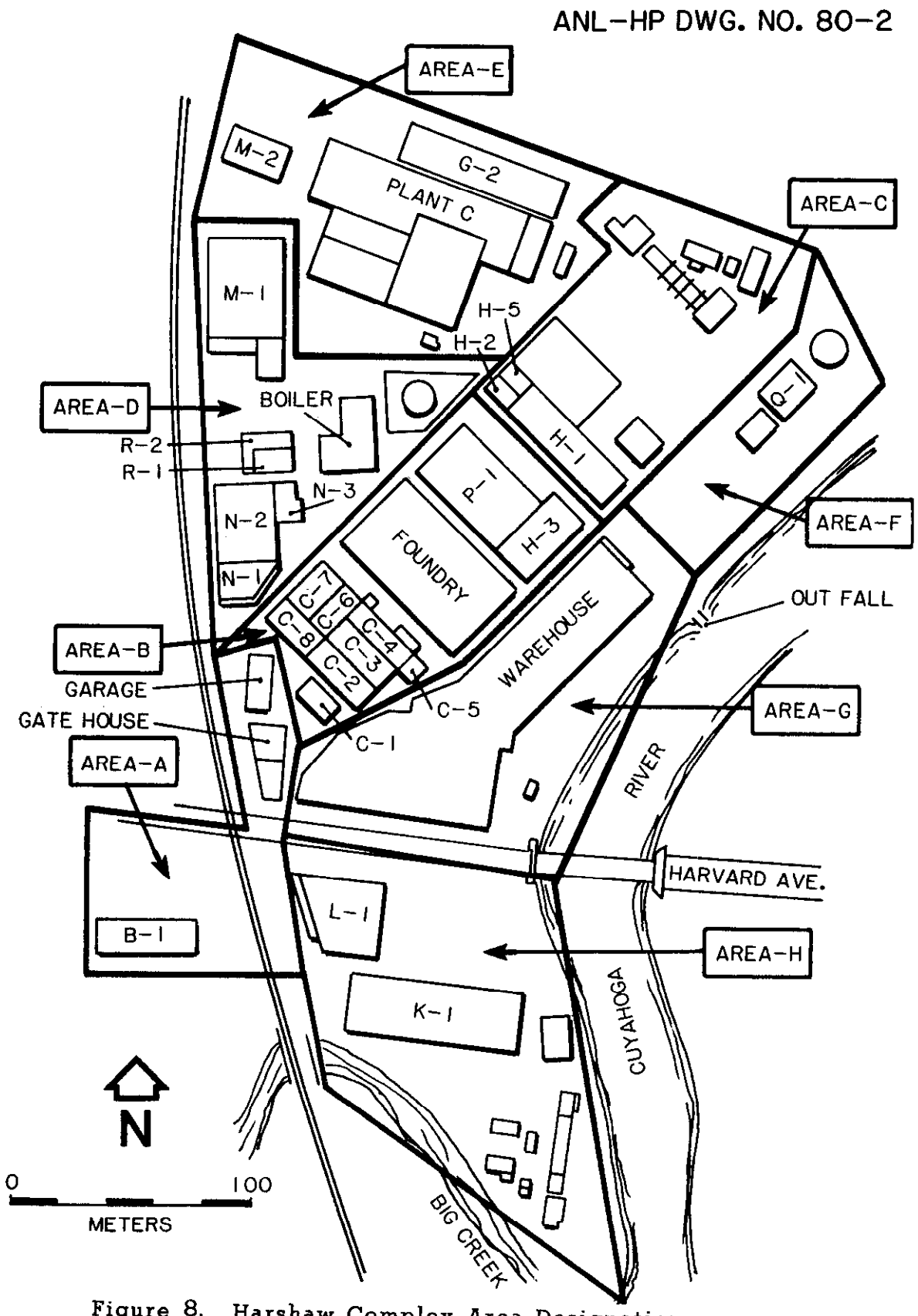



Figure 8. Harshaw Complex Area Designations.

ANL-HP DWG.NO. 80-3

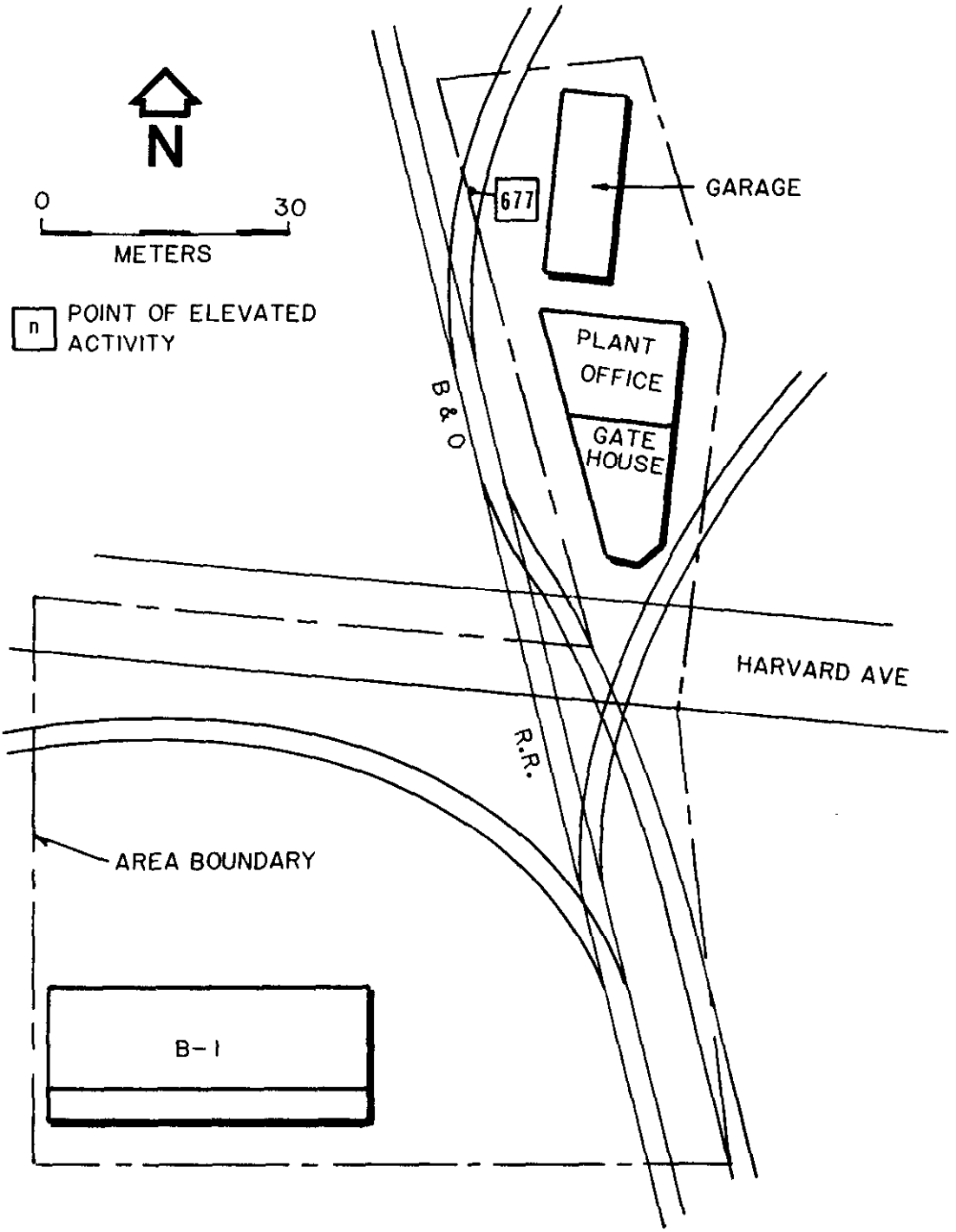



Figure 9. Ground Surveys in Area "A".

ANL-HP DWG. NO. 80-4

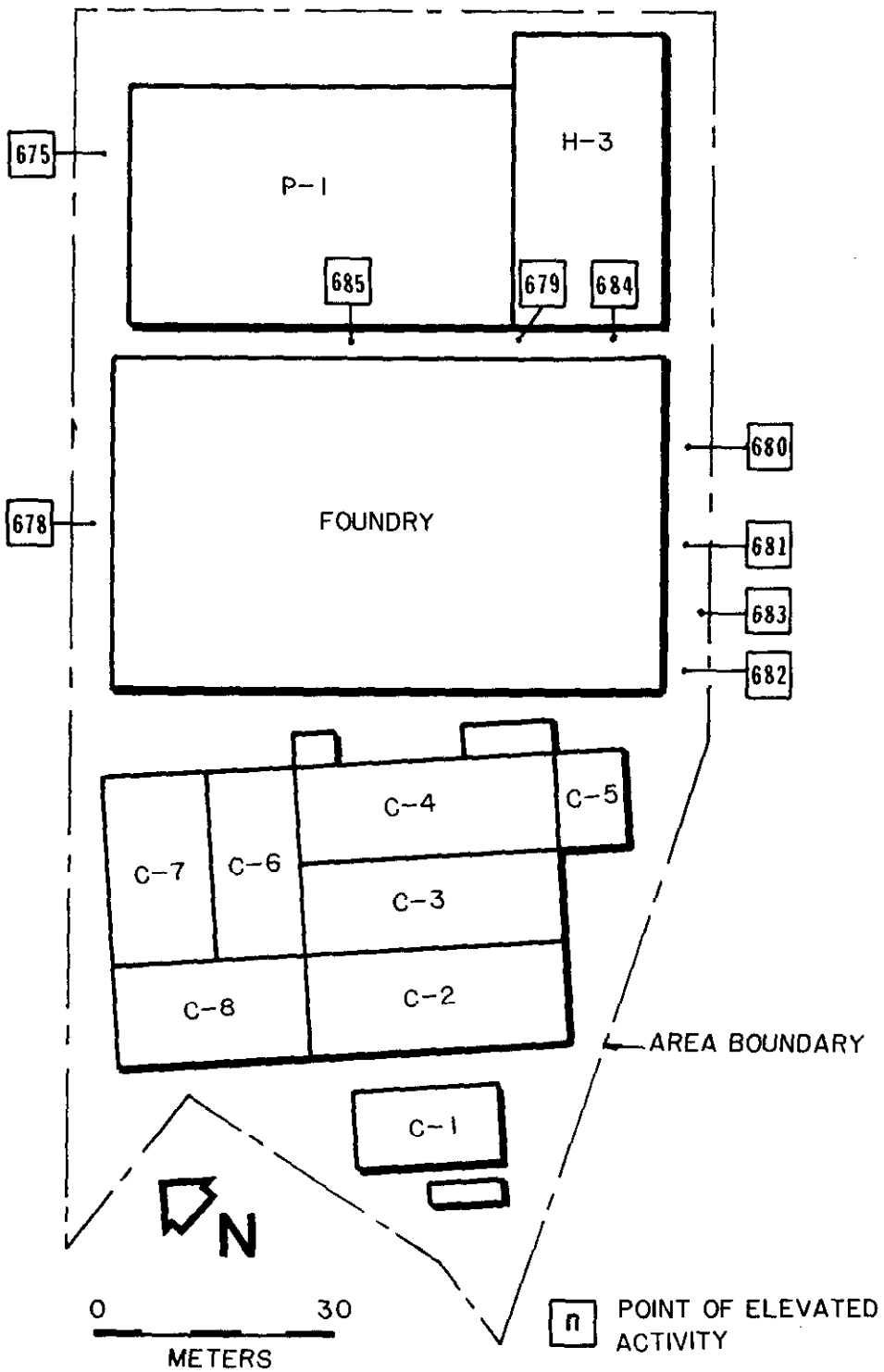



Figure 10. Ground Surveys in Area "B".

ANL-HP DWG. NO. 84-6

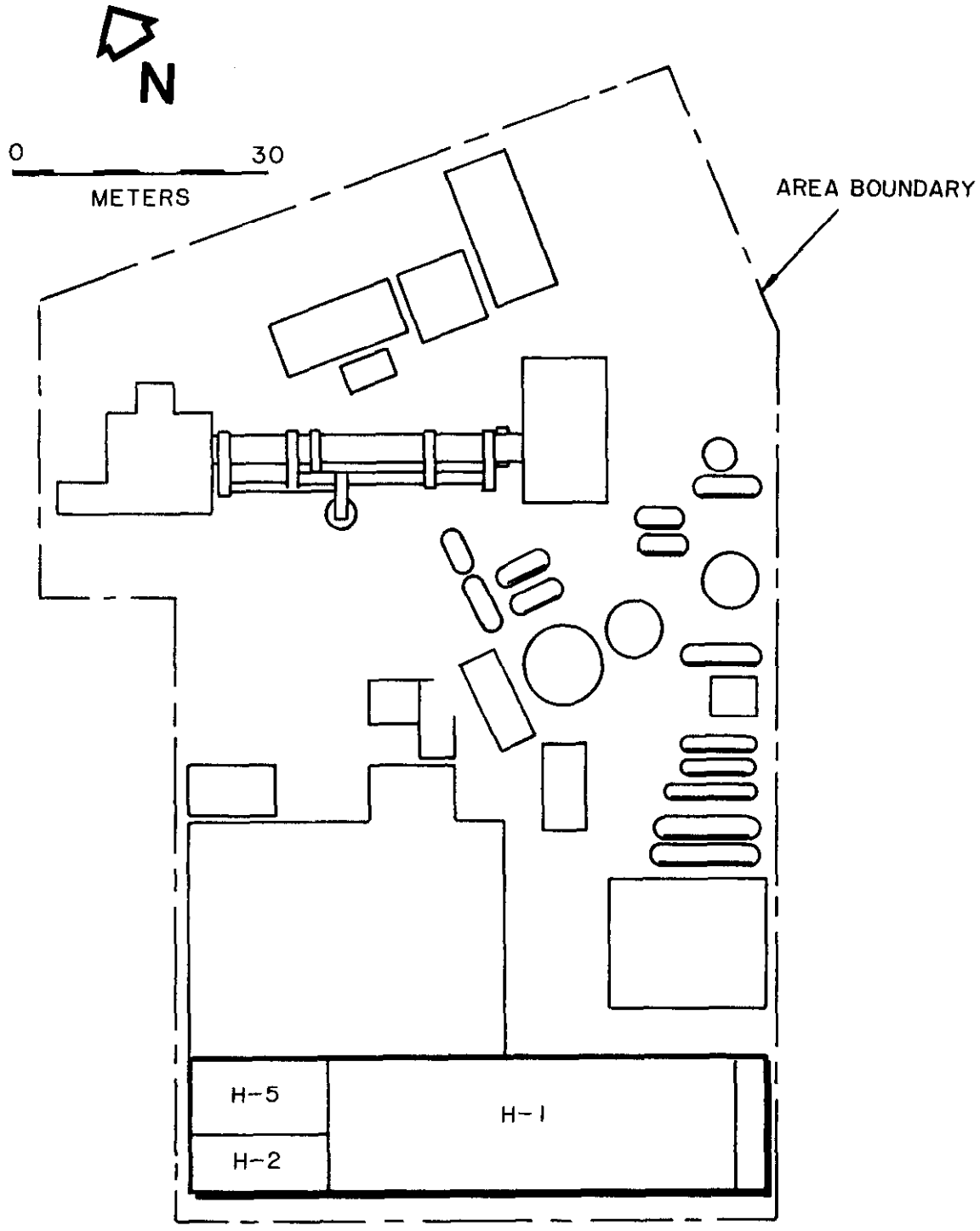



Figure 11. Ground Surveys in Area "C".

ANL-HP DWG.NO. 80-5

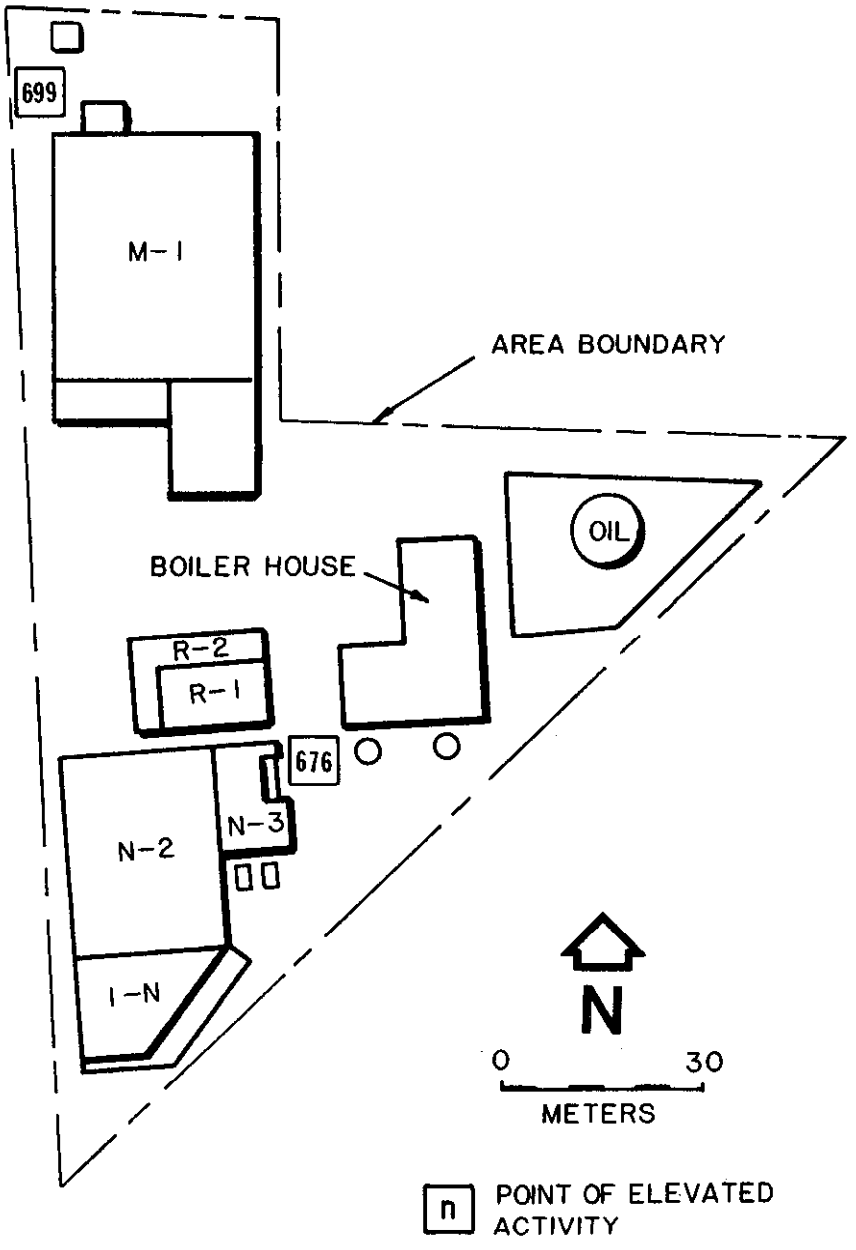



Figure 12. Ground Surveys in Area "D".

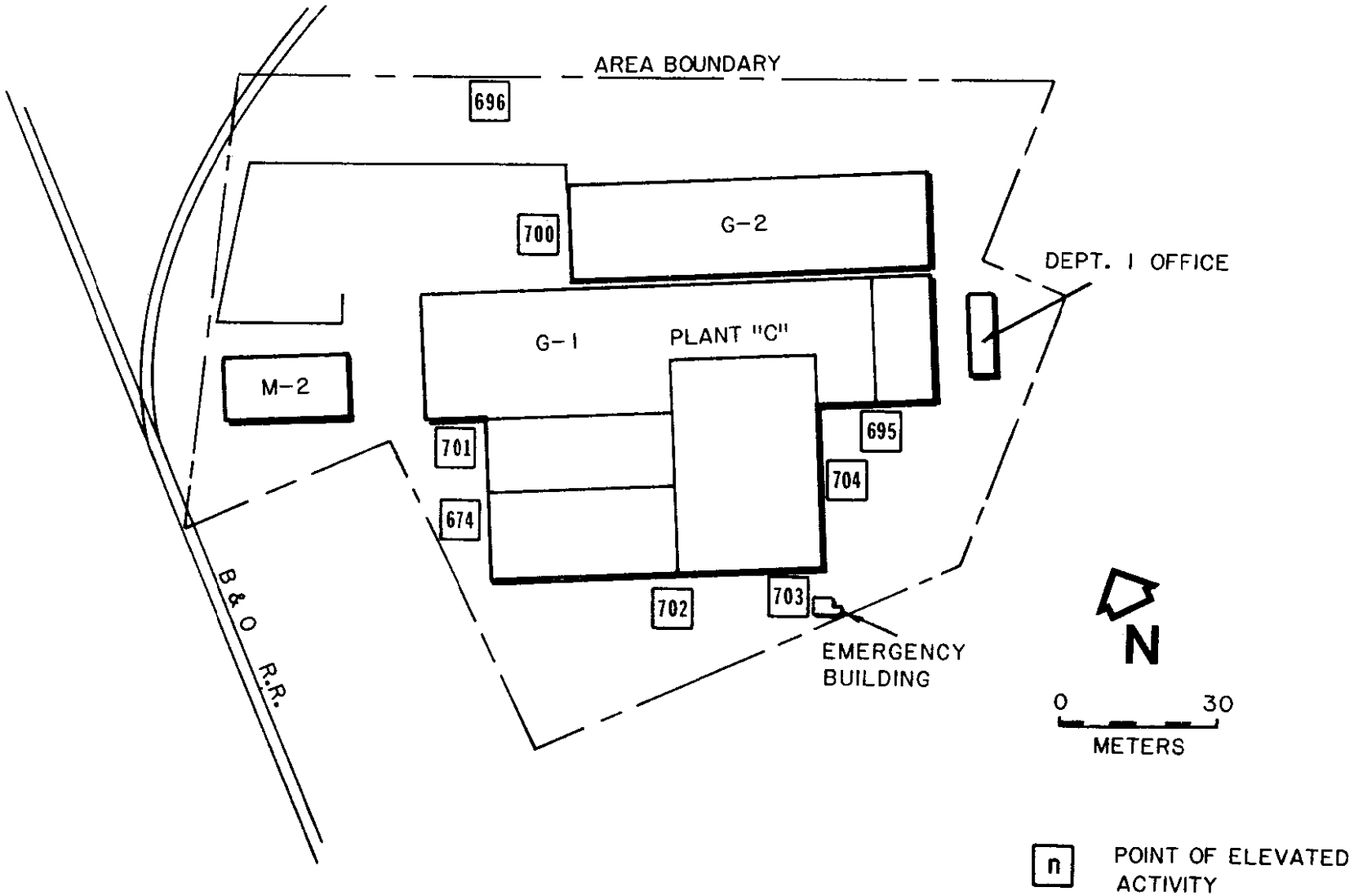



Figure 13. Ground Surveys in Area "E".

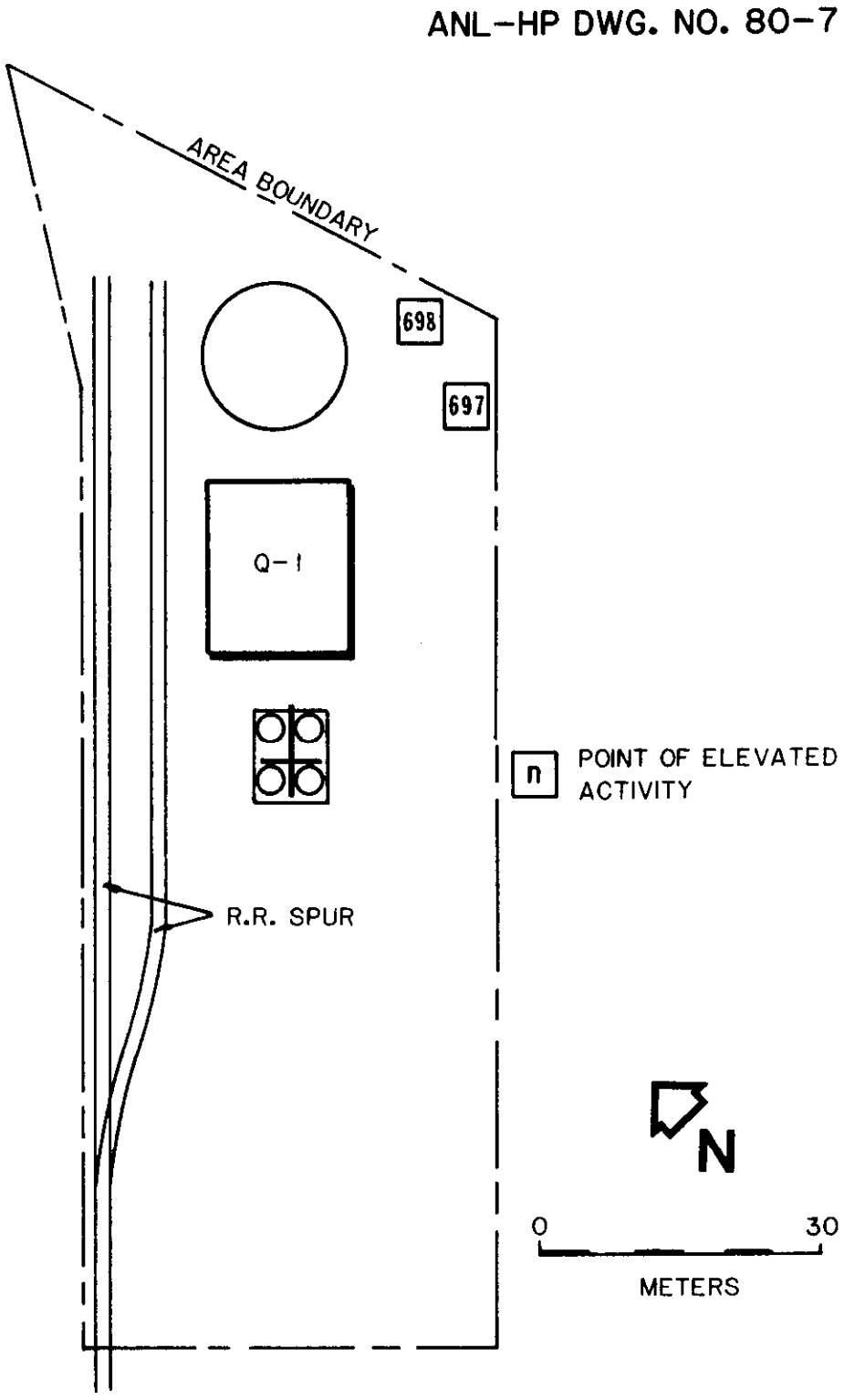



**Figure 14.** Ground Surveys in Area "F".

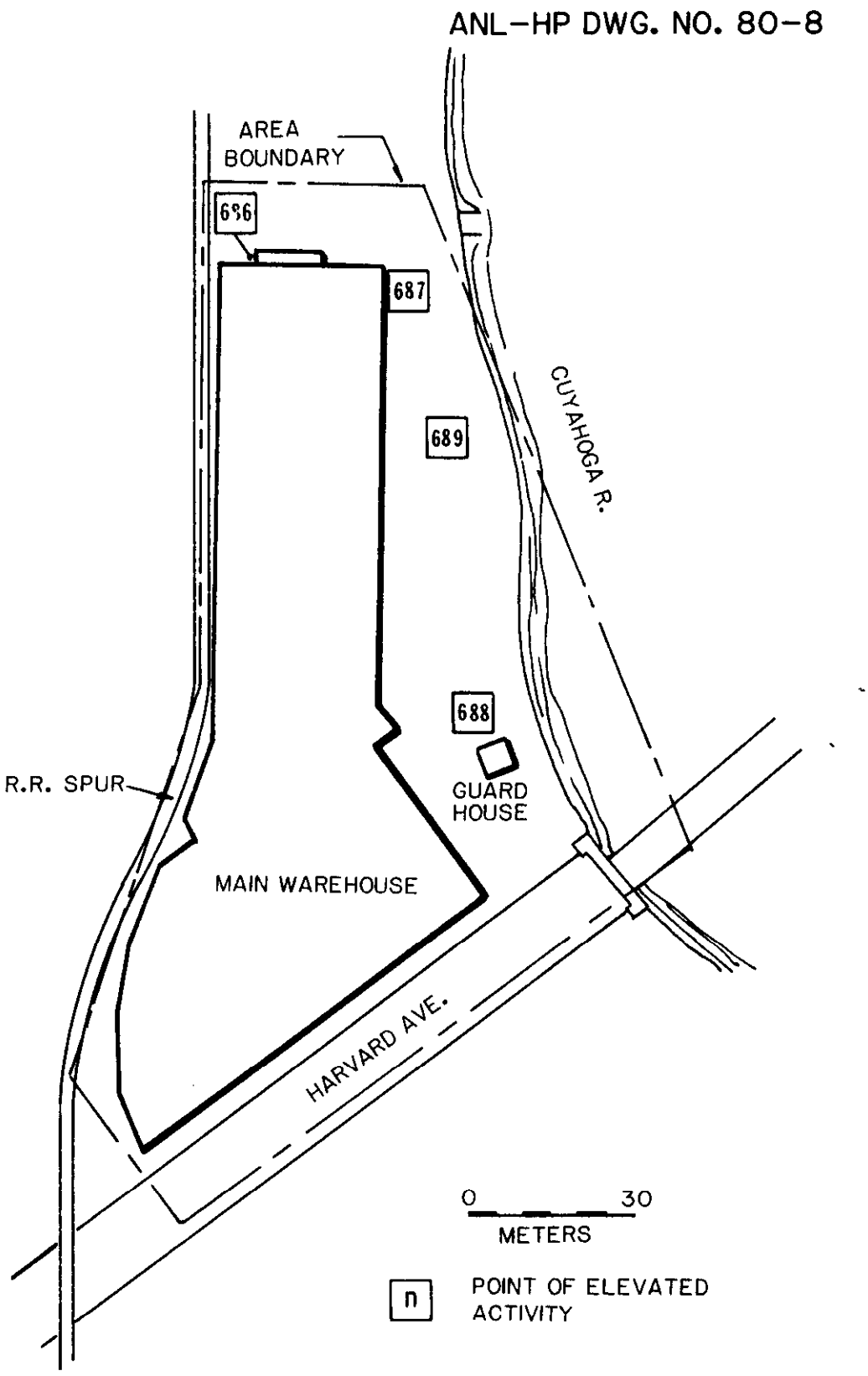



Figure 15. Ground Surveys in Area "G".

ANL-HP DWG. NO. 80-9

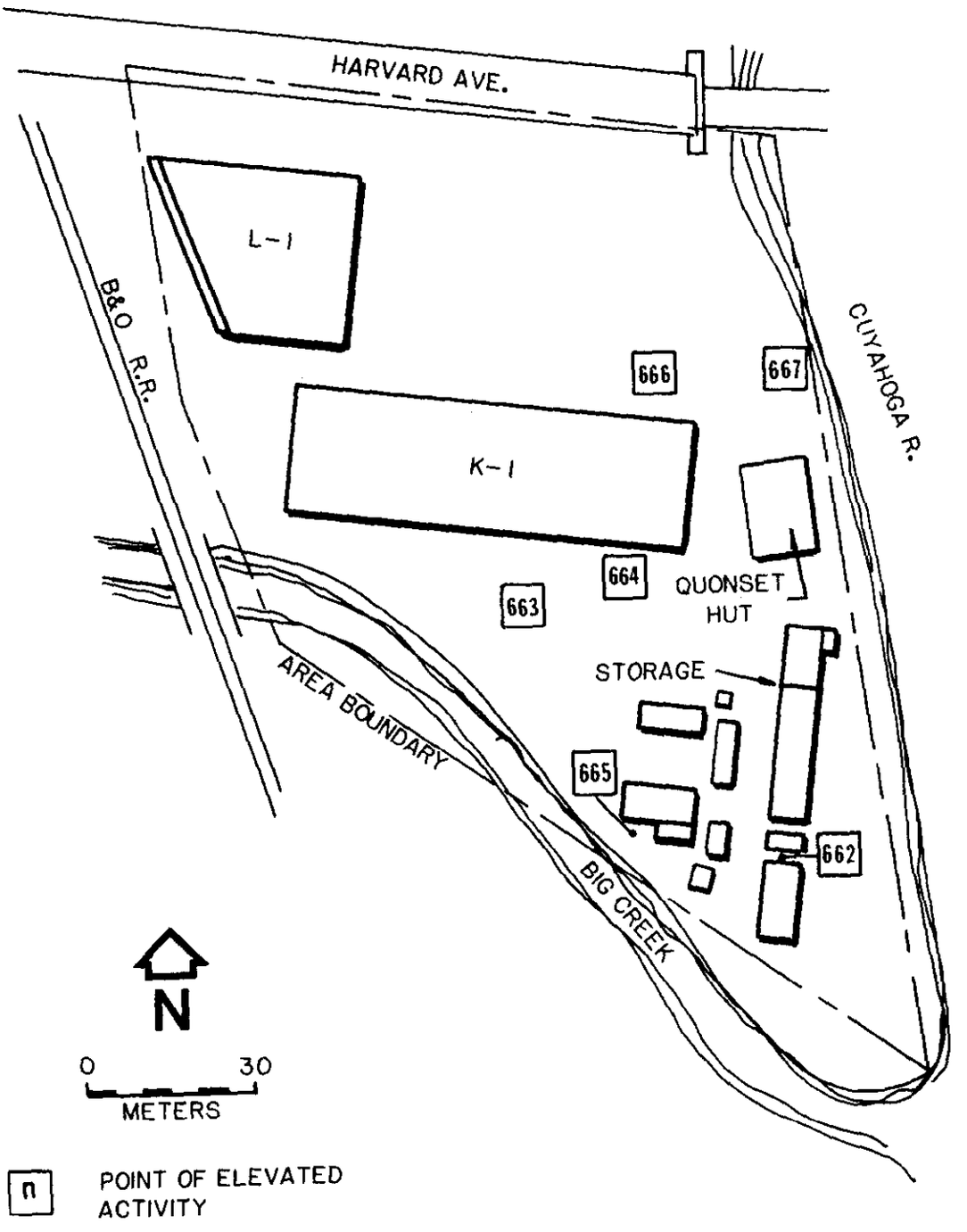



Figure 16. Ground Surveys in Area "H".

ANL-HP DWG. NO. 80-10

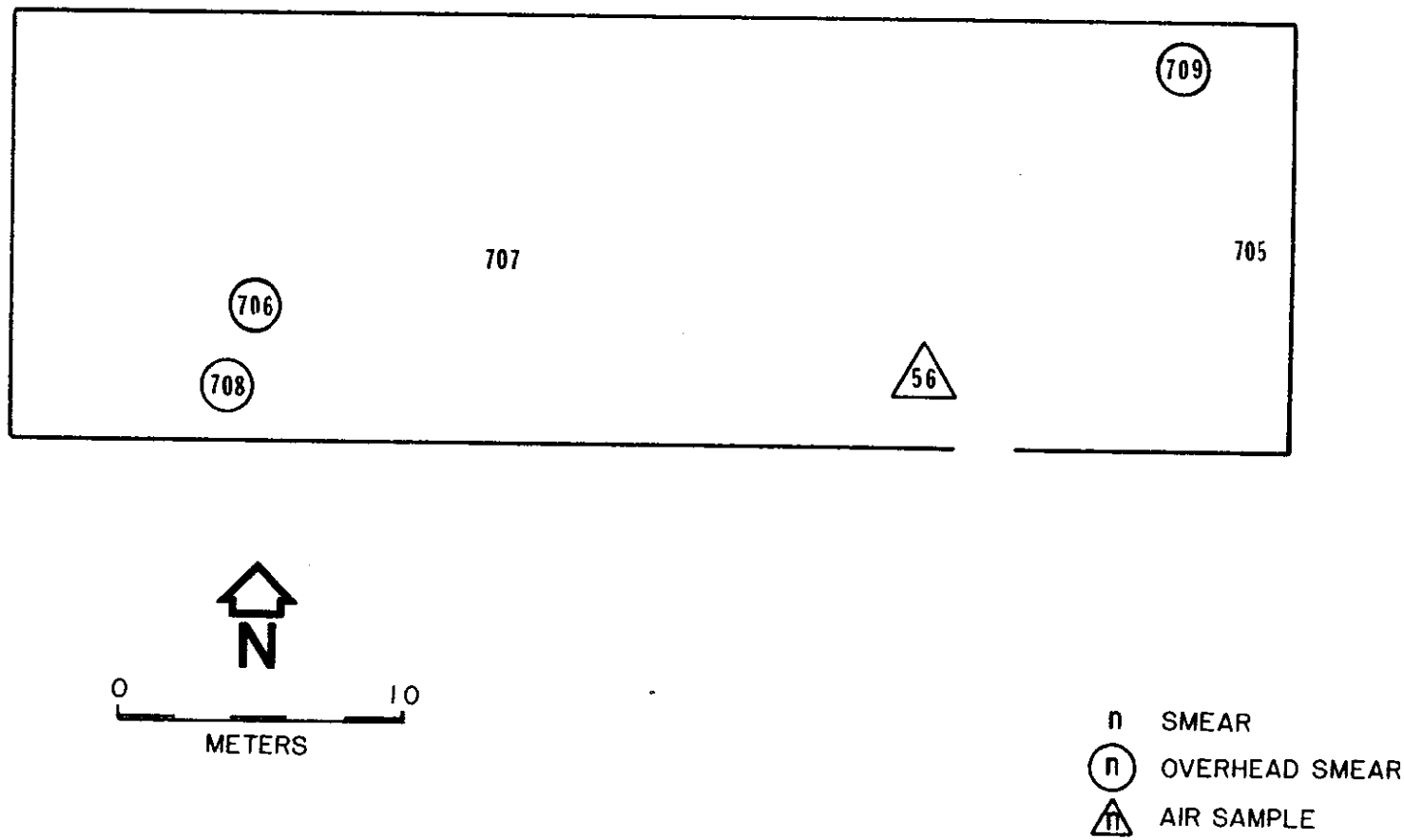



Figure 17. Building B-1 Survey Locations.

ANL-HP DWG. NO. 80-11

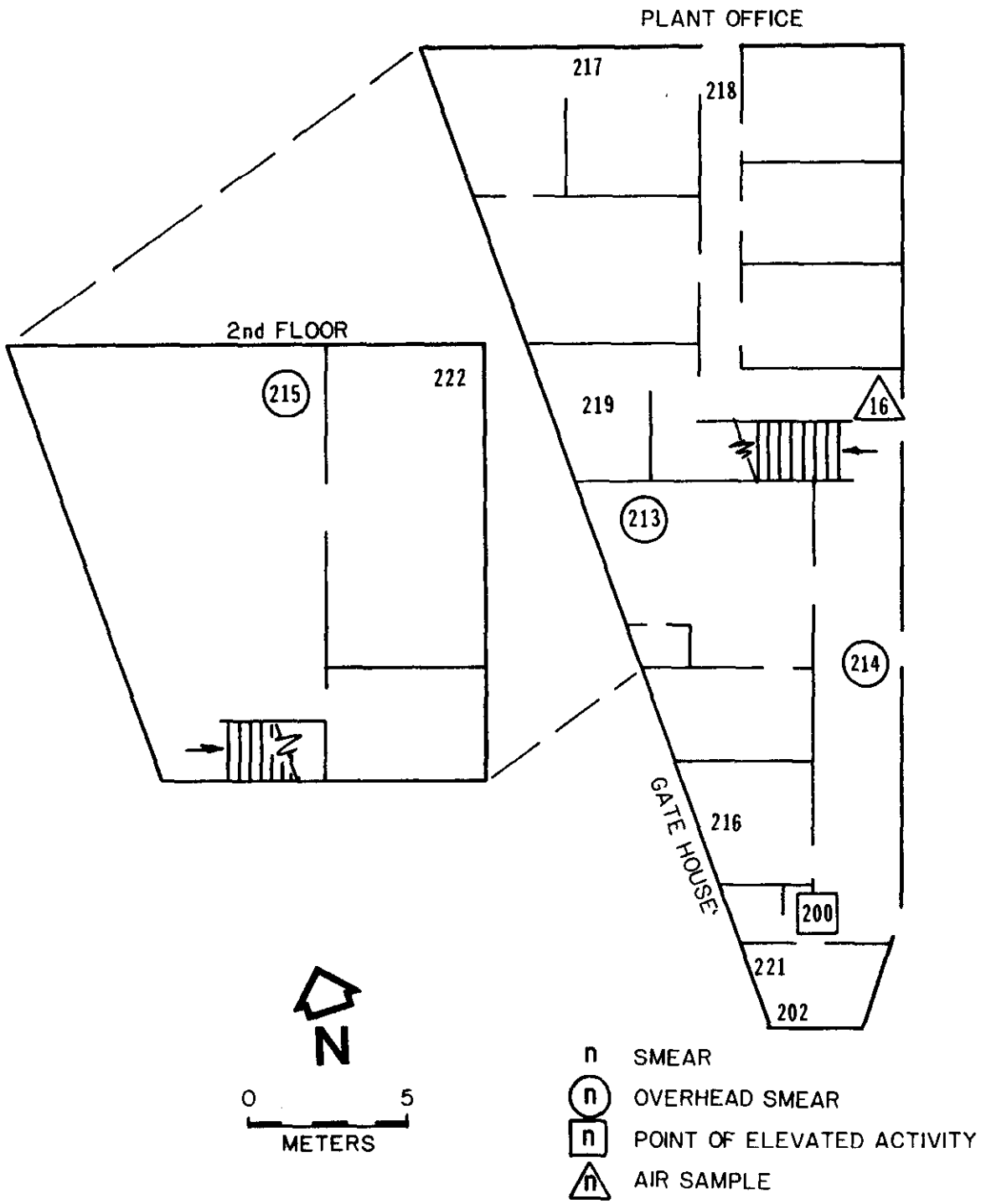



**Figure 18. Plant Office and Gate House Survey Locations.**

ANL-HP DWG. NO. 80-12

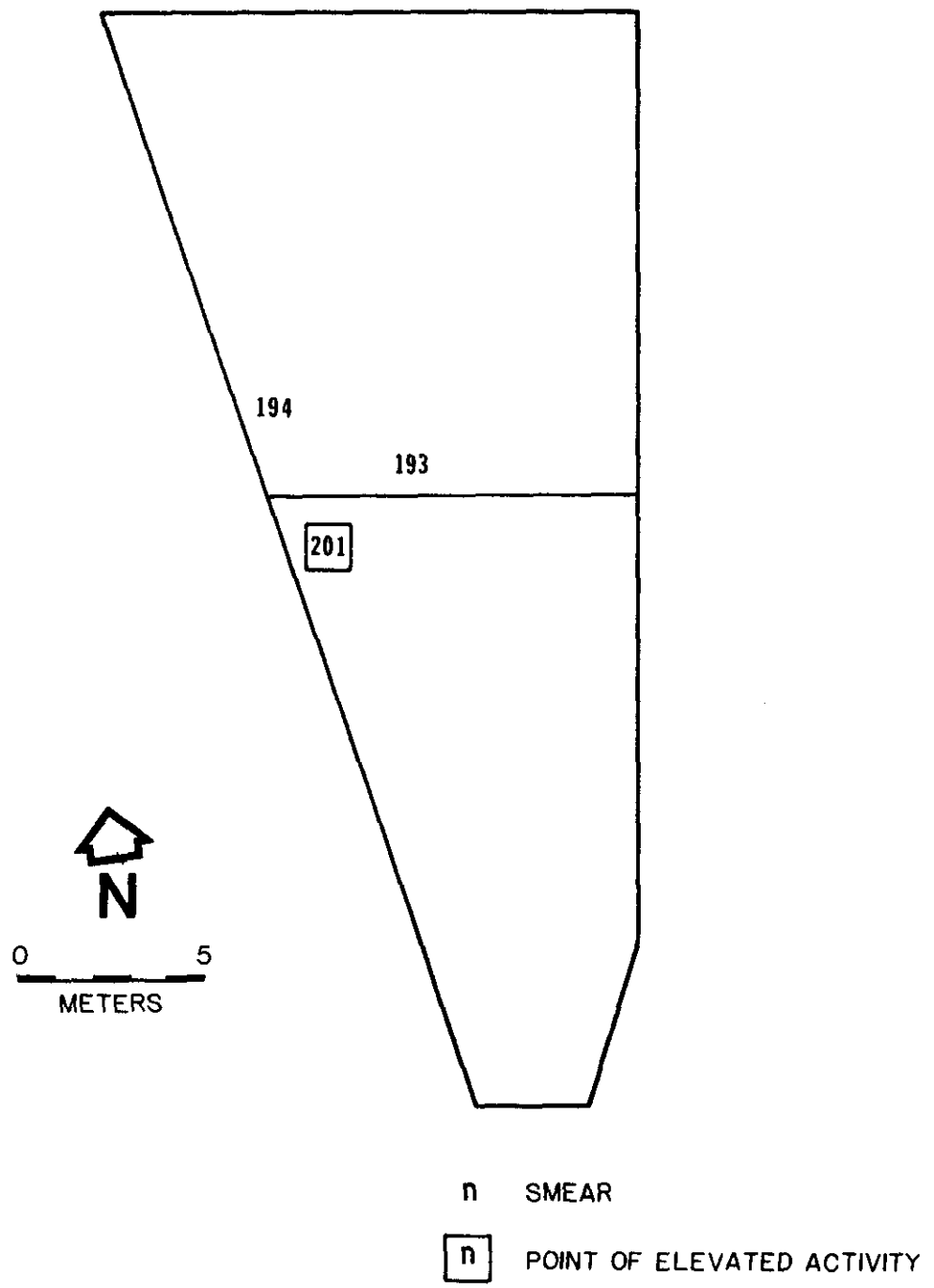



Figure 19. Plant Office and Gate House Roof Survey Locations.

ANL-HP DWG. NO. 80-13

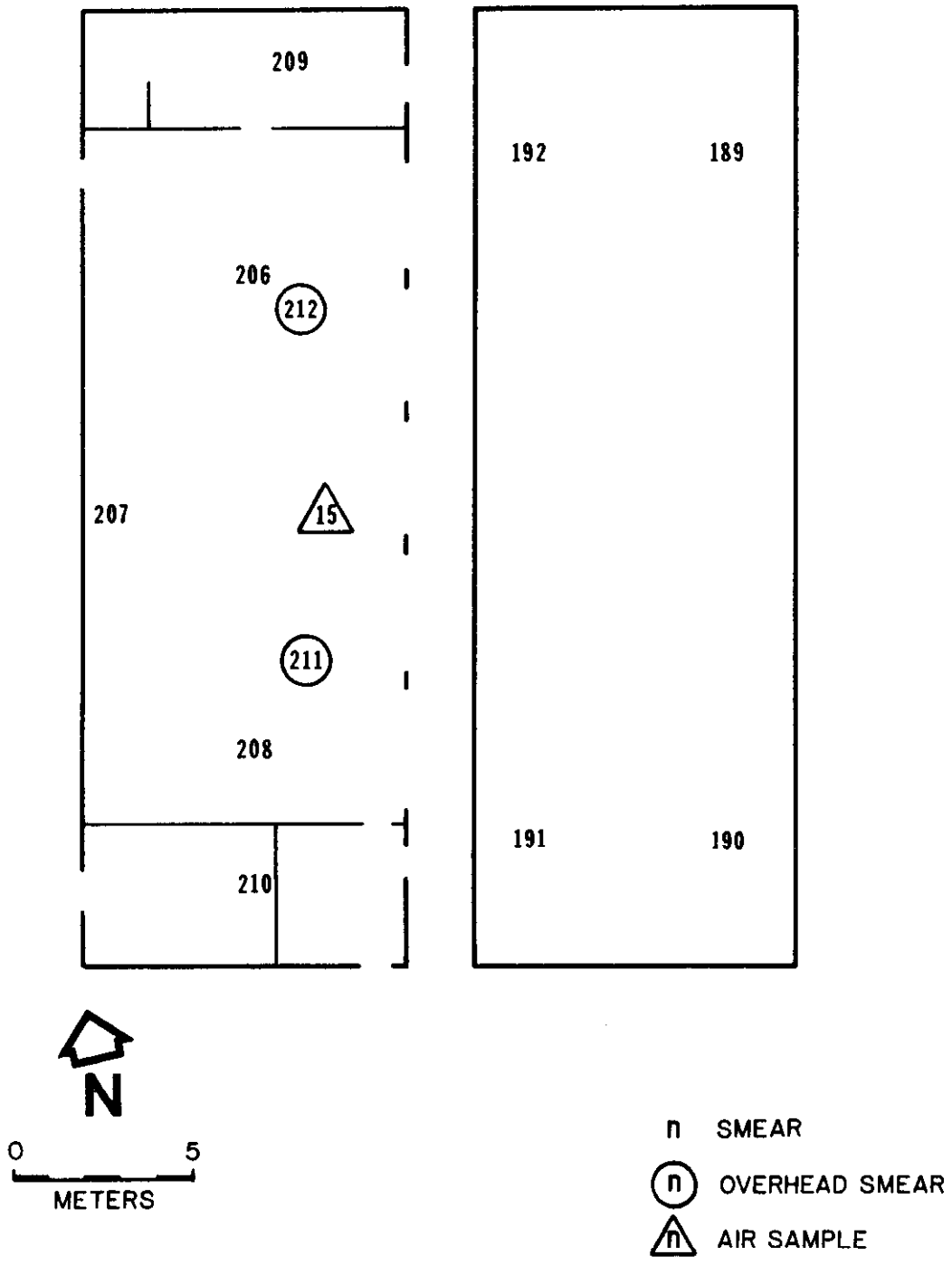



**Figure 20. Garage Ground Floor and Roof Survey Locations.**

ANL-HP DWG. NO. 80-14

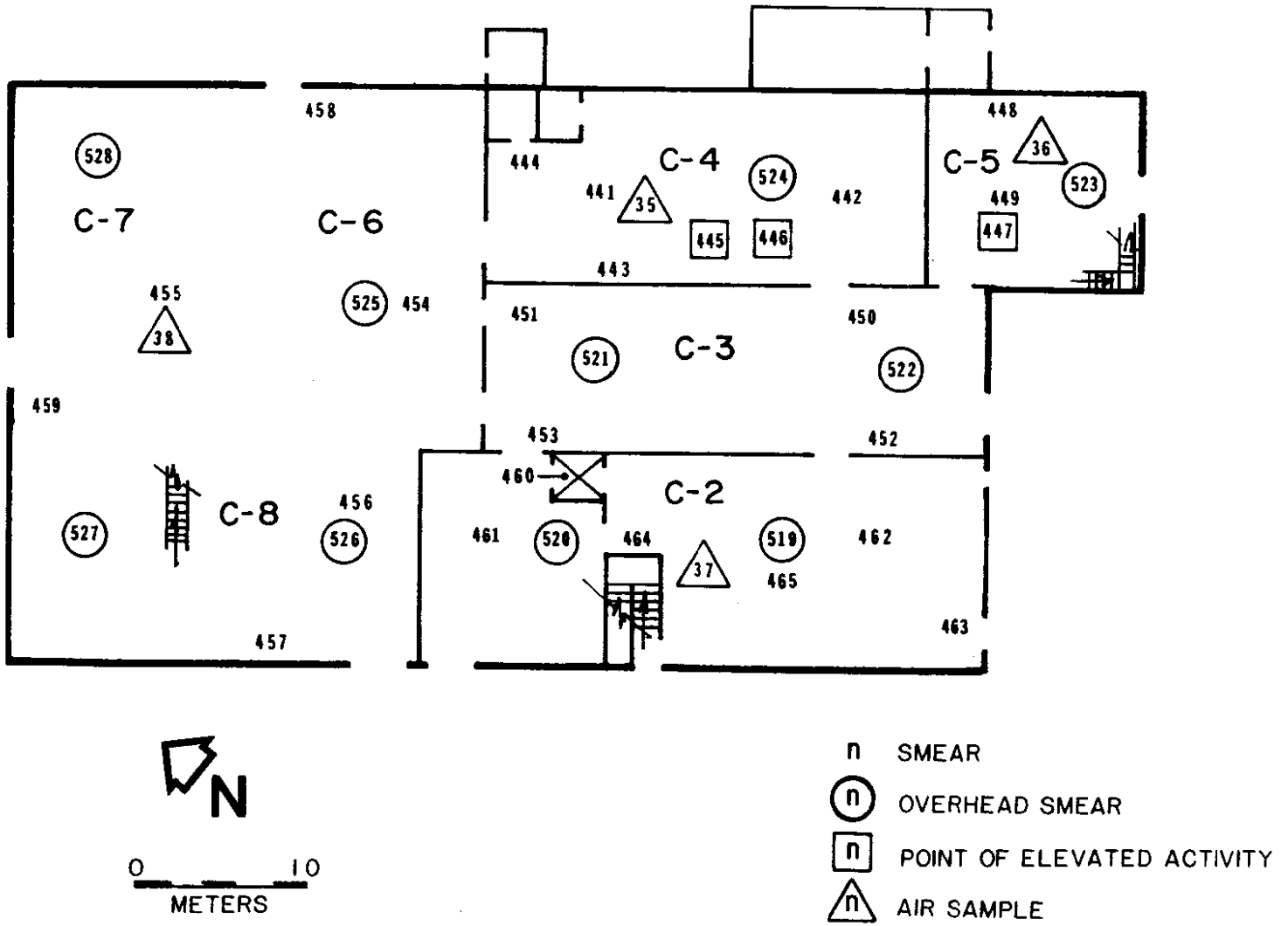



Figure 21. Building C-2 Thru C-8 Ground Floor Survey Locations.

ANL-HP DWG. NO. 80-15

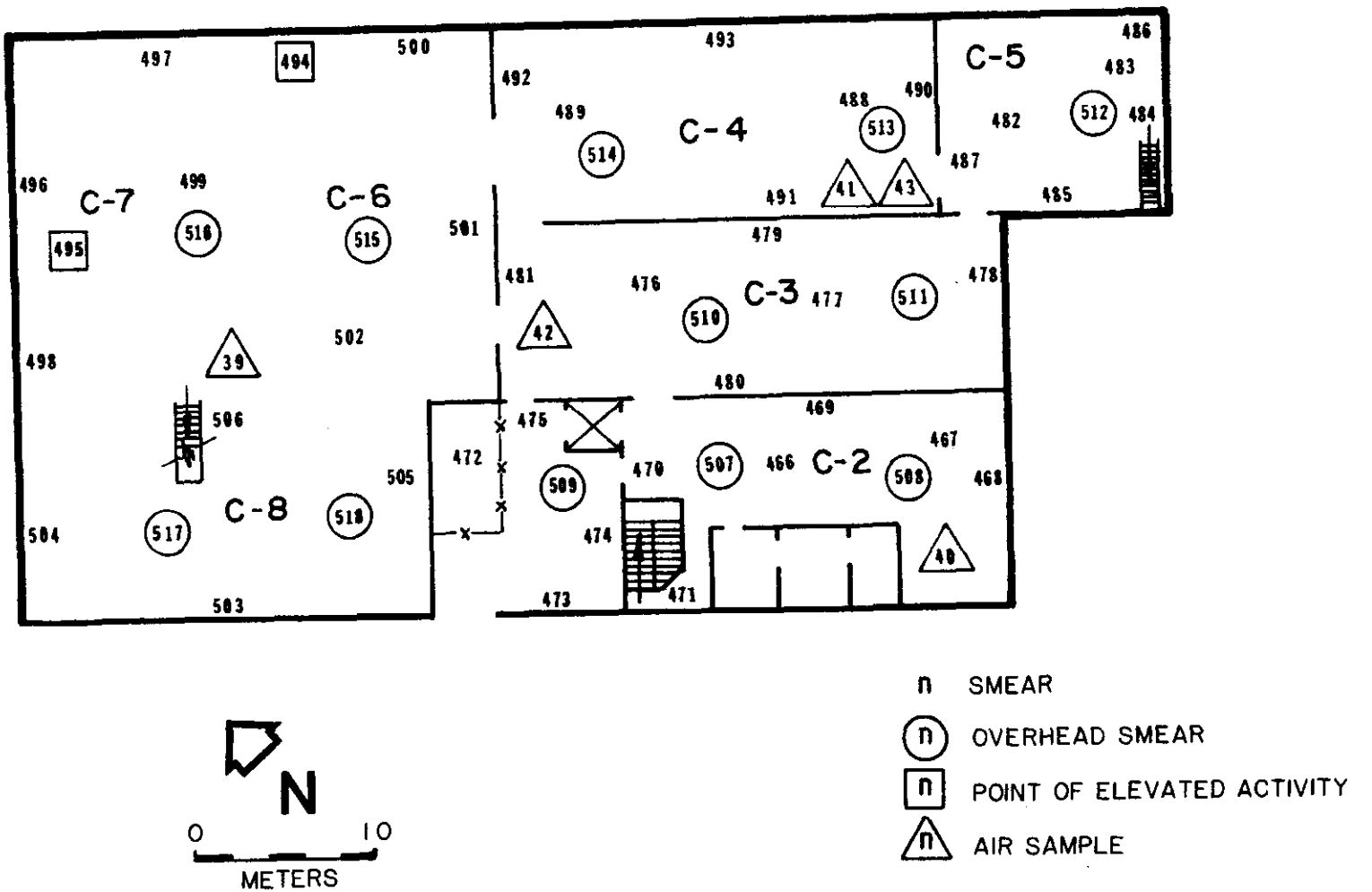



Figure 22. Building C-2 Thru C-8 2nd Floor Survey Locations.

ANL-HP DWG. NO. 80-17

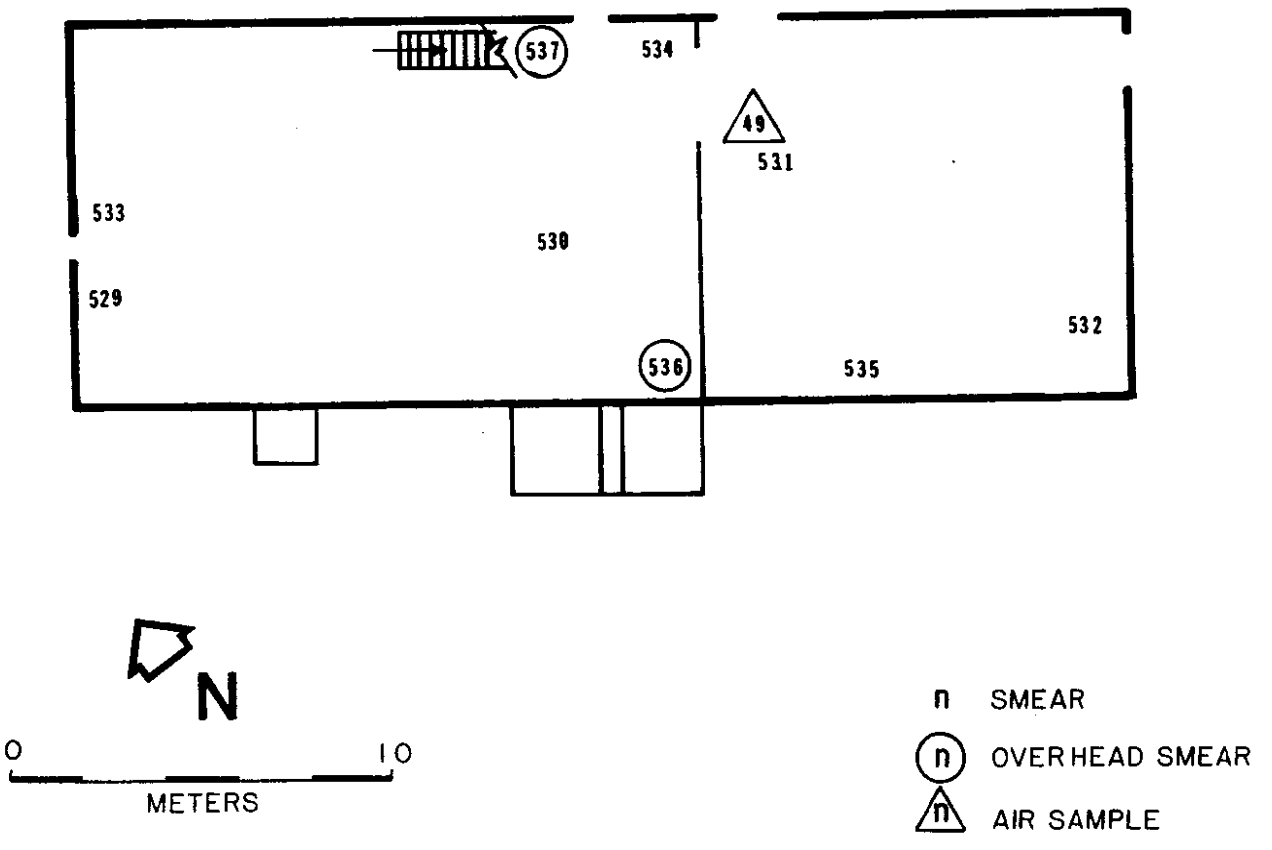



Figure 24. Building C-1 Ground Floor Survey Locations.

ANL-HP DWG. NO. 80-18

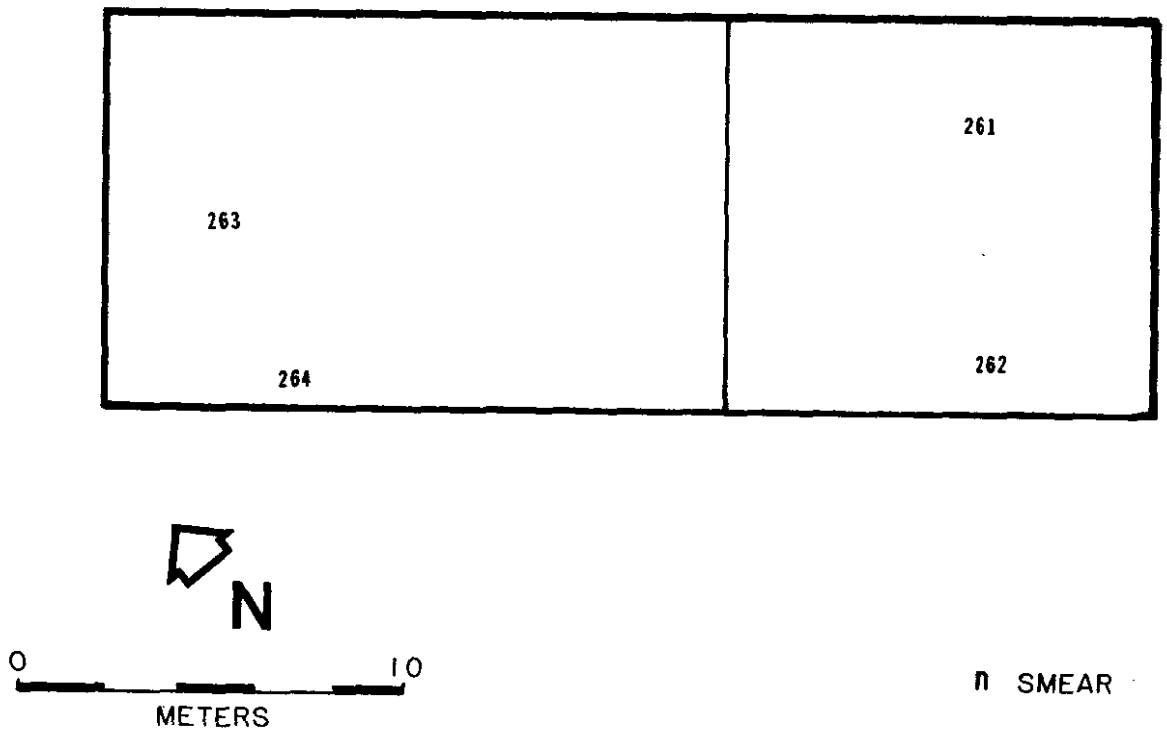



Figure 25. Building C-1 Roof Survey Locations.

ANL-HP DWG. NO. 80-19

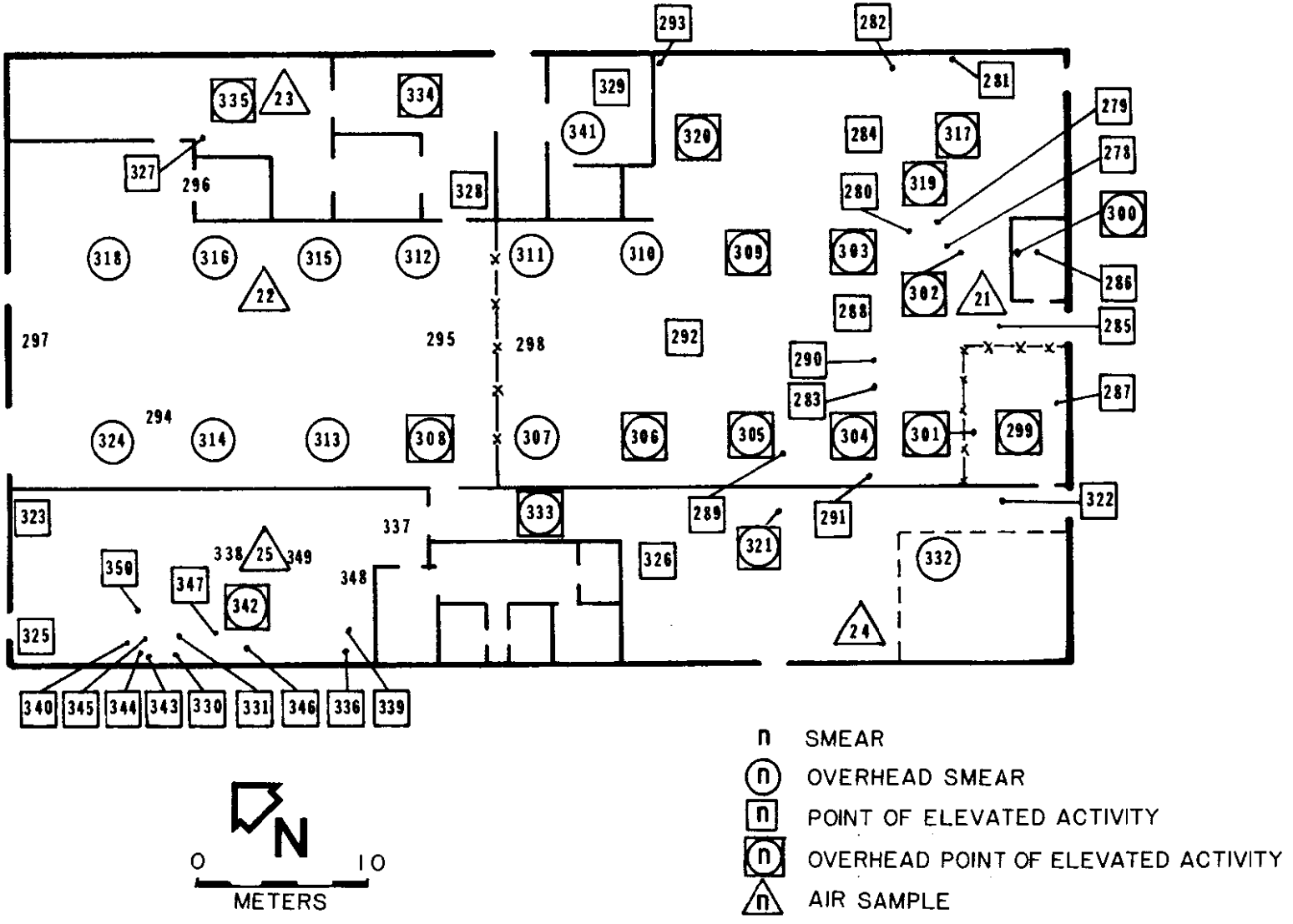



Figure 26. Foundry Ground Floor Survey Locations.

ANL-HP DWG. NO. 80-20

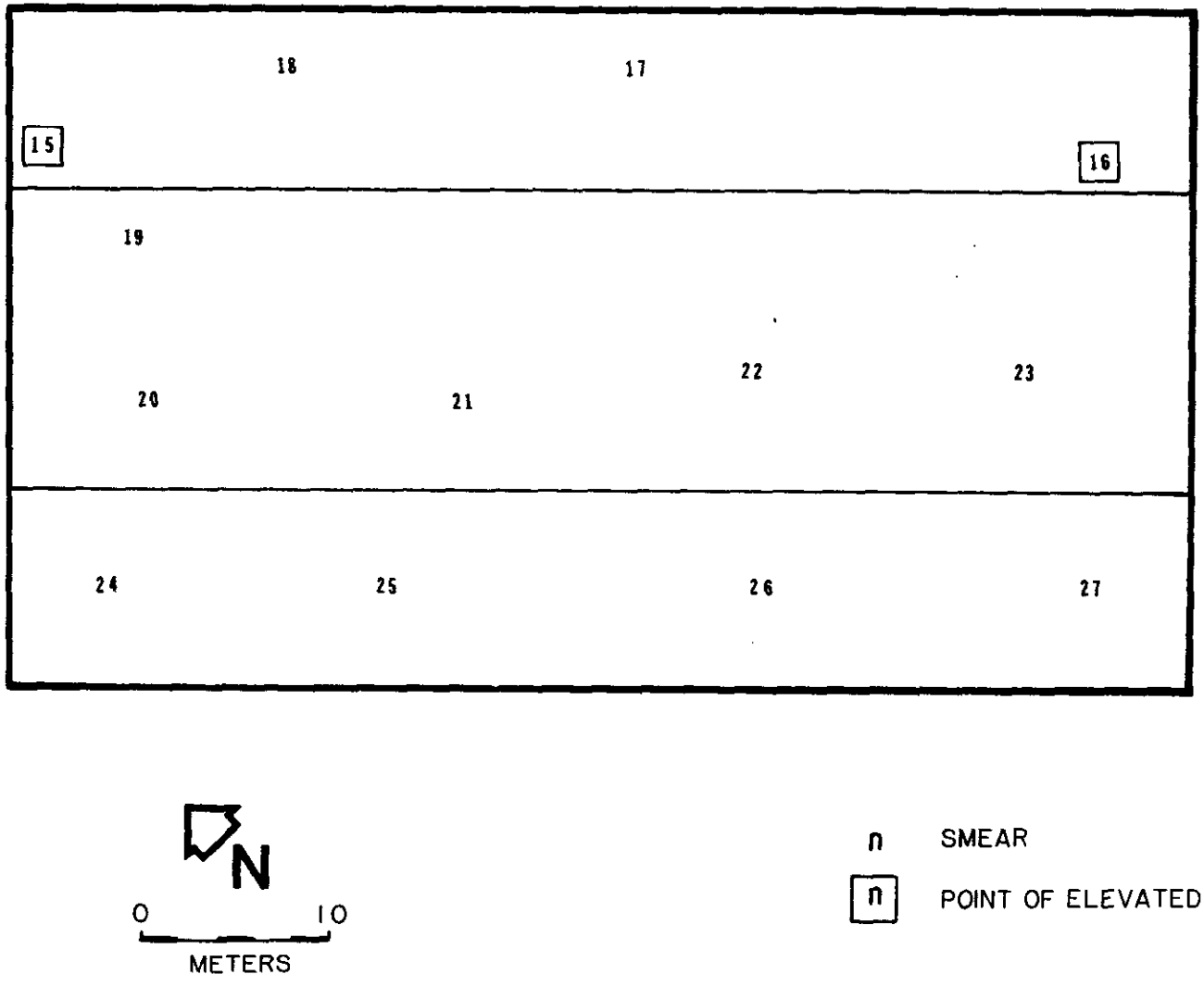



Figure 27. Foundry Roof Survey Locations

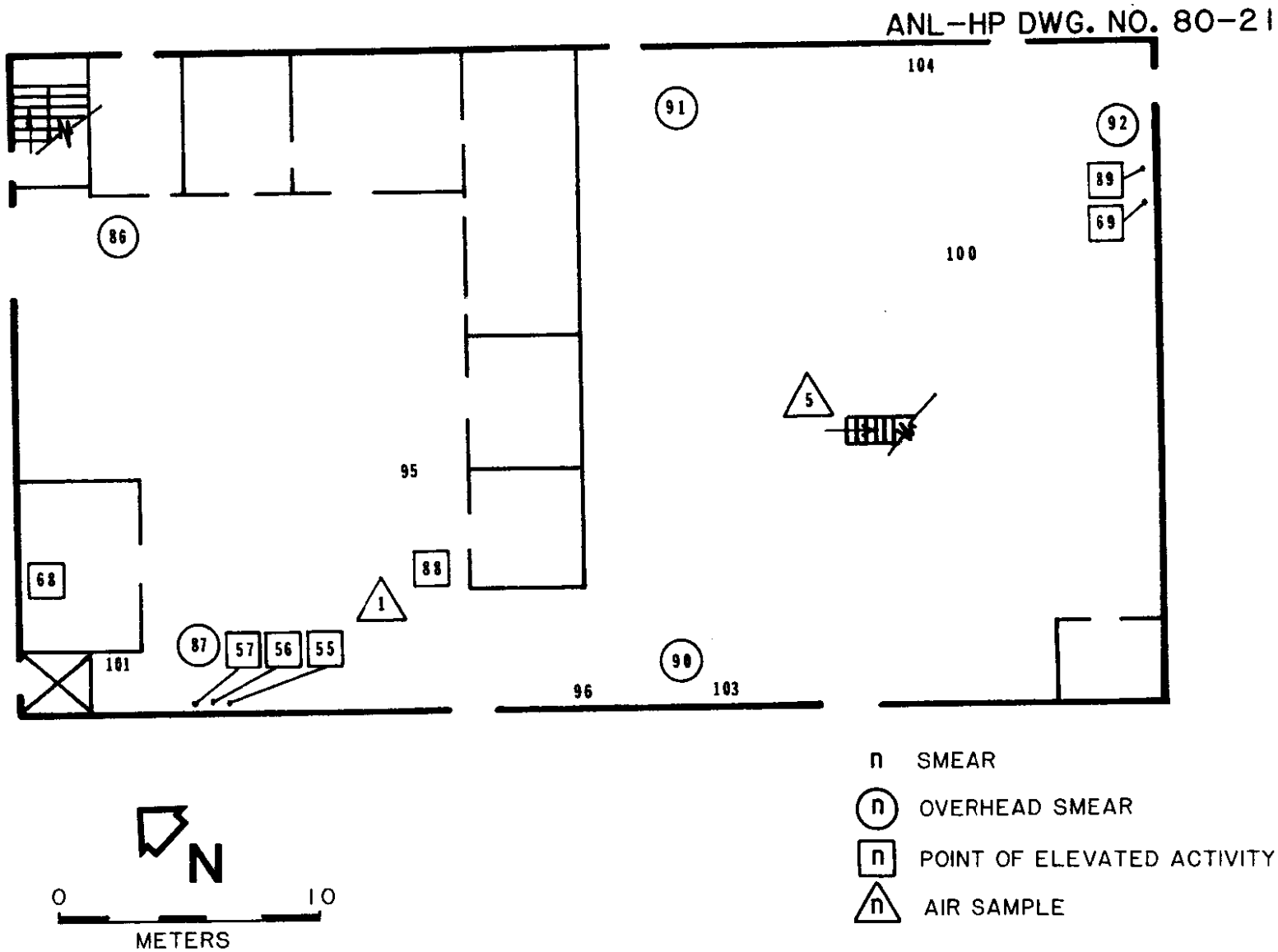



Figure 28. Building P-1 Ground Floor Survey Locations.

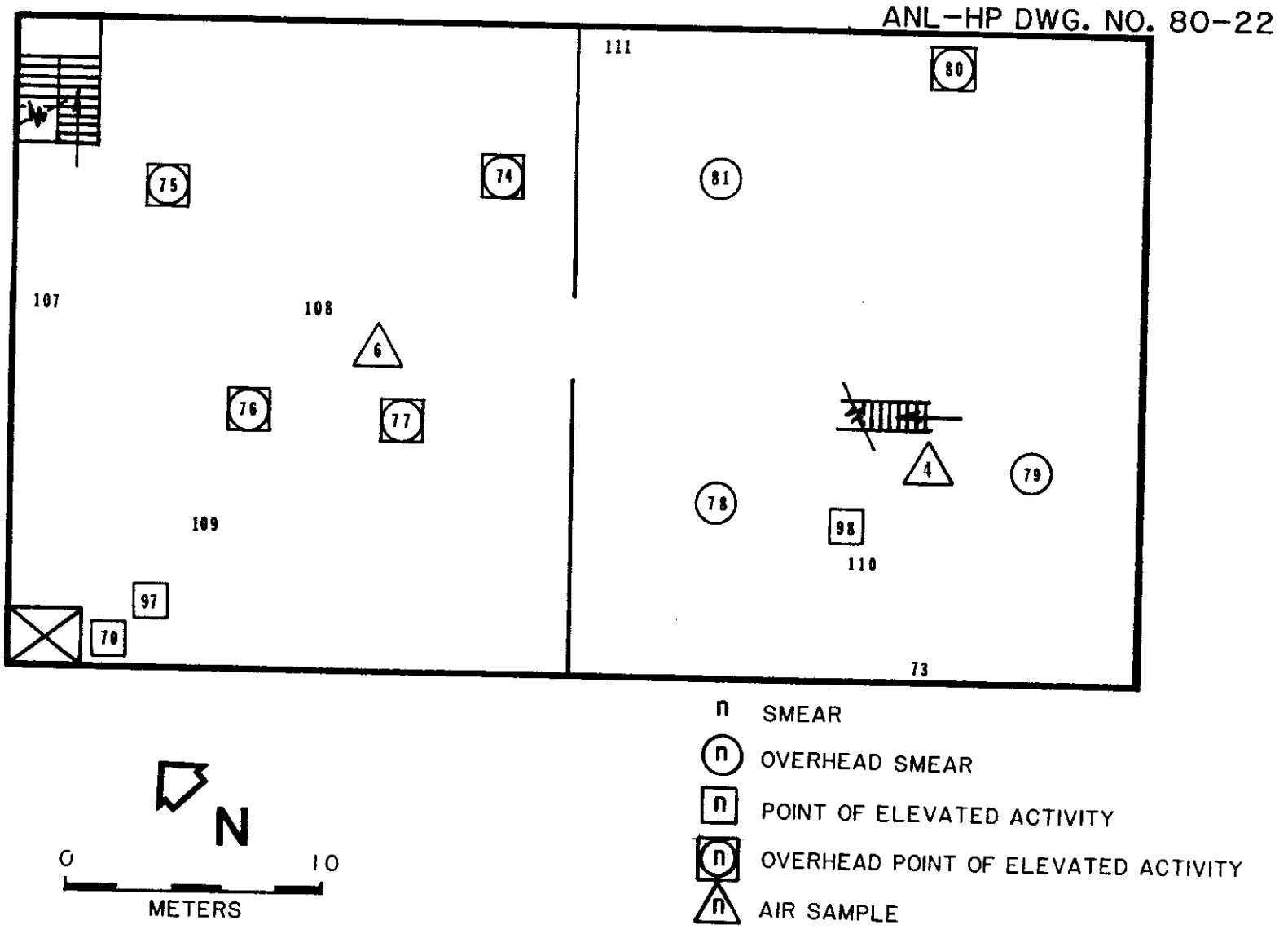



Figure 29. Building P-1 2nd Floor Survey Locations.

ANL-HP DWG. NO. 80-23

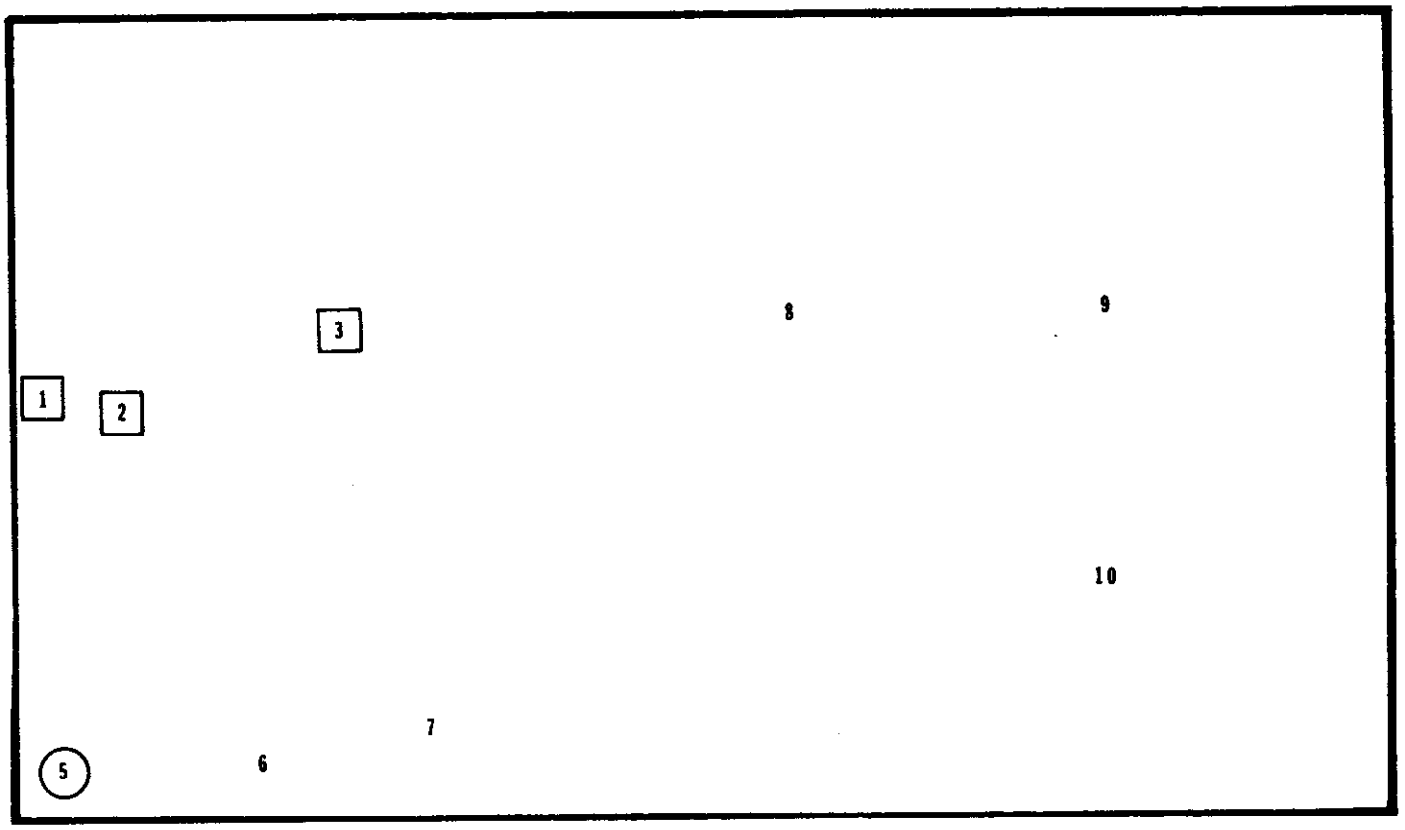



Figure 30. Building P-1 Roof Survey Locations.

ANL-HP DWG. NO. 80-24

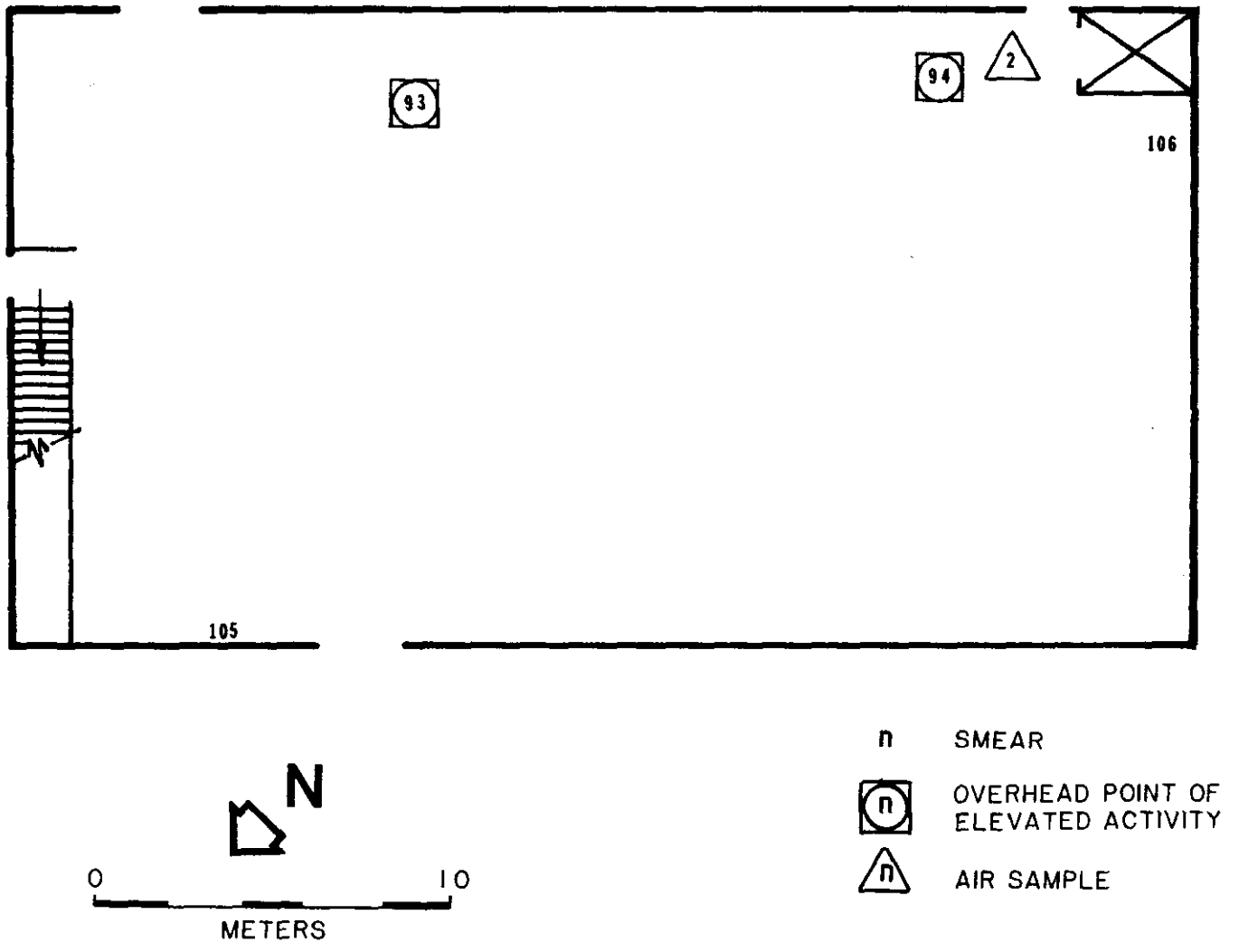



Figure 31. Building H-3 Ground Floor Survey Locations.

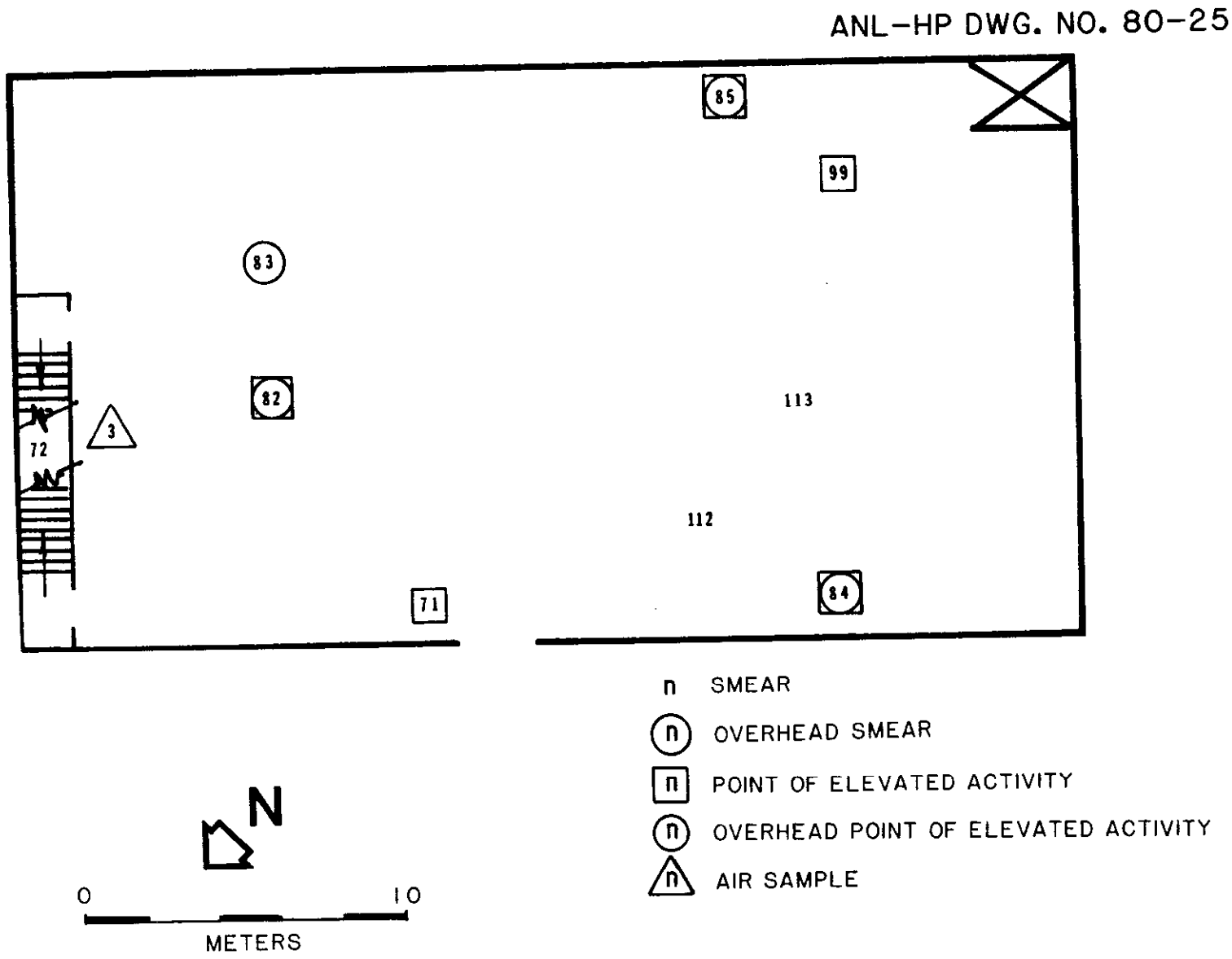
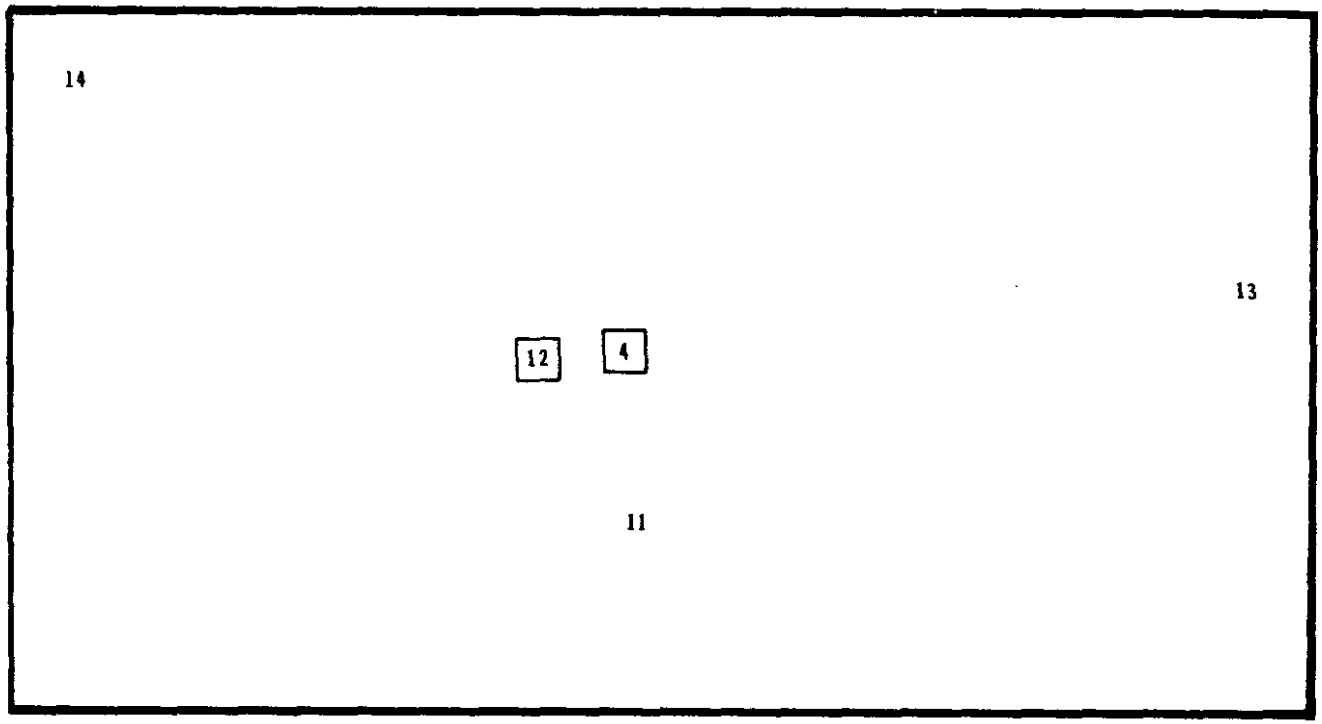



Figure 32. Building H-3 2nd Floor Survey Locations.

ANL-HP DWG. NO. 80-26




n SMEAR

[n] POINT OF ELEVATED ACTIVITY

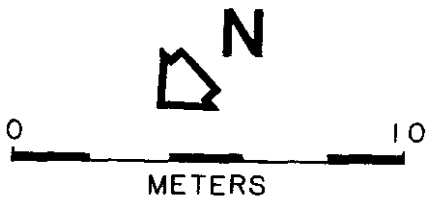



Figure 33. Building H-3 Roof Survey Locations.

ANL-HP DWG. NO. 80-27

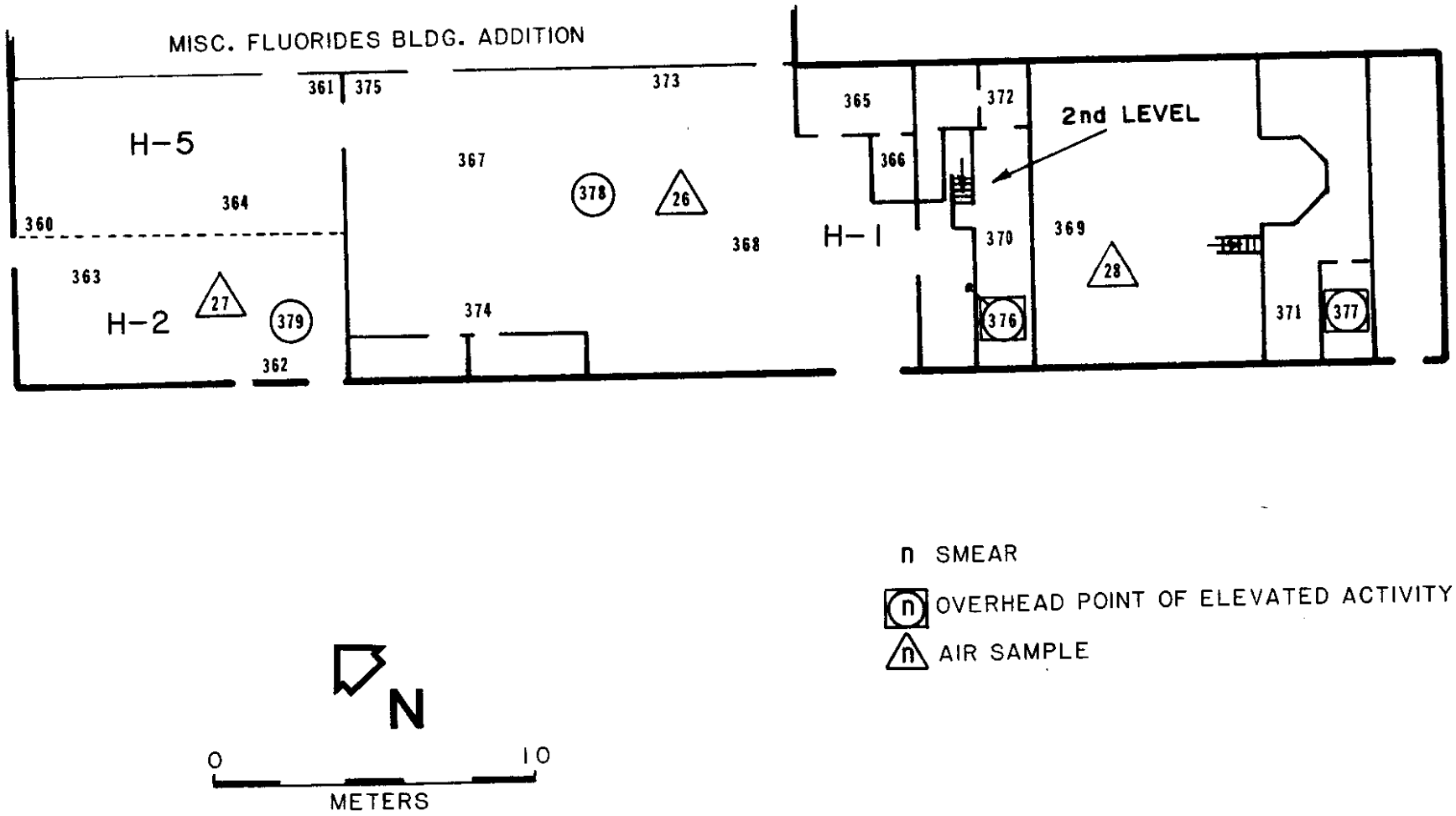
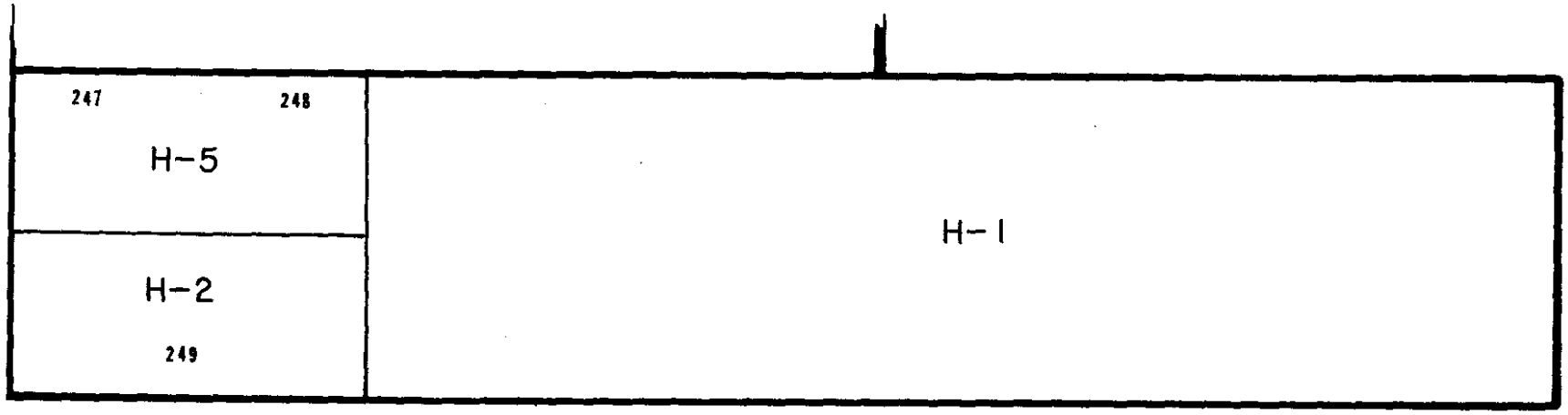
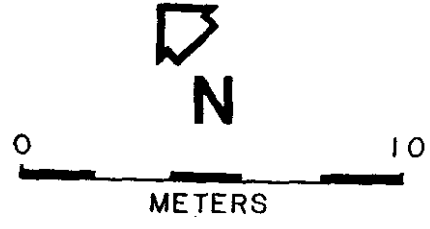



Figure 34. Building H-1, H-2, and H-5 Ground Floor Survey Locations.

ANL-HP DWG. NO. 80-28




n SMEAR

Figure 35. Building H-1, H-2, and H-5 Roof Survey Locations.

ANL-HP DWG. NO. 80-29

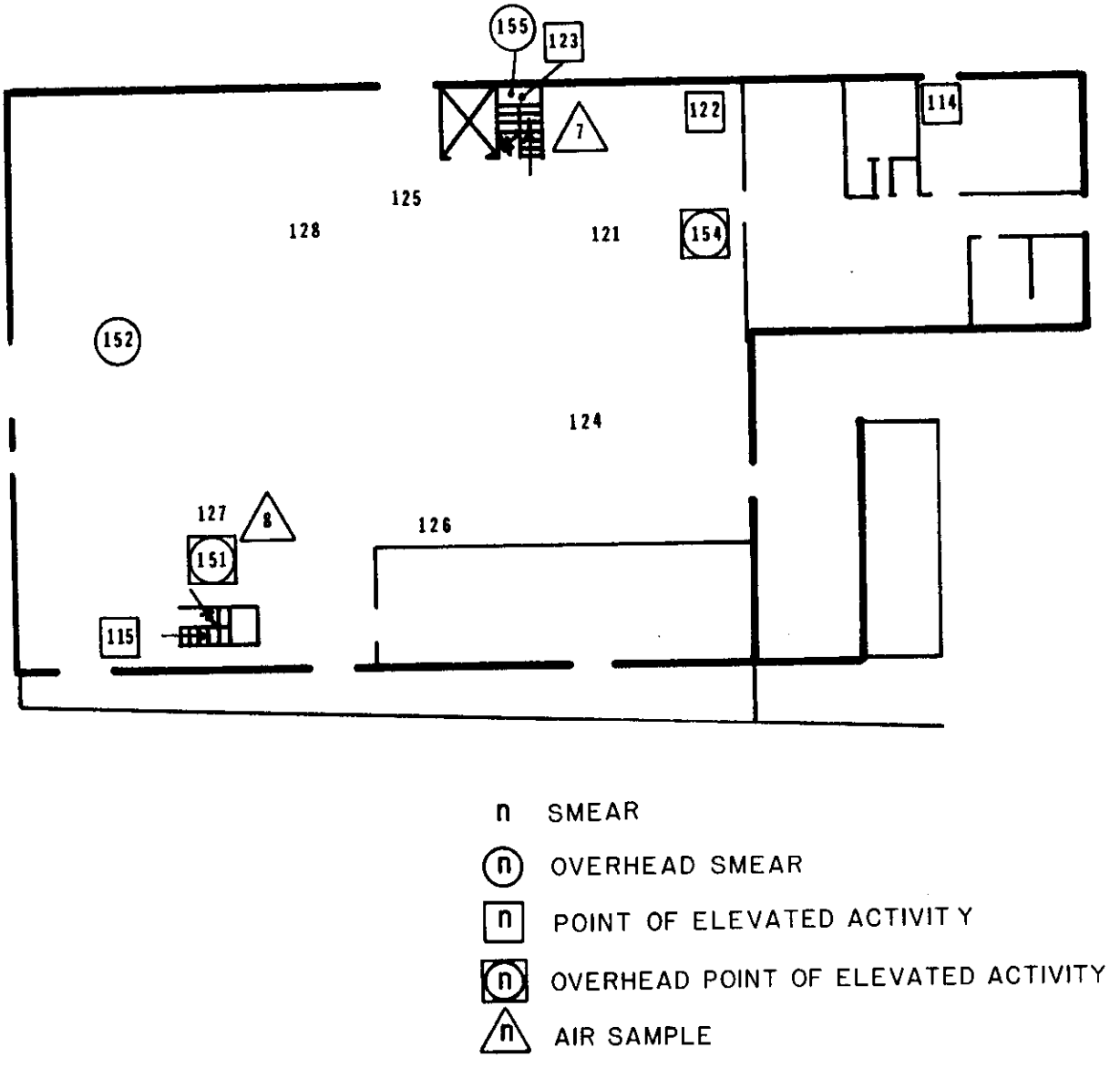
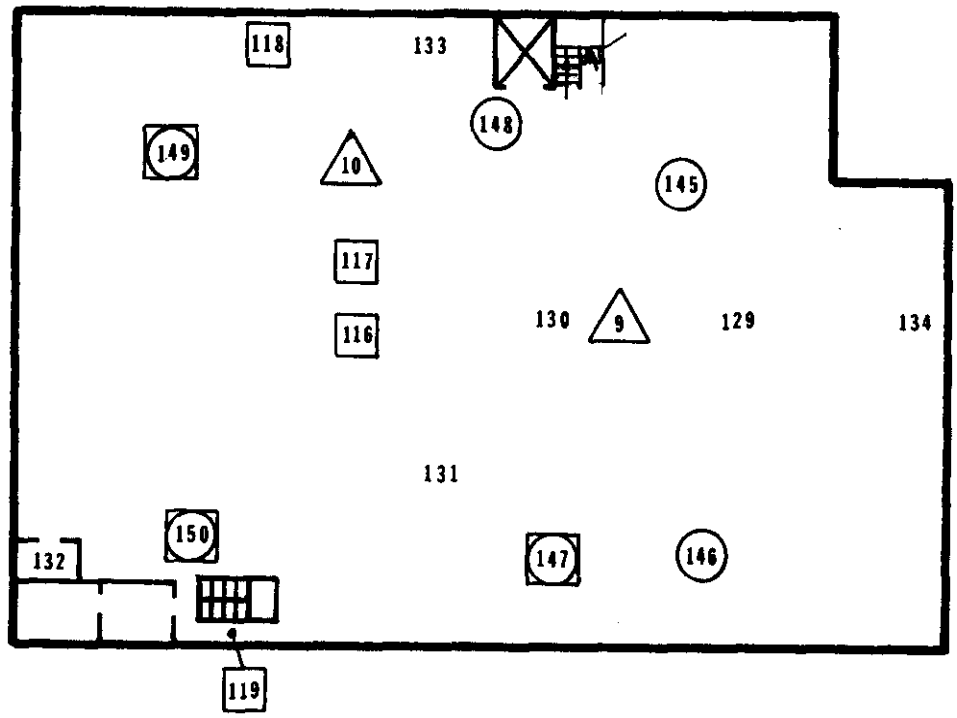



Figure 36. Building M-1 Ground Floor Survey Locations.

ANL-HP DWG. NO. 80-30




n SMEAR

(n) OVERHEAD SMEAR

[n] POINT OF ELEVATED ACTIVITY

([n]) OVERHEAD POINT OF ELEVATED ACTIVITY

△n AIR SAMPLE

N

0 10

METERS

Figure 37. Building M-1 2nd Floor Survey Locations

ANL-HP DWG. NO. 80-31

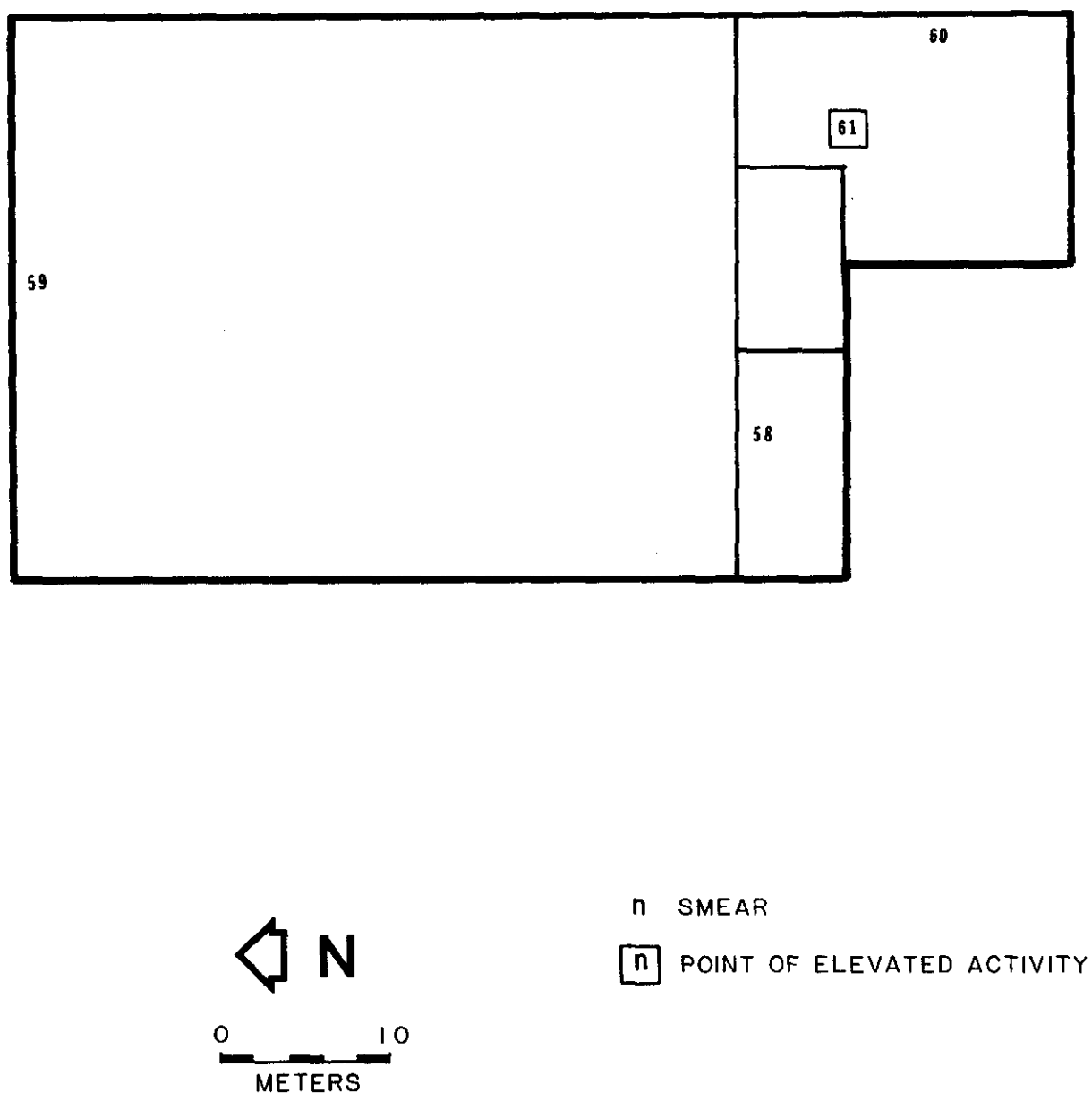



Figure 38. Building M-1 Roof Survey Locations.

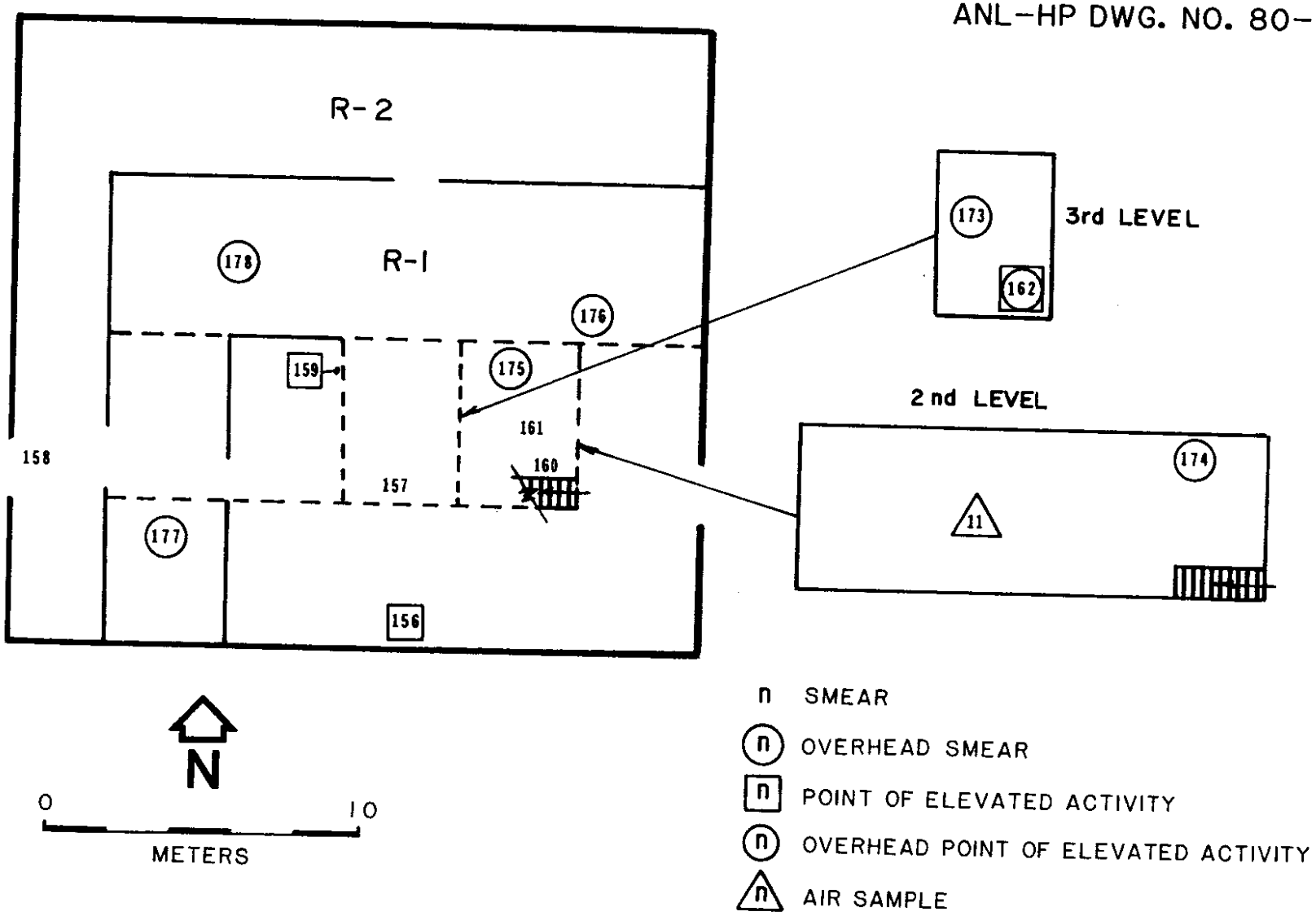



Figure 39. Building R-1 and R-2 Survey Locations.

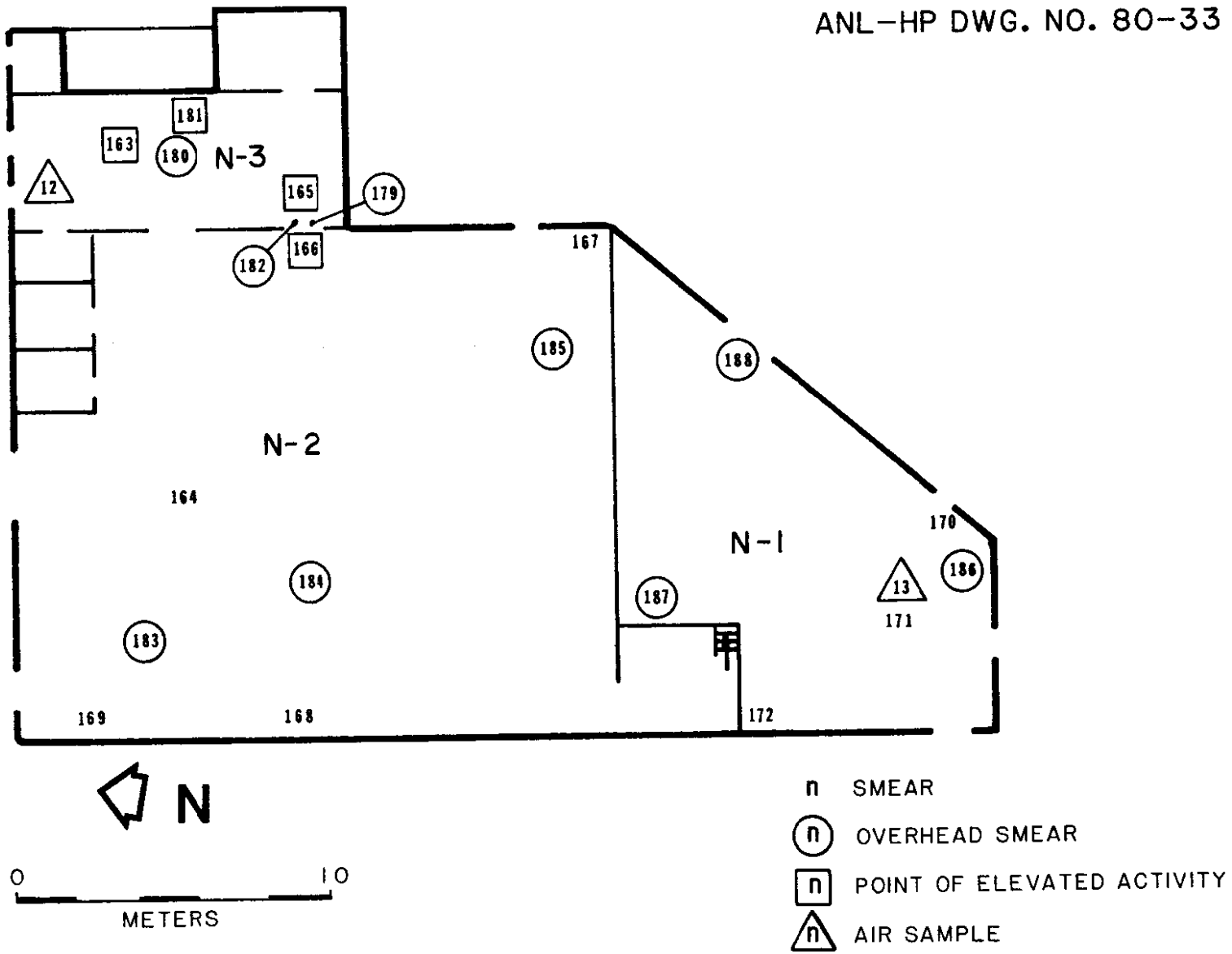



Figure 40. Building N-1, N-2, and N-3 Ground Floor Survey Locations.

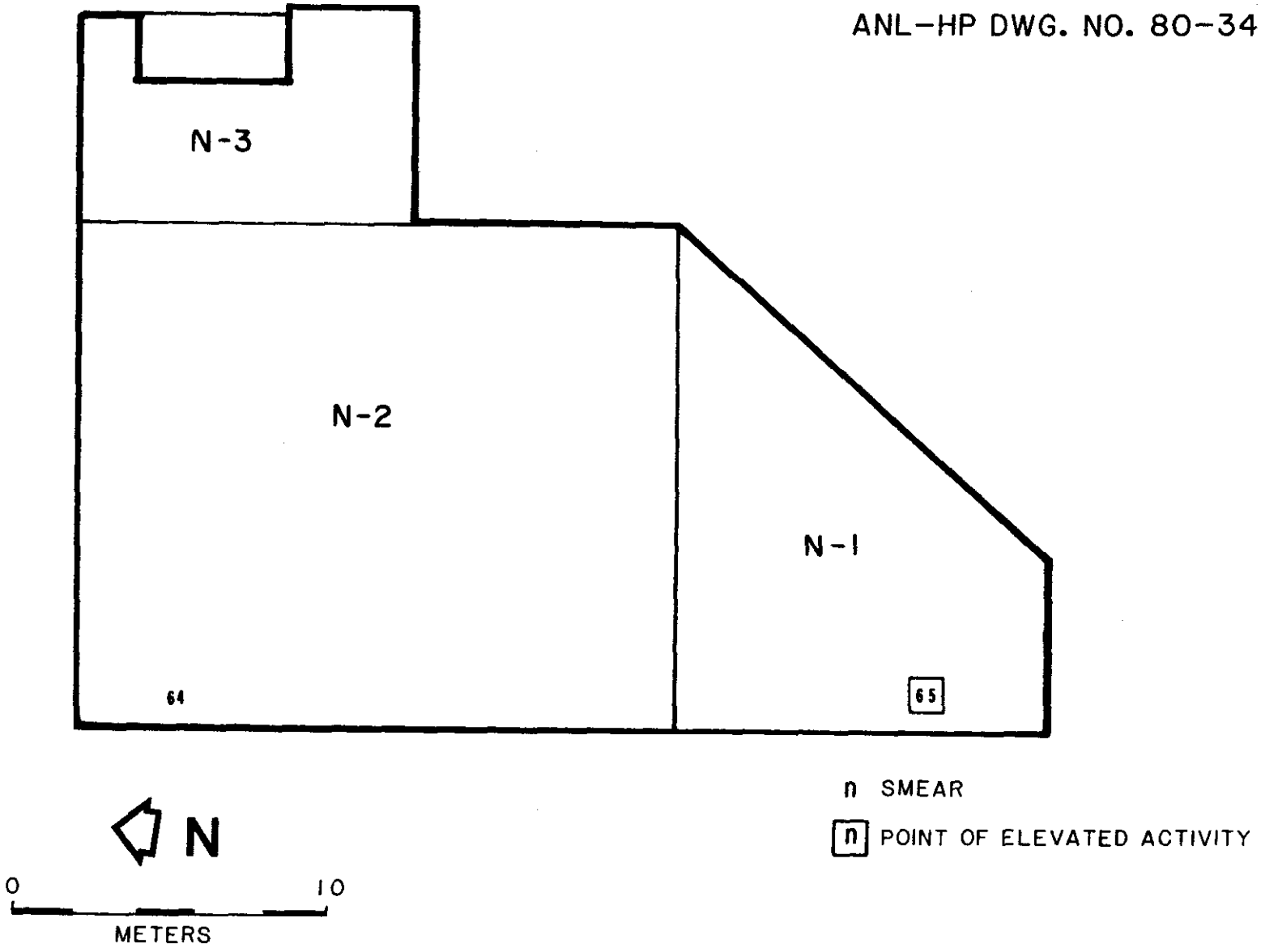



Figure 41. Building N-1, N-2, and N-3 Roof Survey Locations.

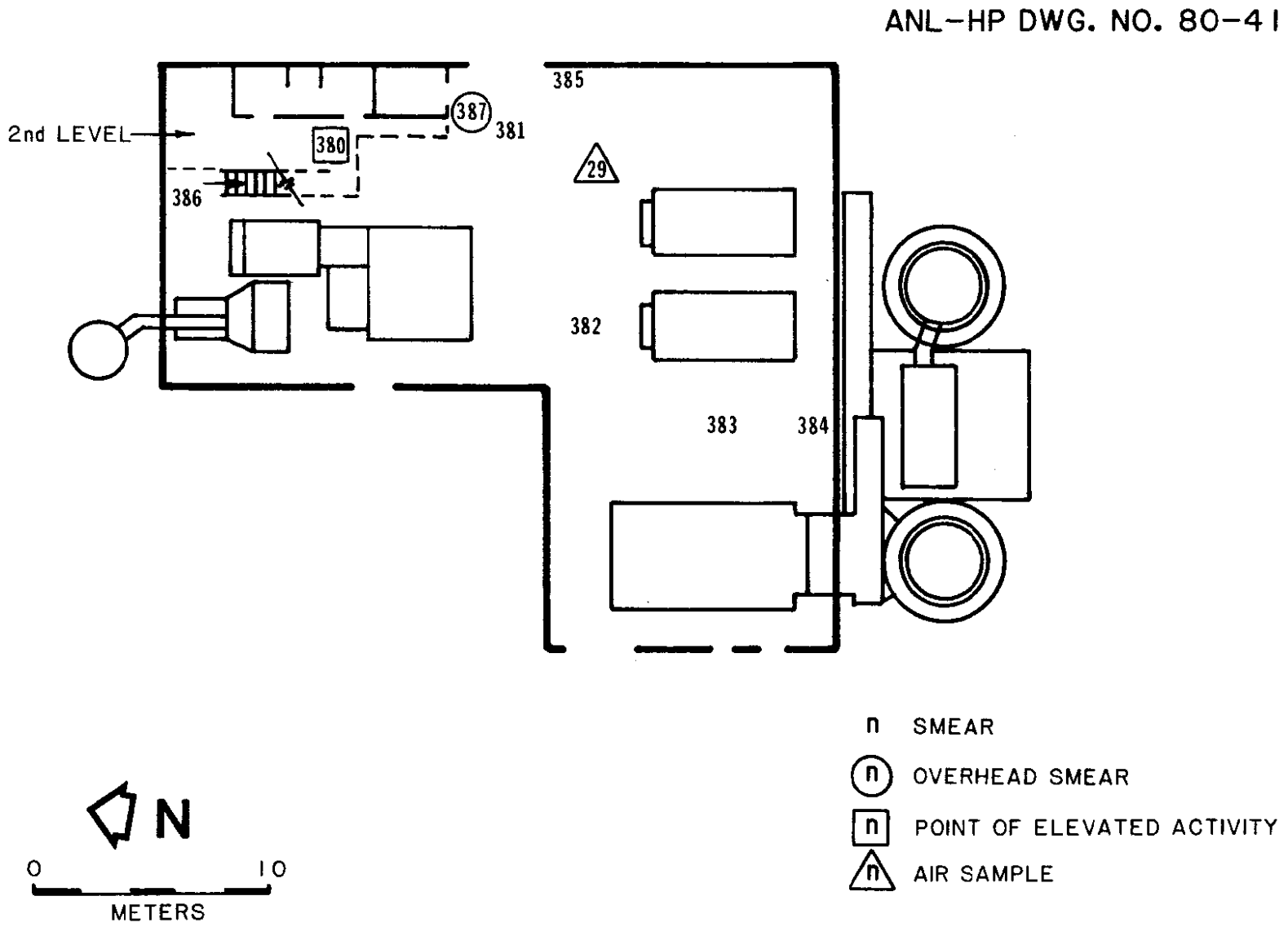



Figure 42. Boiler House Ground Floor Survey Locations.

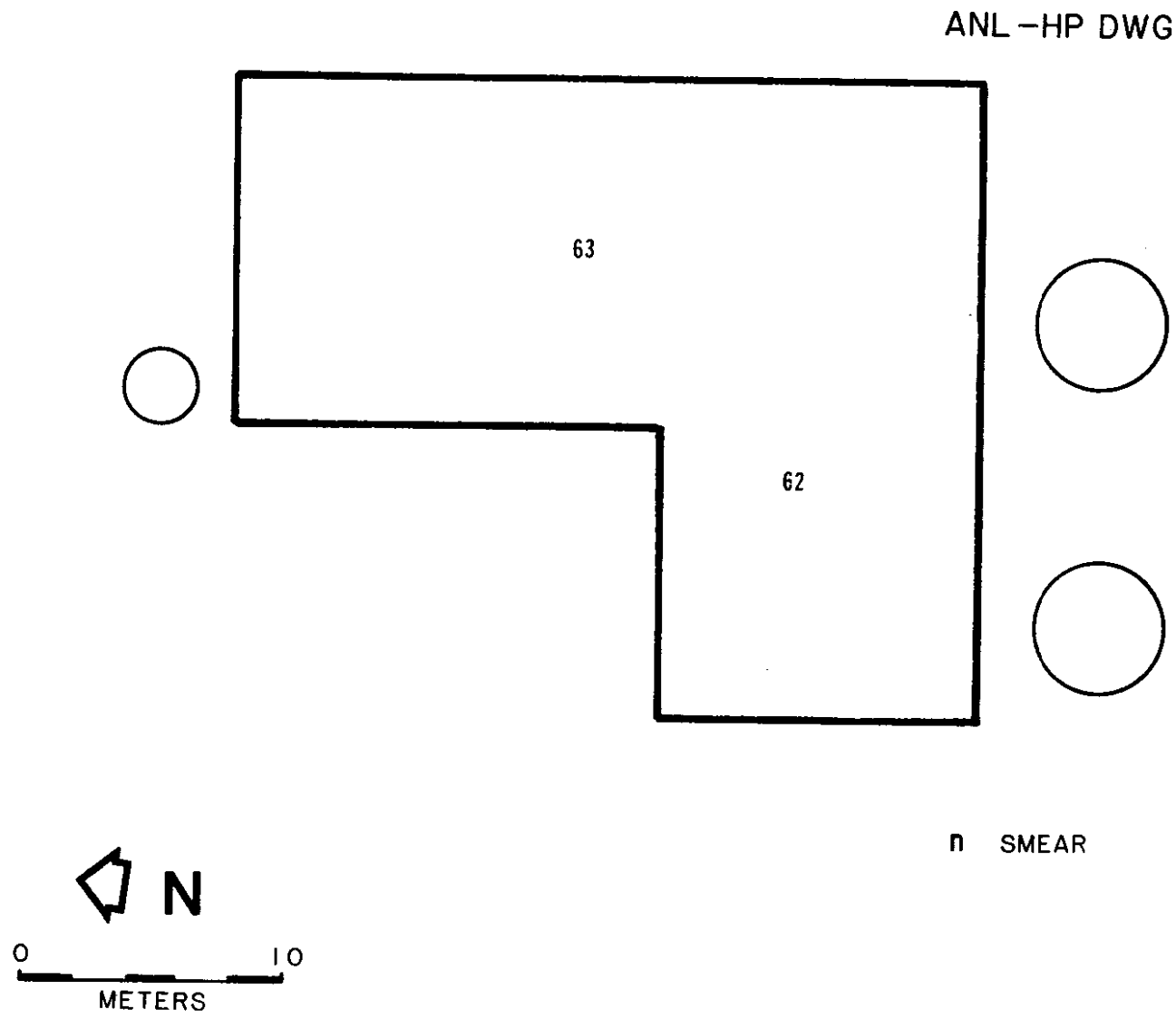



Figure 43. Boiler House Roof Survey Locations.

ANL-HP DWG. NO. 80-42

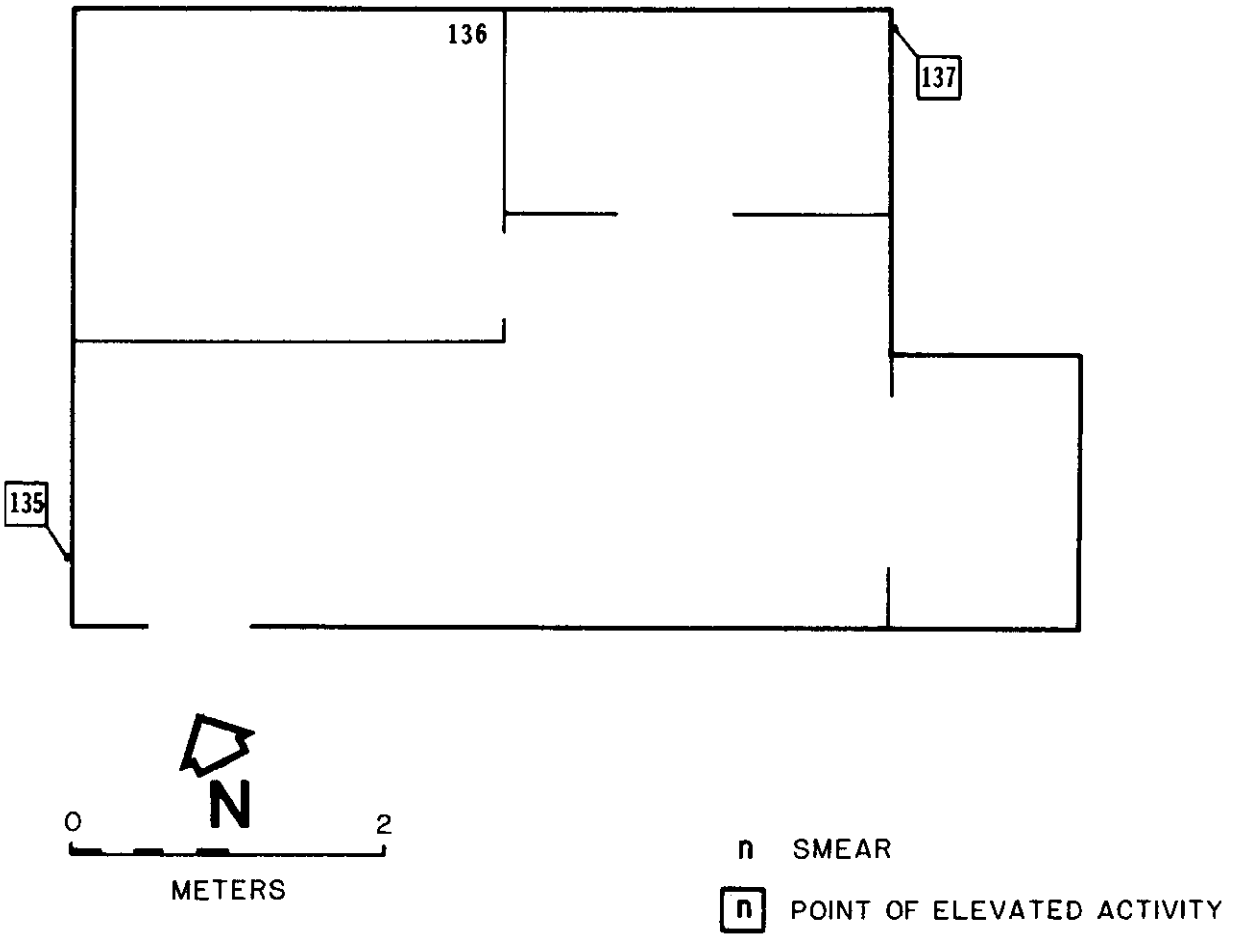



Figure 44. Emergency Building Survey Locations.

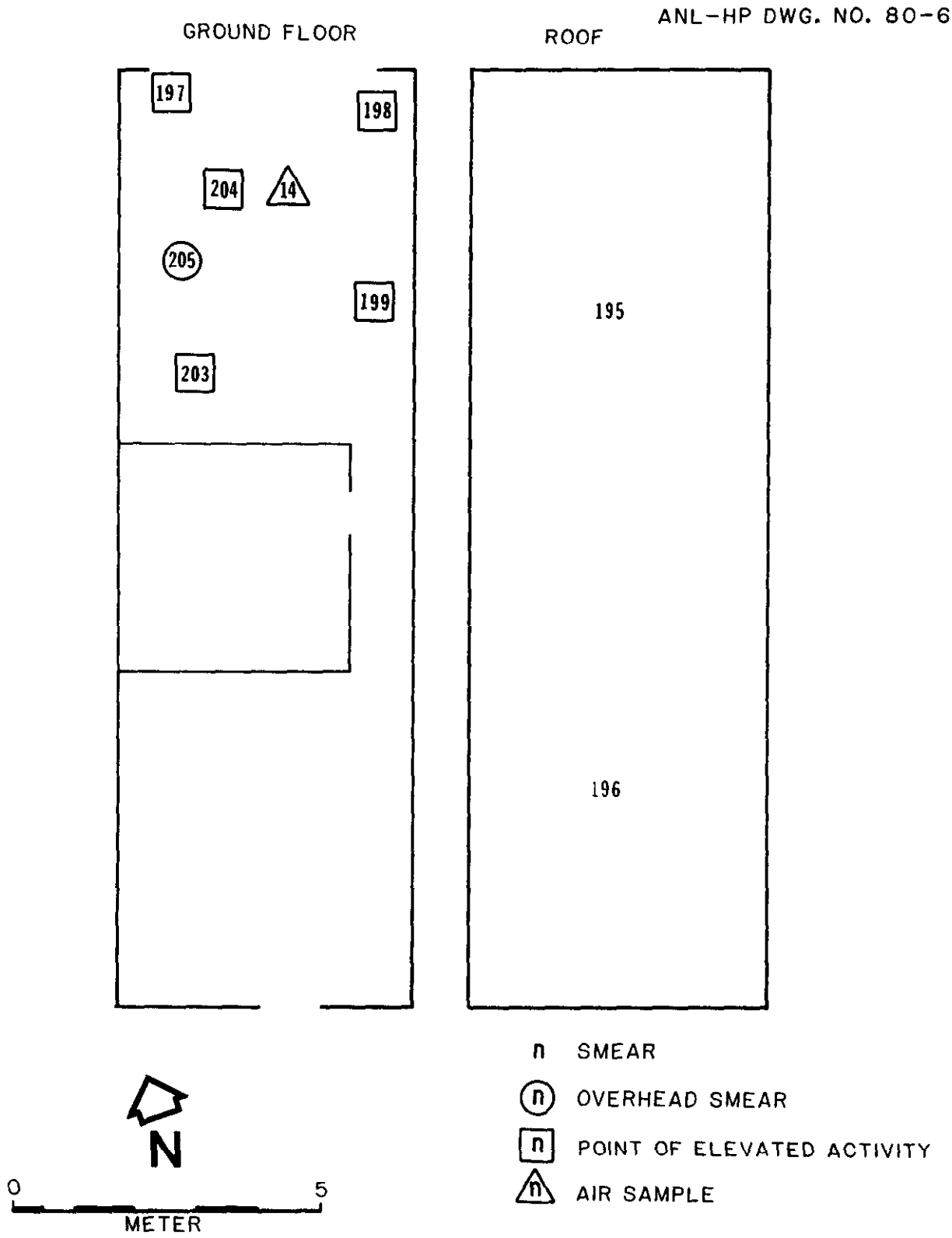



Figure 45. Department 1 Office Ground Floor and Roof Survey Locations.

ANL-HP DWG. NO. 80-47

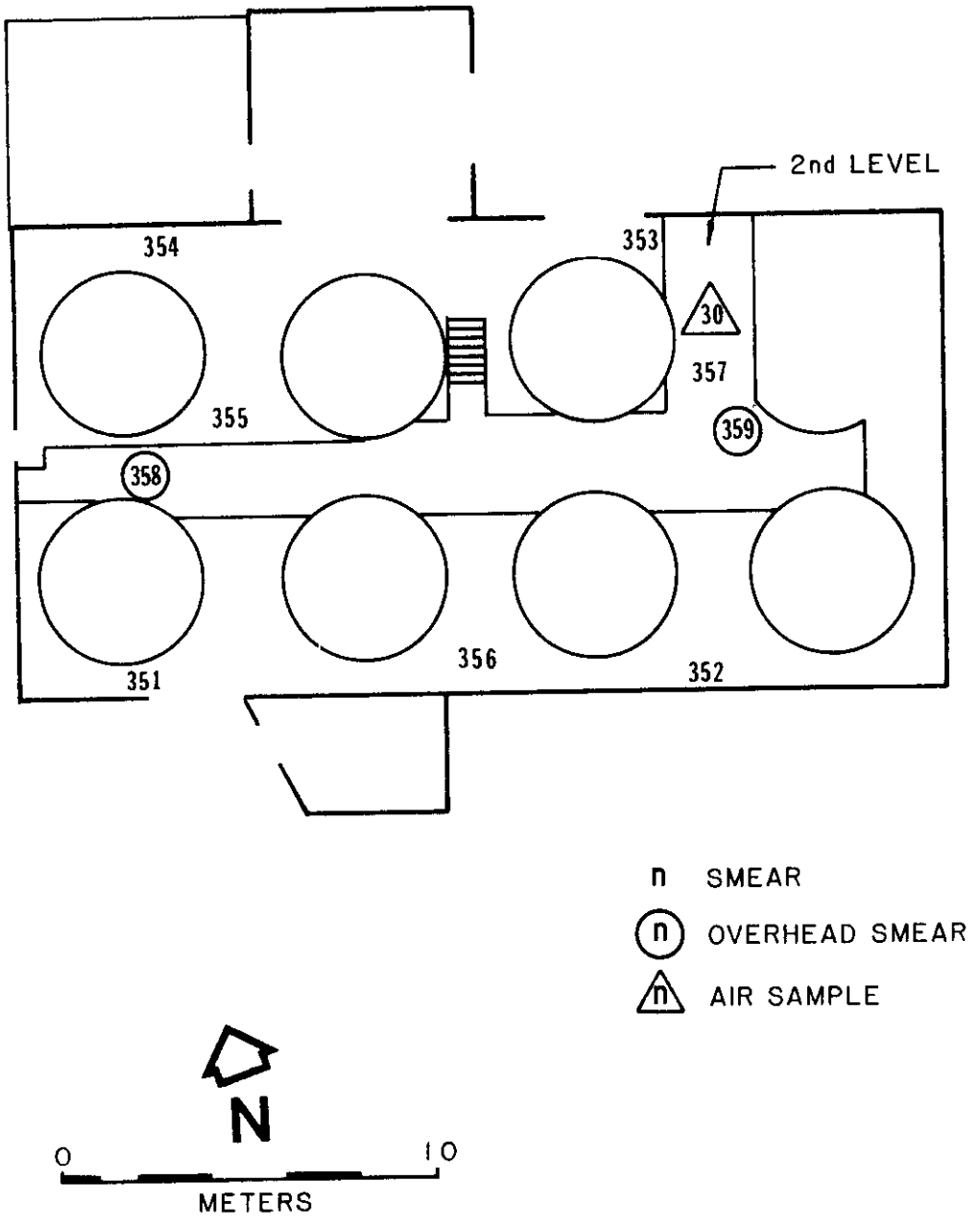



Figure 46. Building M-2 Ground Floor and 2nd Level Survey Locations.

ANL-HP DWG.NO. 80-48

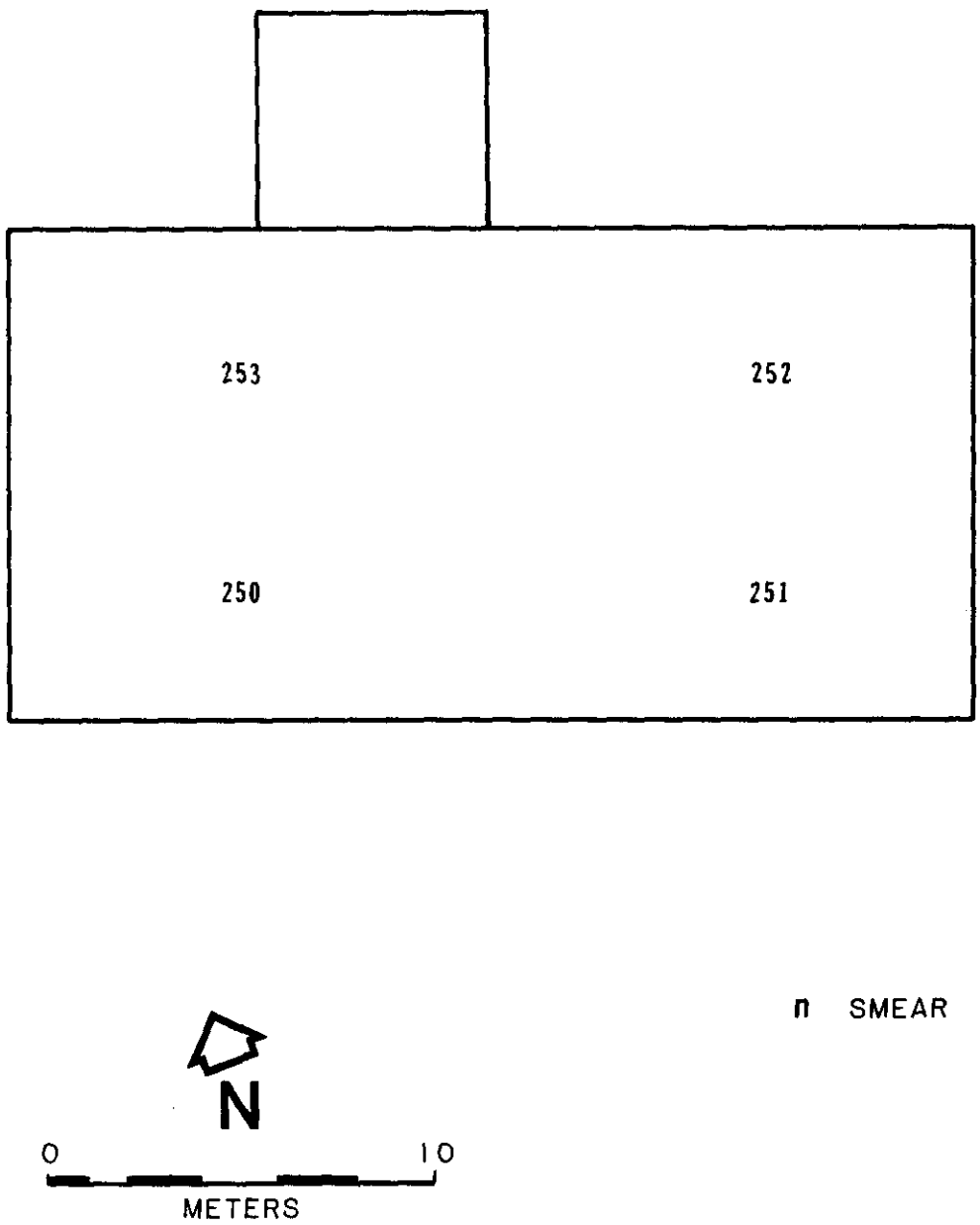



Figure 47. Building M-2 Roof Survey Locations.

ANL-HP DWG. NO. 80-53

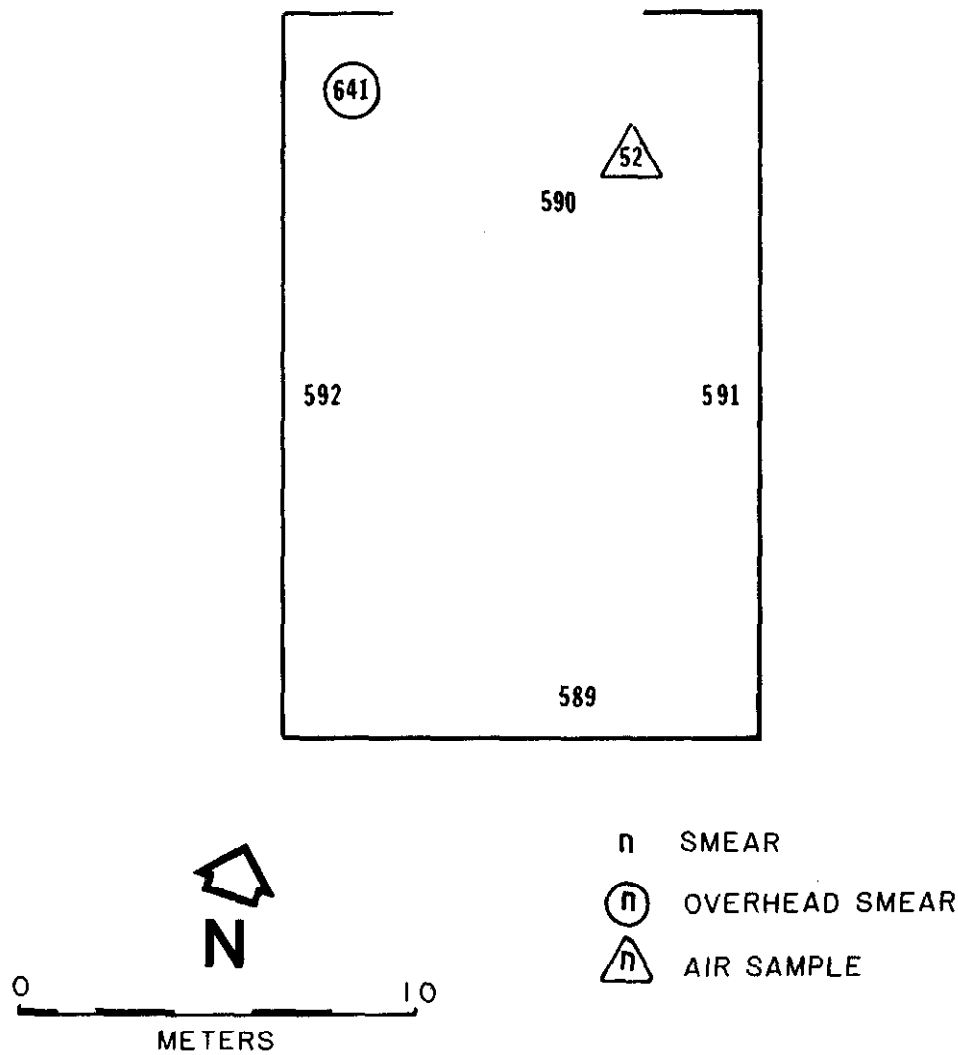



Figure 48. Quonset Building Survey Locations.

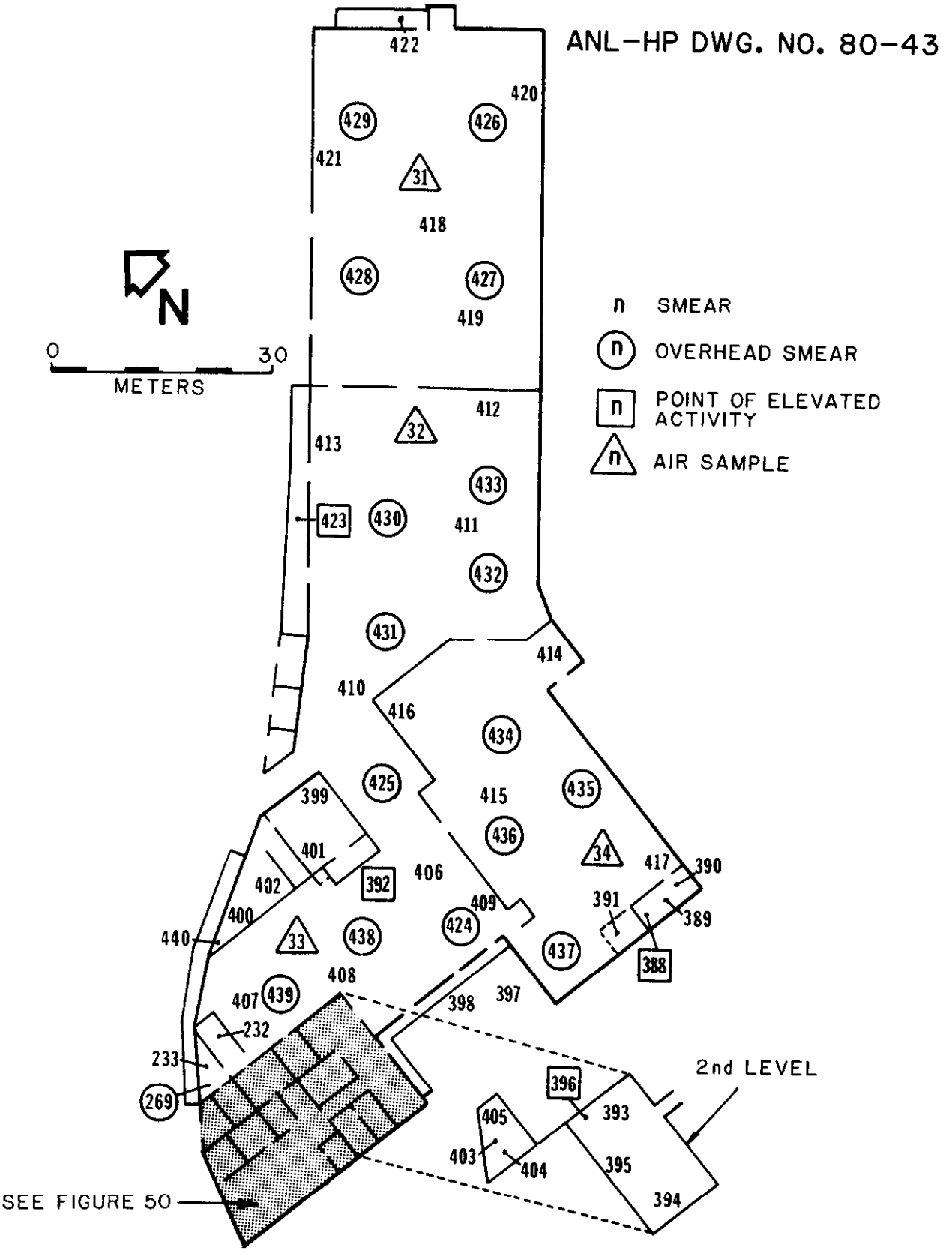



Figure 49. Warehouse Ground Floor and 2nd Level Survey Locations.

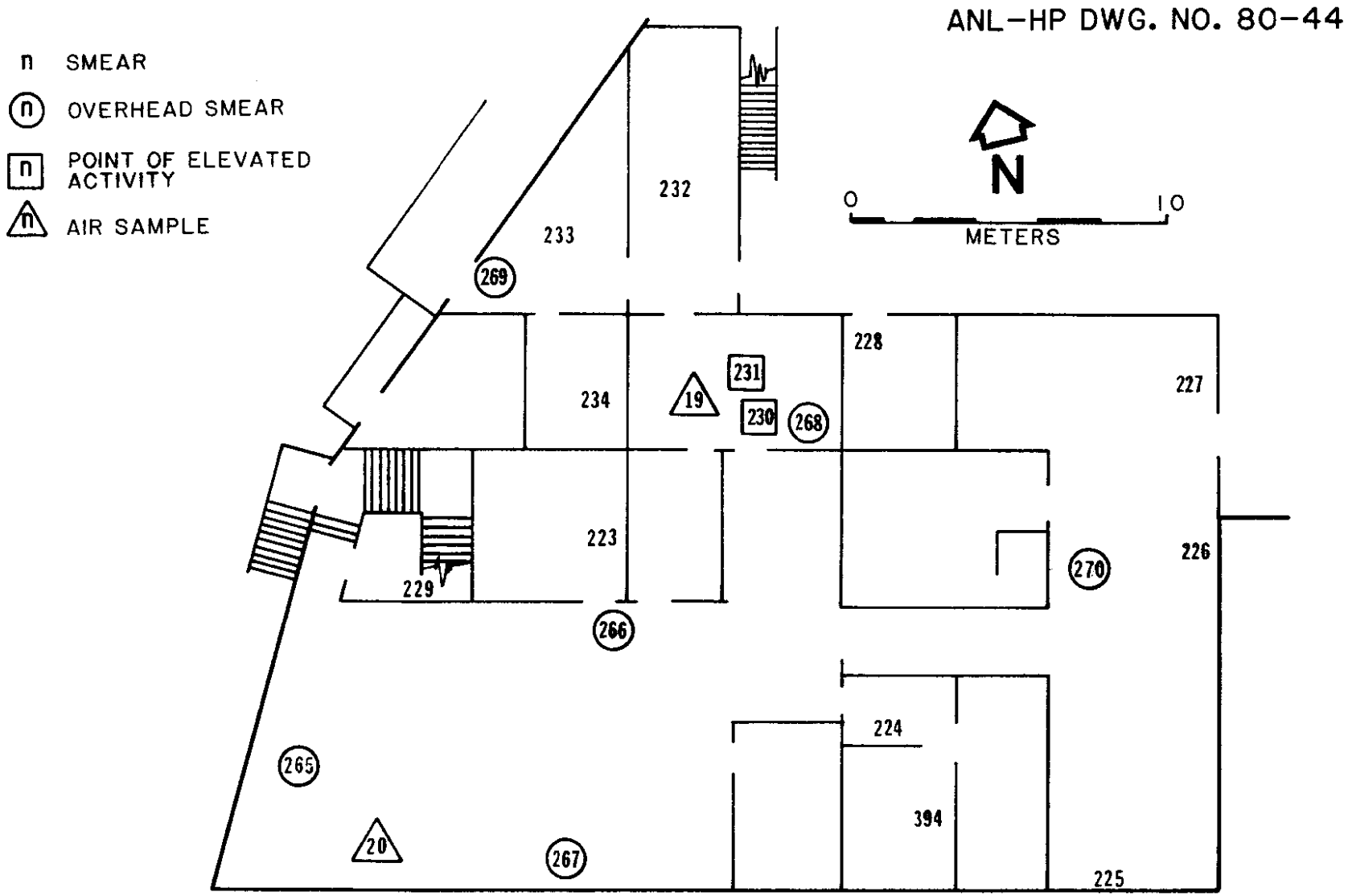



Figure 30. Warehouse Laboratory and Office Survey Locations.

ANL-HP DWG. NO. 80-45

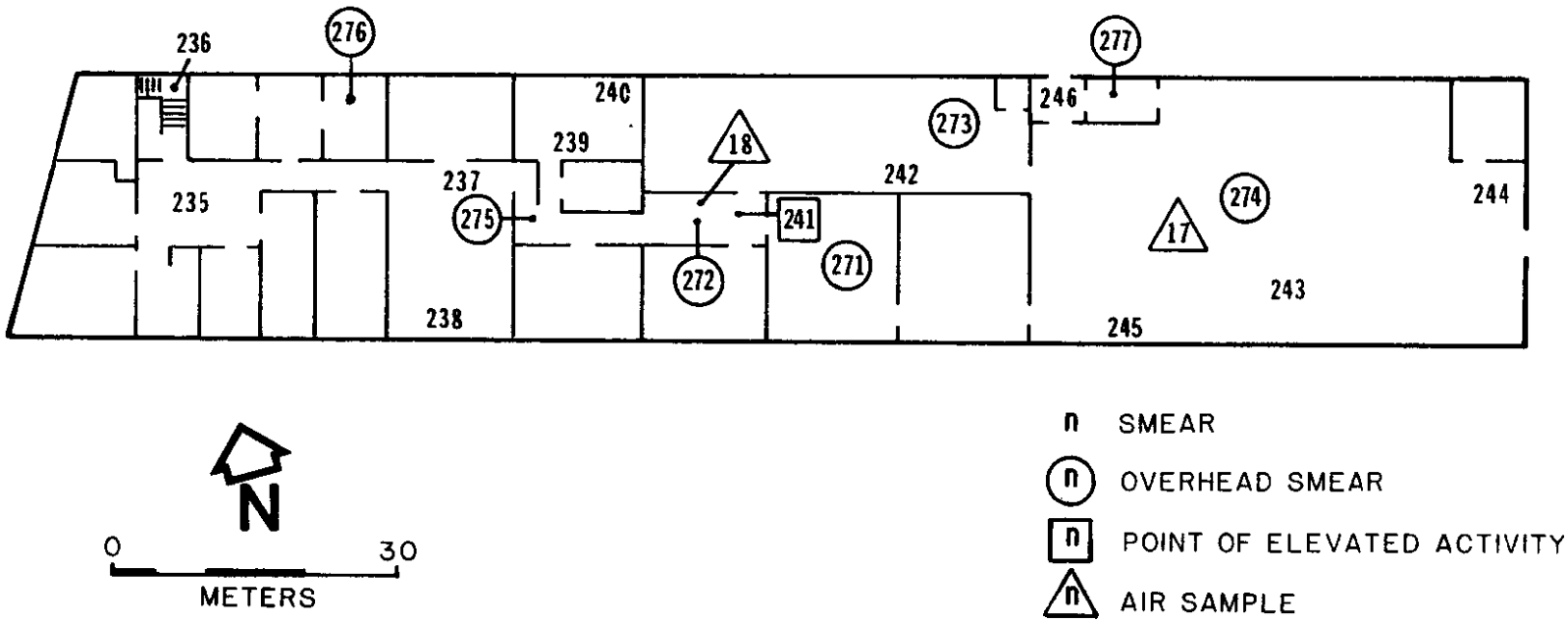



Figure 51. Warehouse 2nd Floor Offices Survey Locations.

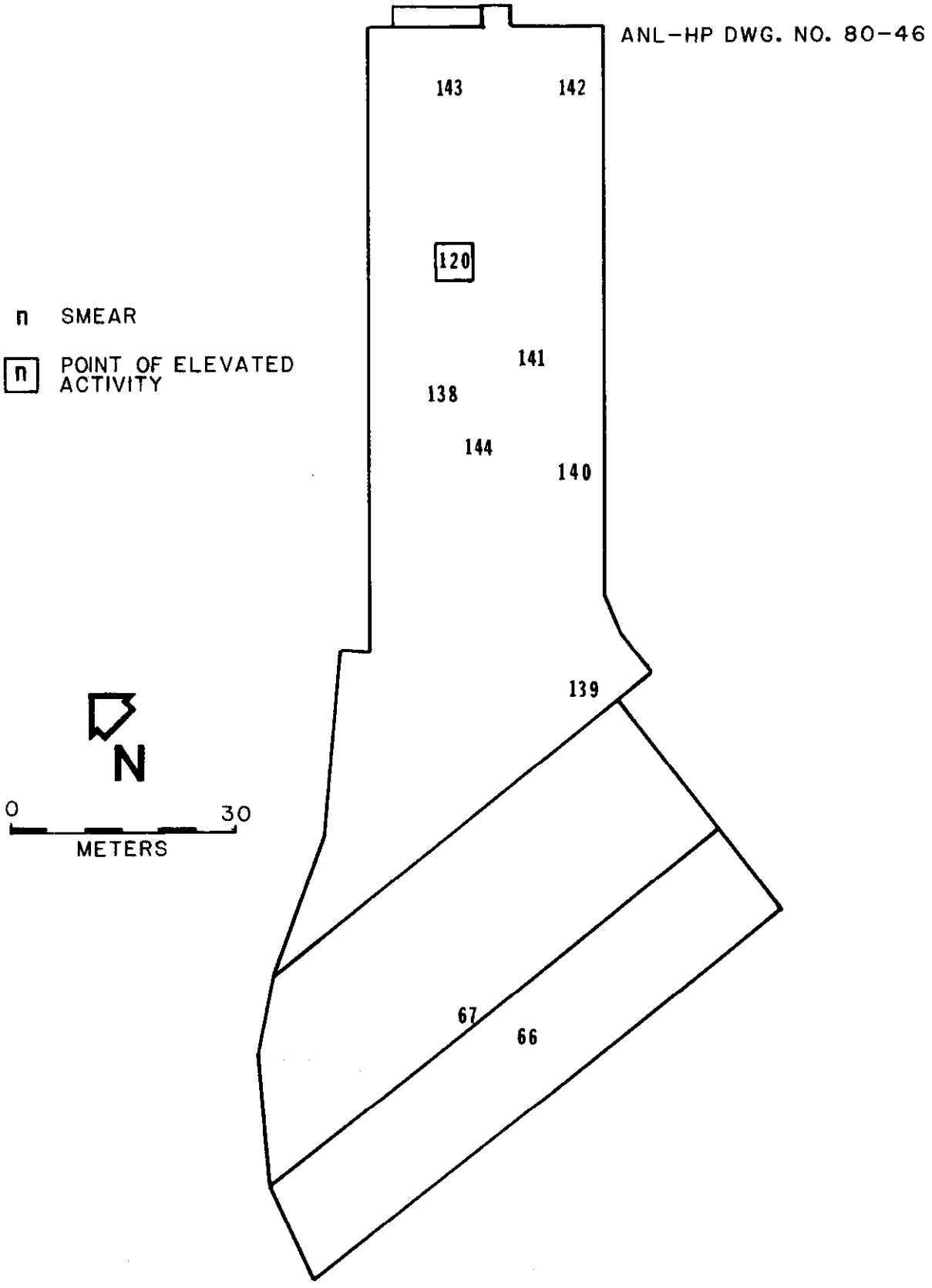



Figure 52. Warehouse Roof Survey Locations.

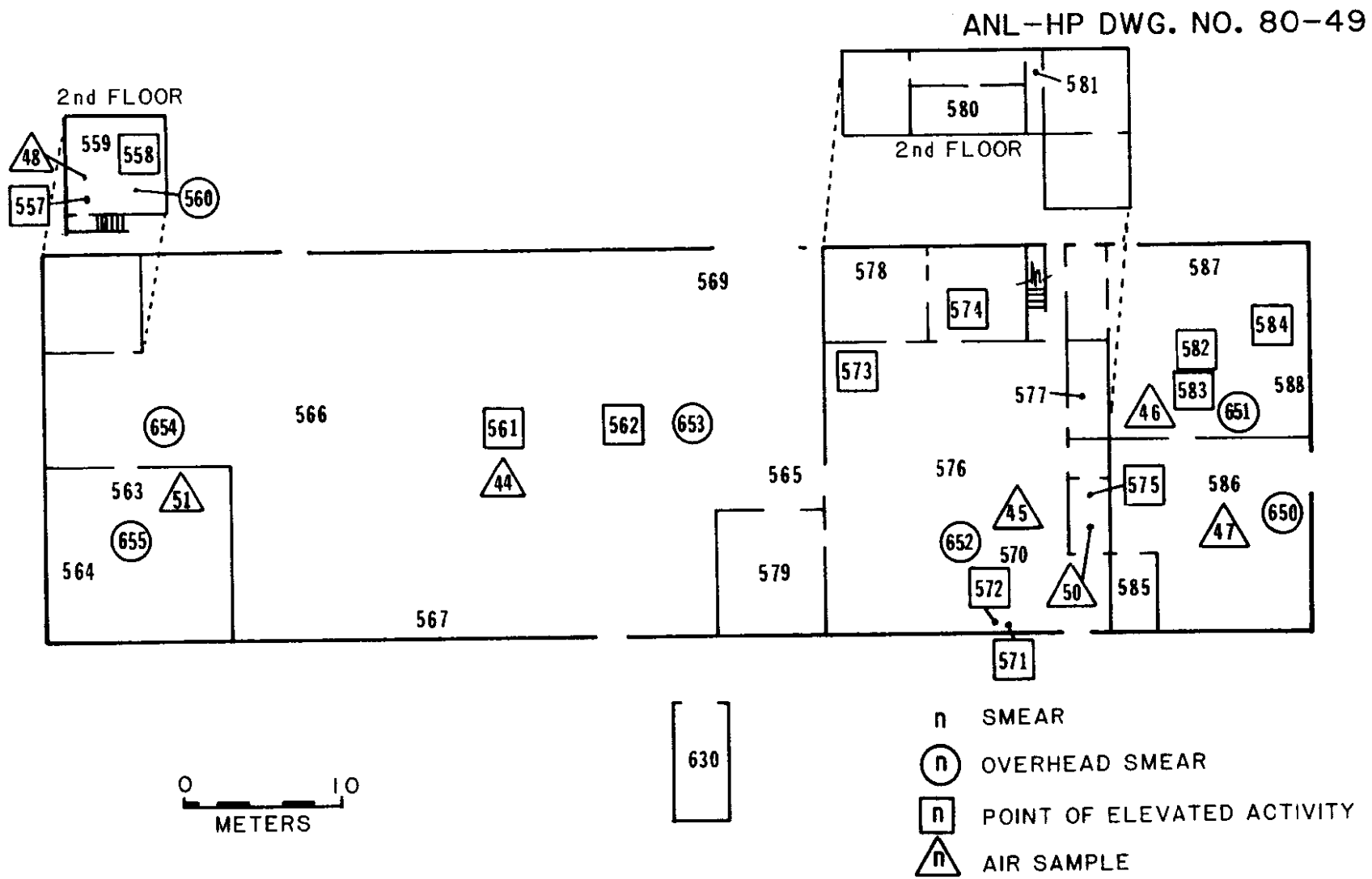



Figure 53. Building K-1 Ground Floor and 2nd Floor Survey Locations.

ANL-HP DWG. NO. 80-50

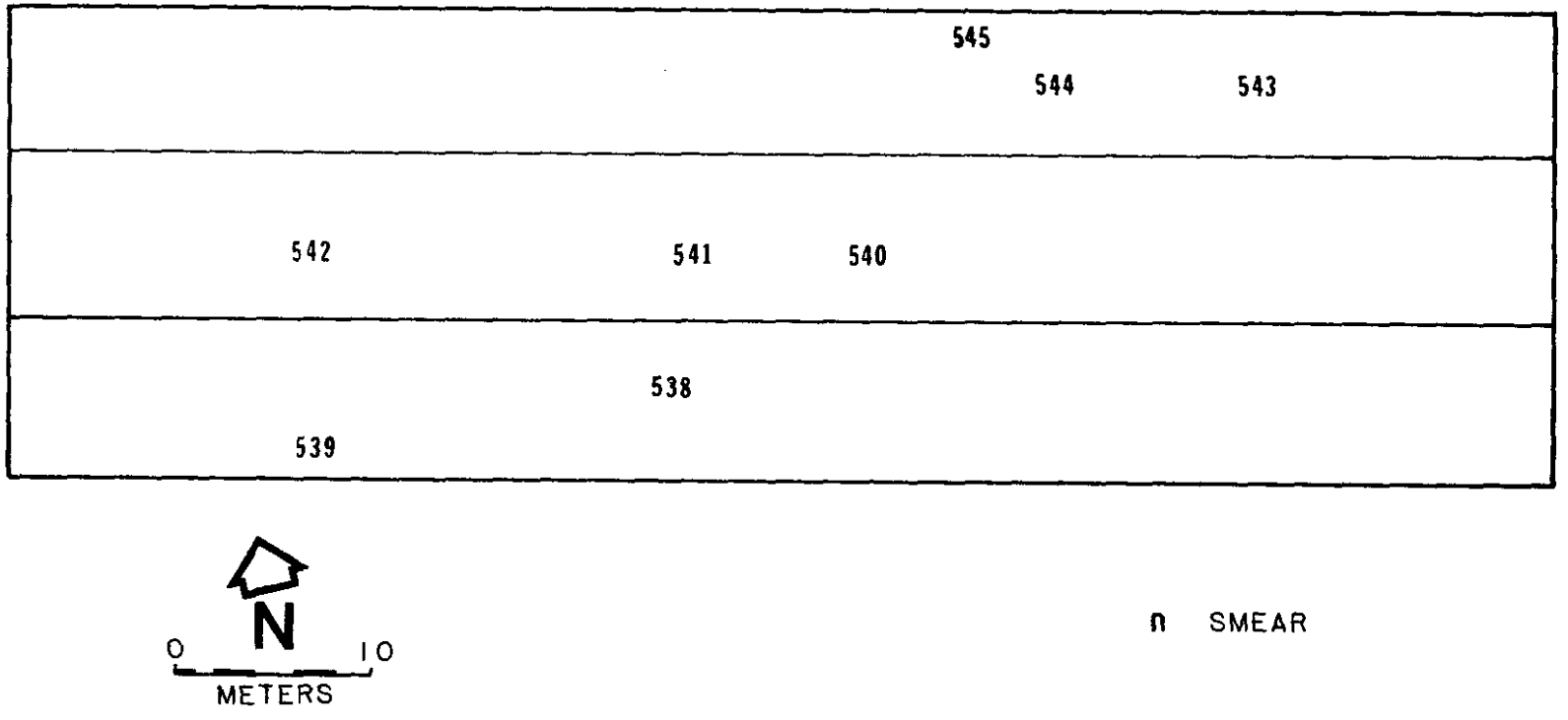



Figure 54. Building K-1 Roof Survey Locations.

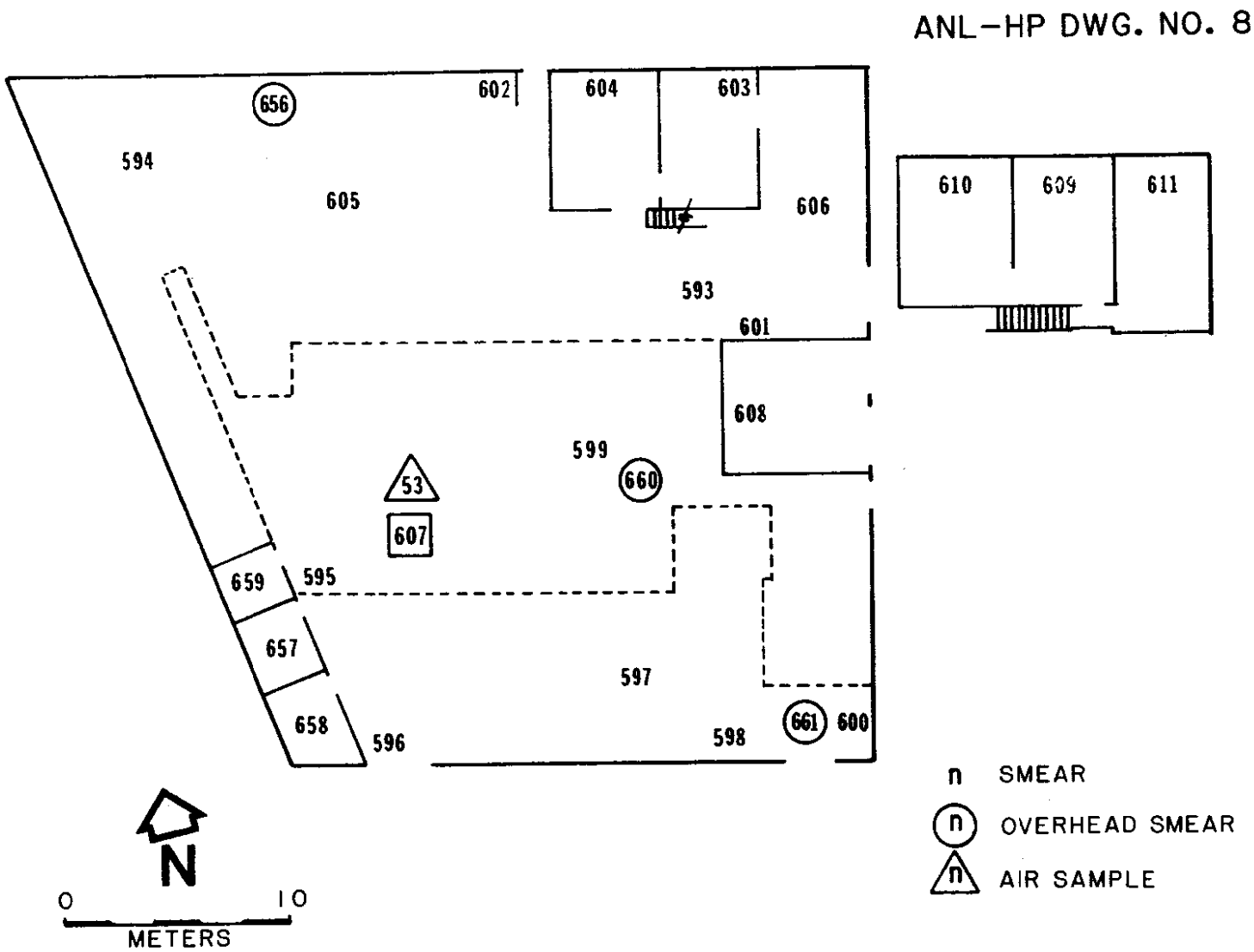



Figure 55. Building L-1 Ground Floor and 2nd Floor Survey Locations.

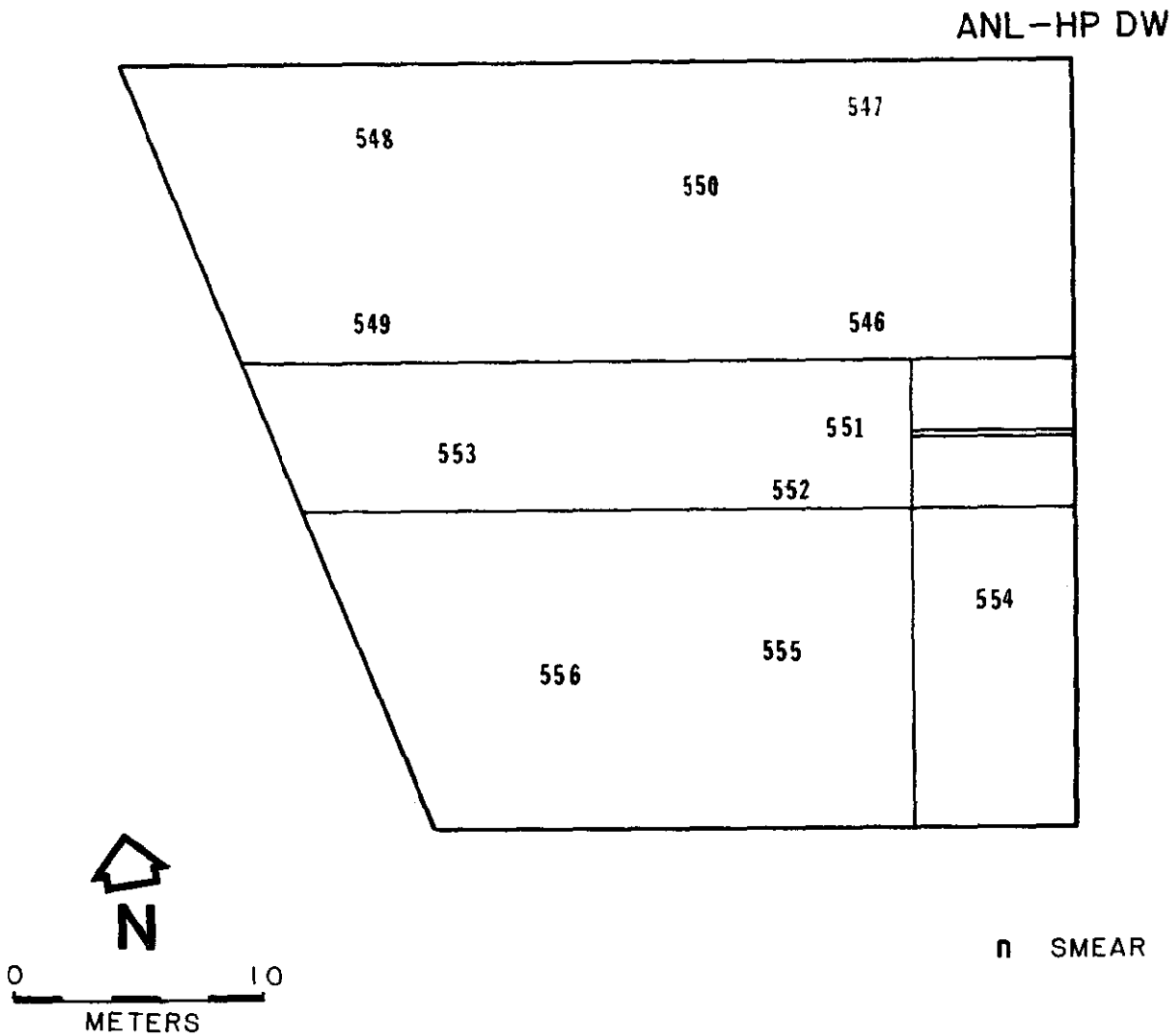



Figure 56. Building L-1 Roof Survey Locations.

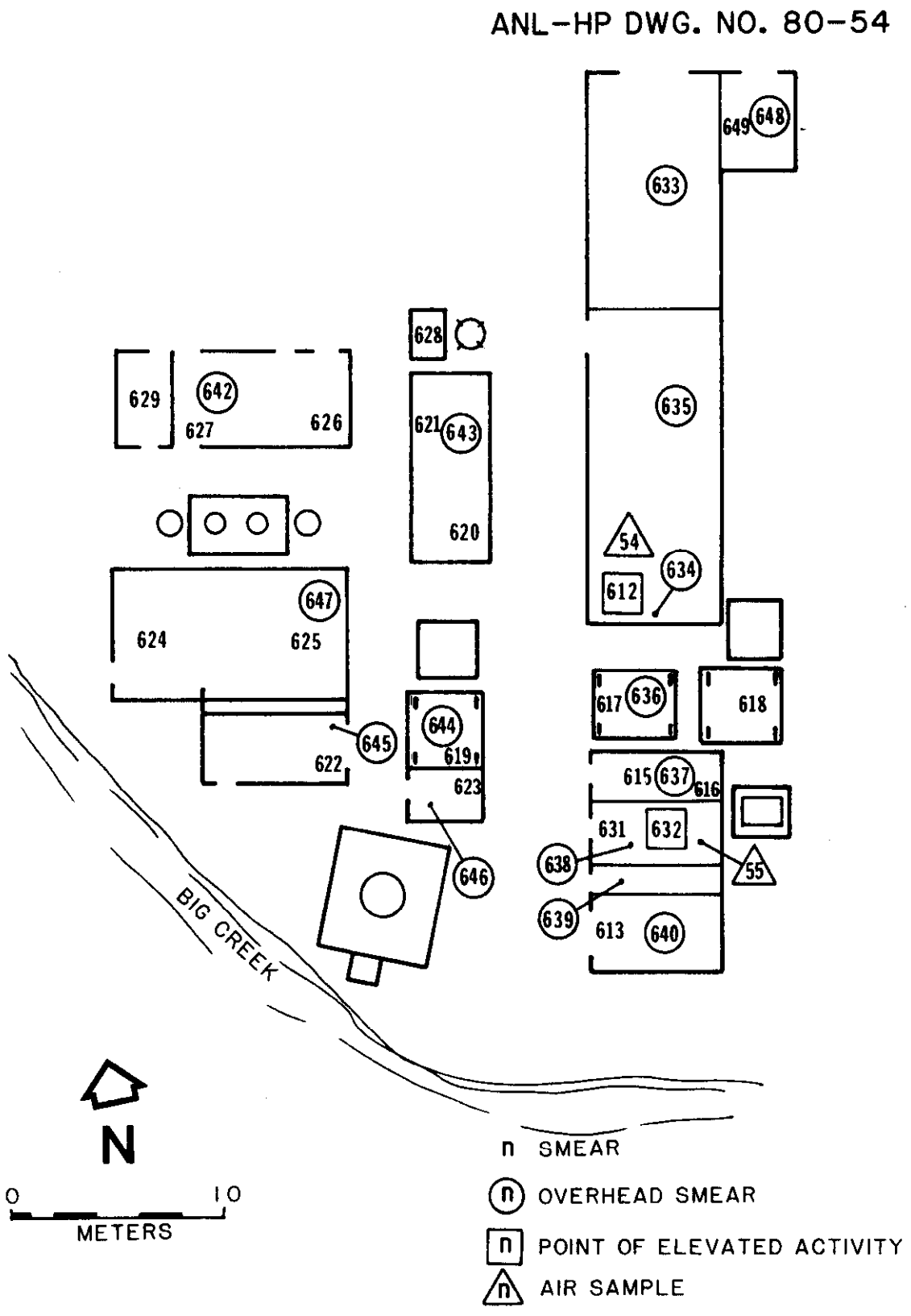



Figure 57. Miscellaneous Buildings in Area H Survey Locations.

# APPENDIX 1

## INSTRUMENTATION

### I. PORTABLE RADIATION SURVEY METERS

#### A. Gas-Flow Proportional Survey Meters

The Eberline PAC-3G was the primary instrument used for surveying. This instrument is a gas-flow proportional alpha counter which utilizes a gas-proportional probe, 61 $cm^2$ (PAC-3G) or 325 $cm^2$ (FM-4G) in area, with a thin double-aluminized Mylar window (~ 0.85 $mg/cm^2$).

Since this instrument has three high-voltage settings, it can be used to distinguish between alpha and beta-gamma contamination. This instrument was initially used in the beta mode. In that mode, the detector responds to alpha and beta particles and x- and gamma-rays. When areas indicated a higher count rate than the average instrument background, the beta mode reading was recorded, and the instrument was then switched to the alpha mode to determine any alpha contribution. In the alpha mode, the instrument responds only to particles with high specific ionization. This instrument is calibrated in the alpha mode, with a flat-plate, infinitely-thin NBS traceable $^{239}Pu$ standard, and in the beta mode with a flat-plate, infinitely-thin NBS traceable $^{90}Sr$-$^{90}Y$ standard. The PAC-3G instruments are calibrated to an apparent 50% detection efficiency.

#### B. Beta-gamma End Window Survey Meter

When an area of contamination is found with a PAC instrument, a reading is taken with an Eberline Beta-gamma Geiger-Mueller Counter, Model E-530 with a HP-190 probe. This probe has a thin mica end window, and is, therefore, sensitive to alpha and beta particles and x- and gamma-rays. A thin piece of aluminum is added to the mica, making the window density ~ 7 $mg/cm^2$. At this density, the instrument is not sensitive to alpha paricles. A maximum reading is obtained with the probe placed in contact with the area of contamination. Another reading is obtained with the probe held 1 m from the contaminated area. This instrument is calibrated with a $^{226}Ra$ standard source.

### II. SMEAR-COUNTING INSTRUMENTATION

The 10-wire instrument consists of a gas-flow proportional probe (ANL design) which uses an Eberline Mini Scaler Model MS-2. The double-aluminized Mylar probe (400 $cm^2$) uses P-10 (90% argon and 10% methane) as the counting gas. This system consists of two Mini Scalers and two probes. One is used for counting in the alpha mode; the other is used in the beta mode. The metal smear holder has been machined so that it can hold ten smears. The probe is placed over the smears and a count is taken.

APPENDIX 1
(cont'd.)

All smears of contaminated areas are counted in a Nuclear Measurements Corporation PC-3A Gas-Flow Proportional Counter (PC counter) with a double-aluminized Mylar spun top. The top is placed over nonconducting media such as paper to negate the dielectric effect. This counter also uses P-10 counting gas. Smears are counted in both the alpha and beta modes of the detector. These instruments are calibrated using $^{239}Pu$ and $^{90}Sr$-$^{90}Y$ NBS traceable sources.

III. AIR-SAMPLING DEVICE

The air samples were collected with a commercial vacuum cleaner modified at ANL. The air was drawn at a flow rate of 20 or 40 $m^3/h$. The particulates in the air were collected on a 200-$cm^2$ sheet of Hollingsworth-Vose (HV-70 0.23 mm) filter paper. The collection efficiency at these flow rates for 0.3-μm particles is about 99.9%.

IV. GAMMA-SPECTRAL INSTRUMENTATION

A Nuclear Data Multichannel Analyzer Model ND-100, with a 7.6-cm-diameter by 7.6-cm-length NaI(Tℓ) crystal was used to determine the gamma spectrum. This instrument was calibrated with $^{60}Co$ and $^{137}Cs$ NBS traceable sources. Samples of contaminated areas were counted with the analyzer, and the radionuclides of contamination were determined.

V. AVERAGE INSTRUMENT BACKGROUND READINGS[a]

| Instrument | Alpha Mode (cts/min) | Beta Mode (cts/min) |
|---|---|---|
| Eberline Floor Monitor FM-4G | 0-50 | 1500-2000 |
| Eberline PAC-3G | 0-50 | 150-200 |
| Nuclear Measurements Corp. PC-3A 2π Internal Gas-Flow Counter | 0.3±0.1[b] | 40.0±1.7[b] |
| Eberline 530 with HP-190 Beta-Gamma End Window | | 0.02 mR/h (at 1 m above floor) |

[a]Background readings were initially taken in the mobile laboratory and rechecked throughout the various areas while surveying.

[b]One standard deviation due to counting statistics.

# APPENDIX 2

## CONVERSION FACTORS

### I. INSTRUMENTATION

The conversion factors used to obtain the readings in units of disintegrations per minute per 100 $cm^2$ (dis/min-100 $cm^2$) and the derivation of those factors are listed below.

A. Conversion Factors

| | PAC-3G | | Floor Monitor (FM-4G) | |
|---|---|---|---|---|
| | Alpha | Beta | Alpha | Beta |
| To 100 $cm^2$ | 1.64 | 1.64 | 0.31 | 0.31 |
| cts/min to dis/min $^{90}Sr$-$^{90}Y$ | - | 2 | - | 2 |
| cts/min to dis/min for $^{239}Pu$ | 2 | - | 2 | - |
| cts/min to dis/min for normal U | 3.5 | 2.7 | 3.0 | 2.5 |
| cts/min to dis/min $^{226}Ra$ plus daughters | 1.7 | 1.7 | 1.7 | 1.8 |

B. Derivation of Conversion Factors

. Floor Monitor

Window Area: ~ 325 $cm^2$
Conversion to 100 $cm^2$ = 0.31 times Floor Monitor readings

. PAC-3G

Window Area: ~ 61 $cm^2$
Conversion to 100 $cm^2$ = 1.64 times PAC reading

. 2$\pi$ Internal Gas-Flow Counter, PC Counter

Geometry: Solid Steel Spun Top - 0.50

Geometry: Mylar Spun Top - 0.43
Mylar spun top counting {double-aluminized Mylar window (~ 0.85 mg/$cm^2$)} utilizes the well of the PC counter and is a method developed and used by the Argonne National Laboratory Health Physics Section for negating the die lectric effect in counting samples on nonconducting media.

APPENDIX 2
(cont'd.)

With a flat-plate, infinitely thin $^{226}Ra$ plus short-lived daughters standard used as a source of alpha emissions, the plate was counted in a $2\pi$ Internal Gas-Flow Counter (PC counter) with the source leveled to an apparent $2\pi$ geometry. The alpha counts per minute (cts/min) reading was found to be $1.86 \times 10^4$ cts/min, or $1.86 \times 10^4 \div 0.51^* = 3.65 \times 10^4$ disintegrations per minute (dis/min) alpha. Since the source was infinitely-thin, the alpha component was used as the total alpha dis/min of the source.

The same $^{226}Ra$ plus daughters source, when counted with the PAC instrument in the alpha mode, was found to be $2.18 \times 10^4$ cts/min at contact. The conversion factor for cts/min to dis/min for the PAC instrument is $3.65 \times 10^4 \div 2.18 \times 10^4 = 1.7$ dis/min per cts/min alpha.

The same source was covered with two layers of conducting paper, each 6.31 mg/cm$^2$, to absorb the alpha emissions. With the PC counter in the beta mode and the paper in good contact with the chamber, the count was found to be $1.17 \times 10^4$ or $1.17 \times 10^4 \div 0.50 = 2.35 \times 10^4$ dis/min beta. With the PAC in the beta mode and in contact with the covered source in the center of the probe, the count was found to be $1.36 \times 10^4$ cts/min. This indicates a conversion factor of $2.35 \times 10^4 \div 1.36 \times 10^4 = 1.7$ dis/min per cts/min beta-gamma. All detectors gave readings similar to those reported above for the alpha and beta-gamma modes.

Utilizing a 1.25 in x 1.25 in x 0.005 in (3.2 cm x 3.2 cm x 0.013 cm) normal uranium foil as a source of uranium alpha emissions, the foil was counted in a PC counter with the source leveled to an apparent $2\pi$ geometry. The same normal uranium source, covered with two layers of conducting paper in good contact with the chamber, each 6.31 mg/cm$^2$ to negate the alpha emissions, was counted for composite beta and gamma emissions in the PC counter. The source was leveled to an apparent $2\pi$ geometry; however, no provision was made for backscatter.

II. SMEAR COUNT

The conversion factors for cts/min-100 cm$^2$ to dis/min-100 cm$^2$ are given below:

A. Conversion Equation (Alpha)

$$\frac{\text{cts/min - (Bkgd)}}{\text{g x bf x sa x waf}} = \text{dis/min } \alpha$$

*The value of 0.51 includes the following factors: geometry (g) = 0.50; backscatter factor (bf) = 1.02; sample absorption factor (sa) = 1.0; window air factor (waf) = 1.0. The product of g x bf x sa x waf is 0.51.

APPENDIX 2
(cont'd.)

A geometry (g) of 0.43 is standard for all flat-plate counting using the Mylar spun top.

A backscatter factor (bf) of 1.0 is used when determining alpha activity on a filter media.

The self-absorption factor (sa) is assumed to be 1, unless otherwise determined.

If the energies of the isotope are known, the appropriate window air factor (waf) is used; if the energies of the isotopes are unknown, the (waf) of $^{239}Pu$ (0.713) is used.

The (waf) for alpha from $^{226}Ra$ plus daughters is 0.55.

B. Conversion Equation (Beta)

$$\frac{\text{cts/min} - \{\beta \text{ Bkgd (cts/min)} + \alpha \text{ cts/min}\}}{g \times bf \times sa \times waf} = \text{dis/min } \beta$$

A geometry (g) of 0.43 is standard for all flat-plate counting using the Mylar spun top.

A backscatter factor (bf) of 1.1 is used when determining beta activity on a filter media.

A self-absorption factor (sa) is assumed to be 1, unless otherwise determined.

If the energies of the isotopes are known, the appropriate window air factor (waf) is used; if the energies of the isotopes are unknown, the (waf) of $^{90}Sr$-$^{90}Y$ (0.85) is used.

The (waf) for betas from $^{226}Ra$ plus daughters is 0.85.

# APPENDIX 3

## RADON-DETERMINATION CALCULATIONS

Calculations for determining radon concentrations in air samples collected with an Argonne National Laboratory-designed air sampler using HV-70 or LB5211 filter media are summarized in this appendix. The basic assumptions and calculations used to derive the air concentrations are also included.

### I. RADON CONCENTRATIONS

The following postulates are assumed in deriving the radon ($^{222}Rn$) concentrations as based on the RaC' alpha count results:

A. RaA, RaB, RaC, and RaC' are in equilibrium.

B. RaA is present only in the first count and not the 100-min. decay count.

C. One-half of the radon progeny is not adhered to airborne particulates (i.e., unattached fraction) and, therefore, is not collected on the filter media.

D. The geometry factor (g) is 0.43 for both the alpha and beta activity.

E. The backscatter factor (bf) for the alpha activity is 1.0.

F. The sample absorption factor (sa) for RaC' is 0.77.

G. The window air factor (waf) for RaC' is 0.8.

H. RaB and RaC, being beta emitters, are not counted in the alpha mode.

I. The half-life of the radon progeny is approximately 36 minutes, based on the combined RaB and RaC half-lives.

J. Thoron and long-lived alpha emitters are accounted for using the 360-minute-decay count and the seven-day count, respectively.

K. For all practical purposes, RaC' decays at the rate of the composite of RaB and RaC, which is about 36 min.

The following postulates are assumed in deriving the thoron ($^{220}Rn$) concentrations:

L. ThA, ThB, ThC and ThC' are in equilibrium.

M. ThA and RaC' have have decayed by the 360-min. decay count.

APPENDIX 3
(cont'd.)

N. The geometry factor (g), backscatter factor (bf), sample absorption factor (sa) and window air factor (waf) are all the same for thoron as for radon.

O. ThB and 64% of ThC, being beta emitters, are not counted in the alpha mode.

P. The half-life of the thoron progeny is 10.64 hours (638.4 min) based on the ThB half-life.

Q. For all practical purposes 36% of the ThC (alpha branch) and the ThC' decay at the same rate as ThB, which is 638.4 min.

R. The counter does not differentiate between the ThC alphas and the ThC' alphas.

The following postulates are assumed in deriving the actinon ($^{219}Rn$) concentrations:

S. AcA, AcB and AcC are in equilibrium.

T. AcA has decayed by the 100-min. decay count.

U. The geometry (g), backscatter (bf), sample absorption (sa) and window air factor (waf) factors are all the same for actinon as for radon.

V. AcB being a beta emitter is not counted in the alpha mode.

W. The half-life of the actinon progeny is 36.1 min. based on the AcB half-life.

X. For all practical purposes, the AcC decays at the same rate as AcB which is 36.1 min.

Y. 84% of the AcC decays by 6.62 MeV $\alpha$ emissions and 16% decays by 6.28 MeV $\alpha$ emissions.

The following postulate is assumed to derive the long-lived concentration:

Z. The long-lived activity, as determined from the seven-day count, is assumed to be constant during the entire counting period. This assumption is valid for isotopes with half-lives longer than a few years.

APPENDIX 3
(cont'd.)

II. EQUATIONS USED TO DERIVE AIR CONCENTRATIONS

$$A_o = \frac{A}{e^{-\lambda t}}$$

Where: $A_o$ = Activity (dis/min) present at the end of the sampling period (usually 40 minutes)

$A$ = Activity (dis/min) at some time, t, after end of the sampling period

$t$ = Time interval (min) from end of sampling period to counting interval (usually $\simeq$ 100 minutes)

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$$

$t_{\frac{1}{2}}$ = Half-life of isotope (min).

Concentration is determined by the equation:

$$C = \frac{A_o \lambda}{f} \times \frac{1}{1-e^{-\lambda t_s}}.$$

Where: $C$ = Concentration (dis/min-$m^3$)

$A_o$ = Activity on filter media at end of sampling period (dis/min)

$f$ = Sampling rate ($m^3$/min = $m^3$/h x 1h/60 min.)

$t_s$ = Length of sampling time (min.)

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$$

$t_{\frac{1}{2}}$ = Half-life of isotope or controlling parent (min).

III. ACTINON CORRECTION

Since the actinon ($^{219}Rn$) progeny (AcA, AcB & AcC) decays at the AcB half-life of 36 min, it cannot be distinguished from the radon ($^{222}Rn$) progeny using standard air sampling with HV-70 or LB5211 filter media and standard alpha counting techniques. A positive displacement pump is used to collect a sample on millipore (0.5 to 0.8 μm) filter media. The sample rate

APPENDIX 3
(cont'd.)

is approximately 20 liters/min for a sampling time of at least 90 min. The center portion of the sample is removed and counted in an alpha spectrometer which exhibits the 6.62 MeV AcC alpha emissions and the 7.69 MeV RaC' alpha emissions. If these two peaks are observed in the spectrum, then the following calculations are performed.

$$B_j = \sum_{i=1}^{n} b_{ij}$$

Where: $b_i$ = the number of counts in channel i of peak j.

$B_j$ = summation of n channels under peak j.

j = 1 for the 6.62 MeV peak of actinon.

j = 2 for the 7.69 MeV peak of radon.

n = total number of channels in the summation.

The fraction of the activity with a 36-minute half-life due to actinon and radon are then:

$$\text{Actinon} = \frac{B_1/.84}{B_1/0.84+B_2}$$

$$\text{Radon} = \frac{B_2}{B_1/0.84+B_2}$$

Where 1 refers to actinon progeny and 2 refers to radon progeny.

IV. EXAMPLE CALCULATION

Data has been created to correspond to values likely to occur if all possible types of contamination are present in the air of a room where the sample is taken. The application of the equations for determining all types of activity and their concentrations are given below.

| | | |
|---|---|---|
| Data | f = 40 $m^3$/60 min | $t_s$ = 40 min |
| at | t = 100 min | $A^s$ = 2000 dis/min |
| at | t = 360 min | A = 140 dis/min |
| at | t = 7 days | A = 5 dis/min. |

For long-lived activity:

$$A_o = A = 5 \text{ dis/min}$$

APPEMDIX 3
(cont'd.)

$$C(L) = A_o/fxt_s = \frac{5}{40/60x40} = 0.19 \text{ dis/min-m}^3$$

For thoron:

$$A_o = \frac{140-5}{\exp - \frac{0.693 \times 360}{638.4}} = 199.6 \text{ dis/min}$$

$$C(Tn) = \frac{199.6 \times \frac{0.693}{638.4}}{40/60} \times \frac{1}{1 - \exp - \frac{0.693 \times 40}{638.4}} = 7.6 \text{ dis/min-m}^3$$

For radon ($^{222}Rn$) and actinon ($^{219}Rn$); activity due to thoron at t = 100 min.

$$A = \frac{135}{\exp - \frac{0.693 \times 260}{638.4}} = 179 \text{ dis/min}$$

Activity due to the isotopes with a 36 minute half-life:

$$A = 2000 - 179 - 5 = 1816 \text{ dis/min}$$

$$A_o = \frac{1816}{\exp - \frac{0.693 \times 100}{36}} = 12,454 \text{ dis/min}$$

$$C(36) = \frac{12,454 \times \frac{0.693}{36}}{40/60} \times \frac{1}{1 - \exp \frac{-0.693x40}{36}} = 669.7 \text{ dis/min-m}^3$$

When an actinon peak is seen at 6.62 MeV, the counts under the two peaks are summed. For example, if 10 channels are summed, the following counts are found.

For 6.62 MeV peak: 44 in 10 channels, where the 6.62 alpha emissions are 84% of the total.

APPENDIX 3
(cont'd.)

For 7.69 MeV peak: 601 counts in 10 channels, where the 7.69 MeV alpha emissions are 100% of the total.

$B_1 = 44$

$B_1/0.84 = 52$ counts

$B_2 = 601$ counts

Actinon = 52/653 = 0.08

Radon = 601/653 = 0.92

C(Rn) = C(36) x Radon% = 669.7 x 0.92 = 616.1 dis/min-$m^3$

C = C(36) x Actinon% = 669.7 x 0.08 = 53.6 dis/min-$m^3$

Since we assume that on the average half of the progeny is not adhered to the airborne particulates, the above concentrations are then multiplied by a factor of (2) to determine actual concentrations. We assume that there is no unattached fraction for the long-lived activity.

C actual = C measured x progeny correction factor

C(L) = 0.19 dis/min-$m^3$

C(Tn) = 7.6 dis/min-$m^3$ x 2 = 15.2 dis/min-$m^3$

C(An) = 53.6 dis/min-$m^3$ x 2 = 107.2 dis/min-$m^3$

C(Rn) = 616 dis/min-$m^3$ x 2 = 1232 dis/min-$m^3$

These would then be the resultant concentrations in dis/min-$m^3$. To convert to pCi/ℓ, divide the concentrations by 2.2 x $10^3$:

$$C(L) = \frac{0.19 \text{ dis/min-m}^3}{2{,}220 \text{ dis/min-m}^3/\text{pCi}/\ell} = 8.6 \times 10^{-5} \text{ pCi}/\ell$$

$$C(Tn) = \frac{15.2 \text{ dis/min-m}^3}{2{,}220 \text{ dis/min-m}^3/\text{pCi}/\ell} = 0.0068 \text{ pCi}/\ell$$

APPENDIX 3
(cont'd.)

$$C(An) = \frac{107.2 \text{ dis/min-m}^3}{2{,}220 \text{ dis/min-m}^3/\text{pCi}/\ell} = 0.048 \text{ pCi}/\ell$$

$$C(Rn) = \frac{1232 \text{ dis/min-m}^3}{2{,}220 \text{ dis/min-m}^3/\text{pCi}/\ell} = 0.55 \text{ pCi}/\ell.$$

# APPENDIX 4

## SAMPLE PREPARATION AND ANALYSES GENERIC PROTOCOL

### I. SOIL SAMPLE PREPARATION

Soil samples are acquired as previously described. These samples are bagged and identified at the collection site and returned to ANL. If there is an indication of radioactive contamination, the sample is sealed in a nalgene jar. At ANL, the soil samples are logged into the soil sample book and weighed. Each sample is weighed (on a tared balance scale) and the weight is marked on the container. This weight is recorded in the soil book as a "wet weight."

After all samples are marked, weighed and recorded, they are dried. Each sample is placed in a pyrex beaker marked with the sample identification number. If more than one beaker is necessary, additional numbers (e.g. 1-3, 2-3, 3-3) are used. The original containers are saved for repackaging the dried samples. The beaker is set in an 80°C oven until the soil is dry (approximatley 48 hours). The sample is returned to the original container and reweighed using a tared balance scale. This weight is also marked on the container and in the soil sample book where it is referred to as a "dry weight."

After all the samples are returned to their original containers, the milling process is started. Each dried sample is transferred to a 2.3-gallon ceramic mill jar containing mill balls (1¼" x 1¼" Burundum cylinders). The mill jar number is marked on the original container. The jars are sealed and the samples are milled for two hours or until sufficient material is produced to obtain 100-g and 5-g samples for analysis. The samples are milled six at a time. A second set of six jars is prepared while the milling of the first set is proceeding. After each sample is milled, the mill balls are removed with tongs and placed in a tray. A large plastic bag is inverted over the mill jar. Both are inverted and shaken until all the soil is transferred to the bag. If the soil plates the inside of the mill jar, a small paint brush is used to loosen the soil before the jar is inverted. A separate brush is used for each jar to prevent cross-contamination of the soil samples.

After milling, each sample is sieved through a number 30 standard testing sieve (600 μm mesh) and transferred to a 12-in x 12-in ziplock bag. Rocks and dross are bagged separately. The bags are marked with the sample number, the sieve number and R(rocks) or S(soil). The balance is tared and the weights of the soil (or rocks) are measured and recorded in the Soil Sample Book. A 100-g sample of the sieved material is transferred to a 4-oz Nalgene bottle. These samples are analyzed by suitable analytical techniques, including, as a minimum, gamma spectroscopy (GeLi) and often radiochemical analyses for plutonium, americium and thorium. A 5-g sample of the sieved material is transferred to a 1-oz Nalgene bottle. One gram of this sample is used for the determination of uranium by laser fluorometry. The bottles containing these weighed samples are marked with sample number and date and this information is recorded in the soil sample book. The rocks (and dross) and remaining soil are placed in storage.

APPENDIX 4
(cont'd.)

The sieves, mill jars, and Burundum milling balls used in this work are classified in two sets. One set is used for background samples exclusively. The other set is used for all samples from suspect areas. Soil samples with elevated levels of radioactivity based on instrument measurements are milled in one gallon Nalgene bottles using Burundum balls from the set used for suspect samples. After use, these balls are either decontaminated (see below) or disposed of as radioactive waste. These Nalgene bottles are always disposed of as radioactive waste. The sieves used for these samples are also from the set used for suspect samples and are decontaminated after using.

II. EQUIPMENT DECONTAMINATION

The care of the milling apparatus is as important as the actual sample preparation. Proper care prevents cross-contamination of successive samples. The beakers used to dry the samples are washed thoroughly by placing a small amount of Haemo-Sol in each beaker and filling with warm water. The beaker is then scrubbed thoroughly on the inside and scoured on the outside with scouring powder. The beakers are then rinsed with tap water (three times) followed by demineralized water (three times) and finally dried thoroughly before reuse.

The milling apparatus (tongs, brushes, milling jars, lids, and milling balls) are rinsed. The tongs and brushes are washed thoroughly with Haemo-Sol. Eight Burundum balls are returned to each milling jar along with about one pint of clean road gravel, one spoon of Haemo-Sol, one spoon of scouring powder with bleach, and one quart of water. The lid is tightened on the jar and the jar is placed on the rolling mill and rolled for approximately two hours or until the balls and the inside of the jar appear to be physically clean. After this time, the mill jar is removed from the rolling mill and its contents are dumped into a screen or basket. The lid and balls are then rinsed thoroughly three times with tap water followed by three times with demineralized water. The inside of the jar is rinsed until it is absolutely clean. The milling apparatus is air dried with warm air. Room air is drawn through these jars using a hose which is attached to a fume hood.

The sieves are rinsed, washed in Haemo-Sol, thoroughly rinsed (three times with tap water, followed by three rinses with demineralized water) and then air dried as above before reuse.

III. WATER AND SLUDGE

Water samples are collected in 0.1-liter, 0.5-liter and/or 1-liter quantities as deemed appropriate. These samples are forwarded directly to a certified radiochemistry laboratory for preparation and analysis. The customary analysis procedure consists of filtration to obtain the suspended solids followed by evaporation to obtain the dissolved solids. Both suspended and dissolved solids are analyzed by appropriate radiochemical analytical techniques.

APPENDIX 4
(cont'd.)

Sludge samples are collected in 0.1-liter bottles and are processed as delineated above for water samples.

IV. VEGETATION, TRASH AND RUBBLE

Samples of potentially contaminated vegetation, trash (e.g. piping, ducts, conduit, etc.), and rubble are collected, bagged, and labeled at the site and returned to ANL for analysis.

Vegetation samples are initially weighed and transferred to Marinelli beakers for gamma spectrometric analysis. Then they are ashed, reweighed, and analyzed by appropriate analytical techniques.

Trash and rubble samples are forwarded to a certified radiochemistry laboratory for analysis.

V. TRITIUM FROM SOLID MATERIALS

Samples of solid materials (e.g., concrete) suspected of containing tritium are collected, broken into small pieces, and submitted to a certified radiochemistry laboratory for analysis. The standard analytical procedure consists of transferring a 20-40 g sample to a ceramic boat followed by heating in a tube furnace at 425°C for a period of two hours (~ 40 min to reach temperature and ~ 80 min heating at temperature). Helium is used as a flow gas through the tube during heating, and the tritium is collected in two traps on the downstream side of the furance. The first trap is immersed in an ordinary ice bath (0°C); the second trap is immersed in a $CO_2$-Freon bath (-57°C). The collected tritiated water from both traps is combined, made up to a known volume, and an aliquot taken for liquid scintillation counting of the tritium.

VI. ANALYSIS PROCEDURES

A 100-gram fraction from each soil sample is analyzed by high-resolution gamma-ray spectroscopy using a germanium crystal detector coupled to a multichannel analyzer. This analysis allows for a quantitative determination of the $^{226}Ra$ decay chain (via the 609 keV γ-ray of $^{214}Bi$) and the $^{232}Th$ decay chain (via the 911 keV γ-ray of $^{228}Ac$) as well as any other gamma emitting radionuclide (e.g. $^{137}Cs$) present in the soil.

The total uranium (elemental) present in the soil is determined by an acid leach of the soil sample followed by laser fluorometry of the leached sample.

Thorium analysis consists of an acid leach of the sample (using a $^{234}Th$ spike for yield determination) followed by plating a thin source of the radiochemically separated thorium and determining the thorium isotopes ($^{228}Th$ and $^{232}Th$) by alpha spectroscopy.

APPENDIX 4
(cont'd.)

The results of the above measurements allow for quantitative determination of the relative amounts of normal uranium, natural uranium, tailings (i.e., $^{226}Ra$ decay chain), thorium ($^{232}Th$), mesothorium ($^{228}Ra$ decay chain), and thorium ($^{228}Th$) decay chain present in the contaminated material.

A mass spectrometric analysis of the uranium fraction is conducted when it is known or is is surmised that depleted or enriched uranium might be present.

# APPENDIX 5

## CALCULATION OF NORMAL-URANIUM SPECIFIC ACTIVITY

The specific activity for normal uranium was obtained by summing the measured specific activities for the individual isotopes weighted according to their normal abundances. Best values for these specific activities were taken from A. H. Jaffey et al. Phys. Rev. C 4 1889 (1971). The percent abundance and half-life for each isotope were taken from the "Table of Isotopes," 7th Edition by C. M. Lederer and V. S. Shirley (1978). Atomic weights were taken from the Handbook of Chemistry and Physics, 52nd Edition (1971).

| Isotope | Specific Activity | Half-life (years) | Abundance (atom %) | Atomic Weight (grams) | Abundance (wt %) |
|---|---|---|---|---|---|
| $^{234}U$ | - | $2.446 \times 10^5$ | 0.0054 | 234.0409 | 0.0053 |
| $^{235}U$ | 4.798 dis/min-μg | $7.038 \times 10^8$ | 0.720 | 235.0439 | 0.711 |
| $^{238}U$ | 0.746 dis/min-μg | $4.4683 \times 10^9$ | 99.275 | 238.0508 | 99.284 |
| | | | 100.0004 | | 100.0003 |

where $(wt\ \%)_i =$

$$\frac{(atom\ \%)_i \quad (atomic\ weight)_i}{\sum_j (atom\ \%)_j \quad (atomic\ weight)_j} = \frac{(atom\ \%)_i \quad (atomic\ weight)_i}{238.02985}$$

Note that the abundance totals 100.0003%. Since it cannot be determined which isotope(s) are in error, the calculations are made with the 0.0003% error unaccounted for.

Specific activity for normal uranium:

$$0.746 \times 0.99284 \times 2 = 1.481 \quad \text{dis/min-μg from } ^{234}U \text{ \& } ^{238}U$$
$$4.798 \times 0.00711 = 0.0341 \quad \text{dis/min-μg from } ^{235}U$$
$$1.515 \quad \text{dis/min-μg for normal U}$$

or $(1.515\ \text{dis/min-μg})/(2.22\ \text{dis/min-pCi}) = 0.683\ \text{pCi/μg}$

where $^{234}U$ is assumed to be in secular equilibrium with the $^{238}U$ parent.

Note that 2.25% of the total activity is due to $^{235}U$ and 48.87% each is due to $^{234}U$ and $^{238}U$.

# APPENDIX 6

## PERTINENT RADIOLOGICAL REGULATIONS, STANDARDS, AND GUIDELINES*

Excerpts From

I. DRAFT AMERICAN NATIONAL STANDARD

N13.12

Control of Radioactive Surface Contamination

on Materials, Equipment, and Facilities to be

Released for Uncontrolled Use

Where potentially contaminated surfaces are not accessible for measurement (as in some pipes, drains, and ductwork), such property shall not be released pursuant to this standard, but shall be made the subject of case-by-case evaluation.

Property shall not be released for uncontrolled use unless measurements show the total and removable contamination levels to be no greater than the values in Table 1 or Table 2. (The values in Table 2 are easier to apply when the contaminants cannot be individually identified.)

Coatings used to cover the contamination shall not be considered a solution to the contamination problem. That is, the monitoring techniques shall be sufficient to determine, and such determination shall be made, that the total amount of contamination present on and under any coating does not exceed the Table 1 or Table 2 values before release.

*These have been retyped for purposes of this report.

APPENDIX 6
(cont'd.)

TABLE 6

SURFACE CONTAMINATION LIMITS*

| Contaminants | | | Limit (Activity) (dis/min-100 $cm^2$)+ | |
|---|---|---|---|---|
| Group | Description | Nuclides (Note 1) | Removable | Total (Fixed plus Removable) |
| 1 | Nuclides for which the nonoccupational MPC$_a$ (Note 2) is $2 \times 10^{-13}$ $Ci/m^3$ or less or for which the nonoccupational MPC$_w$ (Note 4) is $2 \times 10^{-7}$ $Ci/m^3$ or less | $^{227}Ac$<br>$^{241,242m,243}Am$<br>$^{249,250,251,252}Cf$<br>$^{243,244,245,246,247,248}Cm$<br>$^{125,129}I$<br>$^{237}Np$<br>$^{231}Pa$<br>$^{210}Pb$<br>$^{238,239,240,242,244}Pu$<br>$^{226,228}Ra$<br>$^{228,230}Th$ | 20 | Nondetectable (Note 3) |
| 2 | Those nuclides not in Group 1 for which the nonoccupational MPC$_a$ (Note 2) is $1 \times 10^{-12}$ $Ci/m^3$ or less for which the nonoccupational MPC$_w$ (Note 4) is $1 \times 10^{-6}$ $Ci/m^3$ or less | $^{254}Es$<br>$^{256}Fm$<br>$^{126,131,133}I$<br>$^{210}Po$<br>$^{223}Ra$<br>$^{90}Sr$<br>$^{232}Th$<br>$^{232}U$ | 200 | 2000 $\alpha$<br>Nondetectable $\beta,\gamma$<br>(Note 5) |
| 3 | Those nuclides not in Group 1 or Group 2 | | 1000 | 5000 |

APPENDIX 6
(cont'd.)

SURFACE CONTAMINATION LIMITS

*The levels may be averaged over one square meter provided the maximum activity in any area of 100 $cm^2$ is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 $cm^2$, if (1) from measurements of a representative number n of sections it is determined that $1/n \sum_{i}^{n} S_i \geq L$, where $S_i$ is the dis/min-100 $cm^2$ determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 $cm^2$ exceeds 3 L.

+Disintegrations per minute per square decimeter.

NOTES:

(1) Values presented here are obtained from the Code of Federal Regulations, Title 10, Part 20, April 30, 1975. The most limiting of all given MPC values (for example, soluble versus insoluble) are to be used. In the event of the occurrence of mixtures of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fraction shall be less than 1.

(2) Maximum permissible concentration in air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as the National Committee on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), or the Nuclear Regulatory Commission (NRC). From the Code of Federal Regulations, Title 10, Part 20, Appendix B, Table 2, Column 1.

(3) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 $cm^2$.

(4) Maximum permissible concentration in water applicable to members of the public.

(5) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey for unconditional release should be performed in areas where the background is $\leq$ 100 counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

APPENDIX 6
(cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

(All Alpha Emitters, except $U_{nat}$ and $Th_{nat}$, Considered as a Group)*

| Contamination Contingencies | Limit (Activity) (dis/min-100 $cm^2$)+ Removable | Total (Fixed Plus Removable |
|---|---|---|
| If the contaminant cannot be identified; or if alpha emitters other than $U_{nat}$ (Note 1) and $Th_{nat}$ are present; or if the beta emitters comprise $^{227}Ac$ or $^{228}Ra$. | 20 | Nondetectable (Note 2) |
| If it is known that all alpha emitters are generated from $U_{nat}$ (Note 1) and $Th_{nat}$; and if beta emitters are present that, while not identified, do not include $^{227}Ac$, $^{125}I$, $^{226}Ra$, and $^{228}Ra$. | 200 | 2000 $\alpha$ Nondetectable $\beta,\gamma$ (Note 3) |
| If it is known that alpha emitters are generated only from $U_{nat}$ (Note 1) and $Th_{nat}$ in equilibrium with its decay products; and if the beta emitters, while not identified, do not include $^{227}Ac$, $^{125}I$, $^{129}I$, $^{90}Sr$, $^{223}Ra$, $^{228}Ra$, $^{126}I$, $^{131}I$ and $^{133}I$. | 1000 | 5000 |

APPENDIX 6
(cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

*The levels may be averaged over one square meter provided the maximum activity in any area of 100 $cm^2$ is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 $cm^2$, if (1) from measurements of a representative number n of sections it is determined that $1/n \Sigma_n S_i \geq L$, where $S_i$ is the dis/min-100 $cm^2$ determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 $cm^2$ exceeds 3 L.

+Disintegrations per minute per square decimeter.

NOTES:

(1) $U_{nat}$ and decay products.

(2) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 $cm^2$.

(3) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey of unconditional release should be performed in areas where the background is $\leq$ 100 counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

APPENDIX 6
(Cont'd.)

II. U.S. NUCLEAR REGULATORY COMMISSION
DIVISION OF FUEL CYCLE AND MATERIAL SAFETY
WASHINGTON, D.C.
JULY 1982

## GUIDELINES FOR DECONTAMINATION OF FACILITIES AND EQUIPMENT PRIOR TO RELEASE FOR UNRESTRICTED USE OR TERMINATION OF LICENSES FOR BY-PRODUCT SOURCE, OR SPECIAL NUCLEAR MATERIAL

The instructions in this guide, in conjunction with Table 1, specify the radioactivity and radiation exposure rate limits which should be used in accomplishing the decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table 1 do not apply to premises, equipment, or scrap containing induced radioactivity for which the radiological considerations pertinent to their use may be different. The release of such facilities or items from regulatory control will be considered on a case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate residual contamination.

2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table 1 prior to applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.

3. The radioactivity on the interior surfaces of pipes, drain lines, or duct work shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or duct work. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.

4. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated with materials in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer of premises to another organization continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such request must:

   a. Provide detailed, specific information describing the premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.

APPENDIX 6
(Cont'd.)

b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.

5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table 1. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:

   a. Identify the premises.

   b. Show that reasonable effort has been made to eliminate residual contamination.

   c. Describe the scope of the survey and general procedures followed.

   d. State the findings of the survey in units specified in the instruction.

Following review of the report, the NRC will consider visiting the facilities to confirm the survey.

APPENDIX 6
(cont'd.)

TABLE 2
ACCEPTABLE SURFACE CONTAMINATION LIMITS

| NUCLIDES[a] | AVERAGE[bcf] | MAXIMUM[bdf] | REMOVABLE[bef] |
|---|---|---|---|
| U-nat, $^{235}U$, $^{238}U$ and associated decay products | 5000 dis/min-100 $cm^2$ $\alpha$ | 15,000 dis/min-100 $cm^2$ $\alpha$ | 1000 dis/min-100 $cm^2$ $\alpha$ |
| Transuranics, $^{226}Ra$, $^{228}Ra$, $^{230}Th$, $^{228}Th$, $^{231}Pa$, $^{227}Ac$, $^{125}I$, $^{129}I$ | 100 dis/min-100 $cm^2$ | 300 dis/min-100 $cm^2$ | 20 dis/min-100 $cm^2$ |
| Th-nat, $^{232}Th$ $^{90}Sr$, $^{223}Ra$, $^{224}Ra$, $^{232}U$, $^{126}I$, $^{131}I$, $^{133}I$ | 1000 dis/min-100 $cm^2$ | 3,000 dis/min-100 $cm^2$ | 200 dis/min-100 $cm^2$ |
| Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except $^{90}Sr$ and others noted above. | 5000 dis/min-100 $cm^2$ $\beta\gamma$ | 15,000 dis/min-100 $cm^2$ $\beta\gamma$ | 1000 dis/min-100 $cm^2$ $\beta\gamma$ |

APPENDIX 6
(cont'd.)

TABLE 1

ACCEPTABLE SURFACE CONTAMINATION LEVELS

[a]Where surface contamination by both alpha and beta-gamma emitting nuclides exists, the limits established for alpha and beta-gamma emitting nuclides should apply independently.

[b]As used in this table, dis/min (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c]Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d]The maximum contamination level applies to an area of not more than 100 $cm^2$.

[e]The amount of removable radioactive material per 100 $cm^2$ of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

[f]The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

APPENDIX 6
(cont'd.)

III. SURGEON GENERAL'S GUIDELINES
as included in 10 CFR Part 712
Grand Junction Remedial Action Criteria

712.1 Purpose

(a) determination by DOE of the need for, priority of and selection of
appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colorado, to radiation emanating from uranium mill tailings which have been used as construction-related material.

(b) The regulations in this part are issued pursuant to Pub. L. 92-314
(86 Stat. 222) of June 16, 1972.

712.2 Scope

The regulations in this part apply to all structures in the area of Grand Junction, Colorado, under or adjacent to which uranium mill tailings have been used as a construction-related material between January 1, 1951, and June 16, 1972, inclusive.

712.3 Definitions

As used in this part:

(a) "Administrator" means the Administrator of Energy Research and Development or his duly authorized representative.

(b) "Area of Grand Junction, Colorado," means Mesa County, Colorado.

(c) "Background" means radiation arising from cosmic rays and radioactive material other than uranium mill tailings.

(d) "DOE" means the U.S. Department of Energy or any duly authorized representative thereof.

(e) "Construction-related material" means any material used in the construction of a structure.

(f) "External gamma radiation level" means the average gamma radiation exposure rate for the habitable area of a structure as measured near floor level.

APPENDIX 6
(cont'd.)

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) averaging the results of six air samples each of at least 100 hours duration, and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

(h) "Milliroentgen" (mR) means a unit equal to one-thousandth (1/1000) of a roentgen which roentgen is defined as an exposure dose of X or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

(i) "Radiation" means the electromagnetic energy (gamma) and the particulate radiation (alpha and beta) which emanate from the radioactive decay of radium and its daughter products.

(j) "Radon daughters" means the consecutive decay products of radon-222. Generally, these include Radium A (polonium-218), Radium B (lead-214), Radium C (bismuth-214), and Radium C' (polonium-214).

(k) "Remedial action" means any action taken with a reasonable expectation of reducing the radiation exposure resulting from uranium mill tailings which have been used as construction-related material in and around structures in the area of Grand Junction, Colorado.

(l) "Surgeon General's Guidelines" means radiation guidelines related to uranium mill tailings prepared and released by the Office of the U.S. Surgeon General, Department of Health, Education and Welfare on July 27, 1970.

(m) "Uranium mill tailings" means tailings from a uranium milling operation involved in the Federal uranium procurement program.

(n) "Working Level" (WL) means any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of $1.3 \times 10^5$ MeV of potential alpha energy.

712.4 Interpretations

Except as specifically authorized by the Administrator in writing, no interpretation of the meaning of the regulations in this part by an officer or employee of DOE other than a written interpretation by the General Counsel will be recognized to be binding upon DOE.

712.5 Communications

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director, Division of Safety, Standards, and Compliance, U.S. Department of Energy, Washington, D.C. 20545.

APPENDIX 6
(cont'd.)

712.6 General radiation exposure level criteria for remedial action.

The basis for undertaking remedial action shall be the applicable guidelines published by the Surgeon General of the United States. These guidelines recommended the following graded action levels for remedial action in terms of external gamma radiation level (EGR) and indoor radon daughter concentration level (RDC) above background found within dwellings constructed on or with uranium mill tailings.

| EGR | RDC | Recommendation |
|---|---|---|
| Greater than 0.1 mR/h | Greater than 0.05 WL | Remedial action indicated. |
| From 0.05 to 0.1 mR/h | From 0.01 to 0.05 WL | Remedial action may be suggested. |
| Less than 0.05 mR/h | Less than 0.01 WL | No remedial action indicated |

712.7 Criteria for determination of possible need for remedial action

Once it is determined that a possible need for remedial action exists, the record owner of a structure shall be notified of that structure's eligibility for an engineering assessment to confirm the need for remedial action and to ascertain the most appropriate remedial measure, if any. A determination of possible need will be made if as a result of the presence of uranium mill tailings under or adjacent to the structure, one of the following criteria is met:

(a) Where DOE approved data on indoor radon daughter concentration levels are available

(1) For dwellings and schoolrooms: An indoor radon daughter concentration level of 0.01 WL or greater above background.

(2) For other structures: An indoor radon daughter concentration level of 0.03 WL or greater above background.

(b) Where DOE approved data on indoor radon daughter concentration levels are not available:

(1) For dwellings and schoolrooms:

(i) An external gamma radiation level of 0.05 mR/h or greater above background.

APPENDIX 6
(cont'd.)

(ii) An indoor radon daughter concentration level of 0.01 WL or greater above background (presumed).

(A) It may be presumed that if the external gamma radiation level is equal to or exceed 0.02 mR/h above background, the indoor radon daughter concentration level equals or exceeds 0.01 WL above background.

(B) It should be presumed that if the external gamma radiation level is less than 0.001 mR/h above background, the indoor radon daughter concentration level is less than 0.01 WL above background, and no possible need for remedial actions exists.

(C) If the external gamma radiation level is equal to or greater than 0.001 mR/h above background but is less than 0.02 mR/h above background, measurements will be required to ascertain the indoor radon daughter concentration level.

(2) For other structures:

(i) An external gamma radiation level of 0.15 mR/h above background averaged on a room-by-room basis.

(ii) No presumptions shall be made on the external gamma radiation level/indoor radon daughter concentration level relationship. Decisions will be made in individual cases based upon the results of actual measurements.

712.8 Determination of possible need for remedial action where criteria have not been met.

The possible need for remedial action may be determined where the criteria in 712.7 have not been met if various other factors are present. Such factors include, but are not necessarily limited to, size of the affected area, distribution of radiation levels in the affected area, amount of tailings, age of individuals occupying affected area, occupancy time, and use of the affected area.

712.9 Factors to be considered in determination of order of priority for remedial action.

In determining the order or priority for execution of remedial action, consideration shall be given, but not necessarily limited to, the following factors:

(a) Classification of structure. Dwellings and schools shall be considered first.

APPENDIX 6
(cont'd.)

(b) Availability of data. Those structures for which data on indoor radon daughter concentration levels and/or external gamma radiation levels are available when the program starts and which meet the criteria in 712.7 will be considered first.

(c) Order of application. Insofar as feasible remedial action will be taken in the order in which the application is received.

(d) Magnitude of radiation level. In general, those structures with the highest radiation levels will be given primary consideration.

(e) Geographical location of structures. A group of structures located in the same immediate geographical vicinity may be given priority consideration particularly where they involve similar remedial efforts.

(f) Availability of structures. An attempt will be made to schedule remedial action during those periods when remedial action can be taken with minimum interference.

(g) Climatic conditions. Climatic conditions or other seasonable considerations may affect the scheduling of certain remedial measures.

712.10 Selection of appropriate remedial action.

(a) Tailings will be removed from those structures where the appropriately averaged external gamma radiation level is equal to or greater than 0.05 mR/h above background in the case of dwellings and schools and 0.15 mR/h above background in the case of other structures.

(b) Where the criterion in paragraph (a) of this section is not met, other remedial action techniques, including but not limited to sealants, ventilation, and shielding may be considered in addition to that of tailings removal. DOE shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

APPENDIX 6
(cont'd.)

IV. EXCERPTS FROM DOE 5480.1 Chg. 6, Chapter XI

"Requirements for Radiation Protection"

Exposure of Individuals and Population Groups in Uncontrolled Areas. Exposures to members of the public shall be as low as reasonably achievable levels within the standards prescribed below.

Radiation Protection Standards
for Internal and External Exposure
of Members of the Public

| | Annual Dose Equivalent or Dose Commitment | |
|---|---|---|
| Type of Exposure | Based on Dose to Individuals at Points of Maximum Probable Exposure | Based on Average Dose to a Suitable Sample of the Exposed Population |
| Whole body, gonads, or bone marrow | 0.5 rem (or 500 mrem) | 0.17 rem (or 170 mrem) |
| Other organs | 1.5 rem (or 1500 mrem) | 0.5 rem (or 500 mrem) |

CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND

| Element (atomic number) | Isotope | soluble (S) insoluble (I) | Table I Controlled Area Column 1 Air (pCi/ℓ) | Table I Controlled Area Column 2 Water pCi/ℓ) | Table II Uncontrolled Area Column 1 Air (pCi/ℓ) | Table II Uncontrolled Area Column 2 Water (pCi/ℓ) |
|---|---|---|---|---|---|---|
| Radon (86) | Rn 220 | S | 300 | | 10 | |
| | Rn 222 | S | 100 | | 3 | |

APPENDIX 6
(cont'd.)

V. 40 CFCFR Part 192 - HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS FOR URANIUM MILL TAILINGS

(Excerpts have been retyped for the purposes of this report.)

Authority: Section 275 of the Atomic Energy Act of 1954, 42 U.S.C. 2022, as added by the Uranium Mill Tailings Radiation Control Act of 1978, PL 95-604.

Subpart B -- Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.10 Applicability

This subpart applies to land and buildings that are part of any processing site designated by the Secretary of Energy under Section 102 of the Act. Section 101 of the Act, states, in part, that "processing site" means -

(a) any site, including the mill, containing residual radioactive materials at which all or substantially all of the uranium was produced for sale to any Federal agency prior to January 1, 1971, under a contract with any Federal agency, except in the case of a site at or near Slick Rock, Colorado, unless --

(1) such site was owned or controlled as of January 1, 1978, or is thereafter owned or controled, by any Federal agency, or

(2) a license (issued by the {Nuclear Regulatory} Commission or its predecessor agency under the Atomic Energy Act of 1954 or by a State as permitted under Section 274 of such Act) for the production at site of any uranium or thorium product dervied from ores is in effect on January 1, 1978, or is issued or renewed after such date; and

(b) any other real property or improvement thereon which --

(1) is in the vicinity of such site, and

(2) is determined by the Secretary, in consultation with the Commission, to be contaminated with residual radioactive materials derived from such site.

192.11 Definitions

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as defined in Title I of the Act or in Subpart A.

(b) Land means any surface or subsurface land that is not part of a disposal site and is not covered by an occupiable building.

APPENDIX 6
(cont'd.)

(c) Working Level (WL) means any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron Volts.

(d) Soil means all unconsolidated materials normally found on or near the surface of the earth including, but not limited to, silts, clays, sands, gravel, and small rocks.

192.12 Standards

Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:

(a) the concentration of radium-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than --

(1) 5 pCi/g, averaged over the first 15 cm of soil below the surface, and

(2) 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface.

(b) in any occupied or habitable building --

(1) the objective of remedial action shall be, and reasonable effort shall be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL. In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and

(2) the level of gamma radiation shall not exceed the background level by more than 20 microroentgens per hour.

APPENDIX 6
(cont'd.)

V. EXCERPTS FROM LA-UR-79-1865-Rev.,

"Interim Soil Limits for D&D Projects"

TABLE XXIII. Recommended Soil Limits[a,b] (in pCi/g)

| | Inhalation | Ingestion | | External Radiation | All Pathways[c] |
|---|---|---|---|---|---|
| | | Home Gardener | Full Diet | | |
| $^{231}Pa$ | 50 | 740 | 150 | 250 | 40 |
| $^{227}Ac$ | 200[d] | 4,900 | 1,000 | 300 | 120[d] |
| $^{232}Th$ | 45 | 670 | 140 | 40 | 20 |
| $^{228}Th$ | 1,000 | 37,000 | 7,800 | 55 | 50 |
| $^{230}Th$ (No Daught.) | 300 | 4,400 | 940 | 36,000 | 280 |
| $^{238}U$-$^{234}U$ | 750 | 44 | 8 | 6,000 | 40 |
| $^{90}Sr$ | $2x10^6$ | 100 | 19 | - | 100 |
| $^{137}Cs$ | $7x10^6$ | 800 | 1 | 90 | 80 |

[a]Soil limits for $^{241}Am$ and $^{239,240}Pu$ are available from EPA recommendations, and a soil limit for $^{226}Ra$ has been reported by Healy and Rodgers.

[b]Limits are to apply to only one nuclide present in the soil. If more than one is present, a weighted average should apply.

[c]Based on a diet of a home gardener.

[d]Modified from LA-UR-79-1865-Rev. values to correct error.

# APPENDIX 7

## ESTIMATED EXTENT OF CONTAMINATION

Estimates of the extent of the contamination at the assessed site are based on the total volume, mass, and quantity of radioactive material in the contaminated area. The volume is the product of the surface area and the depth of the contamination. The mass is the product of the volume and the density of the material. A density of 1.5 $g/cm^3$ is used for soil. The concentration (pCi/g) of the specific radioisotope is determined by radiochemical analysis of the soil. The total quantity of radioactive material is the product of the concentration of the specific radioisotope and the total mass of material.

Often there is more than one contaminant in the soil (or contaminated material) and the contaminants are not uniformly distributed throughout the material. In these cases, it is necessary to estimate the fraction of the material containing each contaminant in order to assess the total quantity of the radioactive material. This estimate of the fraction of the material containing each contaminant is based on the radiochemical analysis of randomly selected samples.

Estimates of the extent of contamination are usually determined for averaged (Option 1) and maximum, or worst-case, (Option 2) conditions. Sample calculations for the extent of contamination a typical site are as follows:

Volume (average) = 34,800 $ft^2$ (area) x 3.6 ft (avg. depth) = 125,000 $ft^3$
= 3,550 $m^3$

Volume (maximum) = 34,800 $ft^2$ (area) x 9 ft (max. depth) = 314,000 $ft^3$
= 8,880 $m^3$

Mass (average) = 3,550 $m^3$ x 1,500 $kg/m^3$ = 5.33 x $10^6$ kg
Mass (maximum) = 8,880 $m^3$ x 1,500 $kg/m^3$ = 1.33 x $10^7$ kg

Measured $^{226}Ra$ contamination: 14 pCi/g average - 16 pCi/g maximum.

Estimated Total Activity for $^{226}Ra$ (chain):

Average: 5.33 x $10^6$ kg x 14 x $10^{-12}$ Ci/g x $10^{-3}$ g/kg x .05 (fraction)*
= 0.004 Ci

Maximum: 1.33 x $10^7$ kg x 16 x $10^{-12}$ Ci/g x $10^{-3}$ g/kg x .05 (fraction)*
= 0.011 Ci

*This represents the estimate of the fraction of the total mass contaminated with the $^{226}Ra$ chain.

# APPENDIX 8

## EVALUATION OF RADIATION EXPOSURES

### INTRODUCTION

#### A. Types of Radiation

Radiation is the emission or transmission of energy in the form of waves or particles. Examples are acoustic waves (i.e., sound), electromagnetic waves (such as radio, light, x- and gamma-rays), and particulate radiations (such as alpha particles, beta particles, neutrons, protons, and other elementary particles).

The class of radiation of importance to this report is known as ionizing radiation. Ionizing radiations are those, either electromagnetic or particulate, with sufficient energy to ionize matter, i.e., to remove or displace electrons from atoms and molecules. The most common types of ionizing radiation are x- and gamma-rays, alpha particles, beta particles, and neutrons.

X- and gamma-rays are electromagnetic waves of pure energy, having no charge and no mass or existence at rest. Gamma-rays and x-rays are identical except that x-rays originate in the atom and gamma-rays originate in the nucleus of an atom. X- and gamma-rays are highly penetrating and can pass through relatively thick materials before interacting. Upon interaction, some or all of the energy is transferred to electrons which, in turn, produce additional ionizations while coming to rest.

Alpha particles are positively charged particulates composed of two neutrons and two protons, identical to the nucleus of a helium atom. Due to its comparatively large mass and double charge, an alpha particle interacts readily with matter and penetrates only a very short distance before coming to rest, causing intense ionization along its path.

Beta particles are negatively charged free electrons moving at high speeds. Due to its comparatively small mass and single charge, a beta particle's penetration through matter is intermediate between that of the alpha particle and the gamma-ray, causing fewer ionizations per unit path length than an alpha particle.

#### B. Sources of Radiation

Ionizing radiations arise from terrestrial radioactive materials (both naturally occurring and man-made), extra-terrestrial (cosmic) sources, and radiation-producing machines. The sources of ionizing radiation important to this report are radioactive materials and cosmic sources.

Most atoms of the elements in our environment remain structurally stable. With time, an atom of potassium, for instance, may change its association with other atoms in chemical reactions and become part of other

APPENDIX 8
(cont'd.)

compounds, but it will always remain a potassium atom. Radioactive atoms, on the other hand, are not stable and will spontaneously emit radiation in order to achieve a more stable state. Because of this spontaneous transformation, the ratio of protons and neutrons in the nucleus of an atom is altered toward a more stable condition. Radiation may be emitted from the nucleus as alpha particles, beta particles, neutrons, or gamma-rays, depending uniquely upon each particular radionuclide. Radionuclides decay at characteristic rates dependent upon the degree of stability and characterized by a period of time called the half-life. In one half-life, the number of radioactive atoms and, therefore, the amount of radiation emitted, decrease by one half.

The exposure of man to terrestrial radiation is due to naturally occuring radionuclides and also to "man-made" or technologically enhanced radioactive materials. Several dozen radionuclides occur naturally, some having half-lives of at least the same order of magnitude as the estimated age of the earth. The majority of these naturally occurring radionuclides are isotopes of the heavy elements and belong to three distinct radioactive series headed by uranium-238, uranium-235, and thorium-232. Each of these decays to stable isotopes of lead (Pb) through a sequence of radionuclides of widely varying half-lives. Other naturally occurring radionuclides, which decay directly to a stable nuclide, are potassium-40 and rubidium-87. It should be noted that even though the isotopic abundance of potassium-40 is less than 0.012%, potassium is so widespread that potassium-40 contributes about one-third of the radiation dose received by man from natural background radiation. A major portion of the exposure (dose) of man from external terrestrial radiation is due to the radionuclides in the soil, primarily potassium-40 and the radioactive decay-chain products of thorium-232 and uranium-238. The naturally occurring radionuclides deposited internally in man through uptake by inhalation/ingestion of air, food, and drinking water containing the natural radioactive material also contribute significantly to his total dose. Many other radionuclides are referred to as "man made" in the sense that they can be produced in large quantities by such means as nuclear reactors, accelerators, or nuclear weapons tests.

The term "cosmic radiation" refers both to the primary energetic particles of extra-terrestrial origin that are incident on the earth's atmosphere and to the secondary particles that are generated by the interaction of these primary particles with the atmosphere, and reach ground level. Primary cosmic radiation consists of "galactic" particles externally incident on the solar system, and "solar" particles emitted by the sun. This radiation is composed primarily of energetic protons and alpha particles. The first generation of secondary particles (secondary cosmic radiation), produced by nuclear interactions of the primary particles with the atmosphere, consists predominantly of neutrons, protons, and pions. Pion decay, in turn, results in the production of electrons, photons, and muons. At the lower elevations, the highly penetrating muons and their associated decay

APPENDIX 8
(cont'd.)

and collision electrons are the dominant components of the cosmic-ray particle flux density. These particles, together with photons from the gamma-emitting, naturally occurring radionuclides in the local environment, form the external penetrating component of the background environmental radiation field which provides a significant portion of the whole-body radiation dose to man.

In addition to the direct cosmic radiation, cosmic sources include cosmic-ray-produced radioactivity, i.e., cosmogenic radionuclides. The major production of cosmogenic radionuclides is through interaction of the cosmic rays with the atmospheric gases through a variety of spallation or neutron-capture reactions. The four cosmogenic radionuclides that contribute a measurable radiation dose to man are carbon-14, sodium-22, beryllium-7, and hydrogen-3 (tritium), all produced in the atmosphere.

BACKGROUND RADIATION DOSES

Background radiation doses comprise of an external component of radiation impinging on man from outside the body and an internal component due to radioactive materials taken into the body by inhalation or ingestion.

Radiation dose may be expressed in units of rads or rems, depending upon whether the reference is to the energy deposited or to the biological effect. A rad is the amount of radiation that deposits a certain amount of energy in each gram of material. It applies to all radiations and to all materials which absorb that radiation.

Since different types of radiation produce ionizations at different rates as they pass through tissue, differences in damage to tissues (and hence the biological effectiveness of different radiations) has been noticed. A rem is defined as the amount of energy absorbed (in rads) from a given type of radiation multiplied by the factor appropriate for the particular type of radiation in order to approximate the biological damage that it causes relative to a rad of x or gamma radiation. The concept behind the unit "rem" permits evaluation of potential effects from radiation exposure without regard to the type of radiation or its source. One rem received from cosmic radiation results in the same biological effects as one rem from medical x-rays or one rem from the radiations emitted by naturally occurring or man-made radioactive materials.

The external penetrating radiation dose to man derives from both terrestrial radioactivity and cosmic radiation. The terrestrial component is due primarily to the gamma dose from potassium-40 and the radioactive decay products of thorium-232 and uranium-238 in soil, as well as from the beta-gamma dose from radon daughters in the atmosphere. Radon is a gaseous member of the uranium-238 chain. The population-weighted external dose to an individual's whole body from terrestrial sources in the United States has been estimated as 15 mrem per year for the Atlantic and Gulf Coastal Plain,

APPENDIX 8
(cont'd.)

57 mrem per year for an indeterminate area along the Rocky Mountains, and 29 mrem per year for the majority of the rest of the United States. The overall population-weighted external dose for the U.S. population as a whole has been estimated to be 26 mrem per year.

The cosmic radiation dose, due to the charged particles and neutrons from secondary cosmic rays, is typically about 30% to 50% of the total from all external environmental radiation. The cosmic-ray dose to the population is estimated to be 26 mrem per year for those living at sea level, and increases with increasing altitude. Considering the altitude distribution of the U.S. population, the population-weighted external cosmic-ray dose is 28 mrem per year. The population-weighted total external dose from terrestrial plus cosmic sources is thus 54 mrem per year for the U.S. population as a whole.

The internal radiation doses derive from terrestrial and cosmogenic radionuclides deposited within the body through uptake by inhalation/ingestion of air, food, and drinking water. Once deposited in the body, many radioactive materials can be incorporated into tissues because the chemical properties of the radioisotopes are identical or similar to the properties of stable isotopes in the tissues. Potassium-40, for instance, is incorporated into tissues in the same manner as stable potassium atoms because the chemical properties are identical; radioactive radium and strontium can be incorporated into tissues in the same manner as calcium because their chemical properties are similar. Once deposited in tissue, these radionuclides emit radiation that results in the internal dose to individual organs and/or the whole body as long as the radioactive material remains in the body.

The internal dose to the lung is due primarily to the inhalation of polonium-218 and -214 (radon daughters), lead-212 and bismuth-212 (thoron daughters) and polonium-210 (one of the longer-lived radon decay products). The dose to the lung is about 100 mrem per year from inhaled natural radioactivity. The internal dose from subsequent incorporation of inhaled or ingested radioactivity is due to a beta-gamma dose from incorporation of potassium-40, rubidium-87, and cosmogenic nuclides, and an alpha dose from incorporation of primarily polonium-210, radium-226 and -228, and uranium-238 and -234. The dose to man from internally incorporated radionuclides is about 28 mrem per year to the gonads, about 25 mrem per year to the bone marrow, lung, and other soft tissues, and about 117 mrem per year to the bone (osteocytes). The bone dose arises primarily from the alpha-emitting members of the naturally occurring series, with polonium-210 being the largest contributor. The gonadal and soft tissue doses arise primarily from the beta and gamma emissions from potassium-40. The total internal dose from inhaled plus incorporated radioactivity is about 28 mrem per year to the gonads (or whole-body dose), about 125 mrem per year to the lung, about 25 mrem per year to the bone marrow, and about 117 mrem per year to the bone (osteocytes).

APPENDIX 8
(cont'd.)

The total natural background radiation dose is the sum of the external and internal components. The population-weighted dose for the U.S. population as a whole is about 82 mrem per year to the gonads or whole body, about 179 mrem per year to the lung, about 79 mrem per year to the bone marrow, and about 171 mrem per year to the bone (osteocytes).

Besides the natural background radiation, background radiation doses include contributions from man-made or technologically enhanced sources of radiation. By far, the most significant sources are x-ray and radiopharmaceutical medical examinations. These contribute a population-averaged dose estimated to be 70 mrem per year for the U.S. population as a whole. Fallout from nuclear weapons testing through 1970 has contributed 50-year dose commitments estimated as 80 mrem external, and 30, 20, and 45 mrem internal to the gonads, lung, and bone marrow, respectively. Contributions from the use of fossil fuels (natural gas and coal) and nuclear reactors; mining, milling, and tailings piles; television sets, smoke detectors, and watch dials could be responsible for an additional 5 mrem per year, averaged over the U.S. population as a whole. In addition, the use of radiation or radioactivity for scientific, industrial, or medical purposes may cause workers in the industry and, to a lesser extent, members of the general public, to receive some radiation exposure above natural background.

## EVALUATION OF RADIATION DOSE AND POTENTIAL HAZARD

Radiation, regardless of its sources, is considered to be a hazard because of its potential for producing adverse effects on human life. Very large amounts of radiation received over a brief period, i.e., hundreds of rem delivered within a few hours, can produce severe injury or death within days or weeks. Distributed over longer intervals, however, these same doses would not cause early illness or fatality. At doses and rates too low to produce these immediate symptoms, chronic or repeated exposure to radiation can bring about biological damage which does not appear until years or decades later. These low-level effects are stochastic in nature; their probability rather than their severity increases with dose. Primary among these latent or delayed effects are somatic effects, where insults such as cancers occur directly to the individual exposed, and genetic defects, where, through damage to the reproductive cells of the exposed individual, disability and disease ranging from subtle to severe are transmitted to an exposed person's offspring.

Clinical or observed evidence of a relationship between radiation and human cancers arise from several sources. The most important data come from the victims of Hiroshima and Nagasaki, patients exposed during medical therapy, radium dial painters, and uranium miners. Data exist only for relatively large doses; there have been no direct measurements of increased incidence of cancer for low-level radiation exposures. Evaluation of the available data has lead to estimates of the risk of radiation-induced cancer; estimated risks for the lower doses have been derived by linear extrapolation from the higher doses. All radiation exposures then, no

APPENDIX 8
(cont'd.)

matter how small, are assumed to be capable of increasing an individual's risk of contracting cancer.

Data on genetic defects resulting from radiation exposure of humans is not available to the extent necessary to allow an estimate of the risk of radiation-induced effects. Data from animals, along with general knowledge of genetics, have been used to derive an estimate of the risks of genetic effects.

Estimates of health effects from radiation doses are usually based on risk factors as provided in reports issued by the International Commission on Radiological Protection (ICRP), National Research Council Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), or United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Multiplying the estimated dose by the appropriate risk factor provides an estimate of the risk or probability of induction of health effects to an individual or his descendants as a result of that exposure. The evaluation of these risk factors is presently subject to large uncertainties and, therefore, potential continual revision. The risk factors recommended by the ICRP for cancer mortality and hereditary ill health to the first and second generations are $10^{-4}$ per rem of whole body dose and $4 \times 10^{-5}$ per rem of gonadal dose, respectively. As an example, a whole-body dose of 1 rem would be estimated to add a risk of cancer mortality to the exposed individual of $10^{-4}$, i.e., 1 chance in 10,000. However, a precise numerical value cannot be assigned with any certainty to a particular individual's increase in risk attributable to radiation exposure. The reasons for this are numerous and include the following: (1) uncertainties over the influence of the individual's age, state of health, personal habits, family medical history, and previous or concurrent exposure to other cancer-causing agents, (2) the variability in the latent period (time between exposure and physical evidence of disease), and (3) the uncertainty in the risk factor itself.

To be meaningful, an attempt should be made to view such risk estimates in the appropriate context. One useful comparison is with risks encountered in normal life. Another comparison, potentially more useful, is with an estimation of the risks attributable to natural background radiation. Radiation from natural external and internal radioactivity results in the same types of interactions with body tissues as that from "man-made" radioactivity. Hence, the risks from a specified dose are the same regardless of the source. Rather than going through an intermediate step involving risk factors, doses can also be compared directly to natural background radiation doses.

Besides estimation of risks and comparisons to natural background, doses may be compared to standards and regulations. The appropriate standards, the Department of Energy's "Requirements for Radiation Protection," give limits for external and internal exposures for the whole body and specified organs which are expressed as the permissible dose or

APPENDIX 8
(cont'd.)

dose commitment annually in addition to natural background and medical exposures. There are, in general, two sets of limits, one applicable to occupationally exposed persons and the second applicable to individuals and population groups of the general public. The limits for individuals of the public are one-tenth of those permitted for occupationally exposed individuals. The set of limits important to this report are those applicable to individuals and population groups of the public. The limits for individuals of the public are 500 mrem per year to the whole body, gonads, or bone marrow and 1500 mrem per year to other organs. The limits for population groups of the public are 170 mrem to the whole body, gonads, or bone marrow and 500 mrem per year to other organs, averaged over the group. In either case, exposures are to be limited to the lowest levels reasonably achievable within the given limits.

## Distribution

Internal:

H. Drucker
J. D. DePue
J. G. Ello
K. F. Flynn
C. A. Hunckler
A. L. Justus
J. H. Kittel
N. D. Kretz
D. P. O'Neil
E. G. Pewitt
M. J. Robinet
C. M. Sholeen
W. H. Smith
J. Unik
V. R. Veluri
R. A. Wynveen
OHS/HP Publications File (15)
ANL Patent Dept.
ANL Contract File
ANL Libraries (4)
TIS Files (6)

External:

DOE-TIC, for distribution per UC-70A (133)
H. J. Rauch, Manager, Chicago Operations Office, DOE (10)
J. E. Baublitz, Director, Office of Nuclear Energy, DOE (5)
D. E. Patterson, Director, Office of Operational Safety, DOE (5)