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Management Program

VERIFICATION OF REMEDIAL ACTION CENTER FOR ENERGY AND ENVIRONMENT RESEARCH UNIVERSITY OF PUERTO RICO MAYAGUEZ, PUERTO RICO

G. L. MURPHY AND P.R. COTTEN

Radiological Site Assessment Program
Manpower Education, Research, and Training Division

FINAL REPORT
October 1988

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OF
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INTRODUCTION

The Center for Energy and Environment Research (CEER), formerly the Puerto Rico Nuclear Center (PRNC), was established under the Atoms for Peace Program in 1957. The purpose of the center was to provide a nuclear training and research institution, focusing on the particular needs of Latin America. By 1960, the PRNC, with a one megawatt MTR reactor, was operational. The MTR operated for less than 20,000 megawatt hours. In 1971, the MTR was replaced by a 2 megawatt TRIGA research reactor. The TRIGA reactor was capable of pulsing to 2000 megawatts; however, it was never operated at power levels in excess of 1.2 megawatts. The TRIGA reactor operated for less than 4000 hours before activities were terminated in 1976; the reactor and associated facilities were then scheduled to undergo decommissioning activities. All reactor fuel, selected components, and the control console were transferred to the U.S. Department of Energy (DOE) site at Idaho Falls, Idaho. In addition to reactor operations, trace amounts of various radionuclides were used during the period 1960 to 1976. Research activities were expanded in 1976 to include non-nuclear technologies (hence the name change to CEER). In addition, a recommendation was made in 1976 to transfer title of DOE-owned property to the University of Puerto Rico (UPR).

In 1979, a characterization survey of CEER was performed by Black and Veatch to identify areas requiring remedial action.[1] The survey provided preliminary estimates of the scope of work at the CEER facility; however, the survey did not provide sufficient data and analysis to thoroughly characterize the site. Major areas of contamination identified consisted of irradiated concrete in the reactor pool area; contaminated piping and equipment; contaminated soil; surface contamination in various facilities; and residues and surface contamination in various process and auxiliary systems, piping, and tanks. Although, from April 1980 to September 1981, limited decontamination activities were undertaken by CEER, these efforts were not sufficient to reduce residual contamination to levels acceptable under DOE's Remote Surplus

Facilities Management Program (SFMP). The Oak Ridge Operations Office of DOE contracted with Bechtel National, Inc. (BNI) to conduct further decommissioning at the CEER site. In 1987 BNI performed a more detailed characterization of the site and initiated decontamination efforts. These activities were in accordance with plans prepared by BNI.[2,3] Remedial action continued from April through November 1987. Follow-up survey results, presented in the BNI post-remedial action report, indicate that actions were successful in meeting the DOE guidelines.[4]

It is the policy of DOE to perform independent verification of the effectiveness of remedial actions conducted within SFMP. The Radiological Site Assessment Program of Oak Ridge Associated Universities (ORAU) was selected by the DOE's Oak Ridge Operations Office as the organization responsible for independent verification at the Center for Energy and Environment Research. A survey plan, prepared by ORAU for this project, was approved by the DOE Oak Ridge Operations Offices - Technical Services Division.[5] During the period remedial actions were being conducted, ORAU representatives performed independent measurements and sampling at CEER. In addition, documents describing the project were reviewed, and selected remedial action samples were analyzed for comparison with BNI's results. This report describes the procedures and findings of these verification activities.

FACILITY DESCRIPTION

The CEER site is on Route 108, adjacent to the University of Puerto Rico and the U.S. Department of Agriculture Experiment Station, on the northeast outskirts of Mayaguez, Puerto Rico (Figure 1). The site occupies approximately 4 hectares (10 acres). Figure 2 is a drawing of the CEER site. There are numerous buildings and structures on this site; many of the CEER facilities are currently being utilized by UPR. The most prominent structure is the combined Laboratory and Reactor Building. The Laboratory and Reactor areas are interconnected by an adjoining hallway on the ground floor and second floor levels (Figures 3 and 4); the basement levels of these areas are separated by a concrete wall (Figure 5). Other utilized facilities include a portion of the Nuclear Engineering Complex, the Marine Biology Laboratory, the Administration Building, and portions of the Shop Building (Refer to Figure 2). The main

cooling tower, which supplies the Laboratory Building, is fully operational. The water tower and two other cooling towers have been removed. There are several other smaller structures that remain.

Underground structures or facilities which remain include the retention tank, located at the southern end of the site; the reactor pump room, which is adjacent to the Reactor Building; and the Hot Waste Tank valve pit area, adjacent to the Laboratory Building.

PROCEDURES

Objectives

The objectives of the verification were to confirm that the surveys, sampling, and analyses conducted prior to, during, and following remedial action and associated project documentation provide an accurate and complete description of the condition of the property and, thereby, confirm that remedial actions have been effective in meeting established criteria.

Procedures

General Approach

1. Radiological survey reports, work plans, and the post-remedial action report (references 1-4) were reviewed. Data were evaluated to assure that areas exceeding DOE-established site guidelines (Appendix A) were identified and had undergone remedial action. Post-remedial action radionuclide concentrations, surface contamination levels, and direct radiation levels were compared to guidelines, and the post-remedial action report and data were reviewed for general thoroughness and accuracy.

2. Survey teams from ORAU visited the site and performed visual inspections and independent gamma scans, exposure rate measurements, surface contamination measurements, and soil sampling on representative portions of both remediated and non-remediated areas.

Dates of these independent surveys were June 15 to June 23, 1987; August 26 and 27, 1987; September 8 to November 13, 1987; and December 2 to 4, 1987.

3. Because ORAU was not present during restoration of the Laboratory Building foundation, nine soil samples and one composite soil sample (composed of 19 independent samples), collected by BNI during the post-remedial action survey, were obtained from BNI and independently analyzed by the ORAU laboratory to determine radionuclide concentrations and to confirm the accuracy of BNI analysis.

Facility Survey

General

Independent radiological surveys were performed in all remediated areas. In addition, 100% of the non-remediated buildings throughout the facility were surface scanned and contamination measurements were collected.

Reference Grids

The reference grid system established by BNI was used by ORAU. A 2 m x 2 m grid (typically) was used in rooms greater than 10 m^2 dimension and in rooms with contamination levels exceeding guidelines. The lower walls were gridded up to 2 m. The upper walls, ceilings, and equipment were referenced to the floor and lower wall grids. Measurements and samples from ungridded surfaces were referenced to pertinent building features.

Surface Scans

The floor and lower walls in areas selected for verification were surface scanned using NaI(Tl) gamma scintillation detectors, ZnS alpha detectors, and "pancake" GM beta-gamma detectors. Where surface areas and conditions permitted, floor scans for alpha and beta contamination were conducted with a gas-proportional floor monitor. Upper wall and overhead surface scanning on ledges, beams, piping, fixtures, equipment, and ductwork was conducted using

hand-held alpha and beta-gamma detectors. Elevated areas were marked for additional measurements.

Exposure Rate Measurements

Exposure rates were measured at the surface and at 1 m above the surface throughout the facilities, using NaI(Tl) gamma scintillation detectors, cross-calibrated on site with a pressurized ionization chamber (PIC).

Measurements of Surface Contamination Levels

In gridded areas, measurements of contamination were performed in randomly selected grid blocks. Approximately 120 grid-block measurements were performed in the Laboratory and Reactor Building, the Shack Building, and the S-4 Building. Figures 6 to 18 indicate locations of measurements in gridded areas in the Laboratory Area; Figures 19 to 27 indicate locations of measurements in the Reactor Area, Figures 28 and 29 indicate measurement locations in the Reactor Pump Room; and Figures 30 and 31 indicate measurement locations in the Shack and S-4 Building, respectively. In each grid block surveyed, direct measurements of beta-gamma contamination levels were systematically performed at the center and four points midway between the center and grid block corners. Direct measurements for alpha contamination were not collected based on scanning results, which indicated less than the detector sensitivity. Smears for removable beta contamination were performed at the location in each block, where the highest direct beta-gamma reading was obtained.

In ungridded areas, total and removable contamination levels were measured at random single point locations on the floors, walls, ceilings, and miscellaneous overhead objects. Approximately 210 single-point measurements were performed at locations of remedial action and 200 single-point measurements were performed in non-remediated areas throughout the CEER facility. Locations of measurements in ungridded areas in the Marine Biology Building, Administration Building, Shop Building, and Nuclear Engineering Complex are shown on Figures 32 to 35.

Soil Sampling

Soil samples were collected from excavations in the Reactor Pump Room (Figure 36) and Hot Waste Tank Pit (Figure 37). Samples were also collected from a pile of soil, removed during the Waste Tank Excavation (Figure 38).

Ten post-remedial action samples collected by BNI from an excavation beneath the Laboratory and Reactor Building, were obtained for separate analysis; locations of these samples are shown on Figures 39 and 40.

Miscellaneous Sampling

Concrete samples were collected from the Thermal Column and Beam Tube areas of the reactor. Sludge was obtained from the south sump of the Reactor Room and a sample of roofing material was collected from the roof of the Laboratory and Reactor Building.

Water Sampling

Treated water from the reactor pool, retention tank, and water used for decontamination purposes was pumped into tank trucks for temporary storage while the Retention tank was being decontaminated. A 4 liter sample of water was collected from each of six trucks. Water from the gamma pool was processed and a sample collected before it was added to other treated water. All treated water was then pumped into the retention tank to await final offsite disposal. A final water sample was collected from all processed waters combined for offsite disposal.

Outdoor Survey

Gridding

The remedial-action contractor subdivided the CEER property into 12 sections (Figure 41) and surveyed each section separately. ORAU utilized surface features to identify survey locations (i.e., fence and property lines,

parking lots and roads). In addition, 10 m grids were established by ORAU in excavated areas.

Surface Scans

Surface scans were conducted at 2 to 5 m intervals throughout open land areas and at 1 to 2 m intervals in excavated areas, using gamma scintillation detectors. Locations of elevated gamma radiation levels were marked for further investigation. Due to adverse weather conditions (daily thundershowers) it was necessary to cover or backfill excavated areas soon after remediation. As a result, only portions of several excavated areas were accessible to ORAU for verification surveys. Scans were performed in the accessible excavations and over restored areas.

Exposure Rate Measurements

Gamma exposure rates were measured at the surface and at 1 m above the surface at 2 to 7 locations in each of the 12 sections, using gamma scintillation detectors.

Soil Sampling

Surface soil samples were collected from a minimum of 3 representative locations from eleven of the twelve area sections (see Figures 42 to 52). For soil sampling locations in Area 6 refer to Figures 37 and 38. Surface soil samples in Area 6 were collected from the floor and side walls of the Hot Waste Tank Pit, soil designated as backfill for the Pit, and at locations of elevated radiation levels identified by surface scans.

Subsurface sampling was performed at locations in the Retention Tank pipeline and the Serpentine piping system and in the vicinity of the Laboratory and Reactor Building, using a split-barrel sampler and hollow-stem auger, provided by a BNI subcontractor. Sampling depth was approximately 5 m or to "refusal". One 60 cm core sample was obtained for each auger flight of drilling depth. This method was used in locations, where backfilling of the area had been completed before verification of open areas could be made. A

total of 7 subsurface locations were sampled from the Retention Tank Pipeline and Serpentine (Figures 53 and 54). Samples were also obtained from the Hot Waste Tank soil backfill in Area 6, using a post-hole digger. Gamma scans of holes, used to obtain subsurface samples, were performed, and radiation profiles in the boreholes were determined by measuring gamma radiation at 30 cm intervals between the surface and the hole bottom. A collimated gamma scintillation detector and portable scaler were used for these measurements.

Background and Baseline Level Determinations

Samples of soil were collected from 12 locations in the Mayaguez area to provide baseline concentrations of radionuclides (Figure 55). Background exposure rates were measured at locations where baseline soil samples were collected. The indoor background exposure rate was established, using NaI detectors which were cross-calibrated with a pressurized ionization chamber, in areas that were not radiologically contaminated but were similar in construction material. Tables 1 and 2 present the background exposure rates and baseline radionuclide concentrations respectively.

Sample Analysis and Interpretation of Results

Samples and direct measurement data were returned to Oak Ridge, Tennessee, for analyses and interpretation. Smears for the determination of removable contamination were counted for gross alpha and gross beta activity. Soil and miscellaneous samples were analyzed by solid state gamma spectrometry. Radionuclides of primary interest were Co-60, Cs-137, Ba-133, Eu-152, Eu-154, U-238, and Th-232. Spectra were also reviewed for other identifiable photopeaks. Selected soil samples were also analyzed for Sr-90 and tritium (H-3) using wet chemistry techniques.

Water samples were analyzed for gross alpha and gross beta concentrations. Selected water samples were analyzed for H-3 and Sr-90.

Major analytical equipment, used in support of this survey, is listed in Appendix B. Appendix C describes the measurement and analytical procedures. Findings of the inspections and radiological surveys were compared with the

post-remedial action report and the DOE guidelines established for the CEER site (Appendix A).

FINDINGS AND RESULTS

Document Review

The Black and Veatch report and the BNI final report were reviewed. The Reactor Building and Pool area were identified as the major source of contamination during the Black and Veatch survey of CEER. The survey also identified scattered contamination on the property grounds. BNI confirmed the Black and Veatch findings during BNI's initial walkover survey. Unidentified areas of contamination at indoor and outdoor locations were also discovered during this survey. These areas included contaminated sumps in the Laboratory and Reactor Building, contaminated drain lines from the hot labs, tile floors in labs which had been flooded, soil, and floor and sub-floor soil in the Reactor Pump Room.

A review of characterization and remedial action data indicated that decisions regarding requirements for remediation were appropriate. The scope of work was expanded by BNI, as needed, to provide effective decontamination of the CEER facility. Visual inspections confirmed that identified areas were remediated to the extent described in the post remedial action report. Data presented in the post remedial action report demonstrate that the remedial actions were effective in meeting the established remedial action guidelines at all identified locations.

Confirmatory Sample Analyses

Table 3 presents the results of gamma spectrometry analyses performed by BNI and ORAU for 10 soil samples collected during remediation of a contaminated area shown in Figure 39 under the Laboratory and Reactor Building. Sample locations have been identified in Figure 40. All samples were processed by BNI (dried, crushed and sieved) before analyzing. The paired results indicate agreement between the means at the 99% confidence level. Most radionuclide concentrations were near or below the detection limits of the analytical

procedure. The only radionuclide with measurable concentrations observed was Cs-137. For this radionuclide, paired data are in agreement within their respective 99% confidence intervals. It is, therefore, ORAU's opinion that the BNI data are accurate and should be accepted as presented.

Background and Baseline Levels

Background exposure rates for a typical building at the CEER site generally ranged from 2 to 5 μR/h. Background exposure rates and baseline radionuclide concentrations in soil from the vicinity of the CEER site are presented in Table 1 and Table 2 respectively. Exposure rates ranged from 2 to 3 μR/h at one meter from the surface and 2 to 4 μR/h on the surface. Cobalt-60 concentrations are <0.1 pCi/g; Cs-137 ranged from <0.1 to 0.4 pCi/g; Ba-133, <0.1 pCi/g; Eu-152, <0.1 pCi/g; Eu-154, <0.1 pCi/g; U-238, <0.5 to 2.2 pCi/g; and Th-232, <0.1 to 0.5 pCi/g.

Laboratory Area Survey

Remediated Areas

Surface scans of remediated areas identified small areas of residual contamination exceeding guidelines at locations in Room 117 (floor), Room 123 (floor/wall), Room 203/205 (floor near sink), and Room 219 (floor). The remedial action contractor was informed of these findings. Further decontamination of these areas was performed immediately and follow-up scans by ORAU verified the effectiveness of the additional cleanup activity. No residual surface contamination was identified by scans in other remediated areas. Exposure rates were in the range of background levels of 2 to 5 μR/h.

The results of final contamination measurements on remediated surface areas are summarized in Table 4. Total beta-gamma levels ranged from <420 to 5600 dpm/100 cm^2. The area exceeding 5000 dpm/100 cm^2 beta-gamma was a small spot on the floor in Room 117. Averaging over 1 m^2 area resulted in a level below the 5000 dpm/100 cm^2 guideline. Removable beta surface contamination ranged from <4 to 10 dpm/100 cm^2.

Non-Remediated Areas

Surface scans and contamination measurements were performed in essentially 100% (49 total) of the non-remediated rooms in the laboratory portion of the Laboratory and Reactor Building. Results of the measurements in these rooms are presented in Table 5. Total beta-gamma contamination levels ranged from <420 to 1700 dpm/100 cm^2; the highest level was located on the upper wall area in Room 200. Removable levels of beta contamination were <4 to 10 dpm/100 cm^2. Exposure rates were consistent with background levels.

Reactor Area Survey

Remediated Areas

Surface scans of remediated areas of the reactor portion of the Laboratory and Reactor Building identified small areas of residual contamination in Rooms R-128, R-129 and R-227. The remedial-action contractor was immediately informed of the ORAU findings and these areas were recleaned and resurveyed. No additional residual contamination was detected during a follow-up survey by ORAU. Scanning was often difficult due to the high background levels in the vicinity of the Reactor Pool. As radiation sources were removed from the Reactor Pool area, scanning of rooms adjacent to and below the Reactor Pool could be surveyed.

A summary of contamination measurement results on remediated surfaces, including the Reactor Pool areas, is presented in Table 6. Total beta-gamma contamination levels ranged from <420 to 3240 dpm/100 cm^2. The highest grid block average was in the "Open-End" of the Pool with a measurement of 1410 dpm/100 cm^2 on the lower east wall. The maximum beta reading of 3240 dpm/100 cm^2 was a small isolated spot on the floor. Removable surface contamination for beta was <4 to 30 dpm/100 cm^2.

The Reactor Pool consists of an "Open-End" and "Stall End", Thermal Column, Beam Tubes and accompanying piping. Although scanning indicated generally elevated gamma radiation, no specific areas of residual contamination could be identified. Exposure rate levels in these areas ranged from

9 to 15 μR/h; at other locations in the building exposure rates were comparable to background levels.

Results of concrete samples collected from the Thermal Column and Beam Tube area of the reactor pool are tabulated in Table 7. Concrete samples from Beam Tubes 1, 2, 5, and 6 were composited before counting. Radionuclide concentration ranges in all samples were: 1.4 to 12 pCi/g, Co-60; <0.1 to 2.3 pCi/g, Cs-137; 8.0 to 23 pCi/g, Ba-133; <0.8 to 2.4, Eu-152; <0.1 to 0.3 pCi/g, Eu-154; <0.8 to 3.1 pCi/g, U-238; and <0.3 to <0.6 pCi/g, Th-232. These results indicate that activation products in the concrete and steel construction materials are the probable source of the elevated exposure rates in this area.

Table 8 presents the radionuclide concentrations in miscellaneous samples collected from reactor area of the Laboratory and the Reactor Building. All concentrations were near or below the sensitivity of the analytical procedure.

Non-Remediated Areas

Surface scans and contamination measurements were performed in 14 rooms (100% of the area) in the non-remediated areas of the Reactor Building. Results of the measurements in these rooms are presented in Table 9. Total beta-gamma contamination ranged from <420 to 730 dpm/100 cm^2, well within the 5000 dpm/100 cm^2 guideline. Removable beta surface contamination ranged from <4 to 16 dpm/100 cm^2.

Reactor Pump Room

A summary of contamination measurements in the Reactor Pump Room is presented in Table 10. A total of 52 direct measurements were obtained and 16 smears were collected. Total contamination measurements ranged from <420 to 4600 dpm/100 cm^2. The maximum direct reading was measured inside an "Off Gas Line". Removable beta contamination from this line was 23 dpm/100 cm^2. Removable contamination measurements for all areas ranged from <4 to 60 dpm/100 cm^2; the highest level was obtained from the north Beam Tube drainline.

Table 11 presents the radionuclide concentrations in soil collected from the Reactor Pump Room Pit, exposed after the removal of a 1500 gallon sump tank. Concentration ranges were: Co-60, <0.1 to 0.2 pCi/g; Cs-137, 0.2 to 2.0 pCi/g; Ba-133, <0.1 pCi/g; Eu-152, <0.1 pCi/g; Eu-154, <0.1 pCi/g; U-238, <0.1 to 3.4 pCi/g; and Th-232, <0.2 to 0.9 pCi/g.

Other Facility Building Surveys

Remediated Areas

Direct beta-gamma measurements ranged from <420 to 2200 dpm/100 cm^2 and <420 to 1500 dpm/100 cm^2 in the Shack and S-4 Buildings, respectively. Removable contamination for the Shack and S-4 Buildings ranged from <4 dpm/100 cm^2 and <4 to 13 dpm/100 cm^2, respectively. A summary of these measurements is provided in Table 10.

Non-Remediated Areas

A summary of the survey findings for all other (non-remediated) CEER facilities is presented in Table 12. For the most part, measurements were below the detection sensitivities for total and removable activities in the Nuclear Engineering Complex and Marine Biology Laboratory. Levels up to 1500 dpm/100 cm^2, beta-gamma, were measured in the Shop Building and the Administration Office Building. Both measurements were taken on ceramic tile flooring, suggesting the presence of natural radioactivity in the tile or glaze.

Water Sampling

Radiochemical analyses of batch samples of water collected from tank trucks used for temporary storage and from the gamma pool are presented in Table 13. Significant levels of H-3 were identified in these samples. Concentrations ranged from 9400 to 32500 pCi/l. Upon completion of decontamination in the Retention Tank, water from the tank trucks and Gamma Pool was transferred to the Retention Tank for onsite storage. Table 14

presents the radionuclide concentrations of the water in the Retention Tank on October 20, 1987.

Outdoor Areas

Remediated Areas

Surface gamma scans of accessible excavated areas of the Waste Retention Tank and Serpentine pipelines and the Hot Waste Tank Area did not identify any locations of significantly elevated contact radiation. Results of soil sampling from these areas are presented in Tables 15 through 18. For almost all of these sampling locations, the radionuclide concentrations were below the measurement sensitivities of the procedures or in the range of baseline concentrations. The maximum concentrations measured at these three excavations: Co-60, 0.1 pCi/g; Cs-137, 0.9 pCi/g; Ba-133, 0.5 pCi/g; Eu-152, <0.2 pCi/g; Eu-154, <0.1 pCi/g; U-238, 6.5 pCi/g; and Th-232, 1.3 pCi/g. A sample of tile from the Retention Tank Pipeline contained U-238 and Th-232 levels of 9.0 pCi/g and 2.3 pCi/g, respectively. All other radionuclides were below detection limits.

Samples of soil, excavated from the Hot Waste Tank area, were collected prior to using that soil to backfill the excavation, after tank removal. Radionuclide concentrations, presented in Table 19, were primarily in the range of baseline levels or below detection limits.

Table 20 presents results of Sr-90 and H-3 analyses on selected soil samples. All concentrations were less than the detection capability of the procedure.

Non-Remediated Areas

Scans of non-remediated outdoor areas identified one location of elevated surface activity in Area 10, near the entrance to the Laboratory and Reactor Building. Table 21 presents the results of radionuclide concentrations in the samples collected from the spot. The primary radionuclide was Co-60, 64.8 pCi/g. The contamination was confined to the upper 15 cm of soil. A

second sample, confirmed that contamination was limited to the surface and that the contaminated soil had been removed by ORAU with the initial sample. No additional areas of residual contamination were identified by the surface scans.

Several areas of elevated exposure rates were noted. Levels ranged from 2 to 58 μR/h at 1 m and 2 to 34 μR/h at contact with an average of approximately 5 μR/h (Table 22). Elevated levels in Areas 2, 4, and 9 were due to trucks or buildings containing waste or stored radioactive materials.

Radionuclide concentrations in soil samples, collected randomly from outdoor areas, are presented in Table 22. Concentration ranges were: Co-60, <0.1 to 2.8 pCi/g; Cs-137, <0.1 to 6.3 pCi/g; Ba-133, <0.1 to 0.1 pCi/g; Eu-152, <0.1 to 0.6 pCi/g; Eu-154, <0.1; U-238, <0.1 to 1.8 pCi/g; and Th-232, <0.1 to 1.0 pCi/g. Concentrations of Sr-90 and H-3 in selected samples (see Table 20) were below detection limits.

COMPARISON OF RESULTS WITH GUIDELINES

Appendix A summarizes the radiological guidelines established by DOE for remedial actions at the CEER site. Several small areas of residual building surface contamination were identified during the verification survey. These were immediately addressed, and levels were reduced below the guidelines. The majority of measurements indicated contamination levels below the detection capabilities of the procedures. The highest level of beta-gamma contamination noted in the facilities was 5600 dpm/100 cm^2 in Room 117 of the Laboratory and Reactor Building. This level is within the 15000 dpm/100 cm^2 limit for small areas of contamination; averaging over 1 m^2 results in satisfying the 5000 dpm/100 cm^2 guideline.

Exposure rates inside buildings were well below the guidelines of 20 μR/h above background. Three locations of elevated exposure rates were noted outside the buildings; however, these were associated with temporarily stored

radioactive waste or material. No residual contamination was identified in these locations.

Concentrations in some individual water samples were above the established release limits of 20000 pCi/l for H-3 or 80 pCi/l of Co-60. After all water was combined, the average concentrations for all radionuclides of concern were within release limits.

One small area of soil, exceeding the Co-60 limit of 20 pCi/g, was identified in Area 10. Sampling effectively removed the contaminant. All other soil samples were well within the established concentration guidelines.

CONCLUSION

During June to December 1987, Oak Ridge Associated Universities' Radiological Site Assessment Program performed independent activities to verify the adequacy of remedial actions at the Center for Energy and Environment Research and the accuracy of documentation supporting the remedial actions. The verification activities included document review, confirmatory laboratory analyses, and independent direct measurements and sample analysis. Based on the results and findings of these activities, it is ORAU's opinion that the remedial action has been effective in satisfying the established criteria for this project. It is also ORAU's opinion that the documentation supporting the remedial action process is adequate and accurate. A verification letter, indicating these opinions, was provided to DOE's Oak Ridge Operations Office in June 1988.[7]

CER24

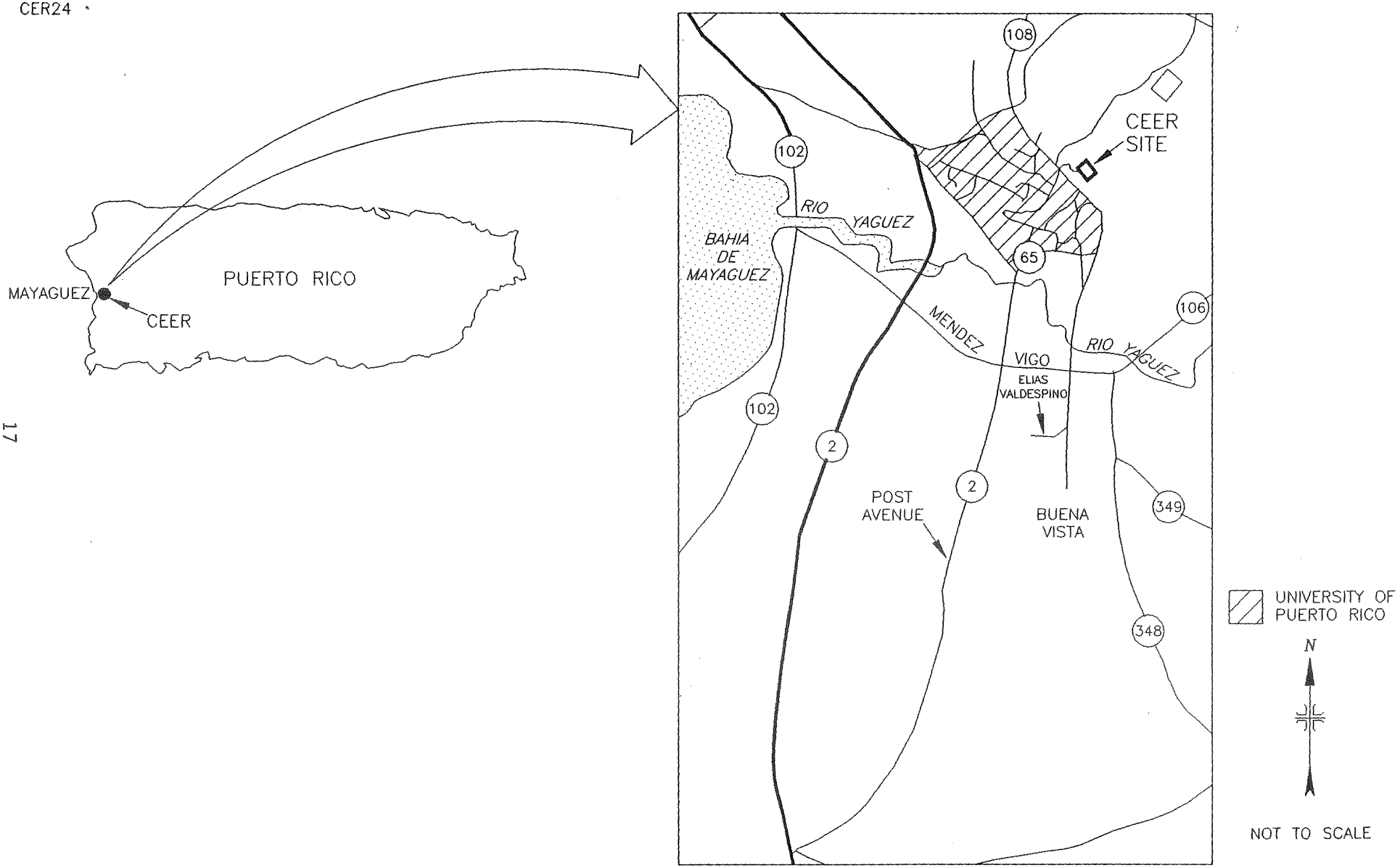

FIGURE 1: Mayaguez Area, Indicating the Location of the Center for Energy and Environment Research, University of Puerto Rico

CER4

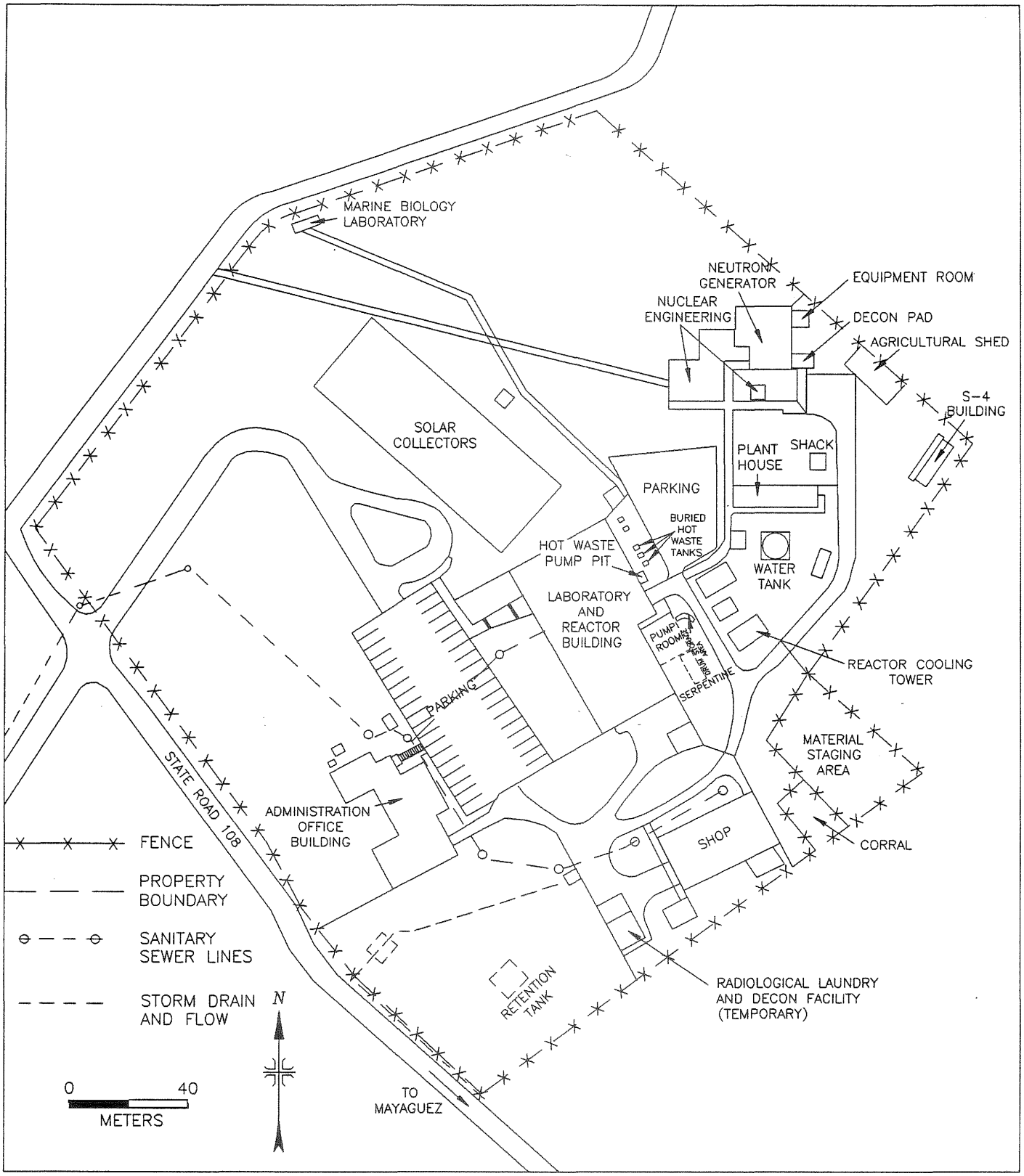

FIGURE 2: Plot Plan of the Center for Energy and Environment Research

CER17

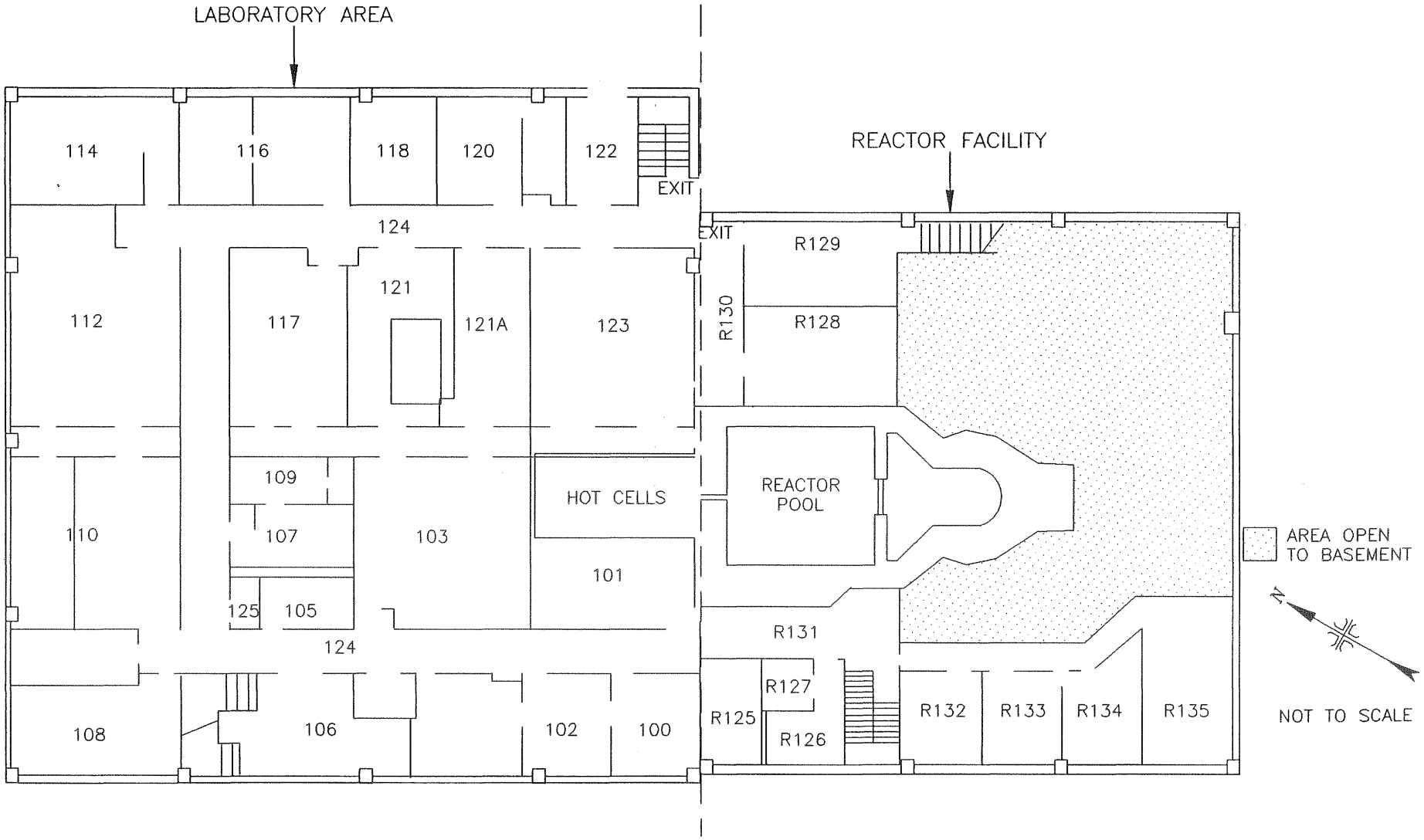

FIGURE 3: Laboratory and Reactor Building—Ground Floor

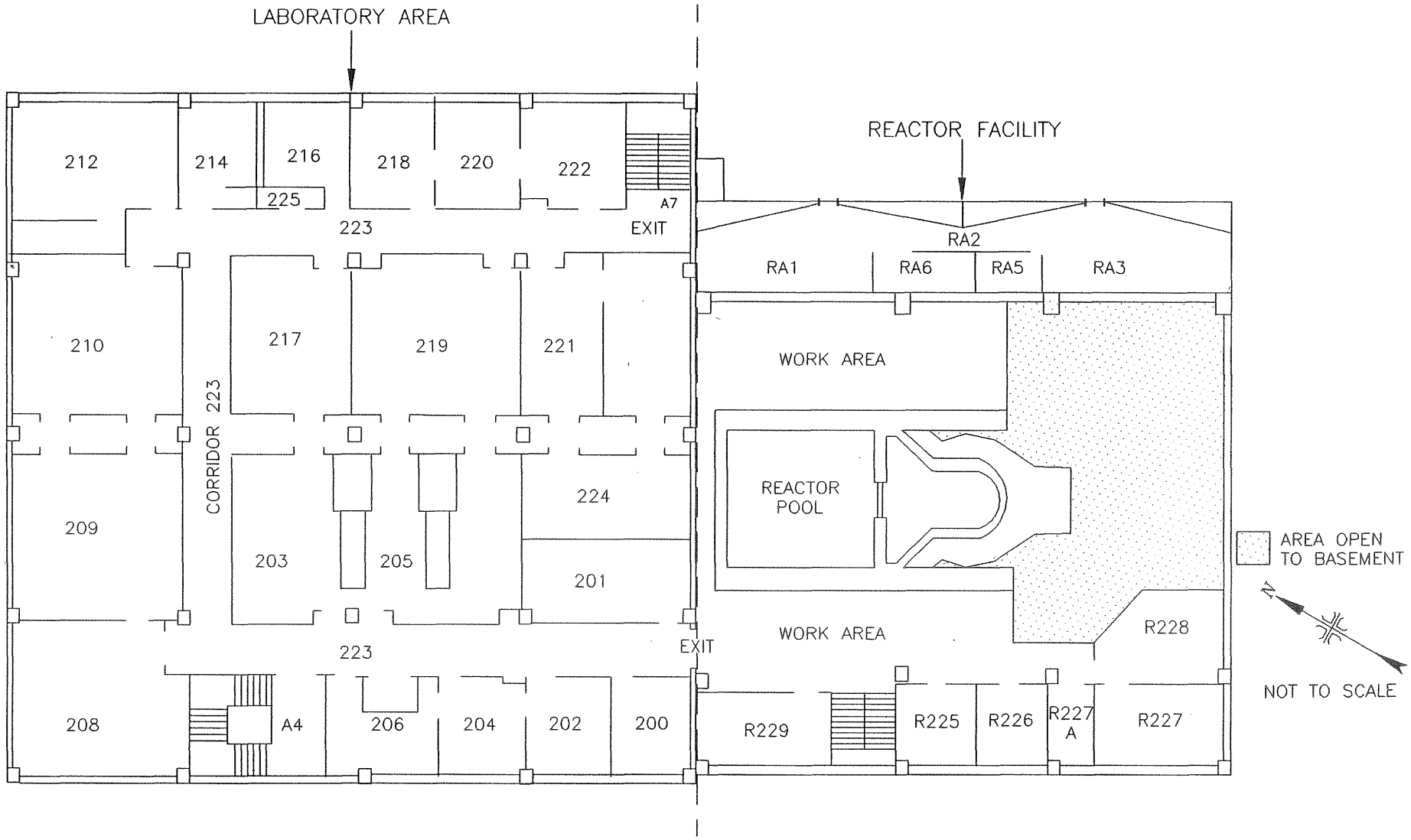

FIGURE 4: Laboratory and Reactor Building—Second Floor

CER10

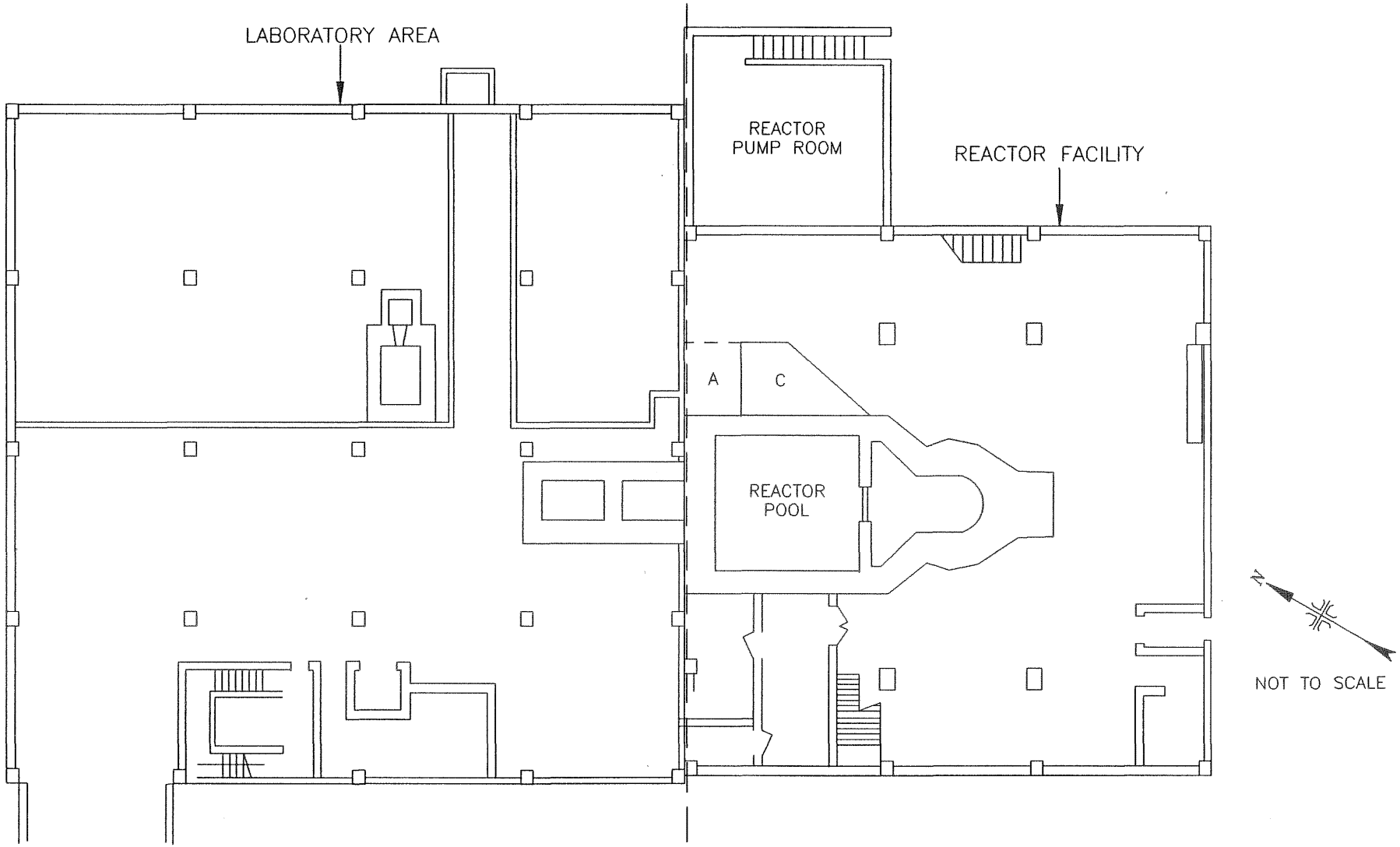

FIGURE 5: Laboratory and Reactor Building—Basement

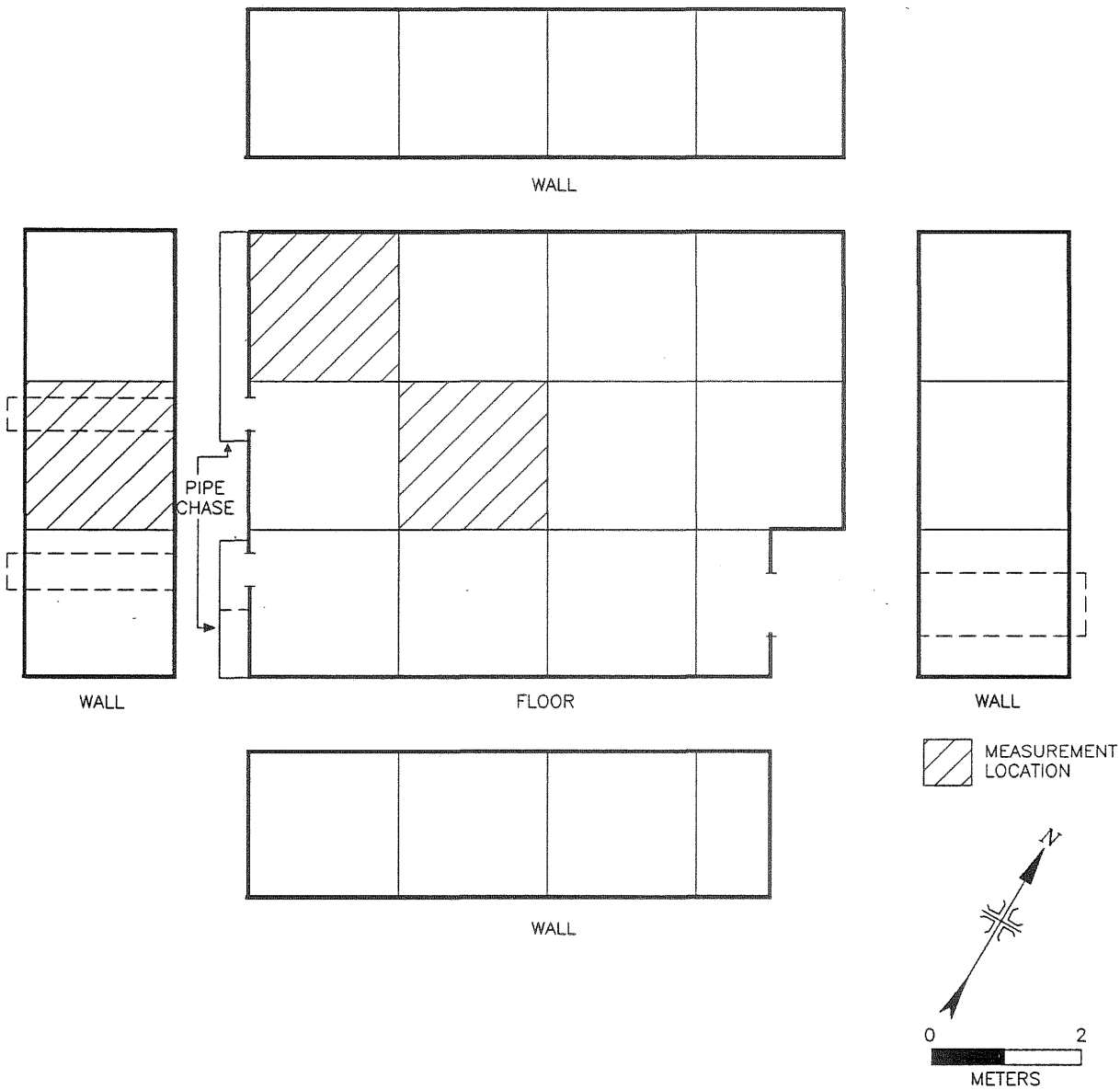

FIGURE 6: Laboratory Area Room 117, Indicating Locations of Surface Cointamination Measurements

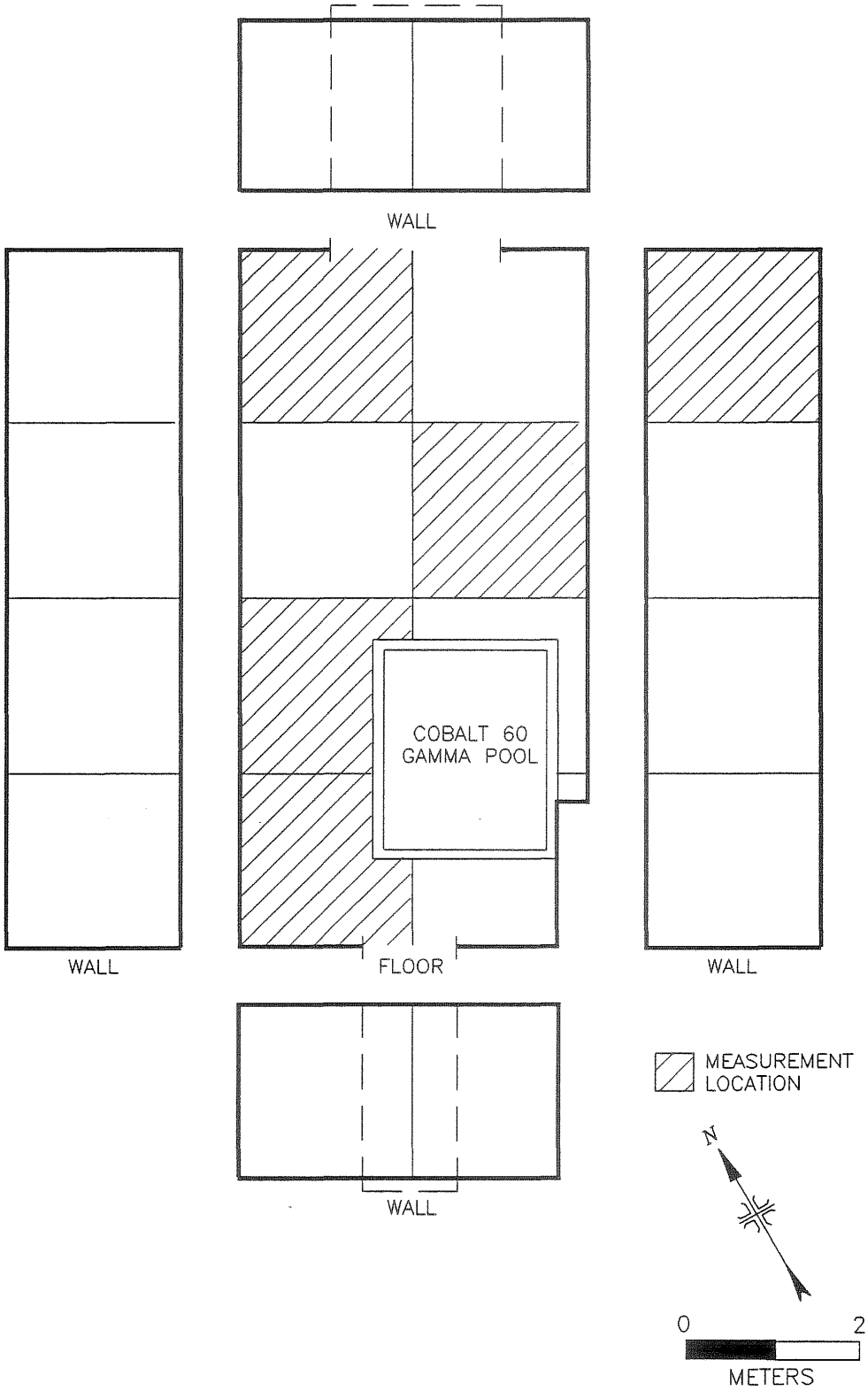

FIGURE 7: Laboratory Area Room 121, Indicating Locations of Surface Contamination Measurements

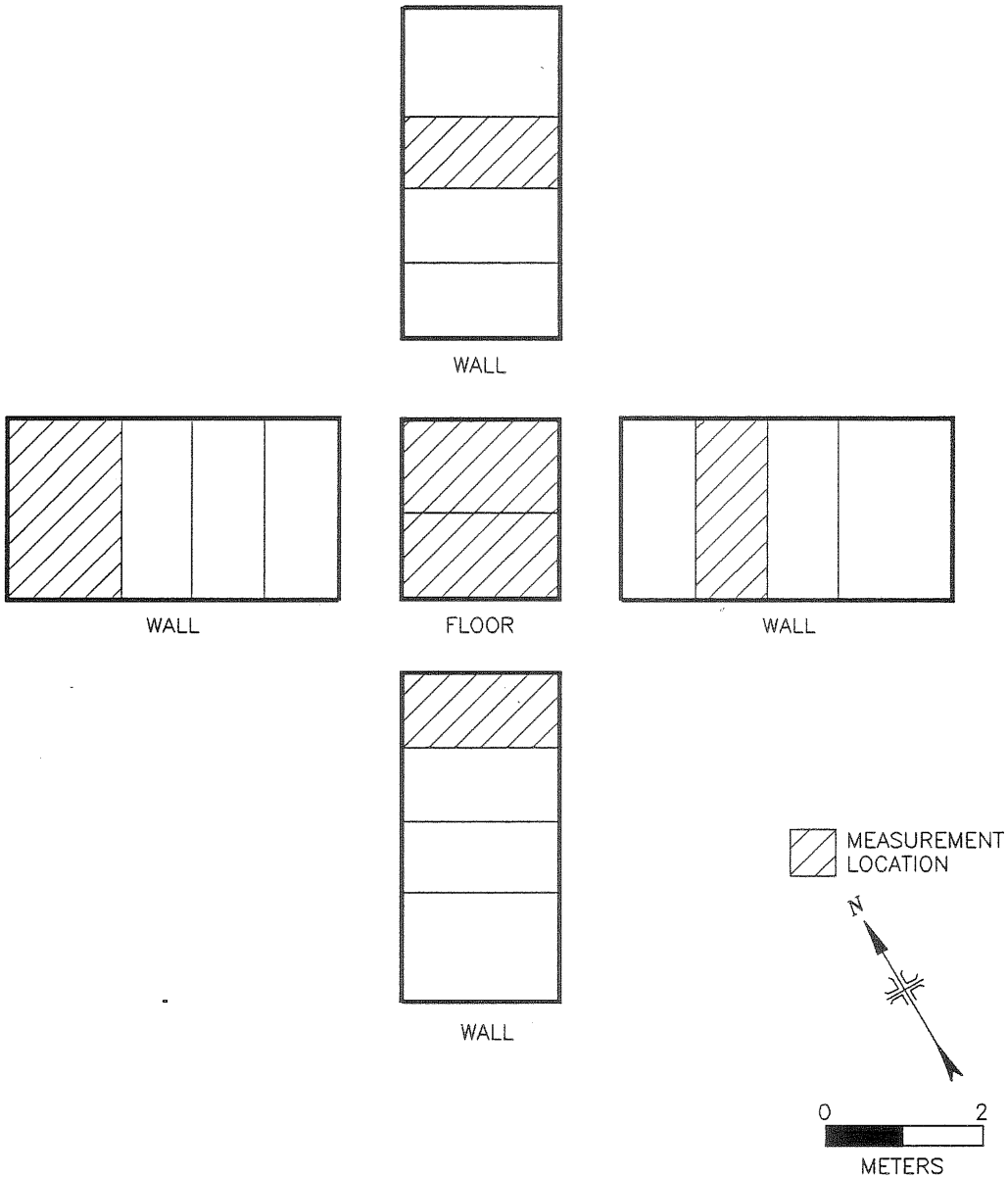

FIGURE 8: Laboratory Area Room 121 Cobalt 60 Pool, Indicating Locations of Surface Contamination Measurements

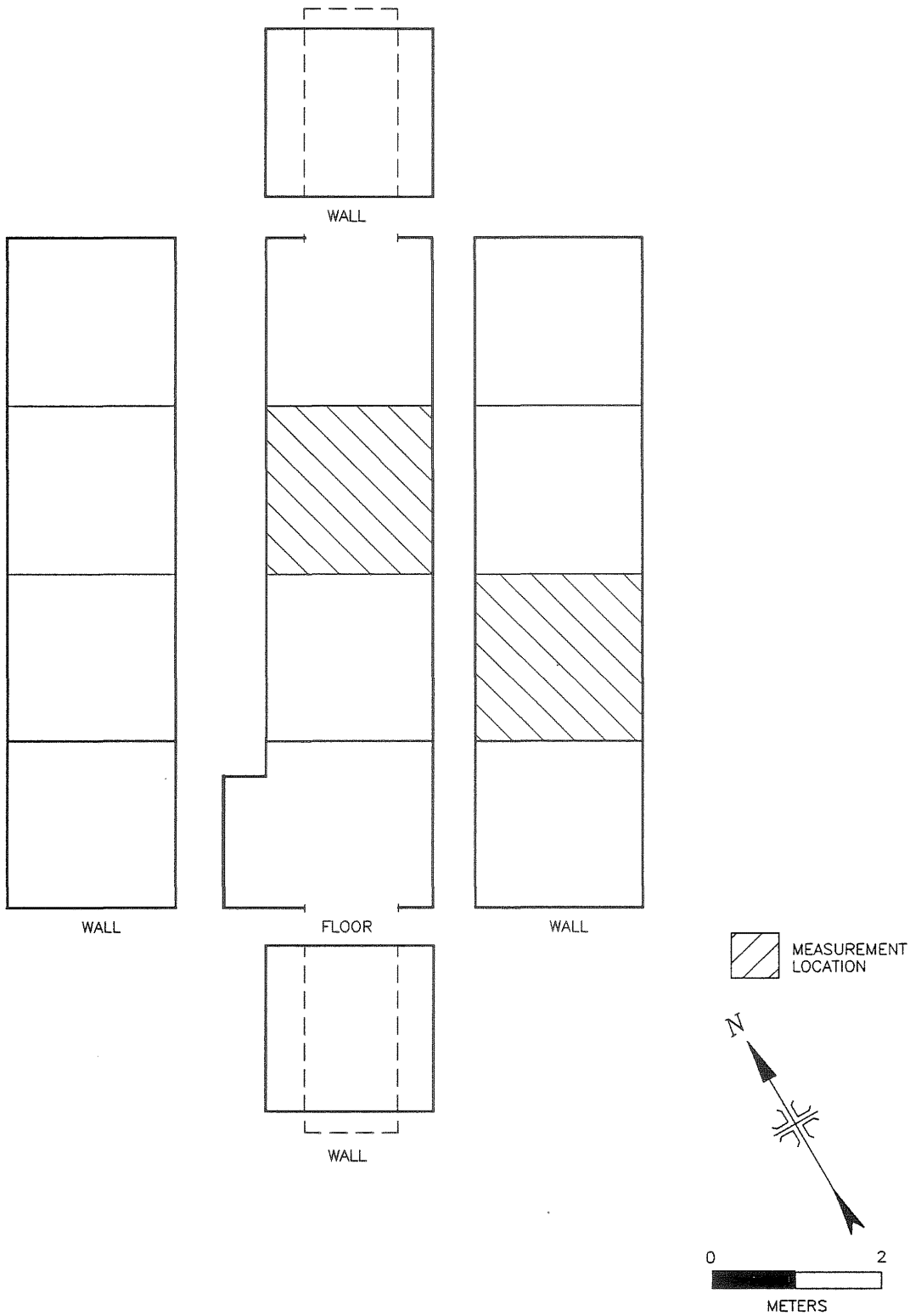

FIGURE 9: Laboratory Area Room 121A, Indicating Locations of Surface Contamination Measurements

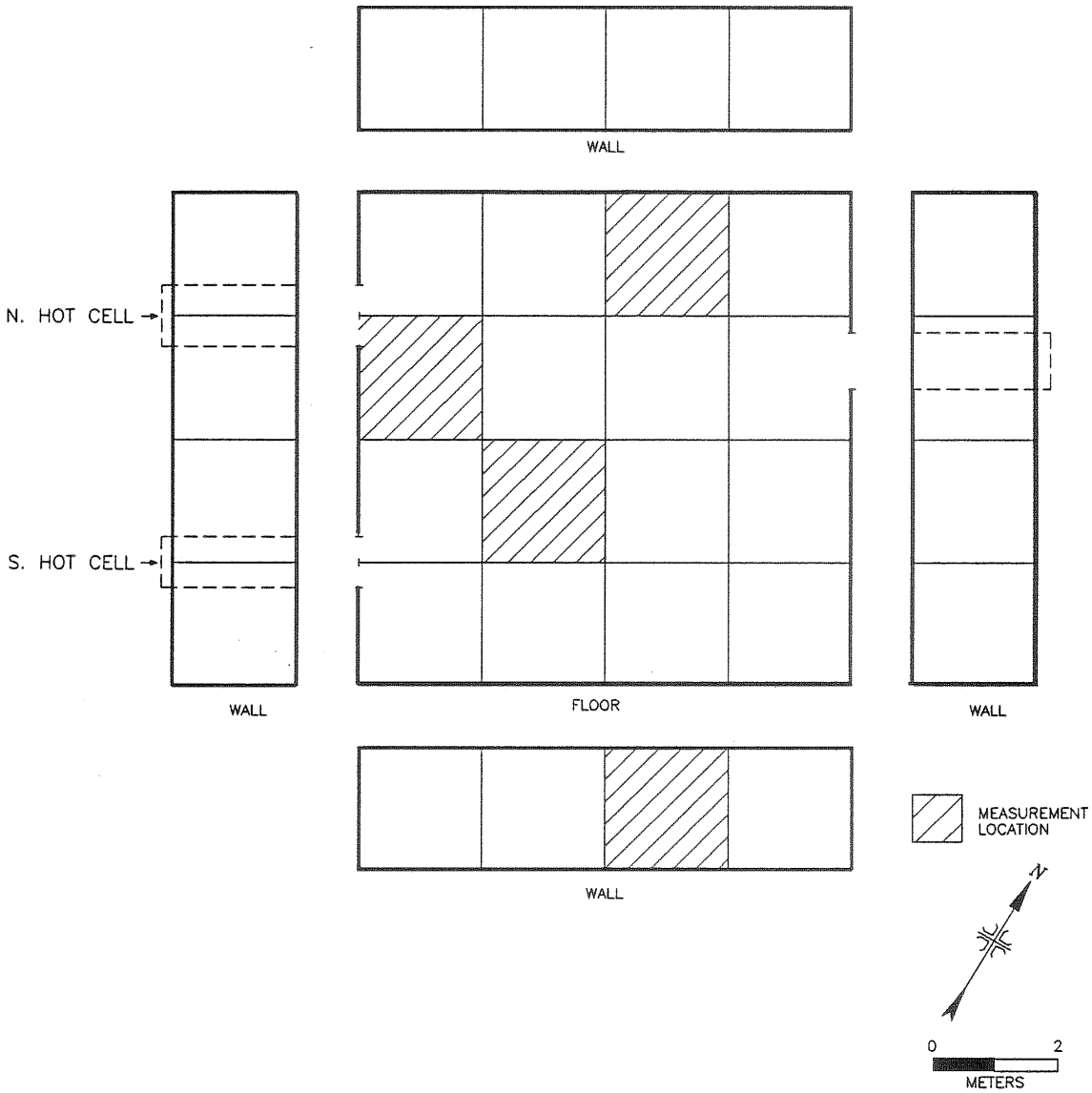

FIGURE 10: Laboratory Area Room 123, Indicating Locations of Surface Contamination Measurements

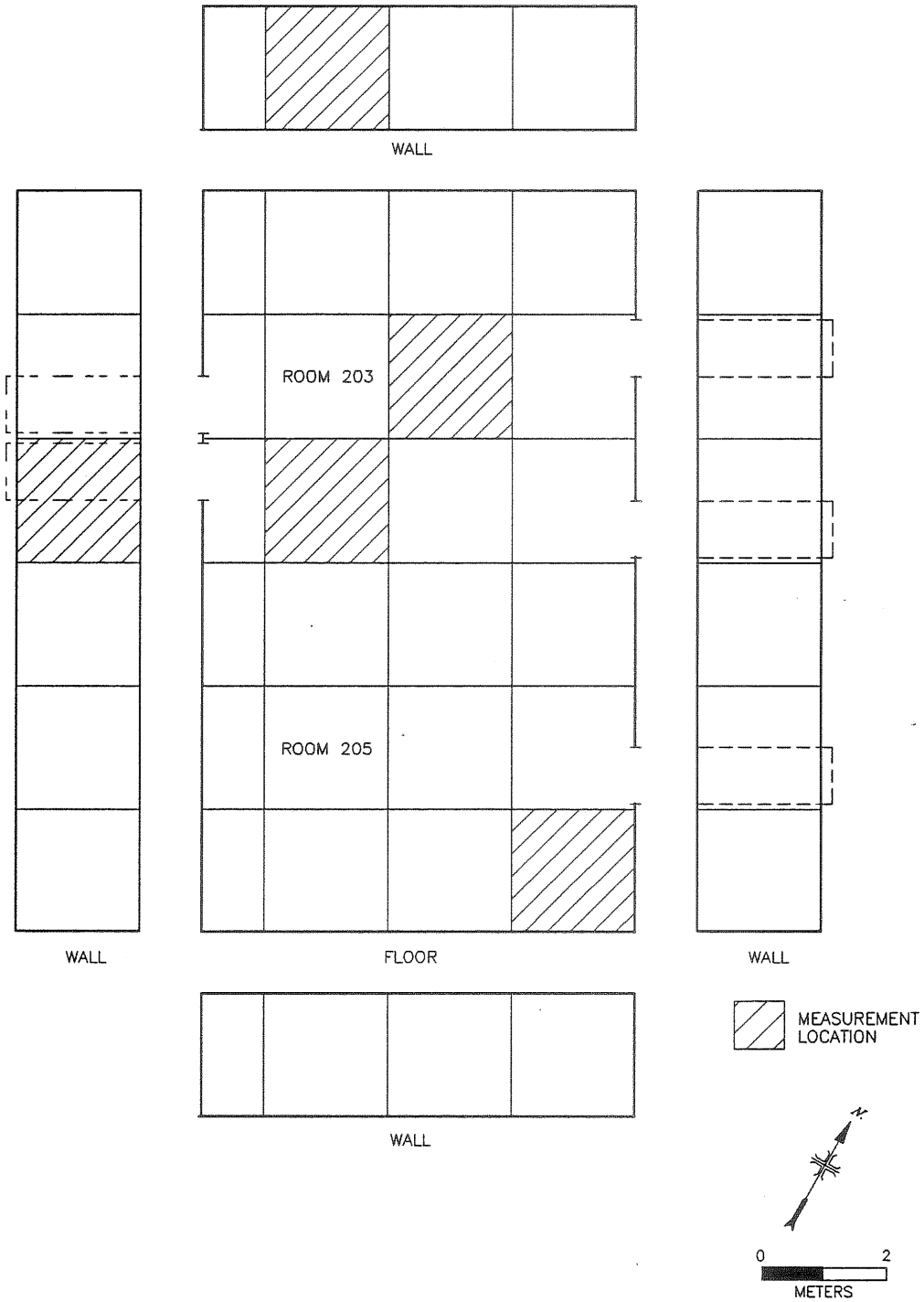

FIGURE 11: Laboratory Area Rooms 203 and 205, Indicating Locations of Surface Contamination Measurements

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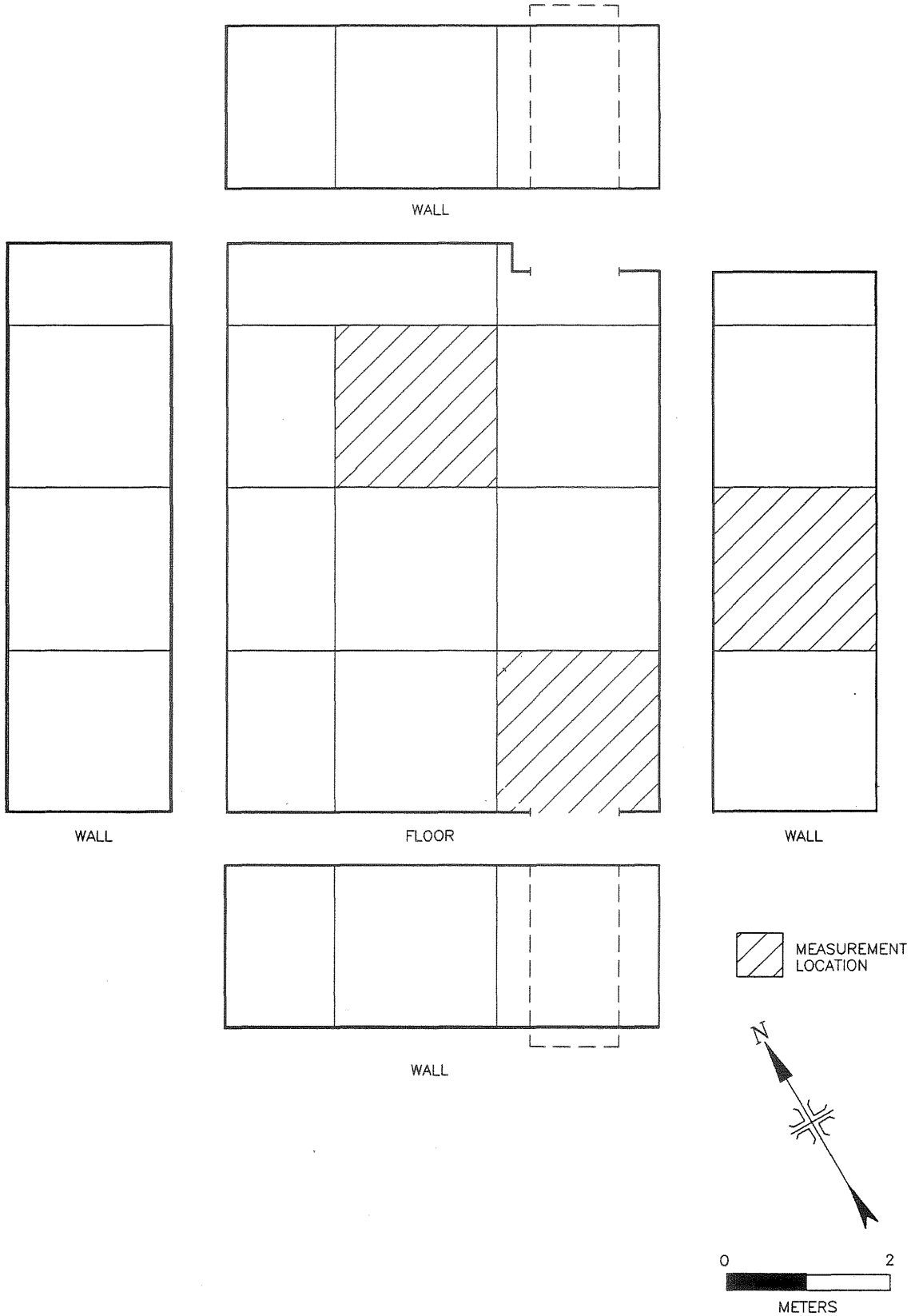

FIGURE 12: Laboratory Area Room 217, Indicating Locations of Surface Contamination Measurements

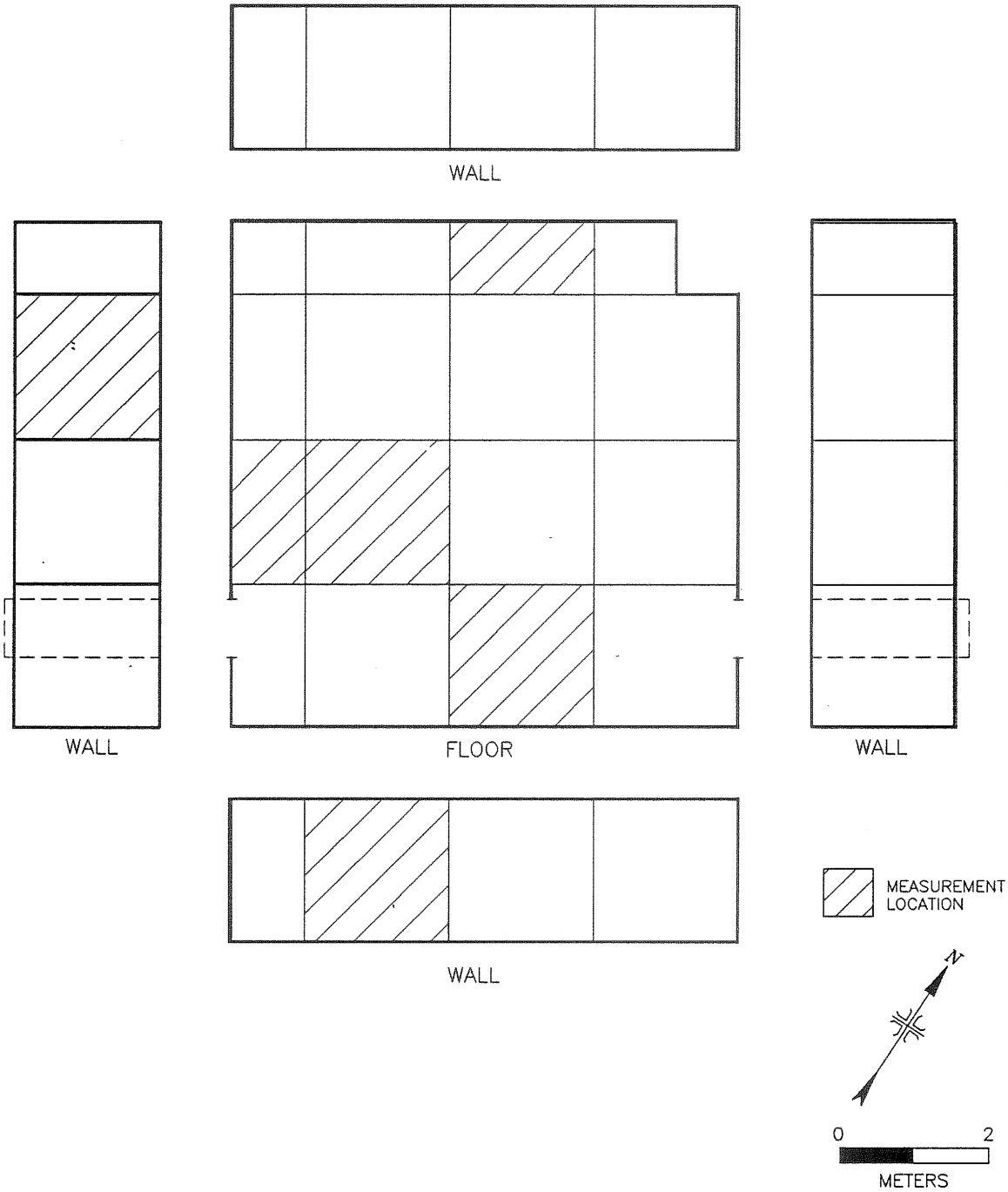

FIGURE 13: Laboratory Area Room 219, Indicating Locations of Surface Contamination Measurements

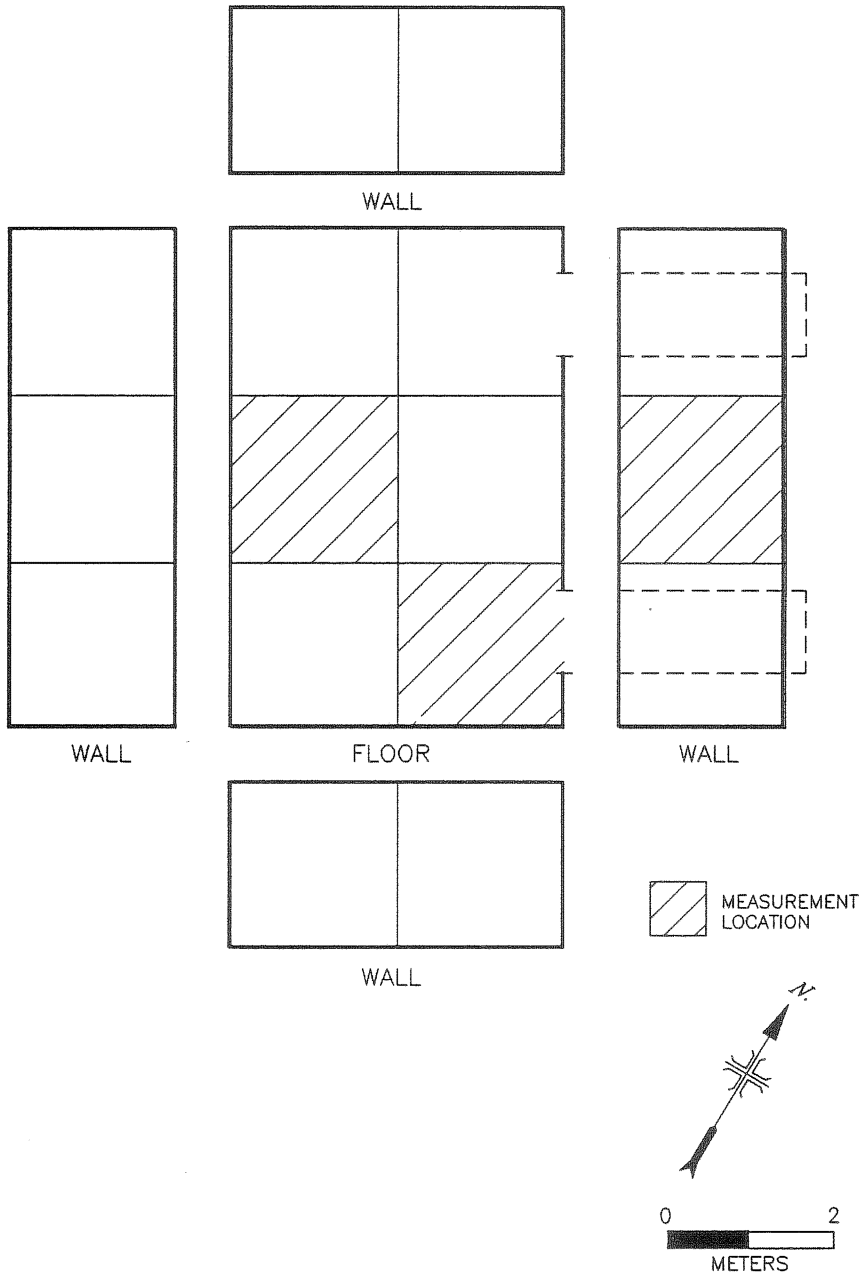

FIGURE 14: Laboratory Area Room 224, Indicating Locations of Surface Contamination Measurements

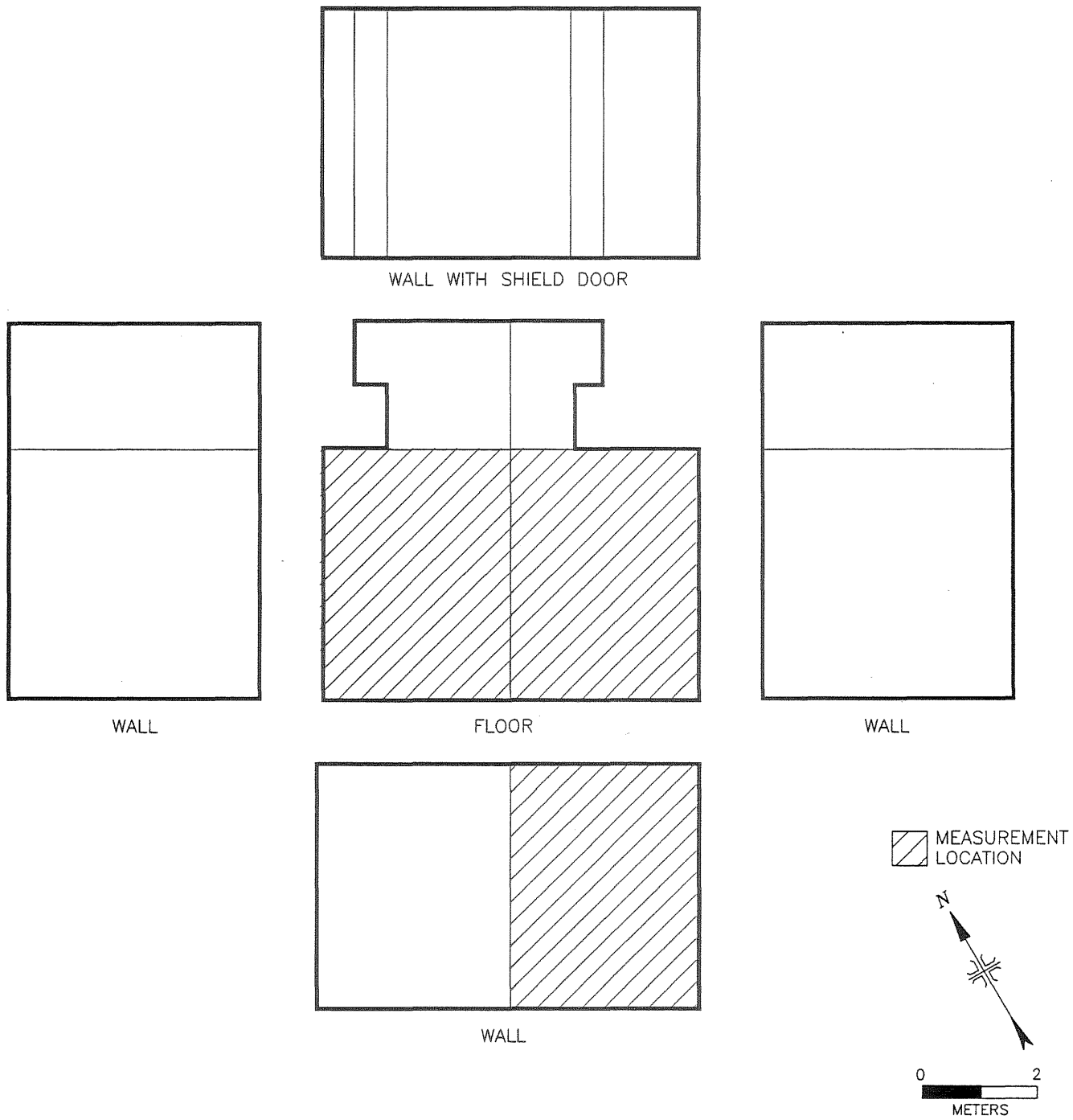

FIGURE 15: South Hot Cell, Indicating Locations of Surface Contamination Measurements

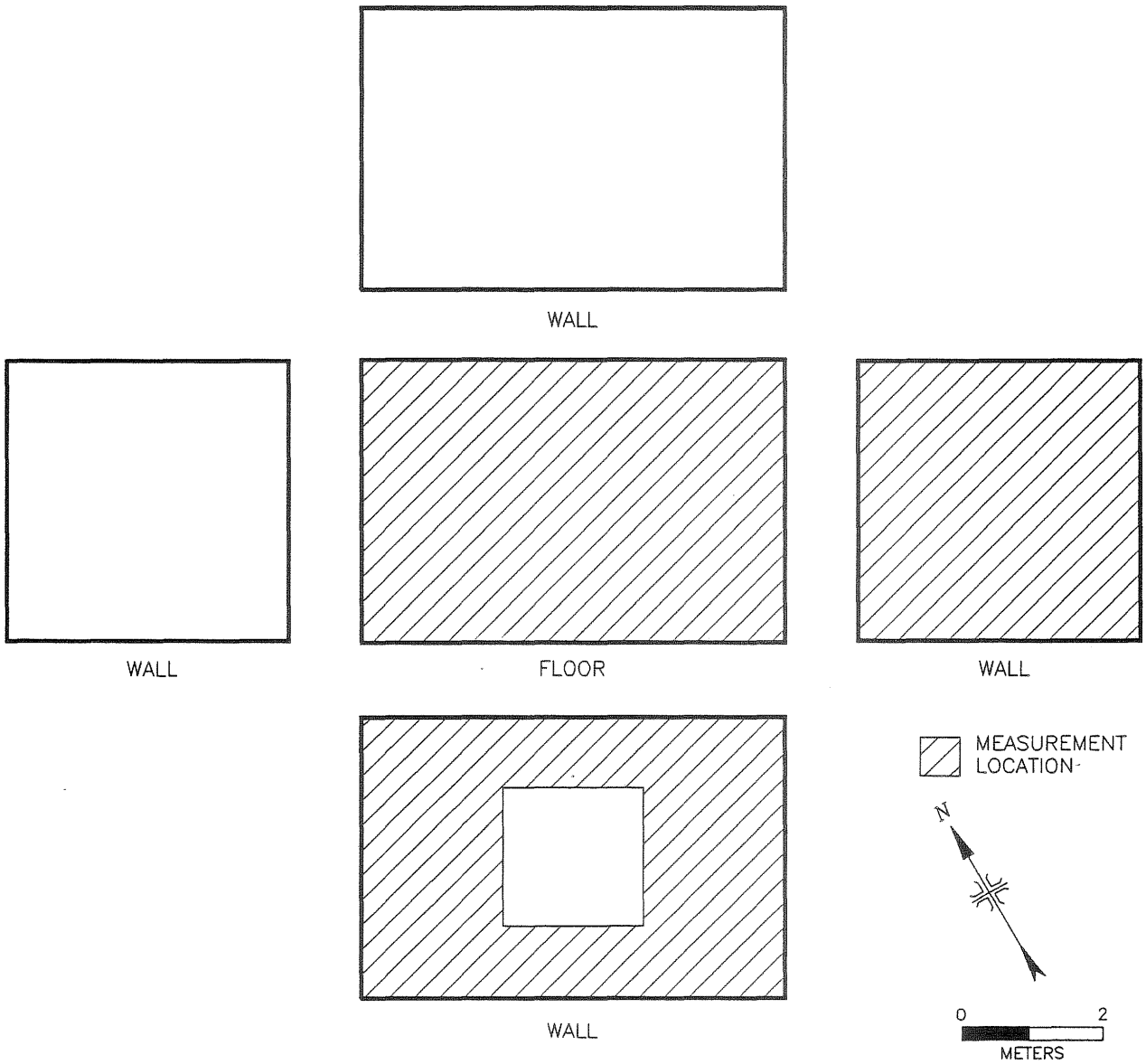

FIGURE 16: Area Below the South Hot Cell, Indicating Locations of Surface Contamination Measurements

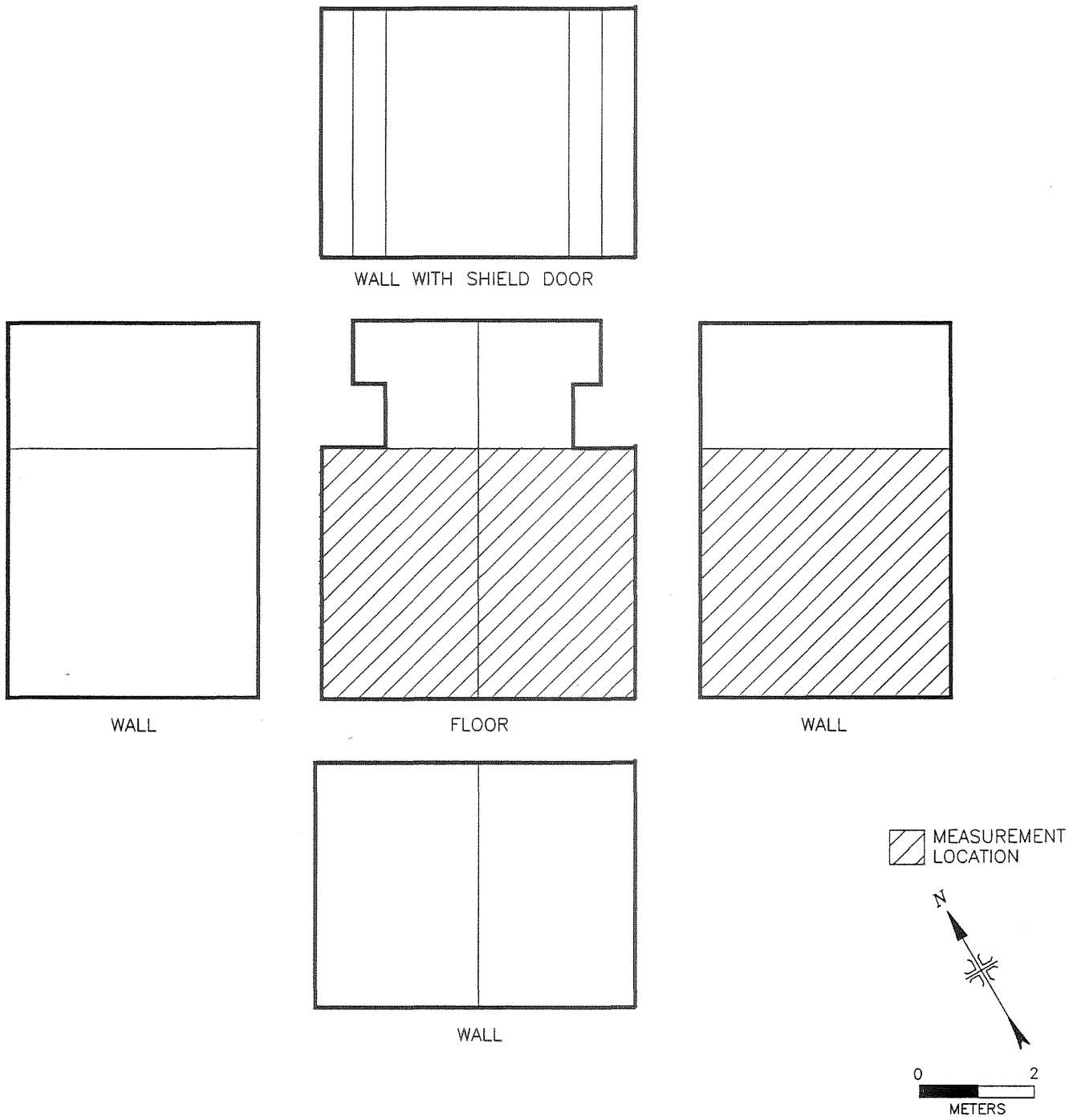

FIGURE 1.7: North Hot Cell, Indicating Locations of Surface Contamination Measurements

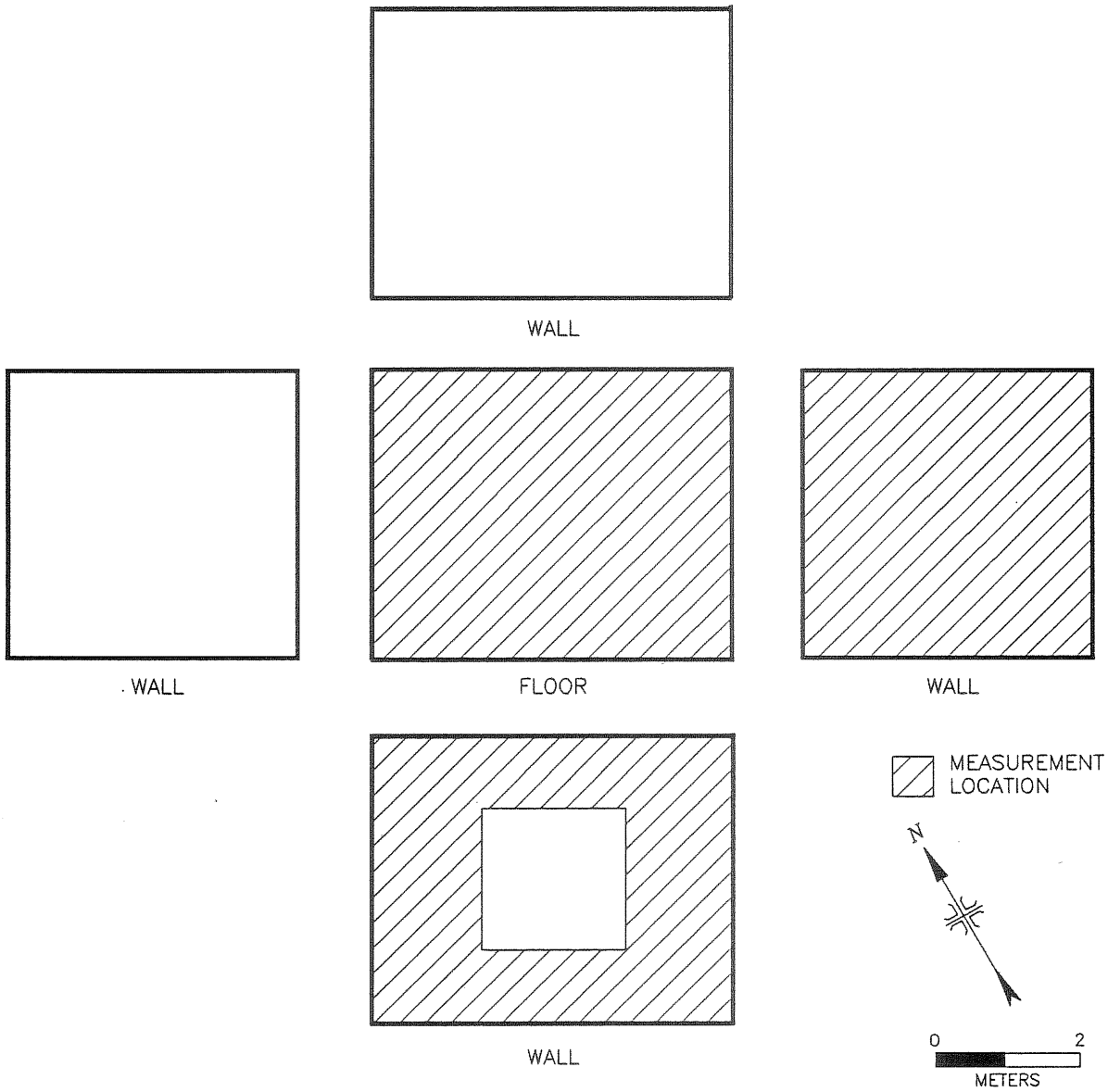

FIGURE 18: Area Below the North Hot Cell, Indicating Locations of Surface Contamination Measurements

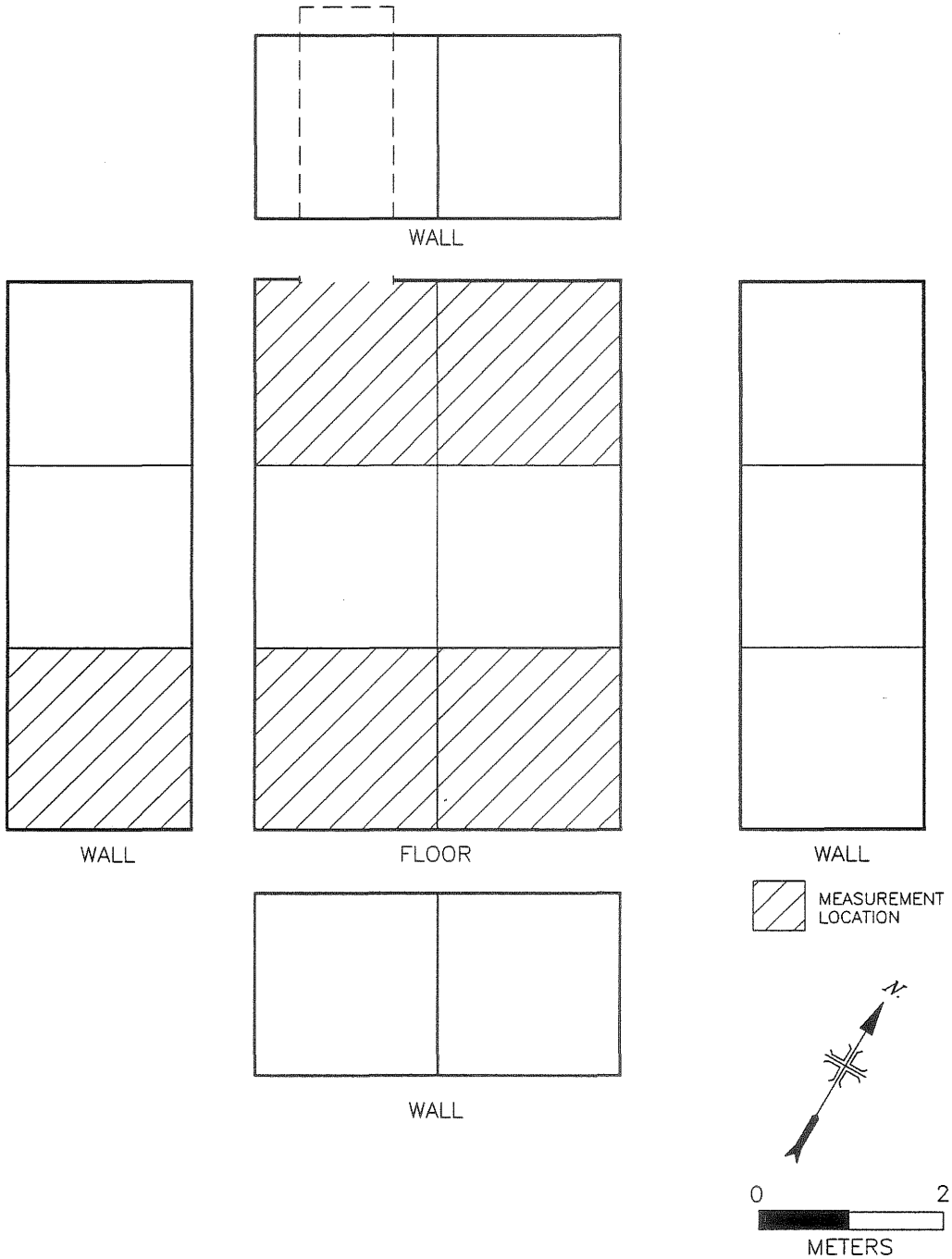

FIGURE 19: Reactor Facility Room R–128, Indicating Locations of Surface Contamination Measurements

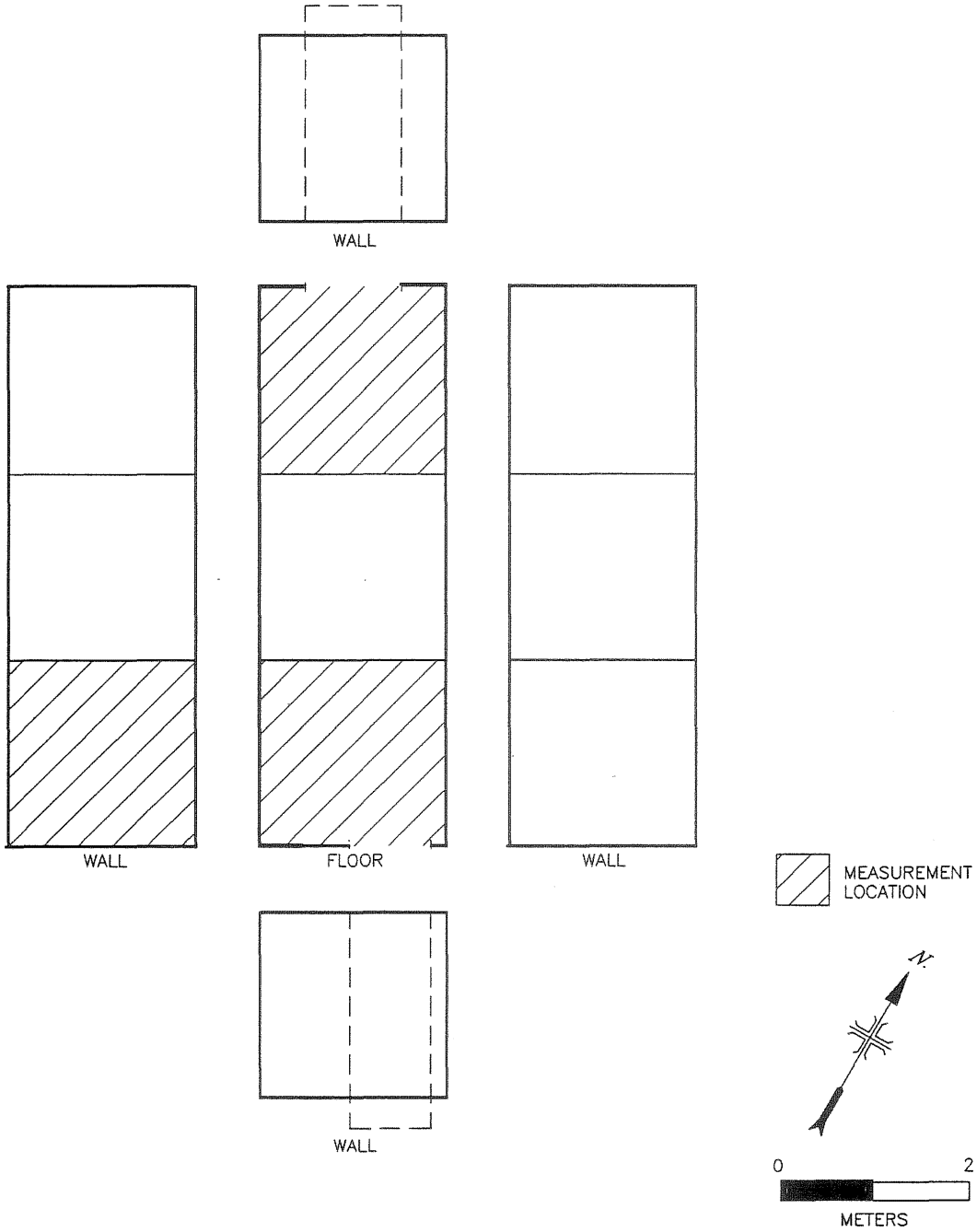

FIGURE 20: Reactor Facility Room R–129, Indicating Locations of Surface Contamination Measurements

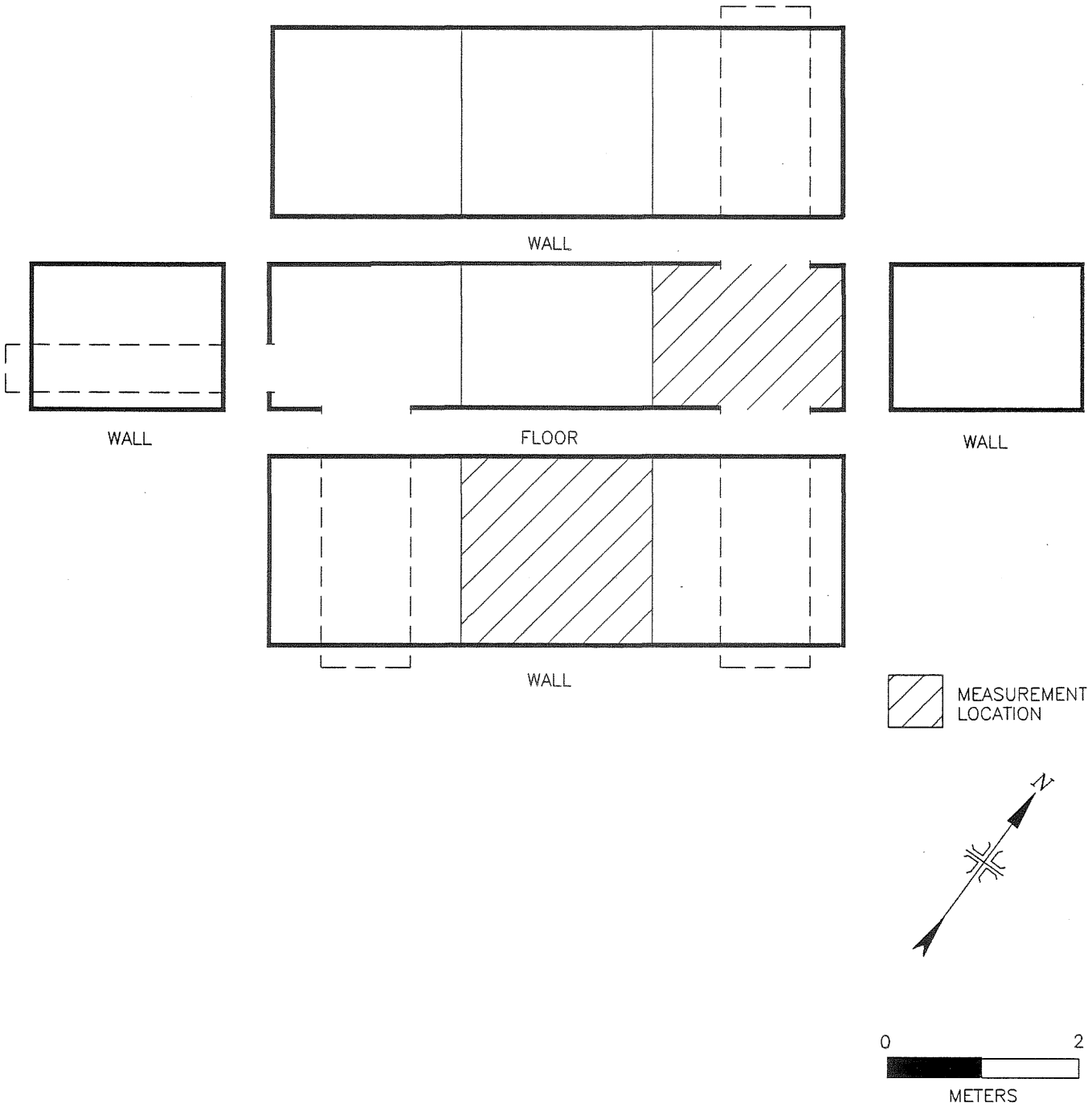

FIGURE 21: Room R-130, Indicating Locations of Surface Contamination Measurements

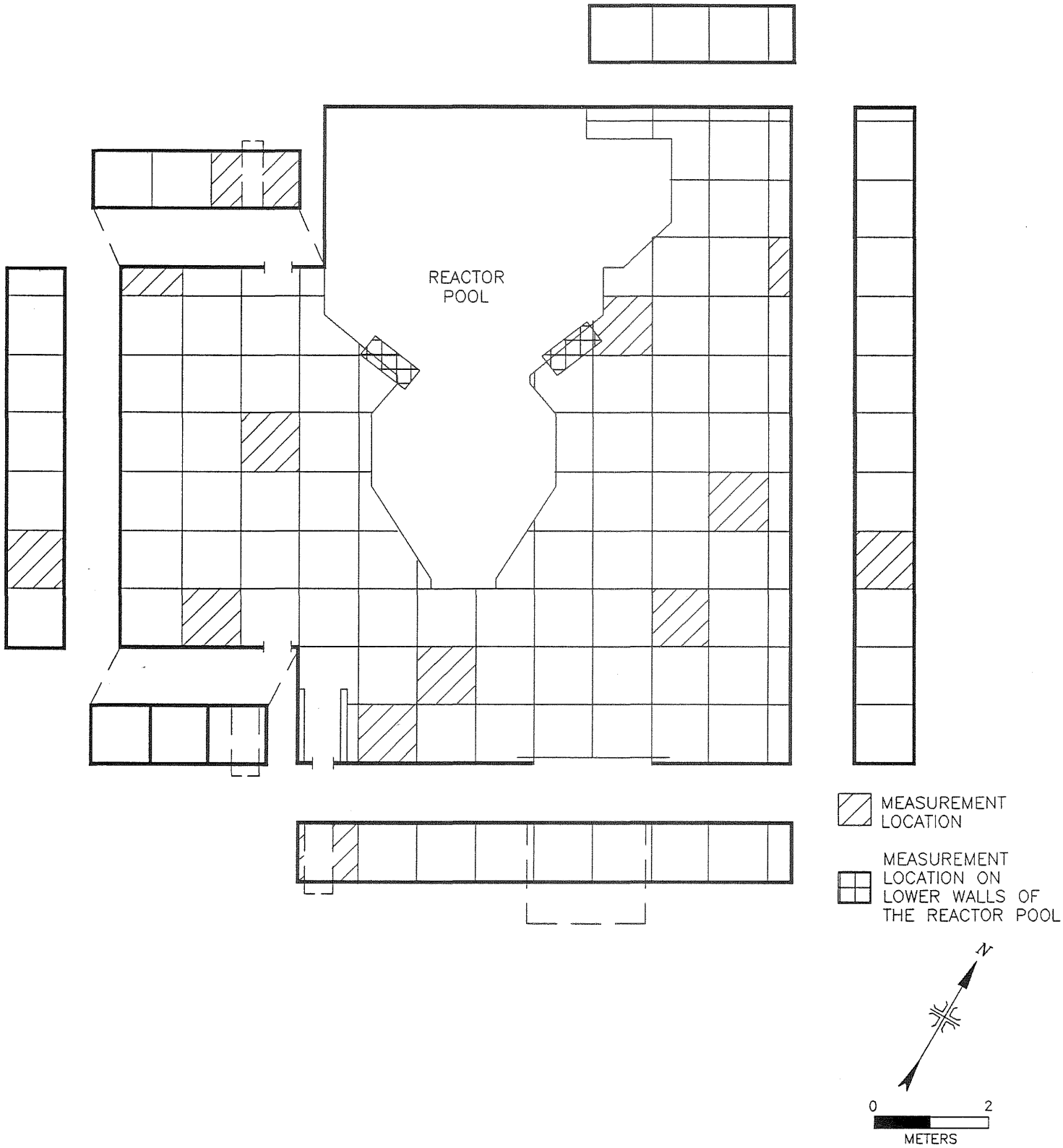

FIGURE 22: Basement Level of the Reactor Facility, Indicating Locations of Surface Contamination Measurements

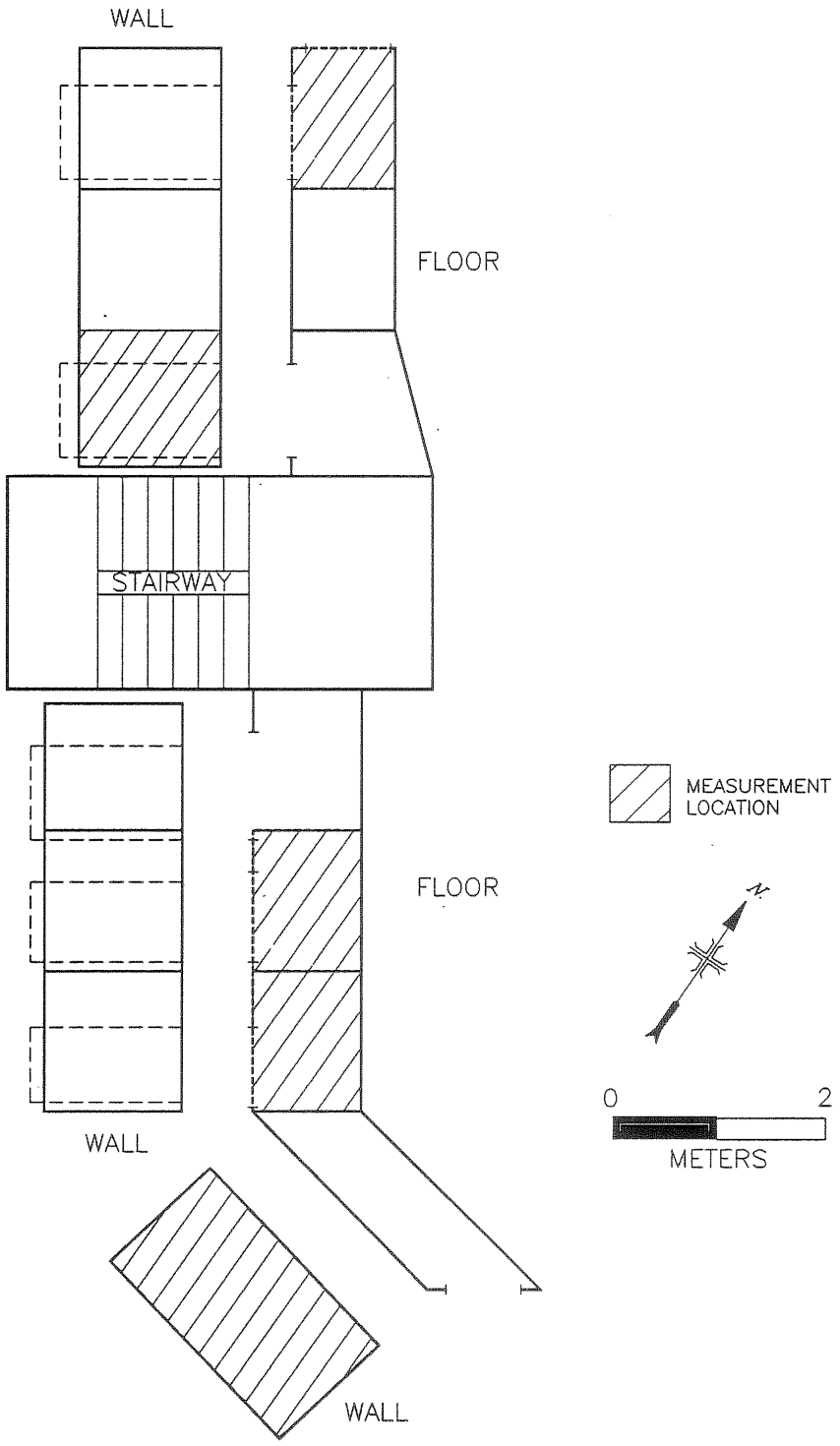

FIGURE 23: First Floor Level of the Reactor Facility Walkway, Indicating Locations of Surface Contamination Measurements

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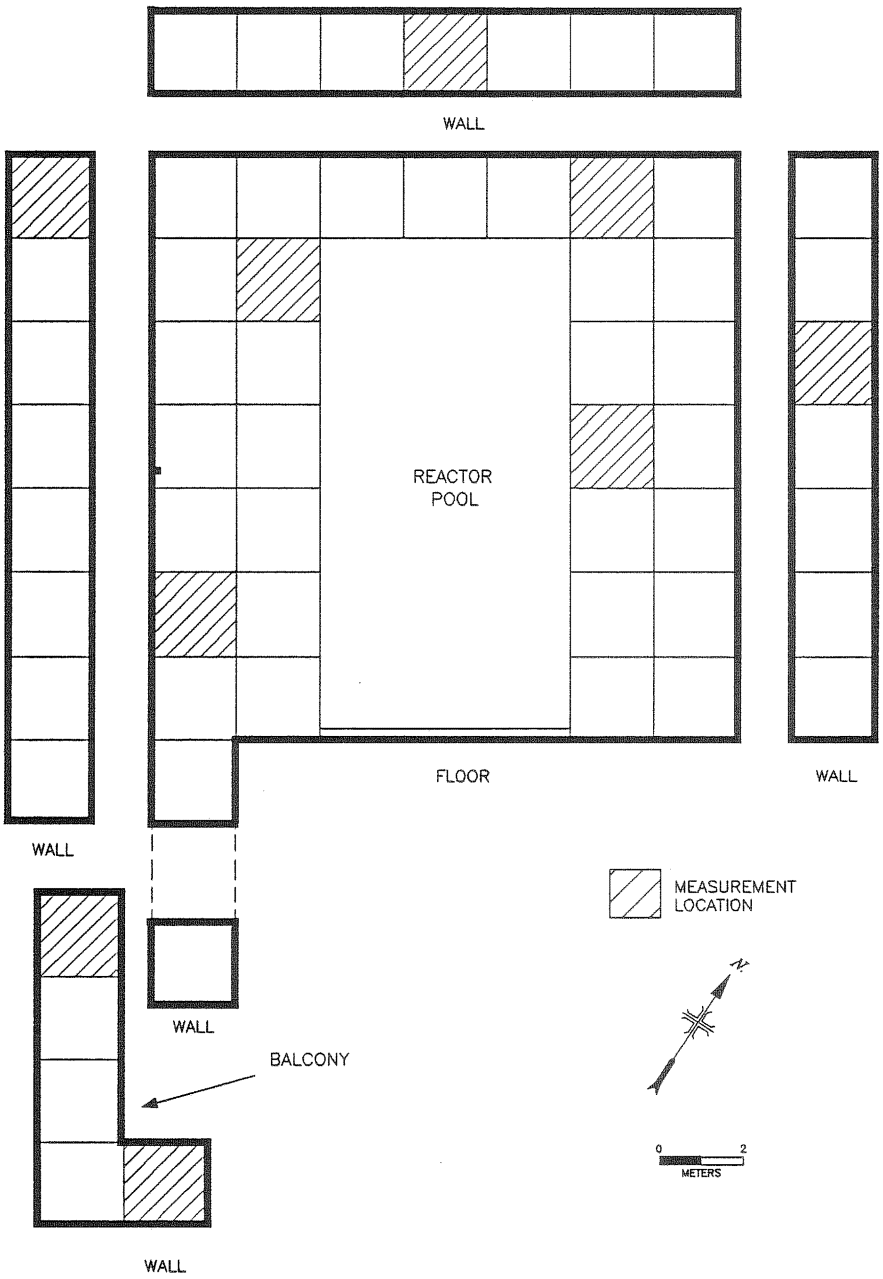

FIGURE 24: Second Floor Level of the Reactor Facility Fuel Handling Area, Indicating Locations of Surface Contamination Measurements

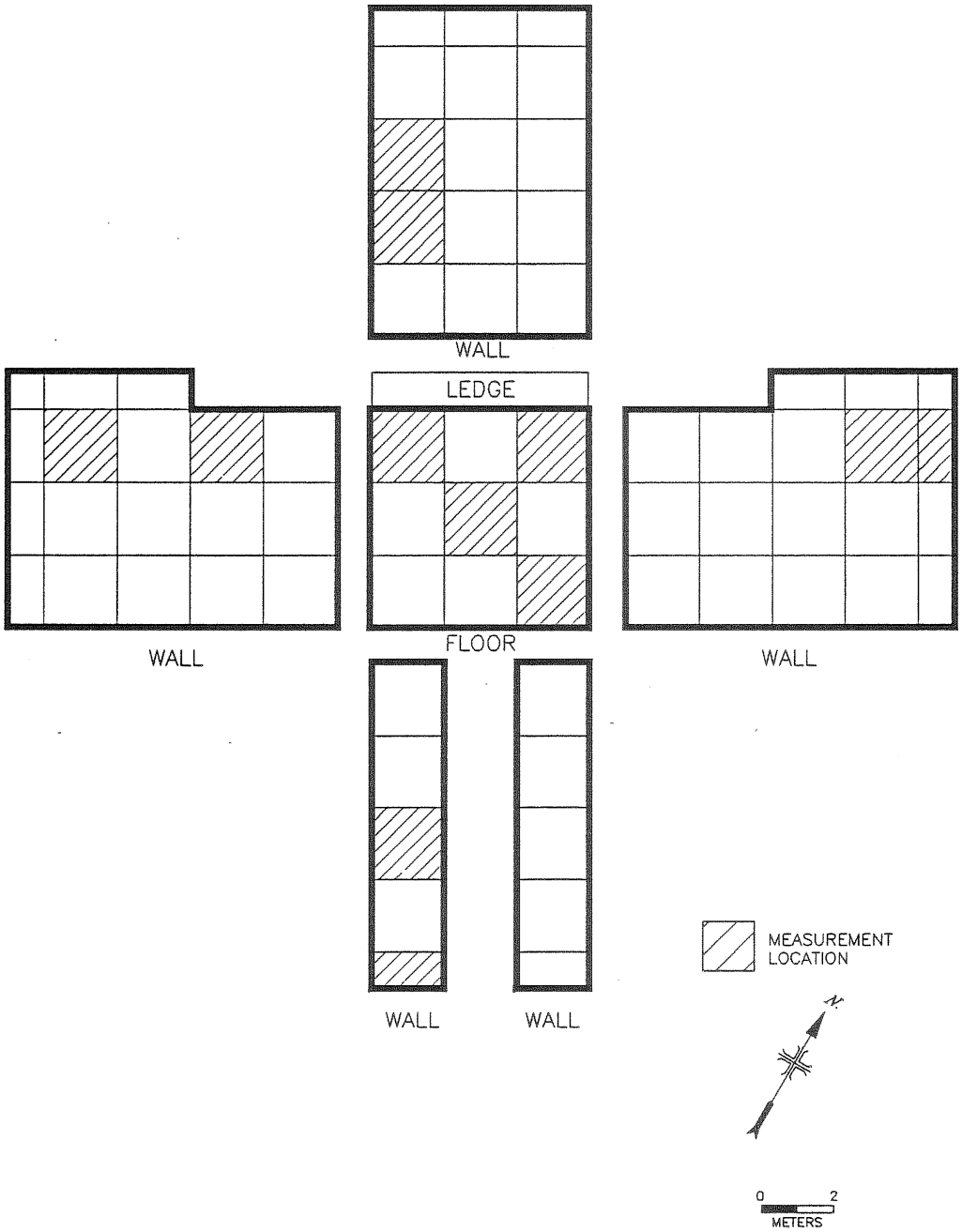

FIGURE 25: Reactor Pool (Open End), Indicating Locations of Surface Contamination Measurements

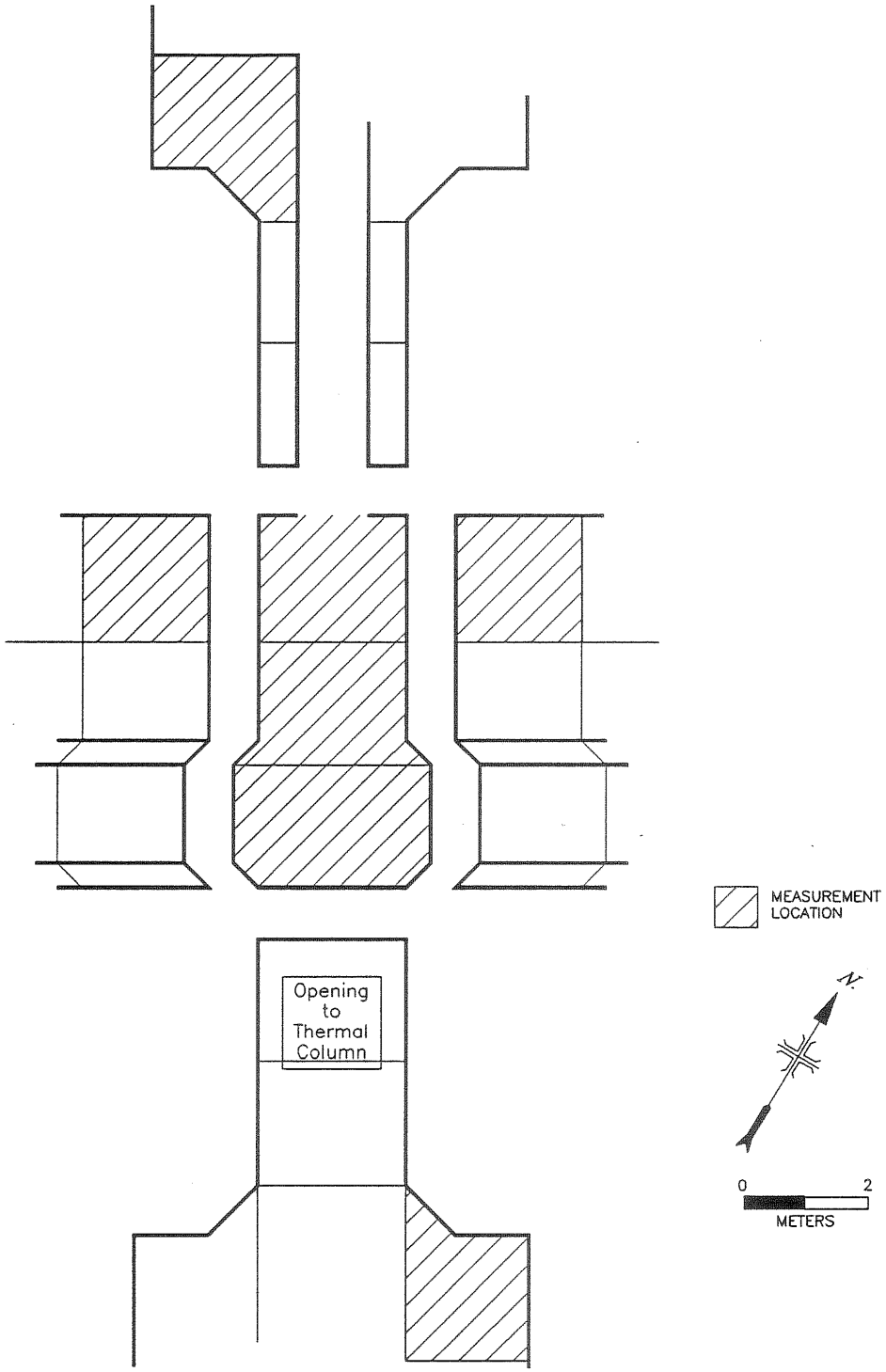

FIGURE 26: Reactor Pool (Stall End), Indicating Locations of Surface Contamination Measurements

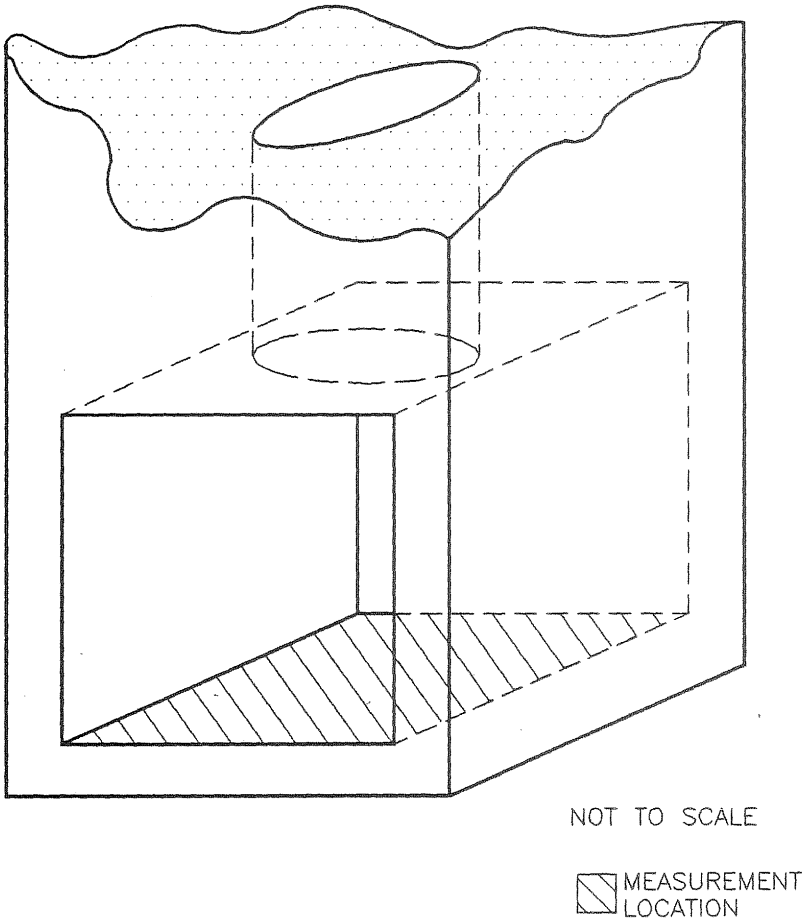

FIGURE 27: Thermal Column, Indicating Locations of Surface Contamination Measurements

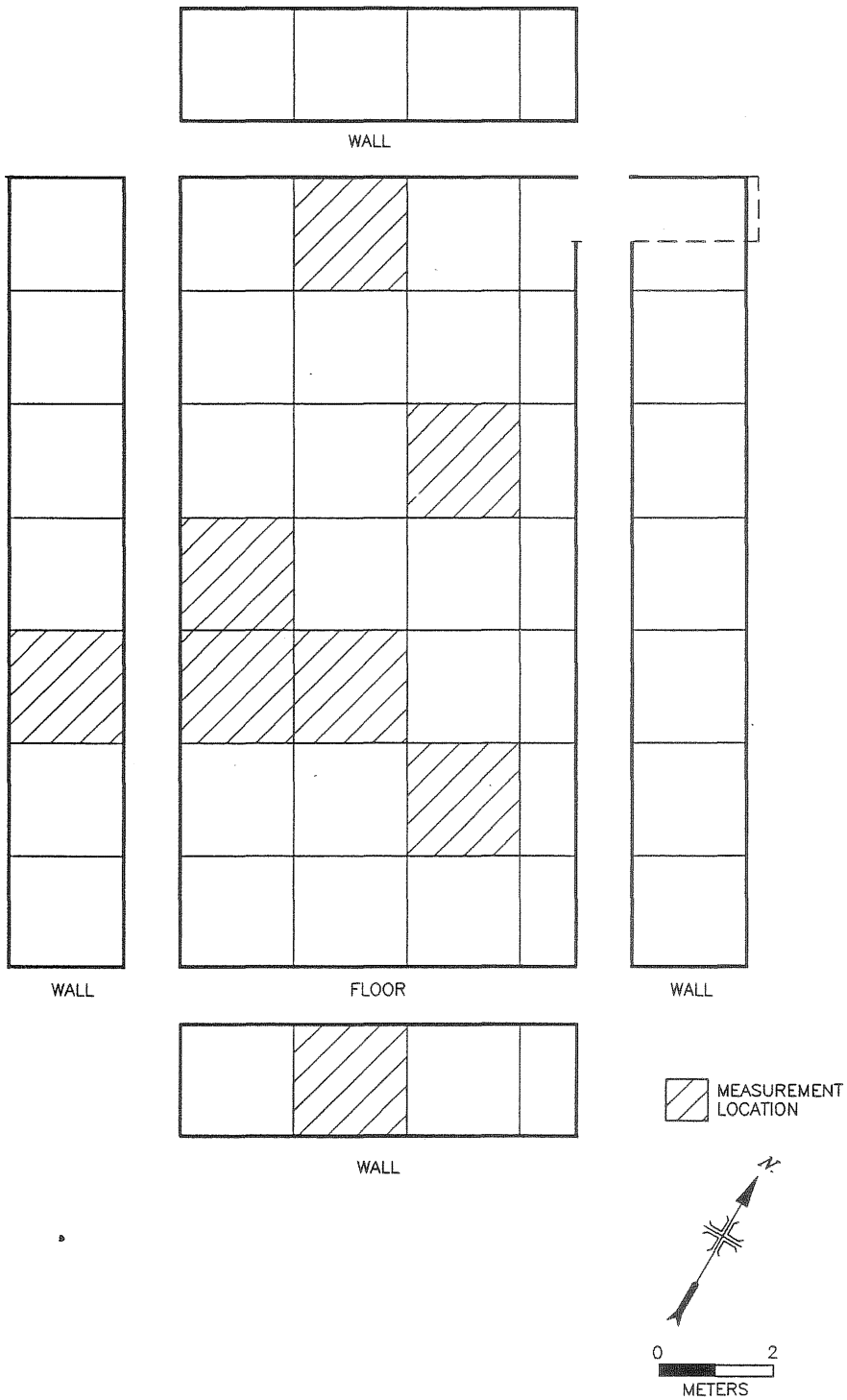

FIGURE 28: Reactor Pump Room, Indicating Locations of Surface Contamination Measurements

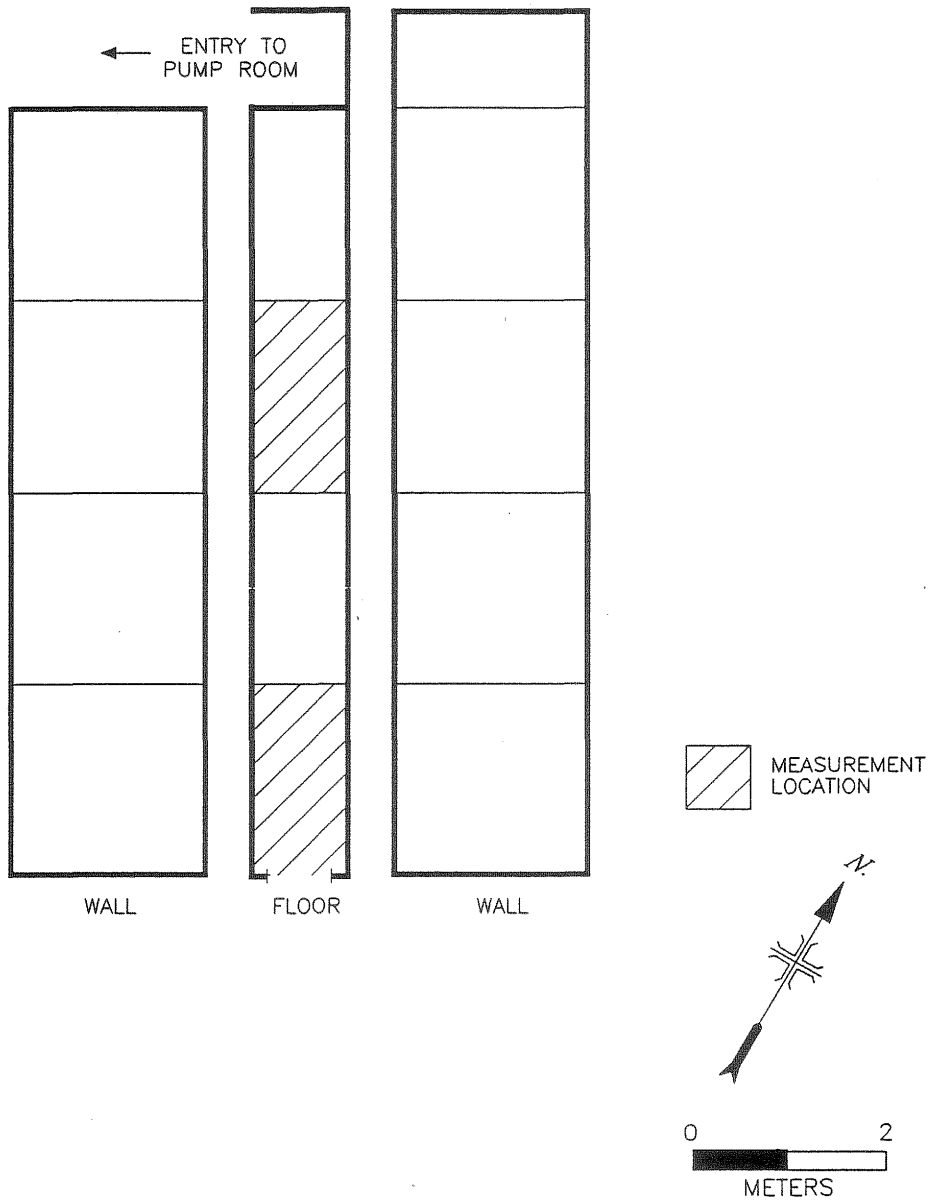

FIGURE 29: Reactor Pump Room Stairwell, Indicating Locations of Surface Contamination Measurements

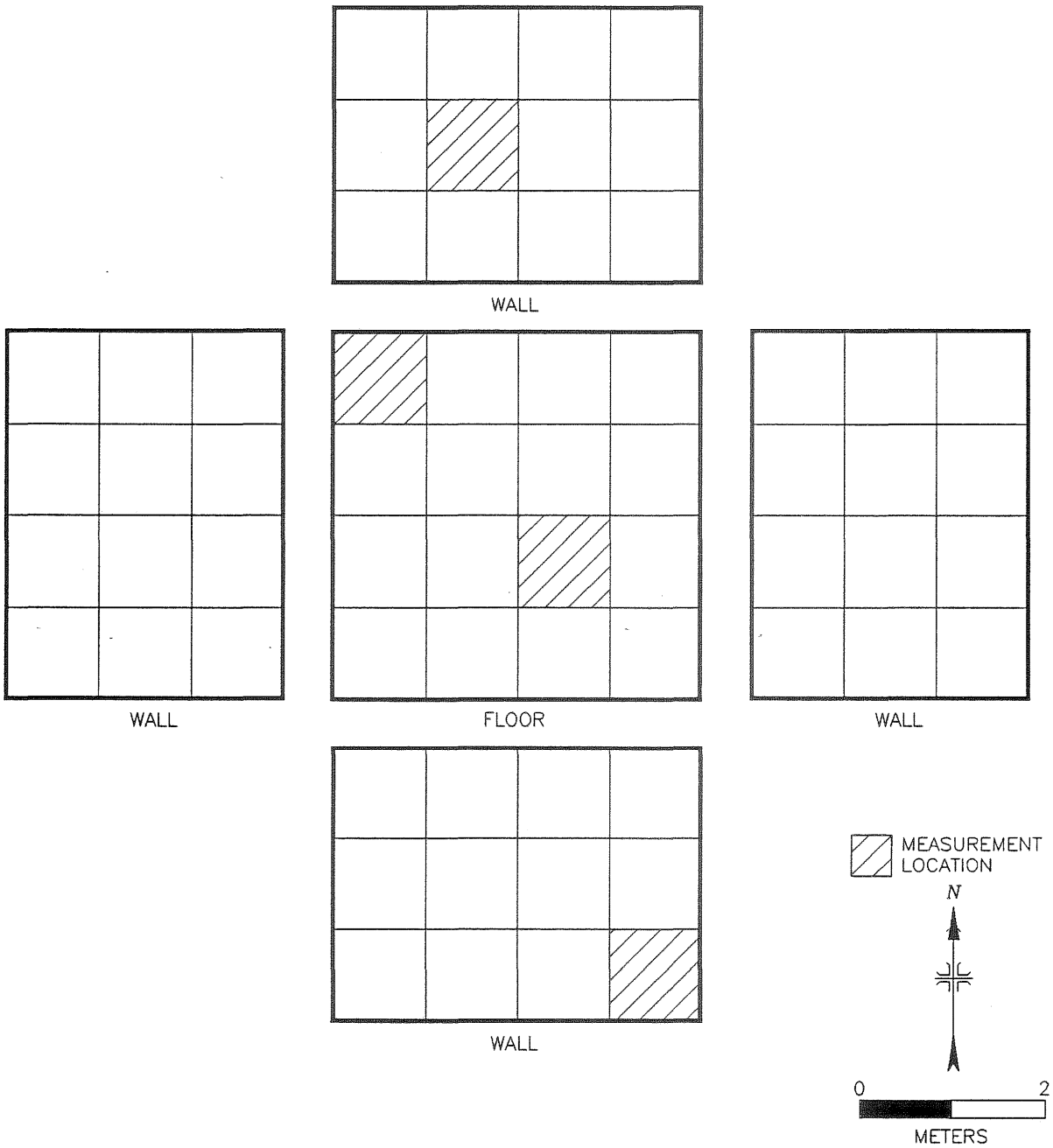

FIGURE 30: Shack Storage Building, Indicating Locations of Surface Contamination Measurements

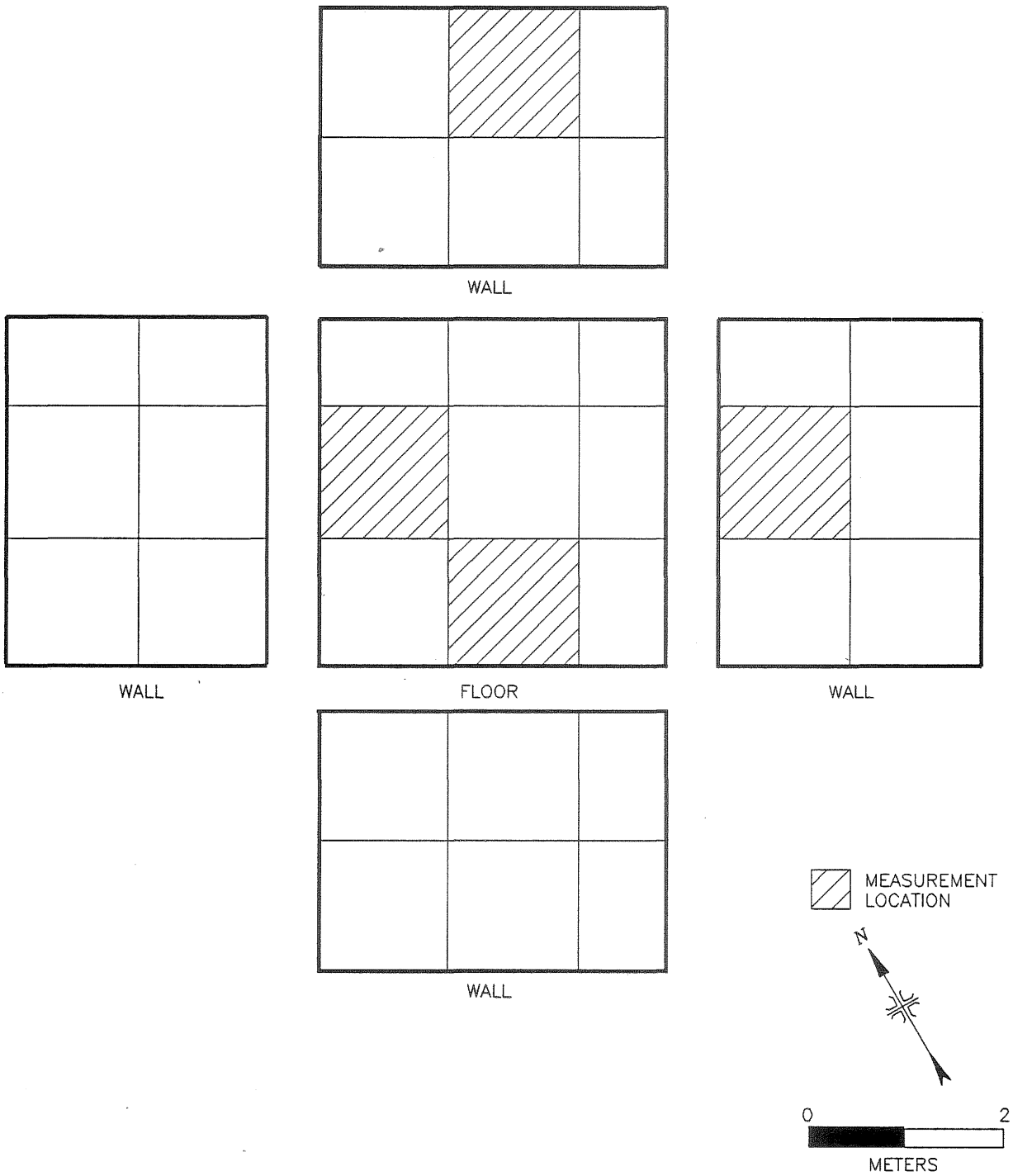

FIGURE 31: S–4 Building, Indicating Locations of Surface Contamination Measurements

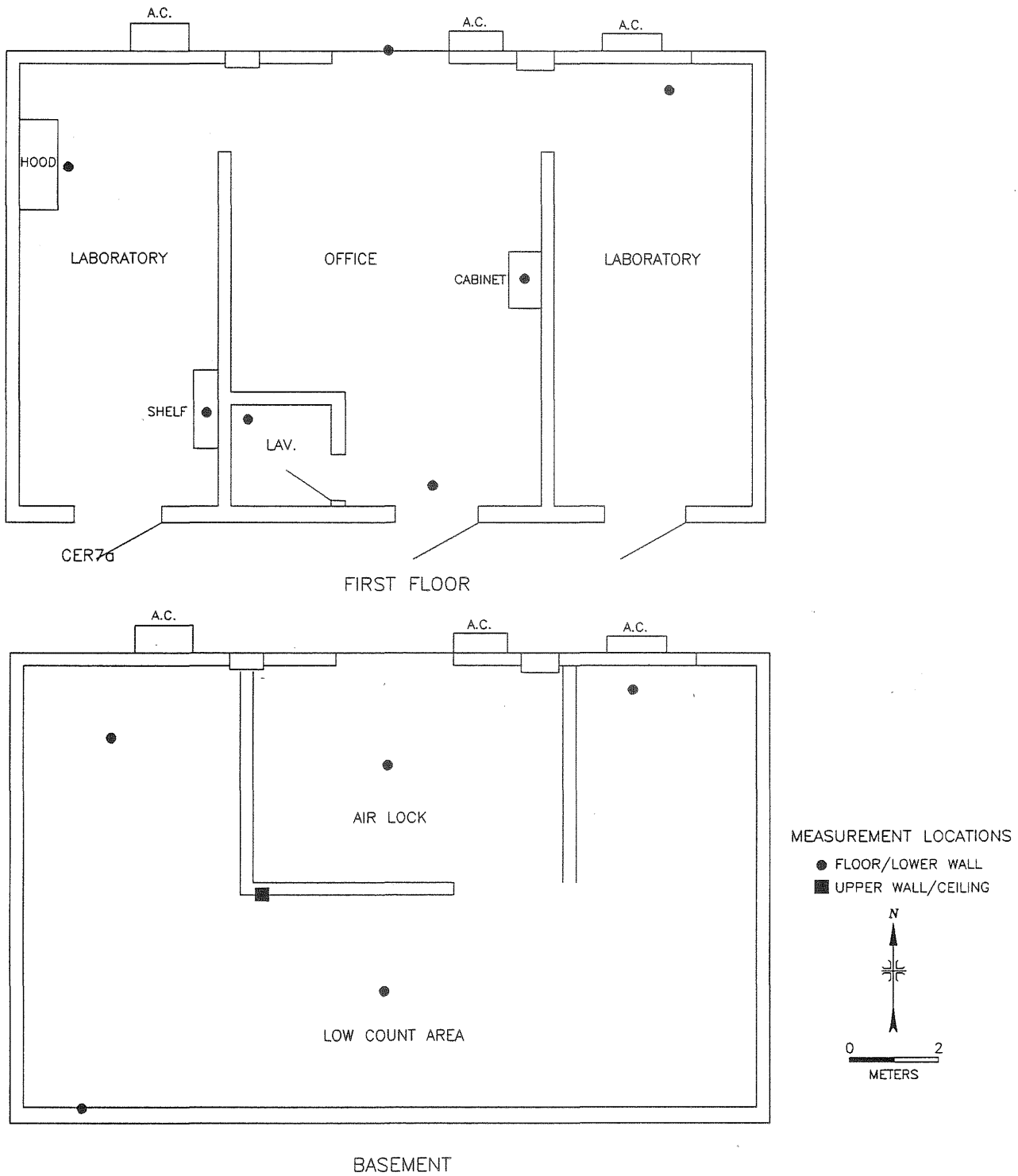

FIGURE 32: Marine Biology Laboratory Building, Indicating Locations of Surface Contamination Measurements

CER15

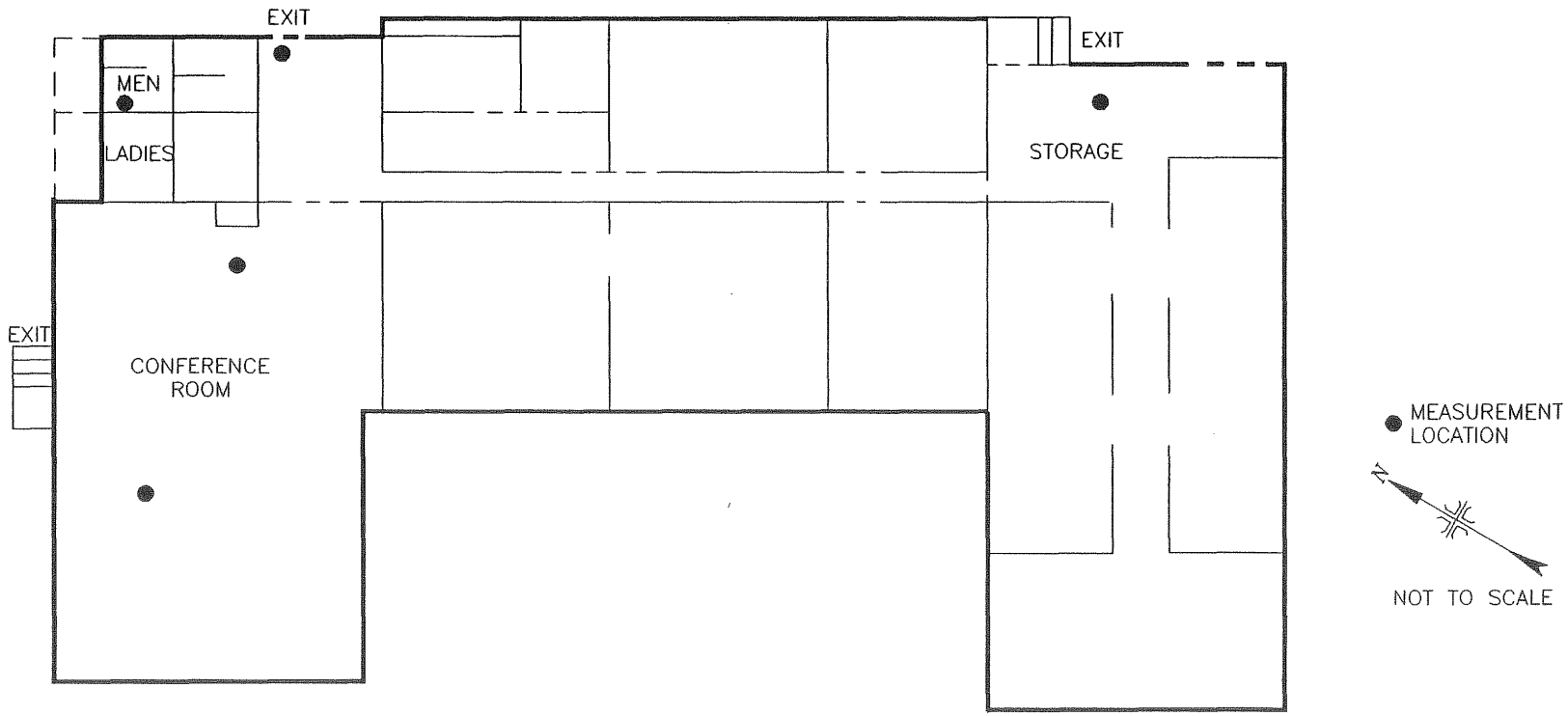

FIGURE 33: Administration Office Building, Indicating Locations of Surface Contamination Measurements

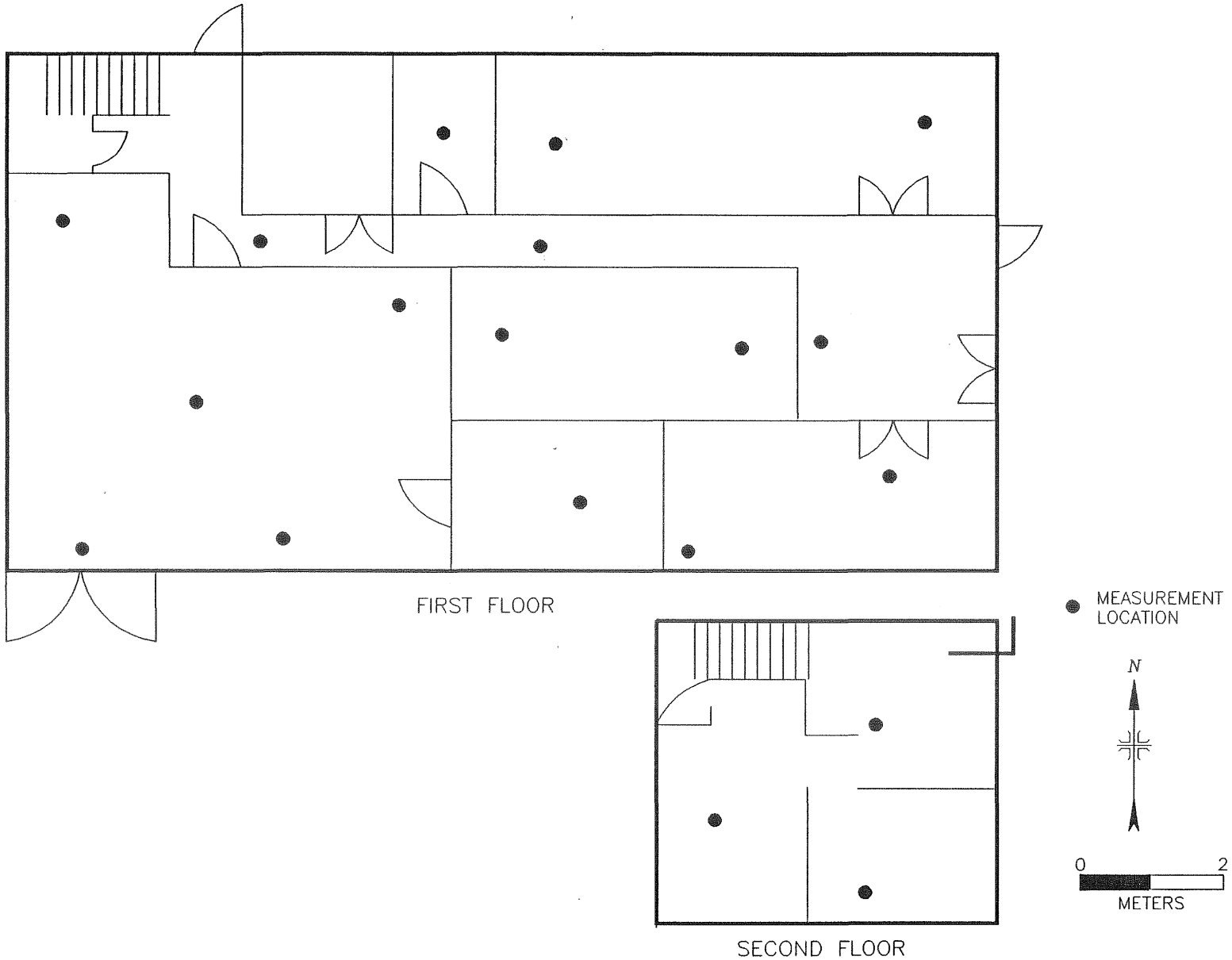

FIGURE 34: Shop Building, Indicating Locations of Surface Contamination Measurements

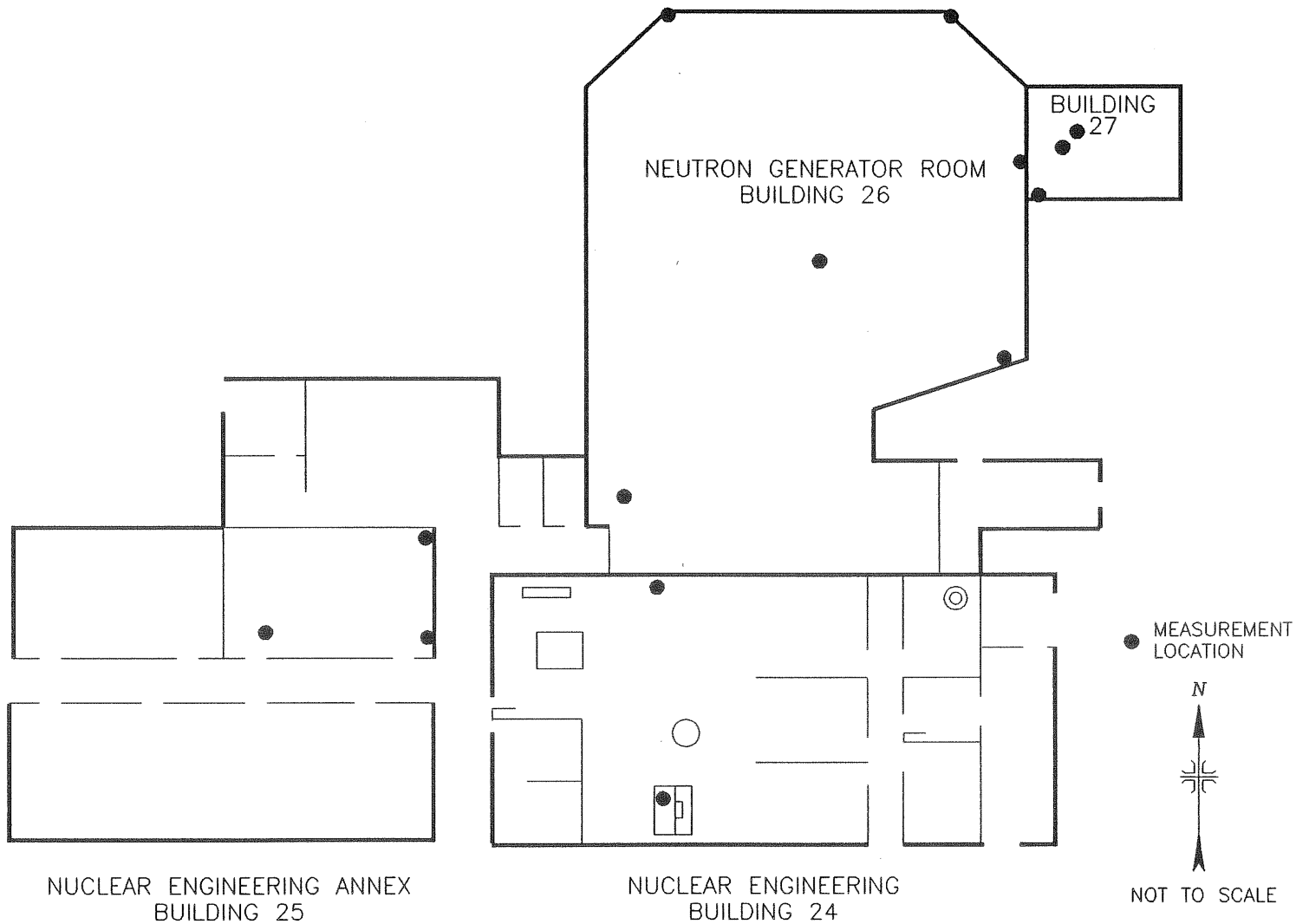

FIGURE 35: Buildings 24, 25, 26 and 27 of the Nuclear Engineering Complex, Indicating Locations of Surface Contamination Measurements

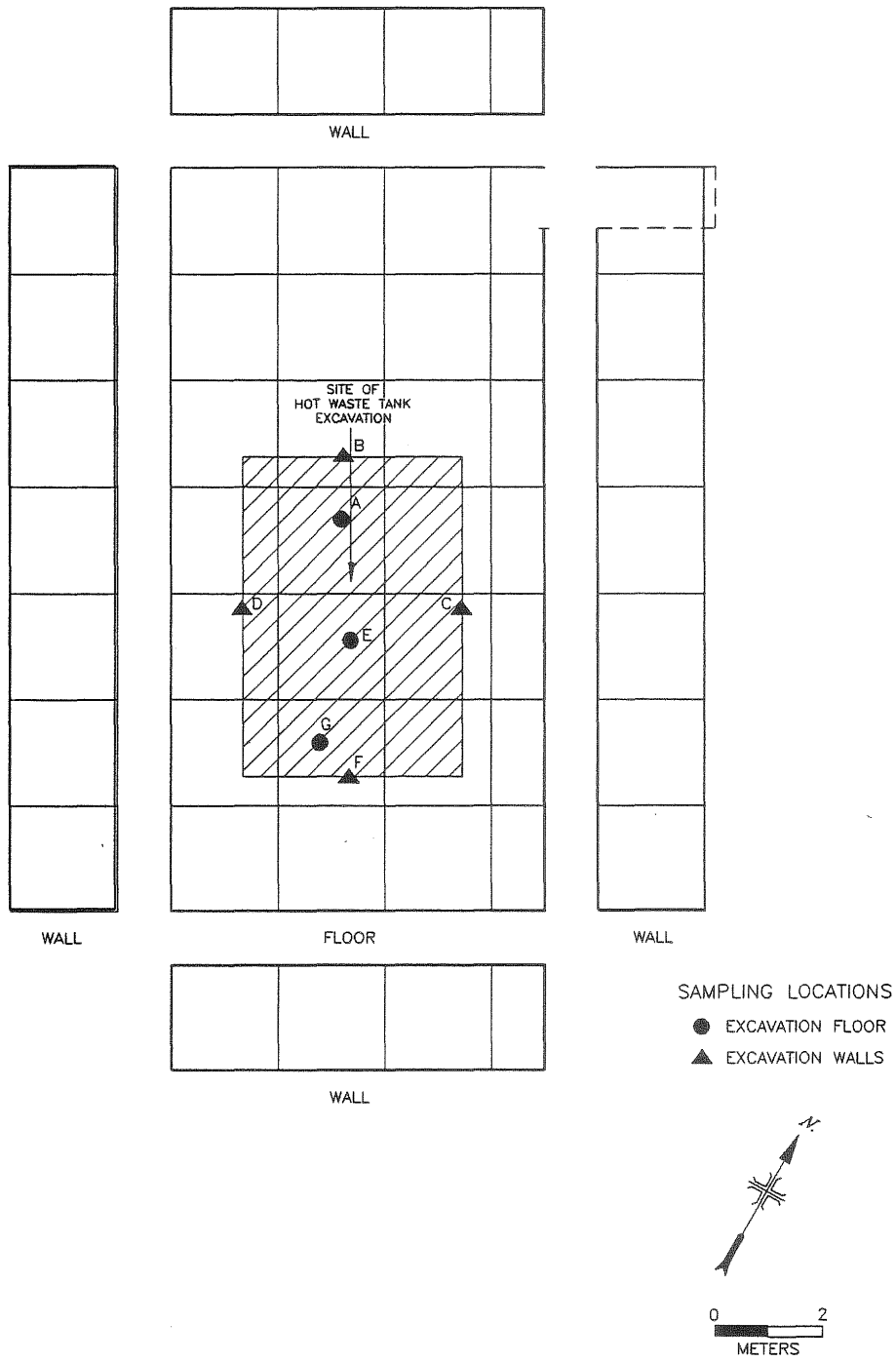

FIGURE 36: Reactor Pump Room, Indicating Locations of Soil Samples from the Former Sump Area

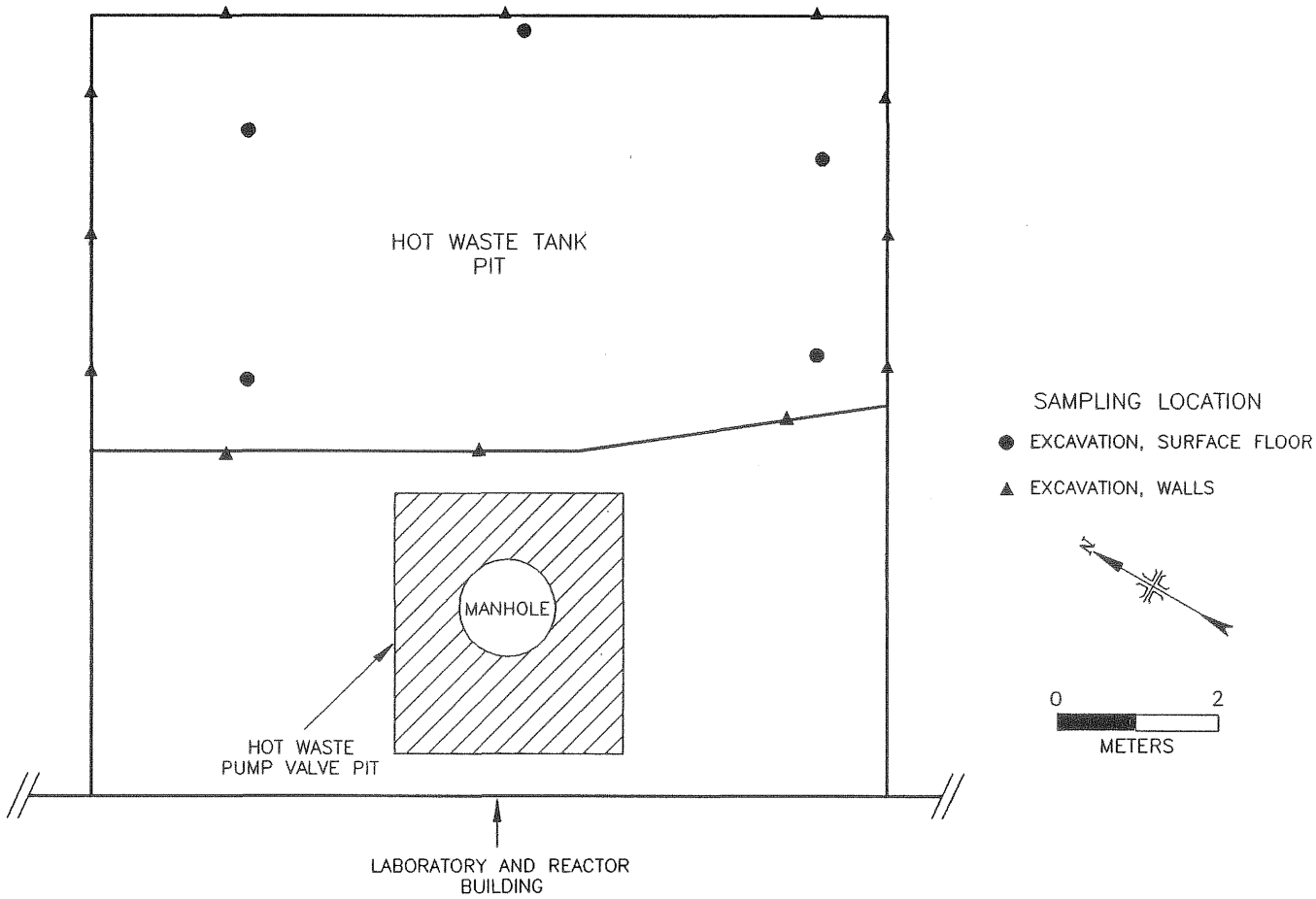

FIGURE 37: Soil Sampling Locations from the Hot Waste Tank Pit

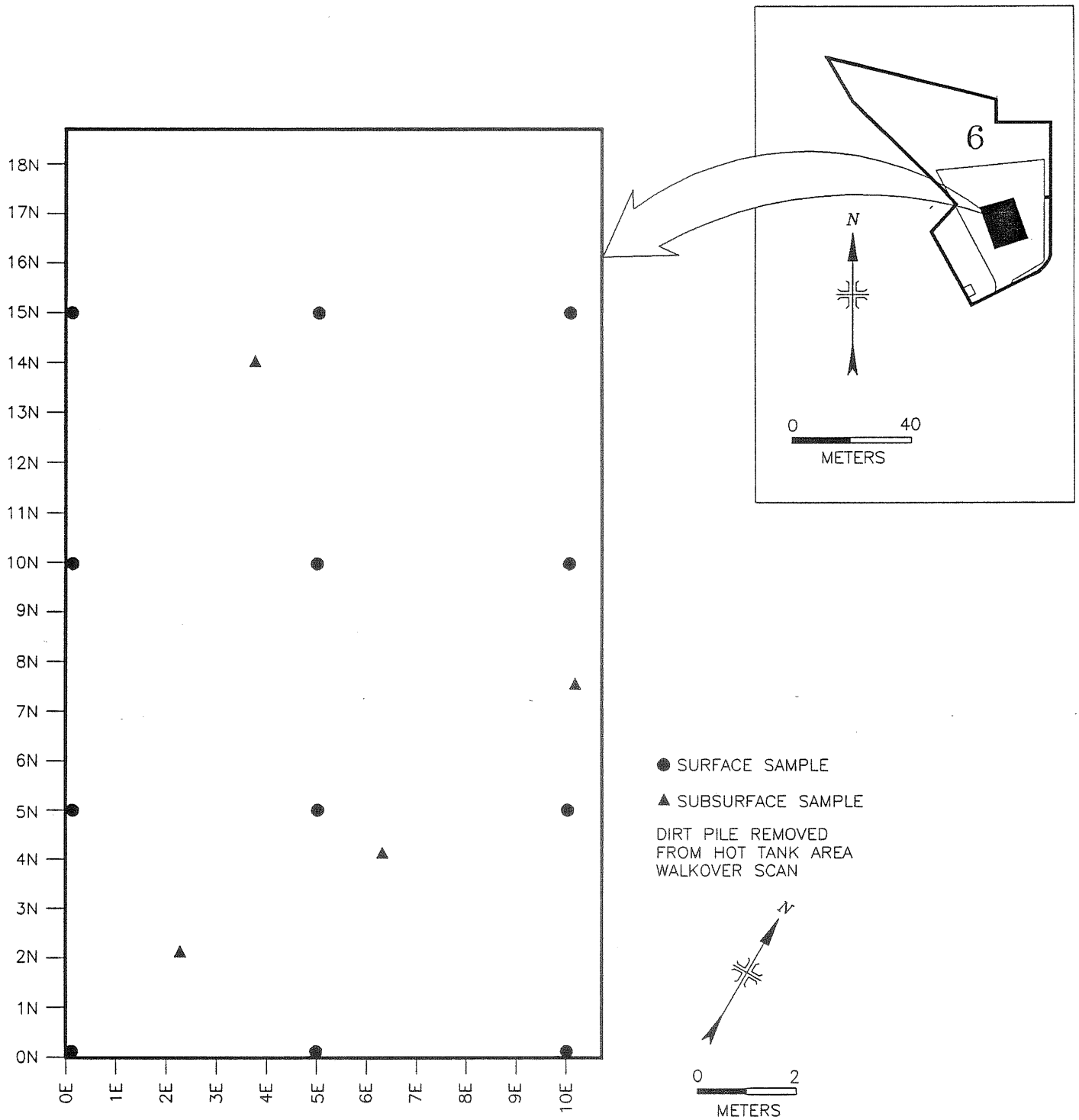

FIGURE 38: Soil Sampling Locations from the Hot Waste Tank Excavated Soil

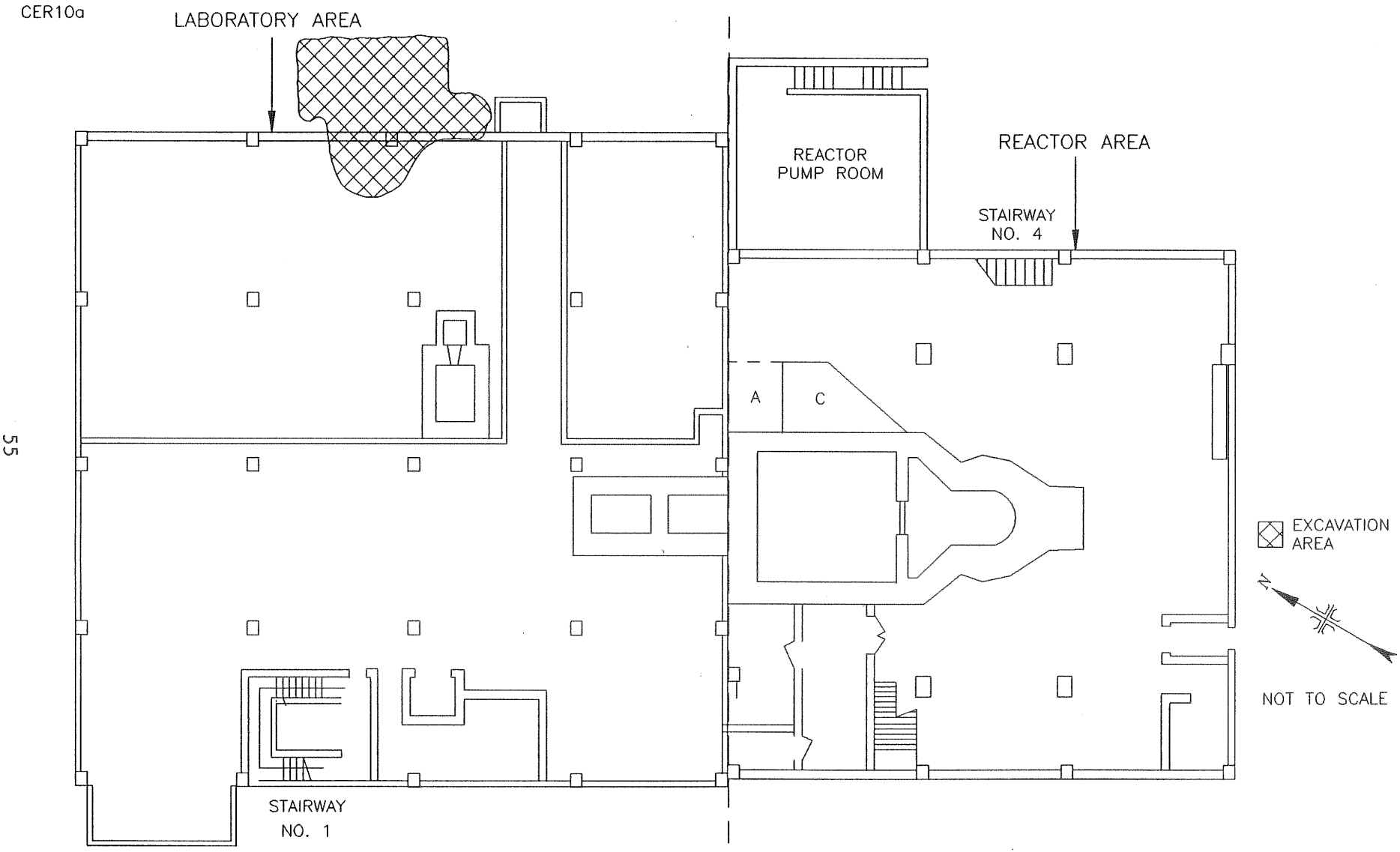

FIGURE 39: Soil Excavation Area Location Beneath the Laboratory and Reactor Building

CER19

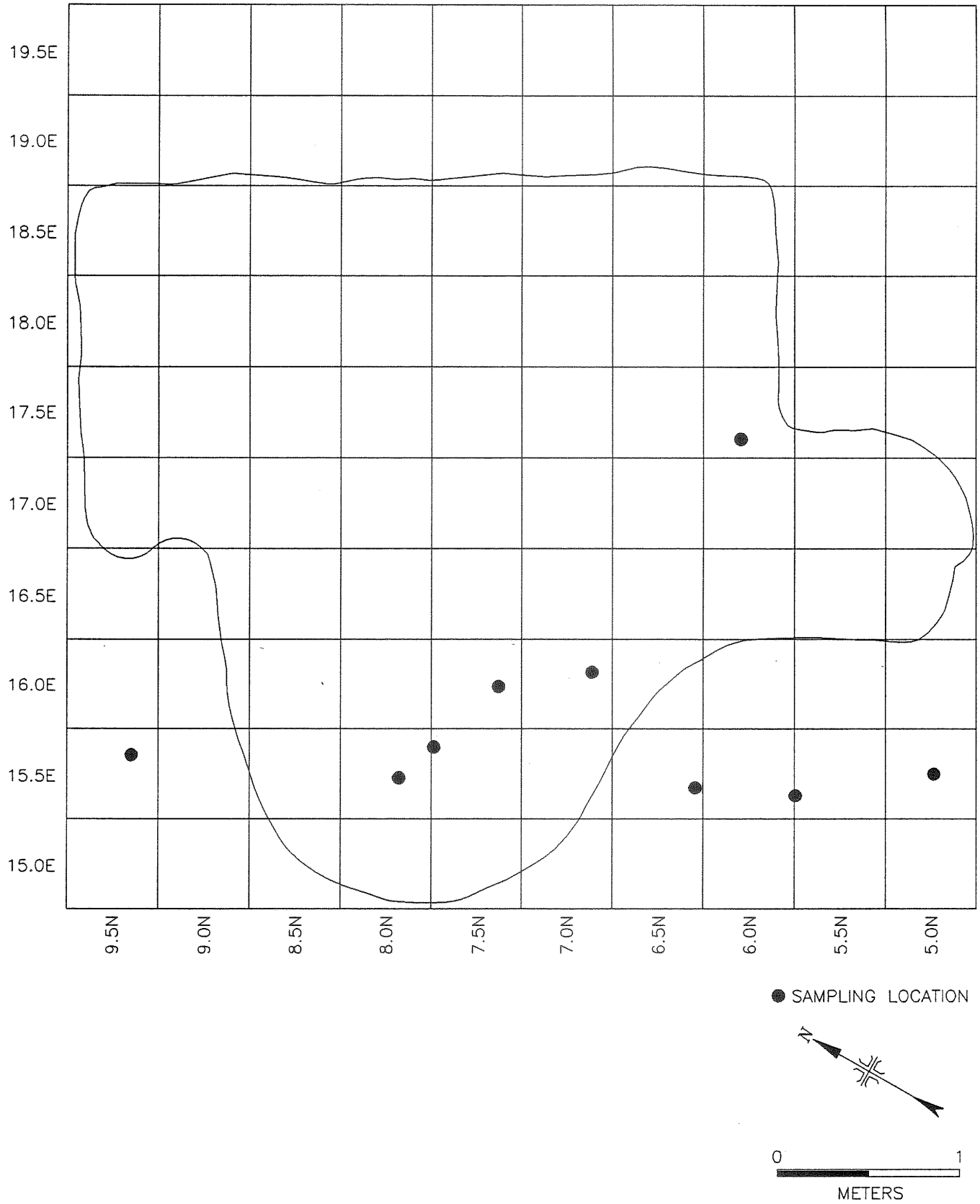

FIGURE 40: Laboratory Area Excavation Soil Sampling Locations

CER4a

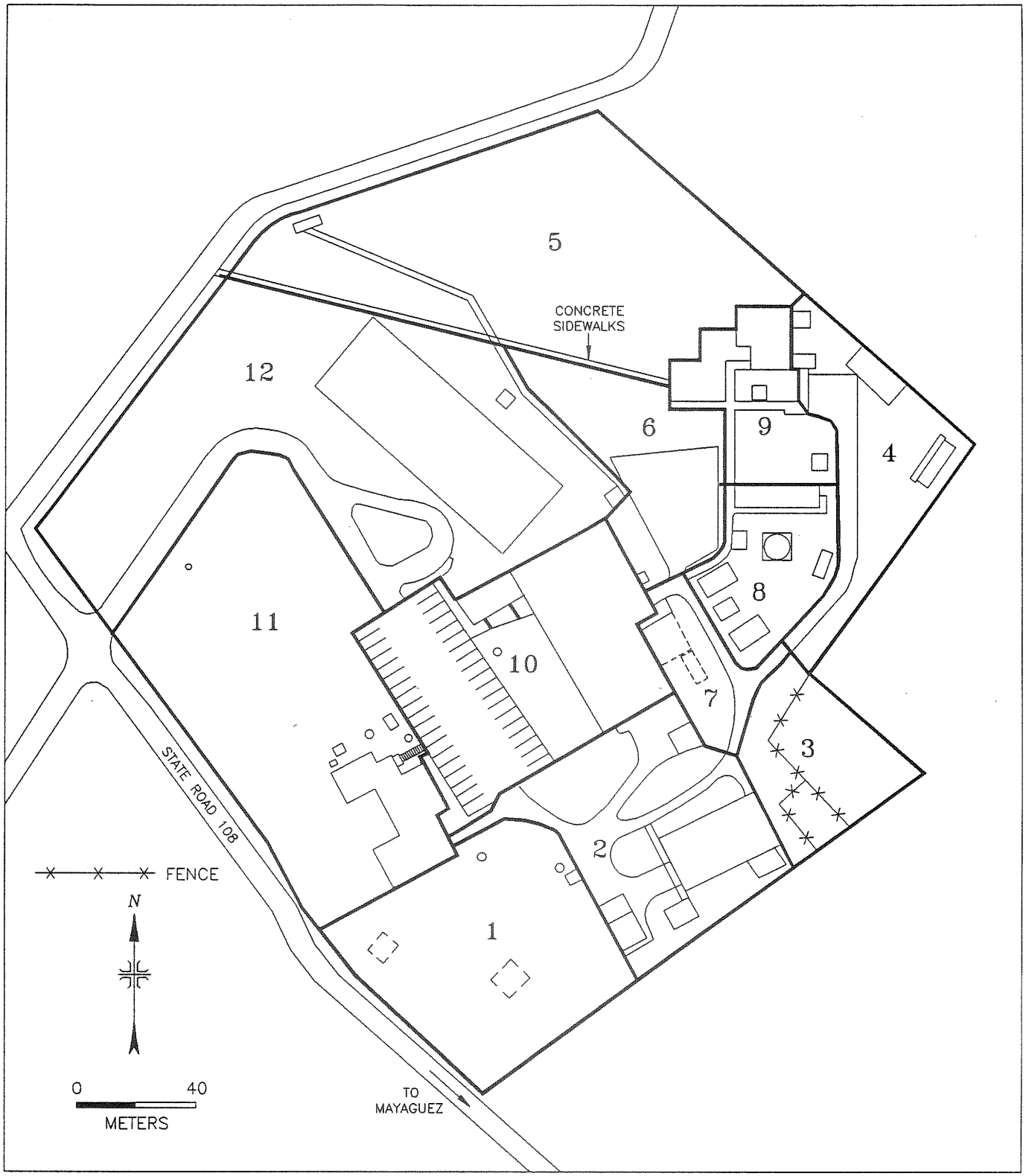

FIGURE 41: Center for Energy and Environment Research Site as Subdivided by BNI for Survey Reference

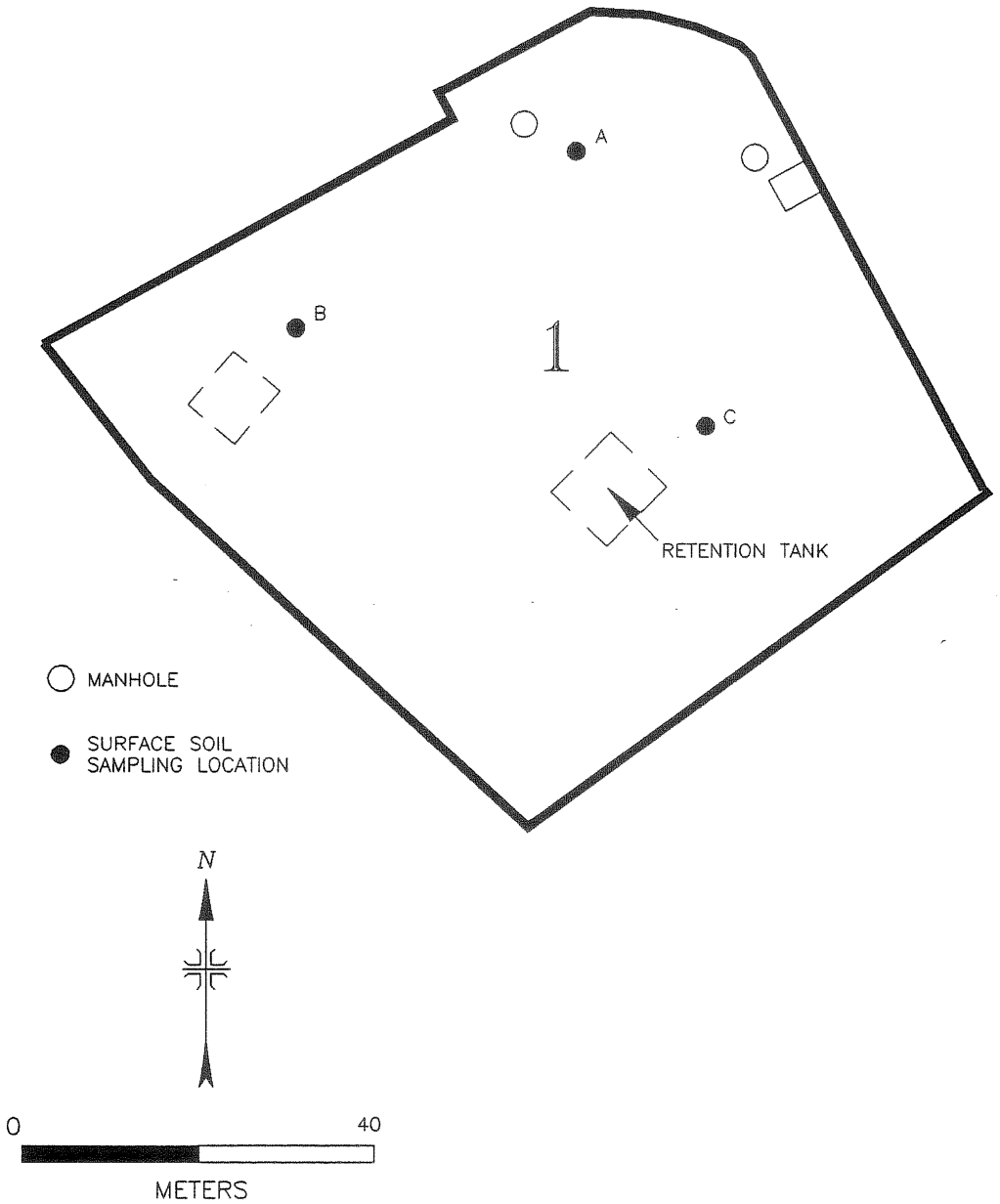

FIGURE 42: Locations of Surface Soil Sampling – Area 1

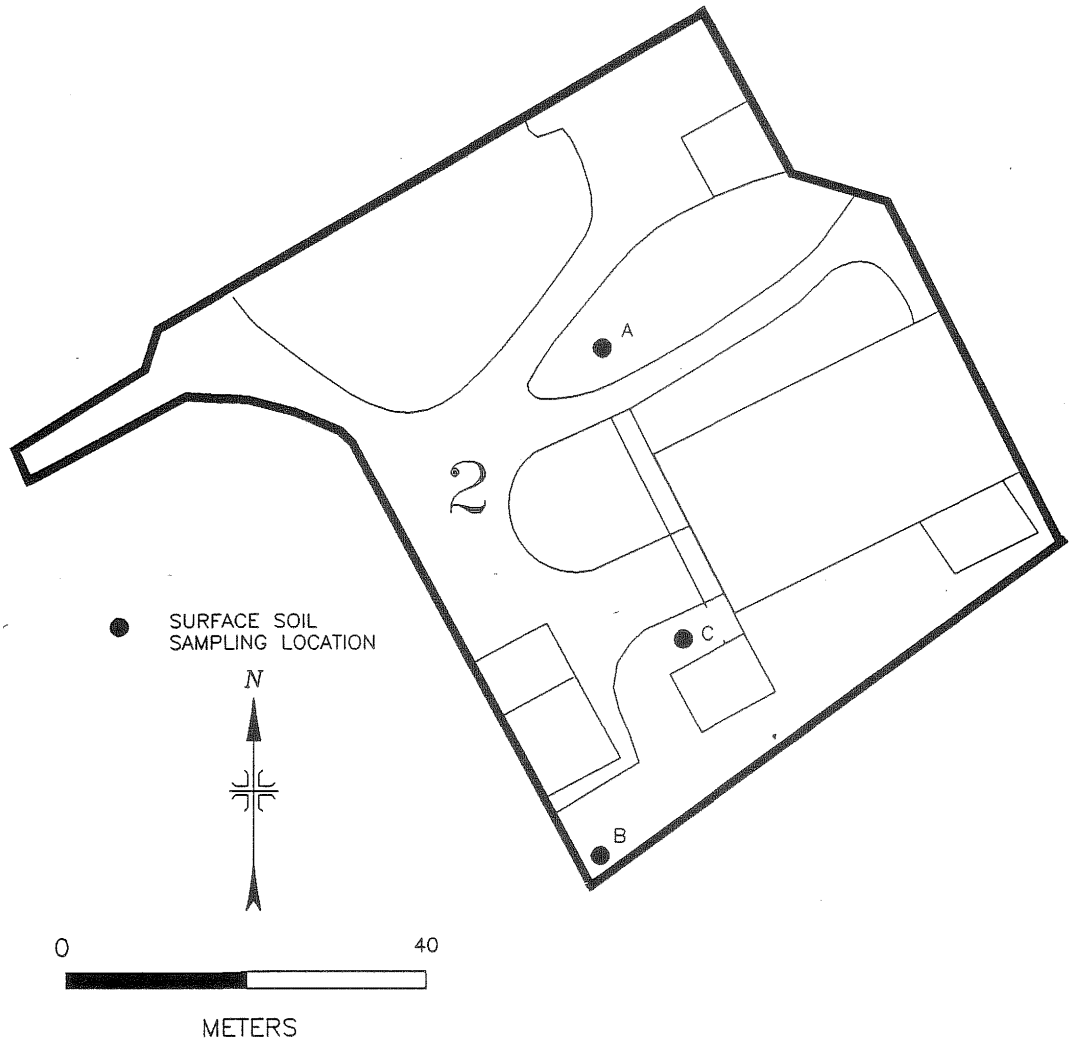

FIGURE 43: Locations of Surface Soil Sampling – Area 2

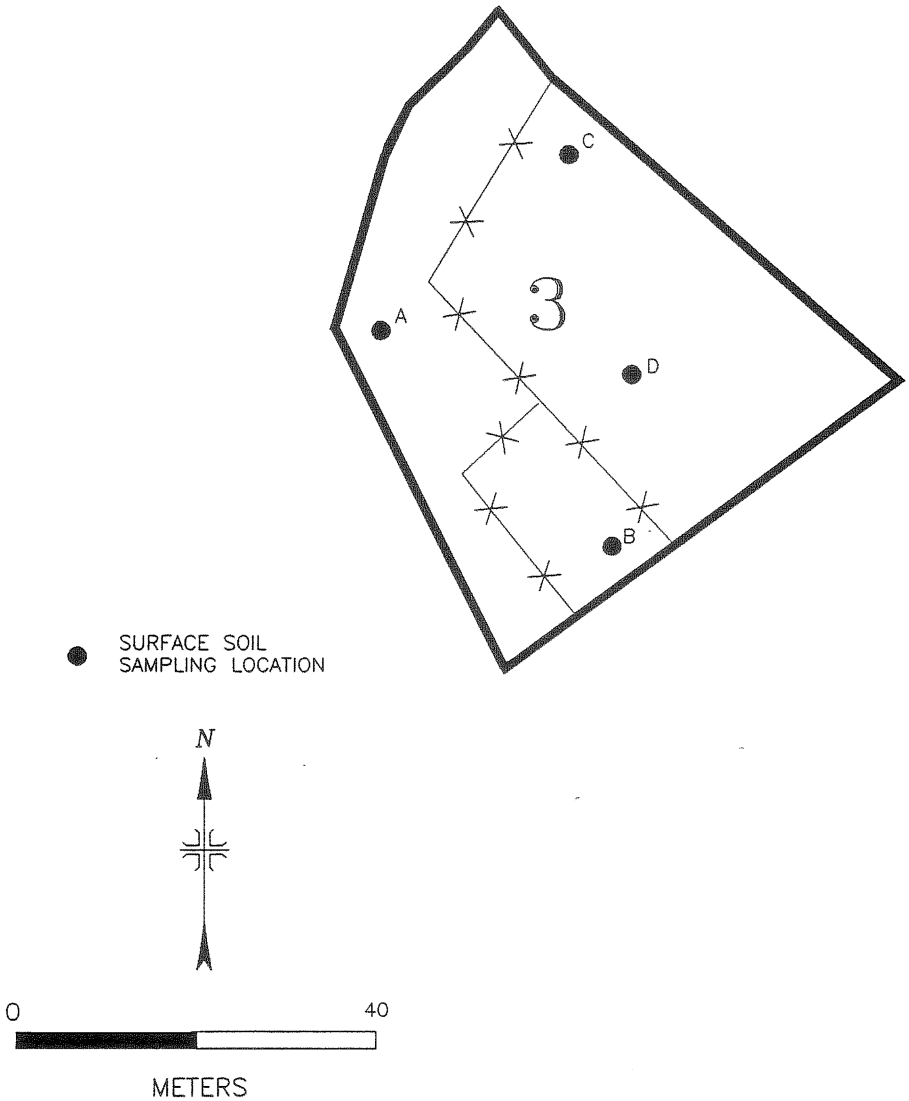

FIGURE 44: Locations of Surface Soil Sampling – Area 3

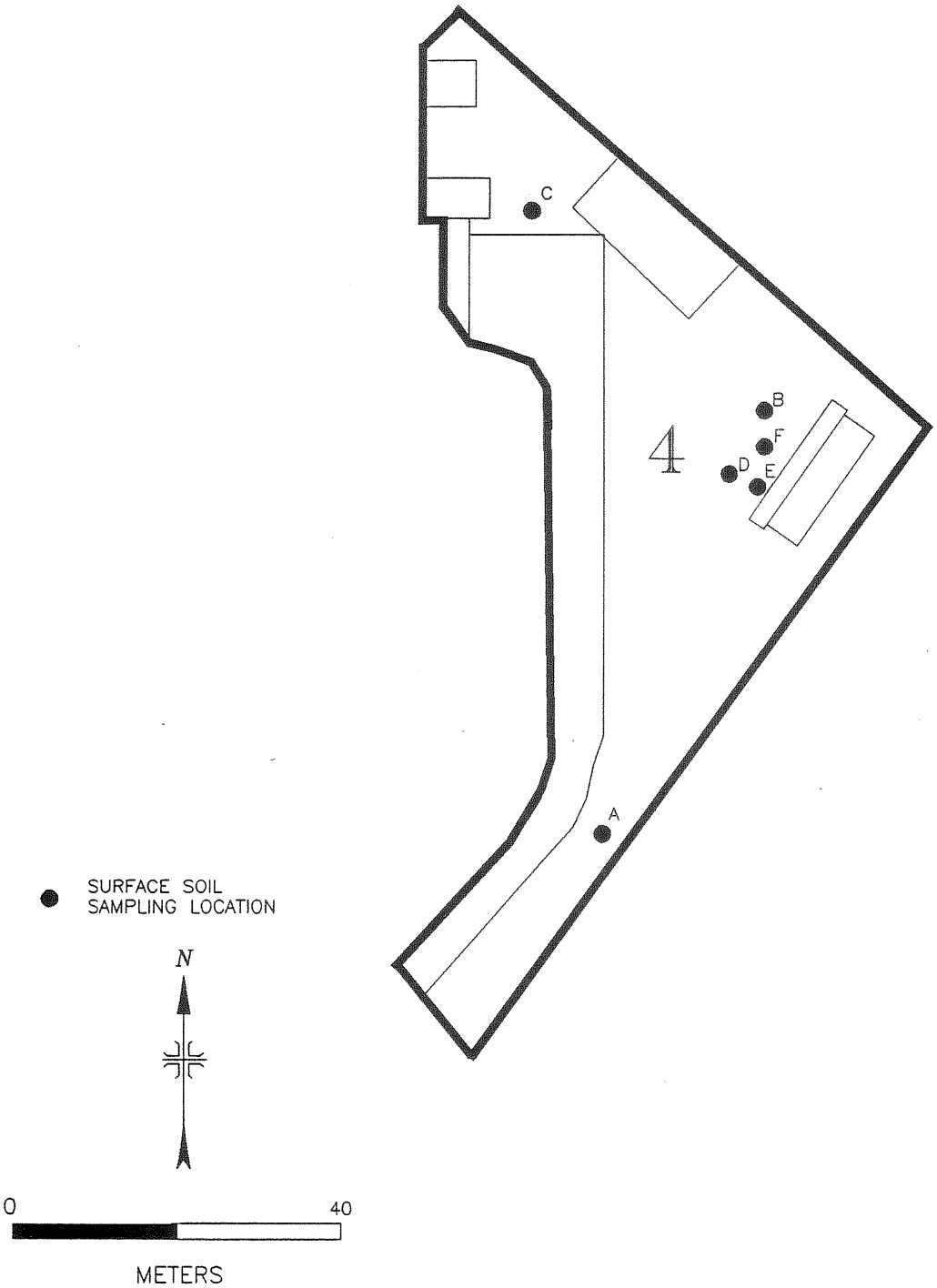

FIGURE 45: Locations of Surface Soil Sampling – Area 4

CER4f

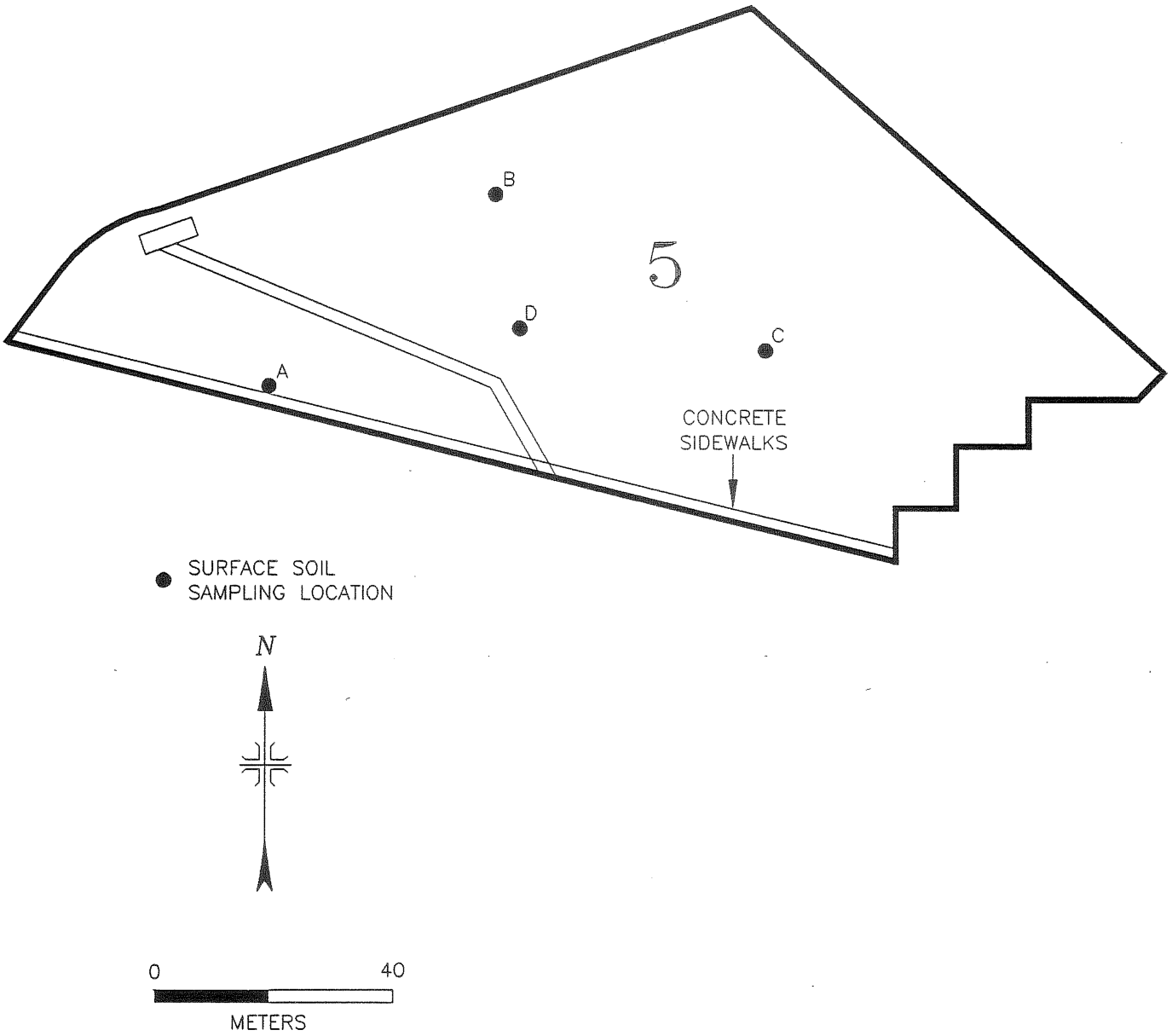

FIGURE 46: Locations of Surface Soil Sampling – Area 5

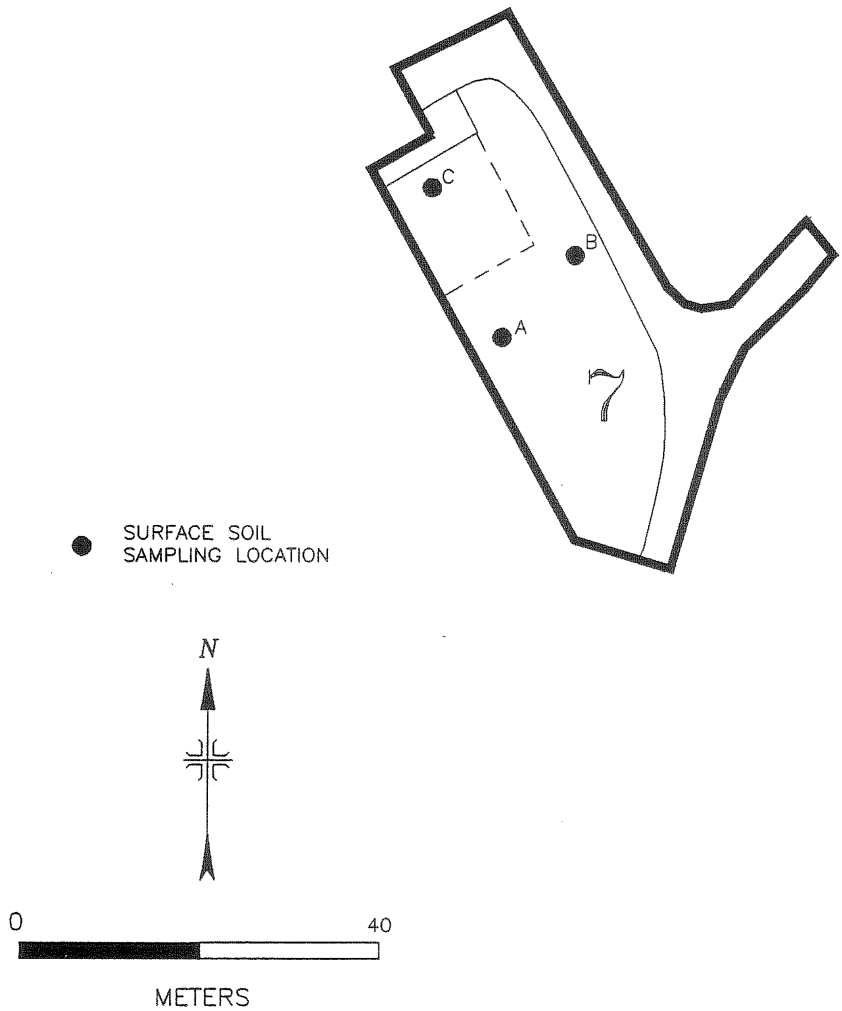

FIGURE 47: Locations of Surface Soil Sampling – Area 7

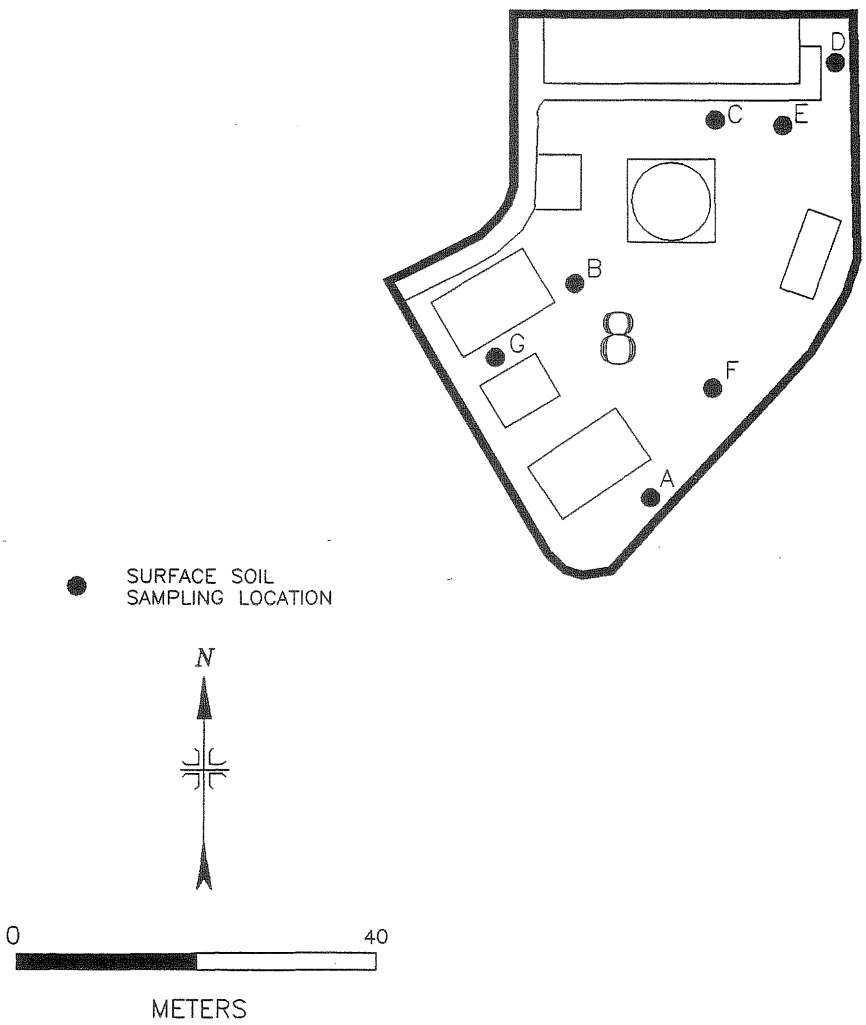

FIGURE 48: Locations of Surface Soil Sampling – Area 8

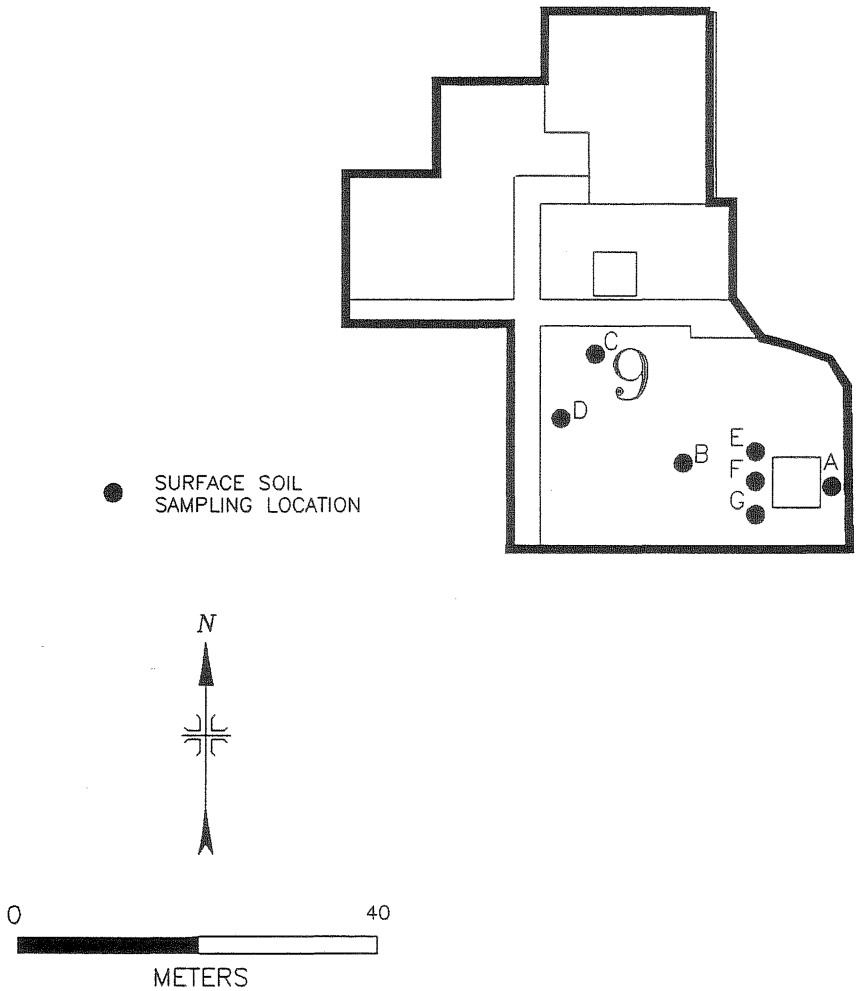

FIGURE 49: Locations of Surface Soil Sampling – Area 9

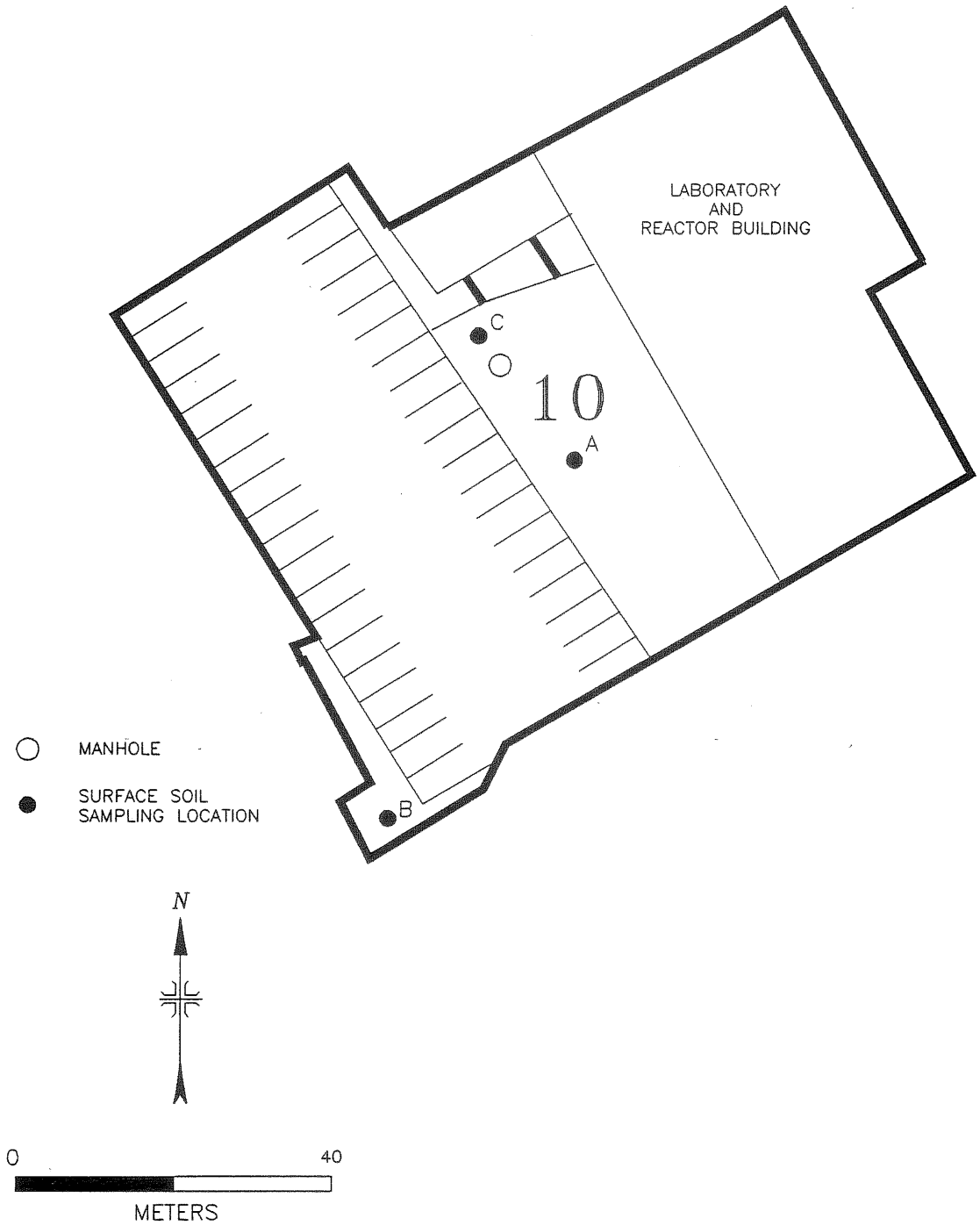

FIGURE 50: Locations of Surface Soil Sampling – Area 10

CER41

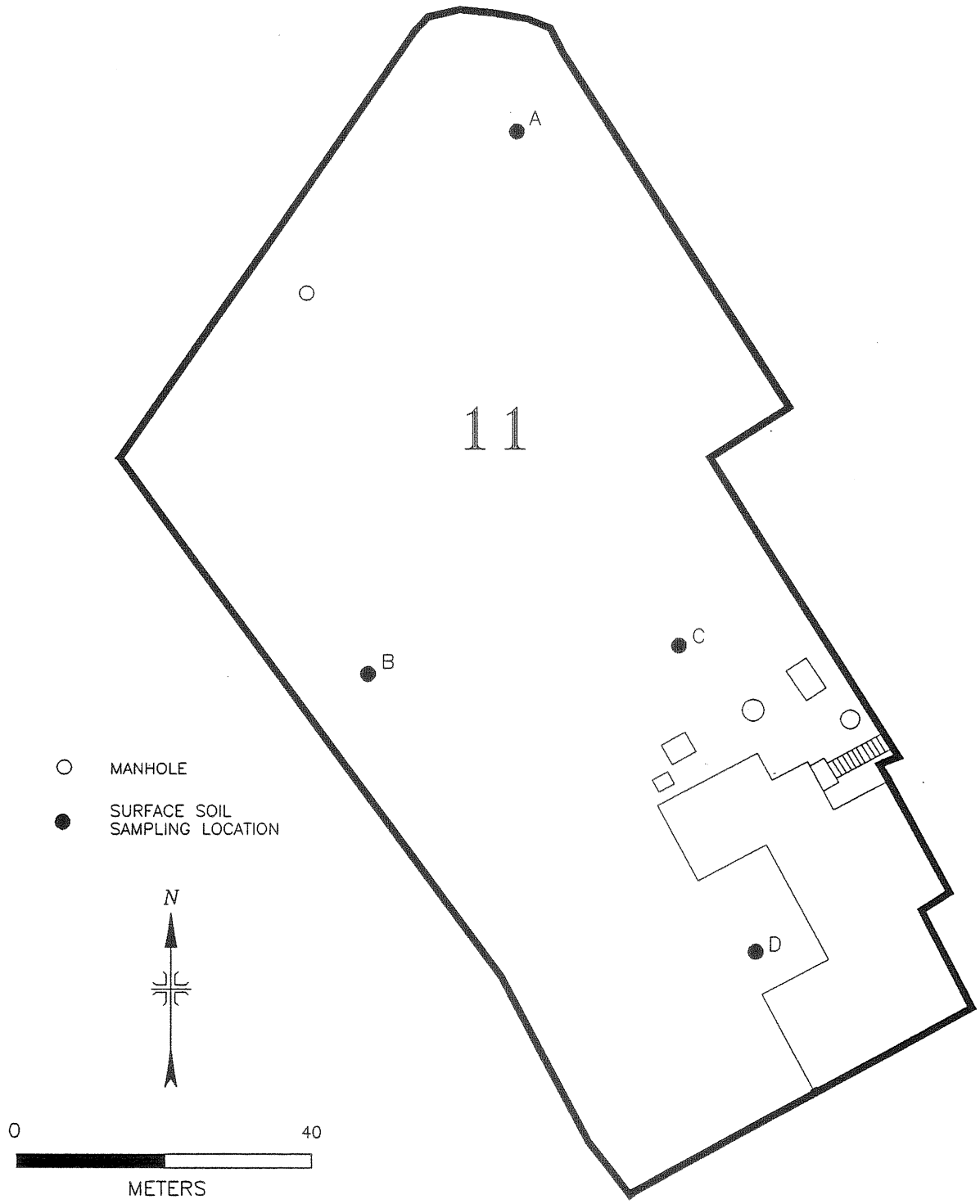

FIGURE 51: Locations of Surface Soil Sampling – Area 11

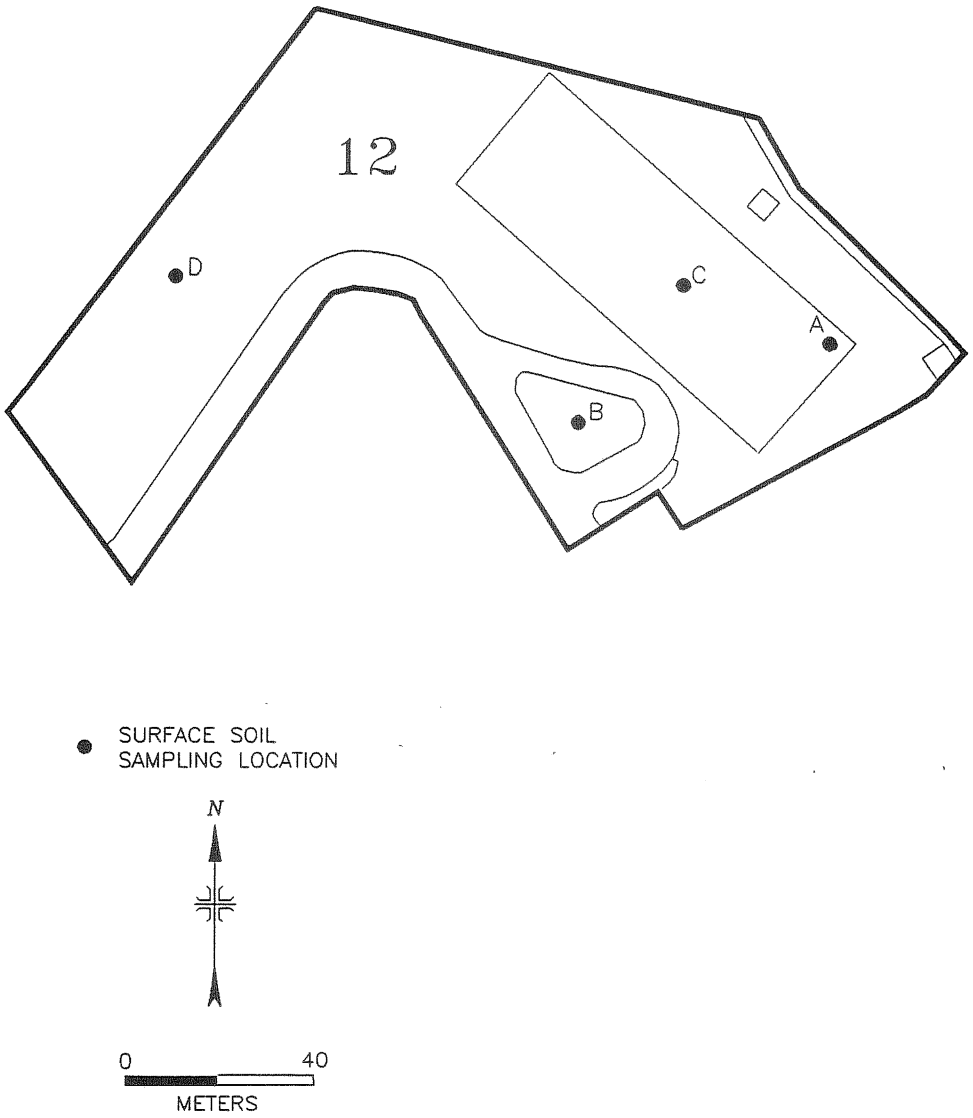

FIGURE 52: Locations of Surface Soil Sampling – Area 12

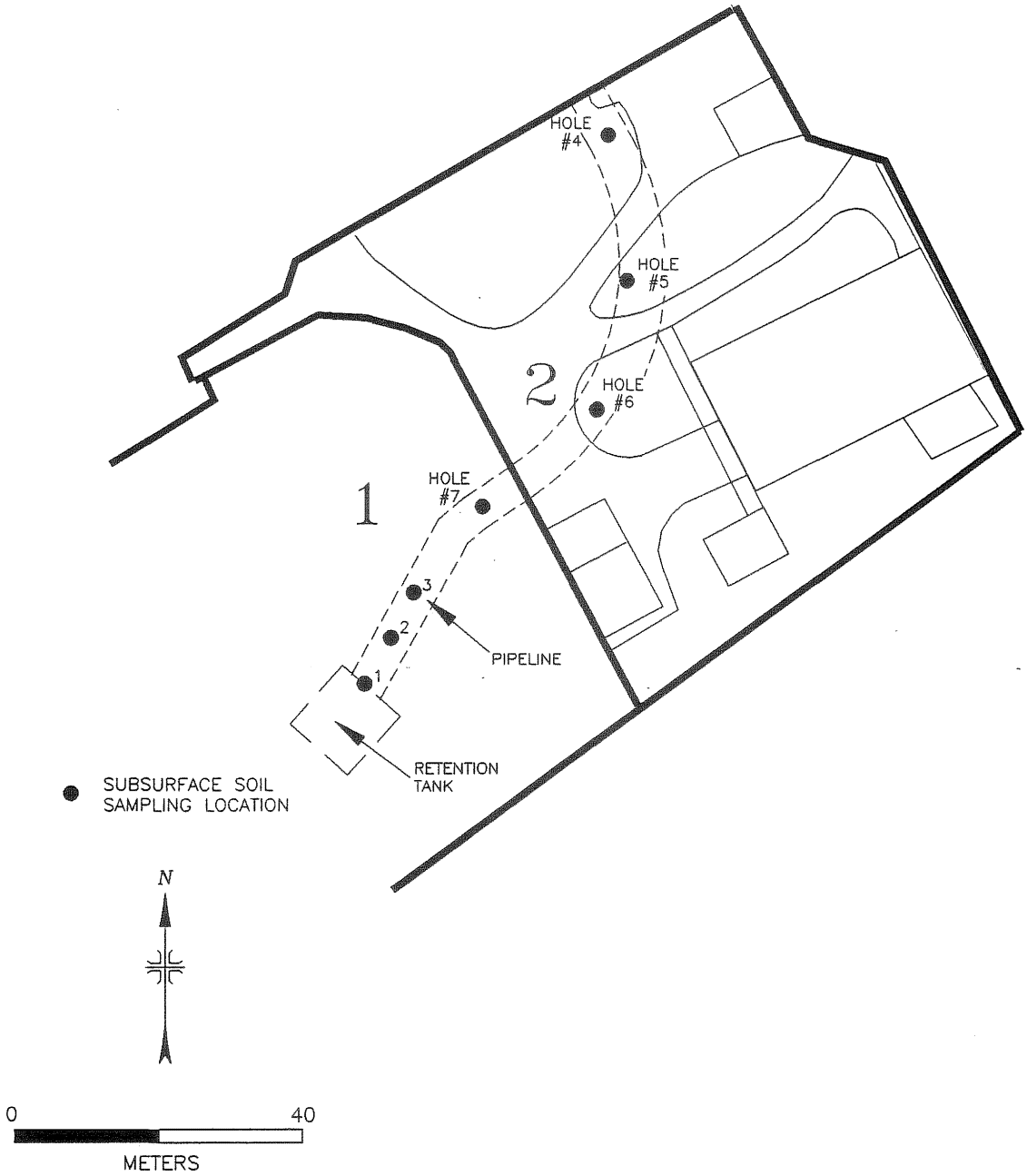

FIGURE 53: Subsurface Soil Sampling Locations in the Vicinity of the Retention Tank Pipeline – Areas 1 and 2

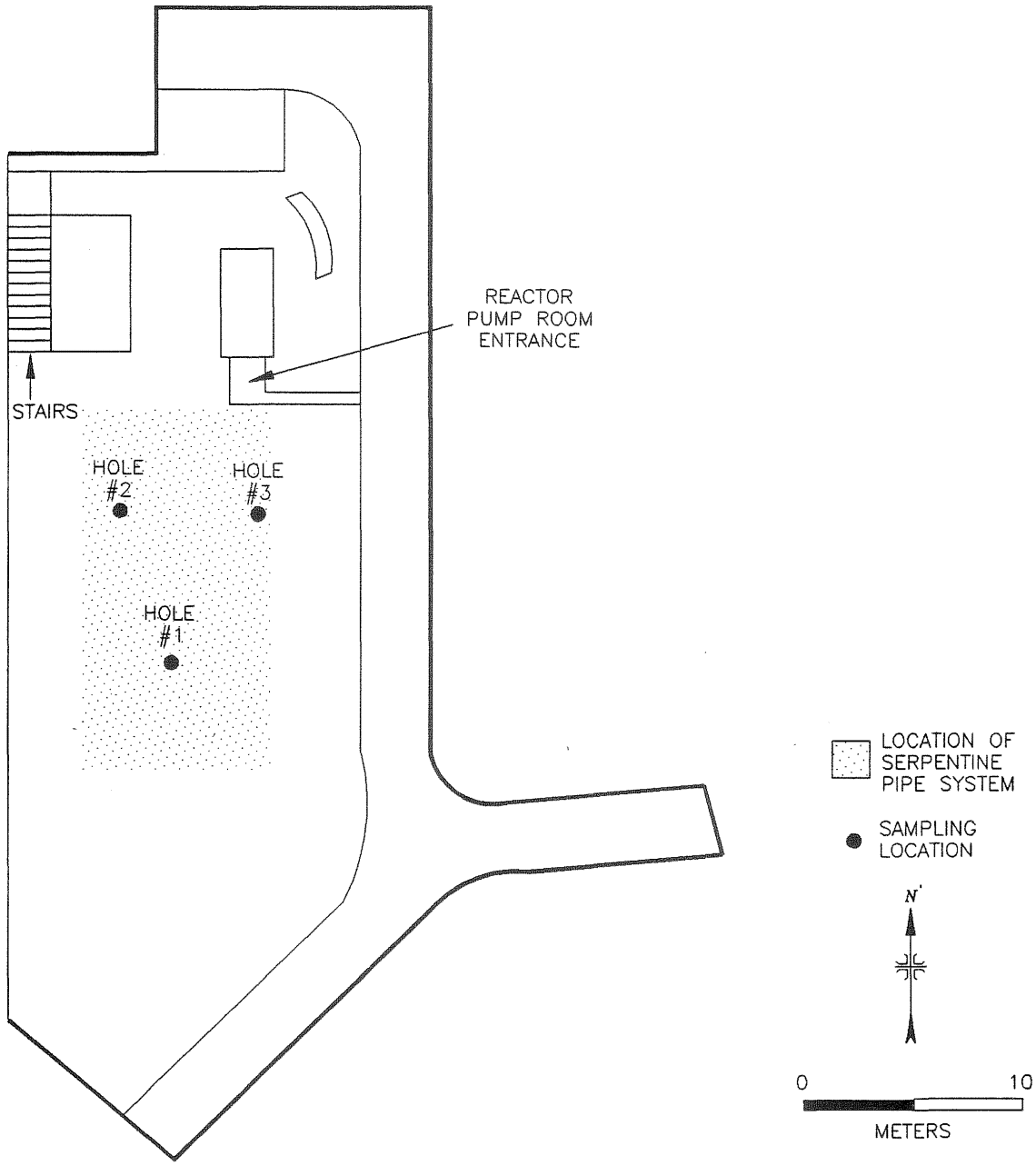

FIGURE 54: Subsurface Soil Sampling Locations in the Vicinity of the Serpentine Pipe System – Area 7

CER1

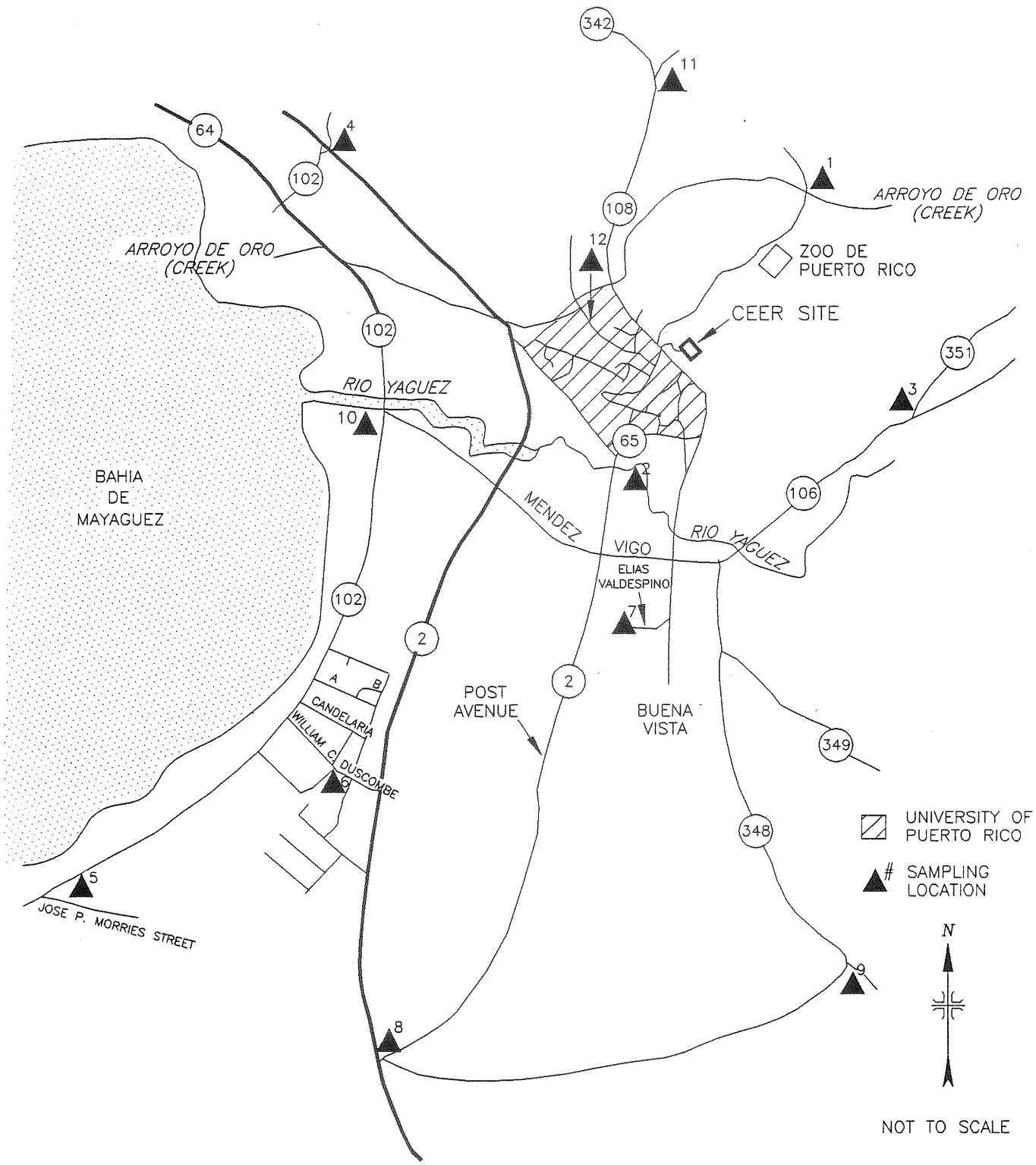

FIGURE 55: Locations of Background Measurements and Baseline Soil Samples from the Vicinity of CEER

TABLE 1

BACKGROUND RADIATION LEVELS
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Location[a]	Gamma Exposure Rates At 1 m Above the Surface (μR/h)	Gamma Exposure Rates At the Surface (μR/h)
1	2	3
2	3	3
3	3	4
4	2	3
5	2	2
6	2	2
7	2	2
8	2	2
9	2	2
10	2	2
11	2	2
12	2	2
Range	2 - 3	2 - 4
Average	2.2	2.4

[a]Refer to Figure 55.

TABLE 2

BASELINE RADIONUCLIDE CONCENTRATIONS IN SOIL
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Location[a]	Radionuclide Concentrations (pCi/g)						
	Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
1	<0.1	<0.1	<0.1	<0.1	<0.1	2.2 ± 0.9[b]	0.5 ± 0.2
2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.7	<0.2
3	<0.1	0.4 ± 0.1	<0.1	<0.1	<0.1	<0.9	<0.2
4	<0.1	0.2 ± 0.1	<0.1	<0.1	<0.1	0.7 ± 1.1	<0.2
5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.5	0.4 ± 0.2
6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.6	<0.1
7	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1	0.8 ± 1.0	<0.1
8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.5	<0.2
9	<0.1	<0.1	<0.1	<0.1	<0.1	<0.7	<0.2
10	<0.1	<0.1	<0.1	<0.1	<0.1	0.5 ± 1.1	0.4 ± 0.4
11	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1	<0.5	<0.1
12	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1	0.3 ± 0.6	<0.1

[a]Refer to Figure 55.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 3

RESULTS OF CONFIRMATORY ANALYSIS ON SOIL SAMPLES
COLLECTED BENEATH THE LABORATORY AND REACTOR BUILDING
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Sample #	Location[a] (meters)	Analysis by	Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
HS2703	7N, 15.5E	ORAU	<0.1	10.0 ± 0.4[b]	<0.1	<0.2	<0.1	<0.6	<0.1
		BNI	<0.2	11.3 ± 0.8	<0.2	<1.0	--[c]	<3.0	<0.5
HS2704	8N, 15E	ORAU	<0.1	1.1 ± 0.1	<0.1	<0.1	<0.1	<0.4	0.2 ± 0.2
		BNI	<0.3	0.6 ± 0.2	<0.3	<0.9	--	<2.1	<0.7
HS2705	9N, 16E	ORAU	<0.1	0.5 ± 0.1	<0.1	<0.1	<0.1	<0.4	<0.1
		BNI	<0.2	0.4 ± 0.2	<0.2	<0.7	--	<2.1	0.4 ± 0.3
HS2706	8N, 16E	ORAU	<0.1	3.2 ± 0.3	<0.1	<0.2	<0.1	<0.6	0.3 ± 0.3
		BNI	<0.3	3.2 ± 0.5	<0.4	<1.0	--	<3.0	0.8 ± 0.6
HS2707	7.5 N, 16.5E	ORAU	<0.1	3.0 ± 0.3	0.1 ± 0.1	<0.2	<0.1	<0.6	0.5 ± 0.2
		BNI	<0.2	2.8 ± 0.5	<0.3	<1.4	--	<3.7	<0.5
HS2708	6.5N, 16E	ORAU	<0.1	1.8 ± 0.2	<0.1	<0.2	<0.1	<0.4	0.3 ± 0.1
		BNI	<0.1	1.5 ± 0.3	<0.2	<0.7	--	<2.7	<0.5
HS2709	6N, 16E	ORAU	<0.1	4.1 ± 0.3	<0.1	<0.2	<0.1	<0.5	<0.1
		BNI	<0.2	4.1 ± 0.5	<0.4	<0.8	--	<2.2	<0.4
HS2710	5N, 16E	ORAU	<0.1	3.6 ± 0.2	<0.1	<0.1	<0.1	<0.5	<0.2
		BNI	<0.2	3.1 ± 0.5	<0.4	<1.1	--	<3.2	<0.5
HS2713	6N, 17E	ORAU	0.1 ± 0.1	5.0 ± 0.3	<0.1	<0.1	<0.1	<0.8	0.3 ± 0.2
		BNI	<0.4	3.8 ± 0.6	<0.3	<1.2	--	<3.6	<0.9
Composite A	HS2703-21	ORAU	<0.1	2.9 ± 0.2	<0.1	<0.2	<0.1	<0.6	<0.2
		BNI	0.03 ± 0.01	2.5 ± 0.1	--	<0.1	--	--	--

[a]Refer to Figure 40.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.
[c]Analysis not performed.

TABLE 4

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS IN
REMEDIATED AREAS OF THE LABORATORY PORTION OF THE LABORATORY AND REACTOR BUILDING
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Block Average	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
117	Floor/Lower Wall[b]	3	1120	<420 - 5600	<4 - 7
	Upper Wall/Ceiling[c]	2	N/A[d]	<420	7 - 8
121	Floor/Lower Wall[c]	6	N/A	<420 - 700	<4 - 10
	Upper Wall/Ceiling[c]	1	N/A	<420	<4
121A	Floor/Lower Wall[b]	2	<420	<420	<4
	Upper Wall/Ceiling[c]	1	N/A	<420	7
123	Floor/Lower Wall[b]	4	512	<420 - 830	<4 - 7
	Upper Wall/Ceiling[c]	1	N/A	<420	<4
203/205[e]	Floor/Lower Wall[b/c]	5	<420	<420	<4 - 4
	Upper Wall/Ceiling[c]	1	N/A	<420	<4
217	Floor/Lower Wall[b/c]	4	<420	<420 - 650	<4 - 8
	Upper Wall/Ceiling[c]	1	N/A	<420	<4
219	Floor/Lower Wall[b/c]	6	<420	<420 - 1700	<4 - 9
	Upper Wall/Ceiling[c]	2	N/A	<420	<4 - 7
224	Floor/Lower Wall[b]	5	<420	<420 - 500	<4 - 6
	Upper Wall/Ceiling[c]	1	N/A	<420	<4

TABLE 4 (Continued)

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS IN
REMEDIATED AREAS OF THE LABORATORY PORTION OF THE LABORATORY AND REACTOR BUILDING
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Block Average	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
Upper South Hot Cell	Floor/Lower Wall[c]	7	N/A	<420 - 510	<4
	Upper Wall/Ceiling[c]	1	N/A	<420	6
Lower South Hot Cell	Floor/Lower Wall[c]	7	N/A	<420 - 1100	<4 - 9
	Upper Wall/Ceiling[c]	1	N/A	<420	<4
Lower North Hot Cell	Floor/Lower Wall[c]	6	N/A	<420 - 1000	<4 - 6
	Upper Wall/Ceiling[c]	1	N/A	<420	<4
Upper North Hot Cell	Floor/Lower Wall[c]	7	N/A	<420 - 570	<4
	Upper Wall/Ceiling[c]	1	N/A	2500	<4

[a]Refer to Figures 6 - 18.
[b]Five point measurement.
[c]Single point measurement.
[d]N/A=Not applicable.
[e]Rooms were gridded together.

TABLE 5

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS
IN NON-REMEDIATED AREAS OF THE LABORATORY PORTION OF THE LABORATORY AND REACTOR BUILDING
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Block Average	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
100	Floor/Lower Wall[b]	2	N/A[c]	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4 - 6
101	Floor/Lower Wall[b]	1	N/A	<420	<4
	Upper Wall/Ceiling[b]	-	-	-	-
102	Floor/Lower Wall[b]	2	N/A	<420	<4 - 8
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
103	Floor/Lower Wall[b]	2	N/A	<420	<4 - 8
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
104	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
108	Floor/Lower Wall[b]	4	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
109	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
110	Floor/Lower Wall[b]	1	N/A	<420	<4
	Upper Wall/Ceiling	-	-	-	

TABLE 5 (Continued)

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS
IN NON-REMEDIATED AREAS OF THE LABORATORY PORTION OF THE LABORATORY AND REACTOR BUILDING
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Block Average	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
112	Floor/Lower Wall[b]	1	N/A	<420	<4
	Upper Wall/Ceiling	-	-	-	-
114	Floor/Lower Wall[b]	1	N/A	<420	<4 - 6
	Upper Wall/Ceiling	-	-	-	<4
116	Floor/Lower Wall[b]	1	N/A	<420	<4
	Upper Wall/Ceiling	-	-	-	-
118	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
120	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
122	Floor/Lower Wall[b]	3	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
200	Floor/Lower Wall[d]	2	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	1700	<4
201	Floor/Lower Wall[d]	1	N/A	<420	10
	Upper Wall/Ceiling[d]	1	N/A	<420	8

TABLE 5 (Continued)

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS
IN NON-REMEDIATED AREAS OF THE LABORATORY PORTION OF THE LABORATORY AND REACTOR BUILDING
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Block Average	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
202	Floor/Lower Wall[b]	2	N/A	<420	<4 - 7
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
204	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
206	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
208	Floor/Lower Wall[b]	1	N/A	<420	<4
	Upper Wall/Ceiling	-	-	-	-
209	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling	-	-	-	-
210	Floor/Lower Wall[b]	3	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
212	Floor/Lower Wall[b]	4	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
214	Floor/Lower Wall[b]	2	N/A	<420	<4 - 6
	Upper Wall/Ceiling	-	-	-	-

TABLE 5 (Continued)

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS
IN NON-REMEDIATED AREAS OF THE LABORATORY PORTION OF THE LABORATORY AND REACTOR BUILDING
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Block Average	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
216	Floor/Lower Wall[b]	1	N/A	700	<4
	Upper Wall/Ceiling	-	-	-	-
221	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling	-	-	-	-
222	Floor/Lower Wall[b]	3	N/A	<420	<4 - 6
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
225	Floor/Lower Wall[b]	1	N/A	<420	<4
	Upper Wall/Ceiling	-	-	-	-
Elevator	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling	-	-	-	-
Basement	Floor/Lower Wall[b]	19	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4

[a]Refer to Figures 3 and 4.
[b]Single point measurement.
[c]N/A=Not applicable.
[d]Five point measurement.

TABLE 6

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS IN
REMEDIATED AREAS OF THE REACTOR FACILITY
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Blocks Averaged	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
Reactor Pool Open End	Floor[b]	4	1400	440 - 3200	<4 - 6
	Lower Wall[b]	8	1410	<420 - 2000	<4 - 16
	Miscellaneous[c]	1	N/A[d]	<420	<4
Reactor Pool Stall End	Floor[b]	3	<420	<420 - 700	<4 - 8
	Lower Wall/Ledges[b/c]	3	<420	<420 - 900	<4 - 9
	Upper Wall/Ledges[b/c]	5	910	<420 - 1600	13 - 30
	Equipment/Piping[c]	4	N/A	<420 - 1500	<4 - 9
Thermal Column	Floor/Lower Wall[c]	5	880	<420 - 1100	<4 - 8
	Beam Tube 1[c]	3	N/A	<480 - 920	<4
	Beam Tube 2[c]	3	N/A	<700 - 1000	<4
	Beam Tube 3[c]	3	N/A	<700 - 1200	<4 - 12
	Beam Tube 4[c]	3	N/A	<420 - 730	<4
	Beam Tube 5[c]	3	N/A	1200 - 1700	<4 - 7
	Beam Tube 6[c]	3	N/A	<420	<4 - 7
Thermal Column Plug	Top and Side Openings[c]	4	N/A	<420 - 500	<4 - 10
First Floor	Floor/Lower Wall[b]	5	<420	<420	<4 - 11
	Upper Wall/Ceiling[c]	4	N/A	<400 - 1000	<4 - 21

TABLE 6 (Continued)

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS IN
REMEDIATED AREAS OF THE REACTOR FACILITY
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Blocks Averaged	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
Second Floor	Floor/Lower Wall[b]	10	<420	<420 - 790	<4
	Ceiling/Upper Wall[c]	11	N/A	<420 - 2200	<4
	Miscellaneous[c] (Equipment/Penetrations)	7	N/A	<420 - 1500	<4 - 6
R-128	Floor/Lower Wall[b]	2	520	<420 - 1500	<4
	Upper Wall/Ceiling/Hood[c]	1	N/A	<420	<4
	Floor, Scabbled Area[c]	3	N/A	760 - 1500	<4 - 6
R-129	Floor/Lower Wall[b/c]	4	<420	<420 - 700	<4 - 6
	Upper Wall/Ceiling[c]	1	N/A	<420	<4
R-130	Floor/Lower Wall[b]	3	<420	<420	<4
	Upper Wall/Ceiling[c]	1	N/A	<420	<4
	Pipe Chase[c]	1	N/A	<420	<4
Basement	Floor/Lower Wall[b]	17	1120	<400 - 1300	<4 - 17
	Upper Wall/Ceiling[c]	15	N/A	<400 - 620	<4 - 9
	Miscellaneous[c] (Equipment/Metal Surfaces)	20	N/A	<400 - 520	<4 - 8

[a]Refer to Figures 19 - 27.
[b]Five point measurement.
[c]Single point measurements.
[d]N/A = Not Applicable.

TABLE 7

RADIONUCLIDE CONCENTRATIONS IN CONCRETE SAMPLES
FROM REMEDIATED AREA OF THE
REACTOR FACILITY
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Sample Description or Location[a]	Radionuclide Concentrations (pCi/g)						
	Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
Concrete Composite From Beam Tubes 1, 2, 5, 6	3.0 ± 0.3	<0.1	23.1 ± 0.6	2.4 ± 0.8	<0.1	<0.8	<0.3
Concrete from Beam Tube 3	1.4 ± 0.4	<0.1	8.0 ± 0.5	<0.8	<0.1	2.5 ± 0.9	<0.4
Concrete from Beam Tube 4	1.4 ± 0.3	<0.1	9.0 ± 0.4	1.0 ± 0.9	<0.2	3.1 ± 1.2	<0.3
Concrete from Thermal Column	3.5 ± 0.3	<0.1	21.5 ± 0.6	2.3 ± 1.1	<0.2	2.9 ± 1.2	<0.4
Concrete from Inlet Pipe in Floor	12.0 ± 7.0	2.3 ± 0.4	13.0 ± 0.5	<0.9	<0.3	2.0 ± 1.5	<0.6

[a]Refer to Figure 26 and 27.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 8

RADIONUCLIDE CONCENTRATIONS IN MISCELLANEOUS SAMPLES
FROM REMEDIATED AREAS OF THE REACTOR FACILITY
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Sample Type	Location[a]	Radionuclide Concentrations (pCi/g)						
		Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
Sludge	South Sump in Reactor Rm	0.2 ± 0.1[b]	0.2 ± 0.1	<0.1	<0.2	<0.1	<0.3	<0.1
Gravel	From Roof of Reactor Bldg	<0.1	1.8 ± 0.2	<0.1	<0.2	<0.1	<0.5	<0.1
Soil	West End of Showers After Cleanup	7.0 ± 0.8	1.6 ± 0.3	1.4 ± 0.2	<1.1	<0.3	<1.0	<0.7

[a]Refer to Figure 5.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 9

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS IN
NON-REMEDIATED AREAS OF THE REACTOR FACILITY
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Block Average	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
RA-1	Floor/Lower Walls[b]	1	N/A	<420	<4
RA-2	Floor/Lower Walls[b]	1	N/A	<420	<4
RA-3	Floor/Lower Walls[b]	1	N/A	<670	<4
RA-5	Floor/Lower Walls[b]	1	N/A	<420	<4
RA-6	Floor/Lower Walls[b]	1	N/A	510	<4
R-132	Floor/Lower Wall[b]	3	N/A	<420	<4 - 8
	Upper Wall/Ceiling[b]	2	N/A	<420	<4
R-133	Floor/Lower Wall[b]	3	N/A	<420	<4 - 6
	Upper Wall/Ceiling[b]	3	N/A	<420 - 730	<4 - 6
R-134	Floor/Lower Wall[b]	4	N/A	<420	<4 - 6
	Upper Wall/Ceiling[b]	2	N/A	<420	<4
R-135	Floor/Lower Wall[b]	7	N/A	<400	<4
	Upper Wall/Ceiling[b]	2	N/A	<400	<4
R-127	Floor/Lower Wall[b]	6	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
R-225	Floor/Lower Wall[b]	2	N/A	<420	<4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4

TABLE 9 (Continued)

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS IN
NON-REMEDIATED AREAS OF THE REACTOR FACILITY
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Room or Area[a]	Location	# of Grid Blocks Or Locations Measured	Highest Grid Block Average	Total Beta-Gamma Contamination (dpm/100 cm^2)	Removable Beta Contamination (dpm/100 cm^2)
R-226	Floor/Lower Wall[b]	2	N/A	<420	<4 - 9
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
R-227A	Floor/Lower Wall[b]	2	N/A	<420	<4 - 16
	Upper Wall/Ceiling	-[d]	-	-	-
R-228	Floor/Lower Wall[b]	4	N/A	<420	<4 - 4
	Upper Wall/Ceiling[b]	1	N/A	<420	<4
R-229	Floor/Lower Wall[b]	3	N/A	<420	<4 - 6
	Upper Wall/Ceiling[b]	1	N/A	<420	<4

[a]Refer to Figures 3 and 4.
[b]Singe point measurement.
[c]Five point measurement.
[d]Dash indicates no measurement collected.

TABLE 10

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS IN THE REACTOR PUMP ROOM
AND OTHER REMEDIATED FACILITY BUILDINGS
CENTER FOR ENERGY & ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Building	Figure	# of Measurements	# of Smears	Total Beta-Gamma Contamination Range (dpm/100 cm^2)	Removable Beta Contamination Range (dpm/100 cm^2)
Reactor Pump Room	28 and 29	47	11	<420 - 4200	<4
Retention Tank	42	9	9	<420	<4 - 9
Manhole-Area 1	42	1	1	<420	<4
Shack	30	16	4	<420 - 2200	<4
S-4	31	16	4	<420 - 1500	<4 - 13

TABLE 11

DIRECT RADIATION LEVELS AND RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL FROM THE REACTOR PUMP ROOM PIT - REMEDIATED AREA
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Sample ID	Location[a]	Exposure Rate (μR/h) 1 m	contact	Radionuclide Concentrations (pCi/g) Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
A	Floor	6	6	<0.1	0.9 ± 0.2[b]	<0.1	<0.1	<0.1	<0.8	<0.2
B	N. Wall	—[c]	6	<0.1	2.0 ± 0.3	<0.1	<0.1	<0.1	3.4 ± 1.6	0.9 ± 0.4
C	E. Wall	—	6	<0.1	0.6 ± 0.2	<0.1	<0.1	<0.1	<0.1	0.7 ± 0.3
D	W. Wall	—	5	0.2 ± 0.1	0.3 ± 0.2	<0.1	<0.1	<0.1	<0.1	<0.3
E	Floor	7	6	0.2 ± 0.1	1.0 ± 0.2	<0.1	<0.1	<0.1	1.4 ± 1.1	<0.2
F	S. Wall	—	5	<0.1	0.2 ± 0.1	<0.1	<0.1	<0.1	<0.8	0.6 ± 0.3
G	Floor	6	5	<0.1	0.6 ± 0.1	<0.1	<0.1	<0.1	0.1 ± 0.1	0.4 ± 0.3

[a]Refer to Figure 36.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.
[c]Measurement not performed.

TABLE 12

SUMMARY OF SURFACE CONTAMINATION MEASUREMENTS IN
OTHER NON-REMEDIATED AREA FACILITY BUILDINGS
CENTER FOR ENERGY & ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Building	Figure	Location	# of Measurements	# of Smears	Total Beta Contamination Range (dpm/100 cm^2)	Removable Beta Contamination Range (dpm/100 cm^2)
Nuclear Engineering (Building 27)	35	Equipment Room	3	3	<420	<4
Neutron Generator (Building 26)	35		6	6	<420	<4
Nuclear Engineering Annex (Building 25) and Building 24)	35	C1E-6	6	6	<420	<4-9
		A-2	2	2	<420	<4
		C1E-11	1	1	<420	<4
		C1E-12	1	1	<420	<4
		Hallway	1	1	<420	<4
Administration Office Building	33		6	6	<420-1500	<4-8
Marine Biology Building	32	1st Floor	7	7	<420- 700	<4-6
Shop Building	34		19	19	<420-1500	<4-7

TABLE 13

RADIONUCLIDE CONCENTRATIONS IN BATCH WATER
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Sample Source	Radionuclide Concentrations (pCi/l)			
	Sr-90	H-3	Gross Alpha	Gross Beta
Truck 397-1	0.4 ± 0.6[a]	32500 ± 900	1.9 ± 0.6	14.2 ± 1.3
Truck 406-2	0.7 ± 0.9	17500 ± 610	3.0 ± 0.8	46.7 ± 2.1
Truck 411-3	0.4 ± 0.6	23240 ± 760	1.0 ± 0.6	4.7 ± 1.0
Truck 4111124-4	<0.5	27300 ± 910	1.8 ± 0.7	24.9 ± 1.6
Truck 436030-5	<0.3	20700 ± 680	1.8 ± 0.7	21.4 ± 1.6
Truck 381-6	0.6 ± 0.6	23120 ± 760	1.2 ± 0.7	24.9 ± 1.6
Gamma Pool	–[b]	9400 ± 400	1.4 ± 0.8	62.1 ± 2.4
Retention Tank	–	19000 ± 490	1.2 ± 0.8	34.6 ± 1.9

[a]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.
[b]Analysis not performed.

TABLE 14

RADIONUCLIDE CONCENTRATIONS IN
RETENTION TANK WATER
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Source	Radionuclide Concentrations (pCi/l)						
	Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
Retention Tank (Collection Date 10/20/87)	33.0 ± 4.9[a]	8.8 ± 4.0	<2.3	<11.9	<3.9	<2.2	<6.6

[a]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 15

DIRECT RADIATION LEVELS AND RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL FROM THE RETENTION TANK PIPELINE TRENCH - AREA 1
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Sample Number	Location[a]	Exposure Rate (μR/h) 1 m	contact	Radionuclide Concentrations (pCi/g) Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
1	0,0	3	3	<0.1	<0.1	<0.1	<0.1	<0.1	0.6 ± 0.4[b]	<0.2
2	10 m	3	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.6	<0.2
3	16.2 m	4	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.7	0.6 ± 0.4

[a]Refer to Figure 53.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 16

RADIONUCLIDE CONCENTRATIONS IN SUBSURFACE SOIL FROM THE
RETENTION PIPELINE EXCAVATION
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Location[a]	Depth	Radionuclide Concentrations (pCi/g)						
		Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
HOLE #4	0 - 60 cm	<0.1	0.1 ± 0.1[b]	<0.1	<0.1	<0.1	0.9 ± 0.6	0.6 ± 0.3
	150 - 210 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.6	0.5 ± 0.3
	300 - 360 cm	<0.1	<0.1	<0.1	<0.1	<0.1	1.0 ± 0.7	0.5 ± 0.4
	450 - 510 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.6	0.4 ± 0.4
HOLE #5	0 - 60 cm	<0.1	<0.1	<0.1	0.1 ± 0.1	<0.1	<0.3	<0.1
	150 - 210 cm	<0.1	<0.1	<0.1	<0.1	<0.1	0.9 ± 1.5	0.5 ± 0.5
	300 - 360 cm	<0.1	<0.1	<0.1	<0.1	<0.1	0.8 ± 0.9	0.5 ± 0.4
	450 - 510 cm	<0.1	<0.1	<0.1	<0.1	<0.1	0.9 ± 1.0	0.4 ± 0.3
HOLE #6	0 - 60 cm	<0.1	<0.1	<0.1	<0.1	<0.1	2.0 ± 1.3	0.8 ± 0.3
	150 - 210 cm	<0.1	<0.1	<0.1	<0.1	<0.1	0.9 ± 0.7	0.5 ± 0.4
	300 - 360 cm	<0.1	<0.1	<0.1	<0.1	<0.1	0.8 ± 0.6	0.5 ± 0.3
	450 - 510 cm	<0.1	<0.1	0.1 ± 0.1	<0.1	<0.1	0.8 ± 1.1	0.4 ± 0.2
HOLE #7	0 - 60 cm	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1	6.5 ± 1.7	0.6 ± 0.4
	150 - 210 cm	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1	0.7 ± 3.4	0.6 ± 0.2
	300 - 360 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.7	0.7 ± 0.3
	450 - 510 cm	<0.1	<0.1	<0.1	<0.1	<0.1	1.2 ± 1.1	0.5 ± 0.3

[a]Refer to Figure 53.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 17

RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL
FROM THE HOT WASTE TANK PIT EXCAVATION - AREA 6
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Location[a]	Radionuclide Concentrations (pCi/g)						
	Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
2N, 2E	<0.1	<0.1	<0.1	<0.2	<0.1	<1.0	<0.2
2N, 8E	<0.1	<0.1	<0.1	<0.1	<0.1	0.1 ± 0.5[b]	0.3 ± 0.2
8N, 10E	<0.1	<0.1	<0.1	<0.1	<0.1	2.0 ± 0.8	0.8 ± 0.4
14N, 2E	<0.1	0.2 ± 0.1	<0.1	<0.1	<0.1	1.2 ± 1.0	0.6 ± 0.3
14N, 8E	<0.1	0.3 ± 0.1	<0.1	<0.2	<0.1	<1.0	1.0 ± 0.3
8N, 6E	0.1 ± 0.1	0.1 ± 0.1	<0.1	<0.1	<0.1	0.9 ± 8.5	0.5 ± 0.2
2N, 1 m, E. Wall	<0.1	<0.1	<0.1	<0.1	<0.1	0.6 ± 8.3	0.7 ± 0.4
14N, 1 m, E. Wall	<0.1	<0.1	<0.1	<0.1	<0.1	2.4 ± 1.3	0.8 ± 0.4
8N, 2 m, E. Wall	<0.1	<0.1	<0.1	<0.1	<0.1	5.0 ± 2.2	<0.4
2E, 1 m, N. Wall	<0.1	0.7 ± 0.1	<0.1	<0.1	<0.1	<0.8	<0.2
6E, 2 m, N. Wall	<0.1	0.9 ± 0.1	<0.1	<0.1	<0.1	0.8 ± 0.4	0.6 ± 0.3
8E, 1 m, N. Wall	<0.1	<0.1	<0.1	<0.2	<0.1	<0.4	<0.1
14N, 1 m, W. Wall	<0.1	<0.1	<0.1	<0.1	<0.1	<1.1	1.3 ± 0.5
8N, 2 m, W. Wall	<0.1	<0.1	<0.1	<0.1	<0.1	1.3 ± 1.0	0.5 ± 0.3
2N, 1 m, W. Wall	<0.1	<0.1	<0.1	<0.1	<0.1	<0.7	<0.2
2E, 1 m, S. Wall	<0.1	<0.1	<0.1	<0.1	<0.1	<0.7	<0.2
6E, 2 m, S. Wall	<0.1	<0.1	<0.1	<0.1	<0.1	<0.6	<0.2
8E, 1 m, S. Wall	<0.1	<0.1	<0.1	<0.1	<0.1	1.3 ± 0.7	0.7 ± 0.3

[a]Refer to Figure 37.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 18

RADIONUCLIDE CONCENTRATIONS IN SUBSURFACE SOIL
FROM THE SERPENTINE PIPELINE AREA - AREA 7
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Location[a]	Depth	Radionuclide Concentrations (pCi/g)						
		Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
Hole #1	0- 60 cm	<0.1	0.2 ± 1.0[b]	<0.1	<0.1	<0.1	<0.7	0.5 ± 0.2
	150-210 cm	<0.1	<0.1	0.5 ± 0.2	<0.2	<0.1	<0.8	0.6 ± 0.3
	300-360 cm	<0.1	<0.1	<0.1	<0.2	<0.1	<0.9	0.8 ± 0.4
	450-510 cm	<0.1	<0.1	<0.1	<0.1	<0.1	2.2 ± 0.9	0.5 ± 0.3
Hole #2	0- 60 cm	<0.1	0.2 ± 0.2	<0.1	<0.1	<0.1	1.2 ± 1.6	0.6 ± 0.7
	150-210 cm	<0.1	<0.1	<0.1	<0.1	<0.1	1.2 ± 1.0	0.5 ± 0.4
	300-360 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.5	<0.1
	450-510 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.8	<0.2
Hole #3	0- 60 cm	0.1 ± 0.1	0.2 ± 0.1	<0.1	<0.1	<0.1	1.9 ± 0.9	0.2 ± 0.2
	150-210 cm	<0.1	<0.1	<0.1	<0.1	<0.1	1.2 ± 1.3	1.0 ± 0.3
	300-360 cm	<0.1	<0.1	<0.1	<0.1	<0.1	1.0 ± 1.3	0.3 ± 0.4
	450-510 cm	<0.1	<0.1	<0.1	<0.1	<0.1	1.0 ± 1.0	0.4 ± 0.4

[a]Refer to Figure 54.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 19

DIRECT RADIATION LEVELS AND RADIONUCLIDE CONCENTRATIONS IN SOIL
EXCAVATED FROM THE HOT WASTE TANK - AREA 6
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Location[a]	Depth	Exposure Rate (μR/h) 1 m	contact	Radionuclide Concentrations (pCi/g) Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
0,0	Surface	3	3	<0.1	0.8 ± 1.6[b]	<0.1	<0.1	<0.1	<0.7	<0.2
5N,0E	Surface	3	3	<0.1	2.6 ± 0.2	<0.2	<1.1	<0.1	<0.9	<0.2
10N,0E	Surface	3	4	<0.1	2.1 ± 0.2	<0.1	0.2 ± 0.1	<0.1	1.3 ± 0.9	0.5 ± 0.3
15N,0E	Surface	3	3	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1	<0.1	0.4 ± 0.2
15N,5E	Surface	3	3	<0.1	0.4 ± 0.1	<0.1	<0.1	<0.1	<0.6	0.5 ± 0.3
10N,5E	Surface	3	3	<0.1	0.4 ± 0.1	0.1 ± 0.1	<0.1	<0.1	<0.5	0.4 ± 0.2
5N,5E	Surface	3	3	<0.1	0.8 ± 0.1	<0.1	<0.2	<0.1	<0.8	<0.2
0N,5E	Surface	3	3	<0.1	0.6 ± 0.1	<0.1	<0.1	<0.1	<0.4	0.4 ± 0.3
0N,10E	Surface	3	3	<0.1	0.7 ± 0.1	<0.1	<1.1	<0.1	<0.7	0.5 ± 0.5
5N,10E	Surface	2	3	<0.1	1.0 ± 2.0	<0.1	<0.2	<0.1	<0.8	0.8 ± 0.3
10N,10E	Surface	3	3	<0.1	0.8 ± 2.0	<0.1	<0.1	<0.1	0.5 ± 0.9	0.6 ± 0.3
15N,10E	Surface	2	3	<0.1	0.4 ± 0.1	<0.1	<0.1	<0.1	0.6 ± 0.7	0.4 ± 0.2
12N,8E	Surface	-	-	0.1 ± 0.1	0.7 ± 0.1	<0.1	0.1 ± 0.1	<0.1	0.7 ± 0.5	0.4 ± 0.3
12N,8E	35-50 cm	-	-	<0.1	0.8 ± 0.2	<0.1	<0.1	<0.1	<0.6	0.3 ± 0.2
12N,8E	70-85 cm	-	-	<0.1	0.5 ± 0.1	<0.1	<0.1	<0.1	<0.6	<0.2
12N,8E	90 cm	-	-	<0.1	0.9 ± 0.1	<0.1	<0.1	<0.1	2.4 ± 0.6	0.5 ± 0.1
14N,4E	Surface	-	-	<0.1	0.2 ± 0.1	<0.1	<0.2	<0.1	0.6 ± 0.5	0.5 ± 0.3

TABLE 19 (Continued)

DIRECT RADIATION LEVELS AND RADIONUCLIDE CONCENTRATIONS IN SOIL
EXCAVATED FROM THE HOT WASTE TANK - AREA 6
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Location[a]	Depth	Exposure Rate (μR/h) 1 m	Exposure Rate (μR/h) contact	Radionuclide Concentrations (pCi/g) Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
14N,4E	35-50 cm	-	-	0.1 ± 0.1	1.4 ± 0.2	<0.1	<0.1	<0.1	<0.7	0.5 ± 0.4
14N,4E	70-85 cm	-	-	<0.1	0.6 ± 0.1	<0.1	<0.1	<0.1	<0.8	<0.2
14N,4E	95 cm	-	-	<0.1	0.3 ± 0.1	<0.1	<0.1	<0.1	0.8 ± 0.7	0.4 ± 0.2
2N,2E	Surface	-	-	<0.1	0.9 ± 0.1	<0.1	<0.1	<0.1	1.1 ± 0.8	0.4 ± 0.3
2N,2E	35-50 cm	-	-	<0.1	1.4 ± 0.2	<0.1	<0.1	<0.1	<0.7	<0.2
2N,2E	70-85 cm	-	-	<0.1	1.8 ± 0.2	<0.1	<0.2	<0.1	<0.9	<0.2
2N,2E	105-112 cm	-	-	<0.1	1.5 ± 0.2	<0.1	<0.1	<0.1	2.0 ± 0.7	<0.3
4N,6E	Surface	-	-	<0.1	1.1 ± 0.1	<0.1	<0.1	<0.1	0.9 ± 1.1	0.4 ± 0.4
4N,6E	35-50 cm	-	-	<0.1	1.0 ± 0.1	<0.1	<0.2	<0.1	<0.9	0.7 ± 0.4
4N,6E	70-85 cm	-	-	<0.1	0.6 ± 0.1	<0.1	<0.1	<0.1	0.7 ± 1.1	0.4 ± 0.2
8N,10E	Surface	-	-	<0.1	0.9 ± 0.1	<0.1	<0.1	<0.1	<0.6	<0.3
8N,10E	35-50 cm	-	-	<0.1	0.7 ± 0.2	<0.1	<0.1	<0.1	<0.6	0.5 ± 0.4
8N,10E	70-85 cm	-	-	<0.1	0.7 ± 0.1	<0.1	<0.1	<0.1	<0.9	<0.2

[a]Refer to Figure 38.
[b]Certainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 20

SR-90 AND H-3 CONCENTRATIONS IN RANDOMLY SELECTED SOIL SAMPLES
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Location[a]	Depth	Radionuclide Concentrations (pCi/l)	
		Sr-90	H-3
Dirt Pile Area 6		<0.1	--[b]
Dirt Pile Area 6		<0.1	--[b]
Dirt Pile Area 6		<0.1	--[b]
Area 5, Location 3		<0.1	--[b]
Area 11, Location 1		<0.1	--[b]
Area 5, Location 4		<0.1	--[b]
Hot Waste Tank Pit		<0.1	--[b]
South Wall Hot Waste Tank Pit		<0.1	--[b]
Area 9, Location 1		<0.1	--[b]
Dirt Pile Area 6		--[b]	<0.6
Dirt Pile Area 6		--[b]	<1.1
Dirt Pile Area 6		--[b]	<0.6
Area 5, Location 2		--[b]	<0.6
Area 11, Location 2		--[b]	<1.0
Dirt Pile Area 6	70 - 85 cm	--[b]	<1.1
Dirt Pile Area 6	95 cm	--[b]	<1.1
Dirt Pile Area 6	Surface	--[b]	<1.0
Hot Waste Pump Pit		--[b]	<0.9
East Wall Hot Waste Pump Pit		--[b]	<1.0
West Wall Hot Waste Pump Pit		--[b]	<1.0
Area 9, Location 2		--[b]	<1.1
Area 4, Location 1		--[b]	<1.0
Area 4, Location 3		--[b]	<1.7
Area 10, Location 1		--[b]	<0.9
Pump Room Pit Floor		<0.1	<0.7
Pump Room Pit Floor		<0.1	<0.7
Pump Room Pit South Wall		<0.9	<0.7
Hole 1	0 - 60 cm	<0.8	<0.6
Hole 4	150 -210 cm	<0.7	<0.7
Hole 5	0 - 60 cm	<0.1	<0.6

[a]Refer to Figures 36 - 38, 45, 46, 49 - 51, and 53.
[b]Analysis not performed.

TABLE 21

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES
FROM THE AREA 10 LOCATION OF ELEVATED RADIATION LEVELS
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Sample #[a] Location	Depth (cm)	Radionuclide Concentrations (pCi/g)						
		Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
C	0-15	64.8 ± 0.5[b]	<0.8	<0.8	<1.7	<0.8	<6.1	<4.1
C	5-15	<0.1	0.5 ± 0.1	<0.1	<0.2	<0.1	<1.2	1.1 ± 0.4

[a]Refer to Figure 50.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.

TABLE 22

DIRECT RADIATION LEVELS AND RADIONUCLIDE CONCENTRATIONS
IN SURFACE SOIL FROM AREAS 1 - 12
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Area	Sample #[a]	Exposure Rate (μR/h) 1 m	contact	Radionuclide Concentrations (pCi/g) Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
1	A	9	8	<0.1	0.7 ± 0.2[b]	<0.1	<0.1	<0.1	<0.7	0.5 ± 0.2
	B	4	3	<0.1	0.6 ± 0.1	<0.1	<0.3	<0.1	<0.6	<0.3
	C	6	6	0.2 ± 0.1	1.0 ± 0.2	<0.1	<0.4	<0.1	<0.8	1.0 ± 0.4
2	A	58	34[c]	<0.1	0.2 ± 0.1	0.1 ± 0.1	<0.3	<0.1	<0.7	0.6 ± 0.4
	B	5	5	2.3 ± 0.5	0.5 ± 0.2	<0.1	<0.6	<0.2	<0.1	<0.4
	C	9	5	<0.1	0.1 ± 0.1	<0.1	<0.3	<0.1	<0.8	0.6 ± 0.4
3	A	2	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.7	0.5 ± 0.3
	B	3	3	<0.1	0.3 ± 0.1	<0.1	<0.2	<0.1	<1.0	1.0 ± 0.5
	C	3	2	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1		<0.1
	D	5	6	<0.1	0.4 ± 0.1	<0.1	<0.1	<0.1	<0.1	0.4 ± 0.4
4	A	3	3	<0.1	0.5 ± 0.1	<0.1	<0.1	<0.1	<0.7	0.7 ± 0.3
	B	37	20[c]	<0.1	2.3 ± 0.3	<0.1	<0.2	<0.1	1.3	<0.3
	C	3	3	<0.1	0.3 ± 0.1	<0.1	<0.1	<0.1	0.8 ± 0.6	0.6 ± 0.3
	D	4	4	<0.1	2.1 ± 0.2	<0.1	<0.3	<0.1	<0.6	0.4 ± 0.3
	E	3	6	0.7 ± 0.2	6.3 ± 0.4	<0.1	<0.3	<0.1	<0.7	<0.2
	F	4	4	0.3 ± 0.1	2.4 ± 0.3	<0.1	<0.3	<0.1	<0.6	0.6 ± 0.4
5	A	2	3	<0.1	0.6 ± 0.1	<0.1	<0.2	<0.1	<1.1	<0.3
	B	3	3	<0.1	0.2 ± 0.1	<0.1	<0.1	<0.1	<0.8	<0.2
	C	3	3	<0.1	0.2 ± 0.1	<0.1	<0.1	<0.1	1.6 ± 0.6	0.3 ± 0.3
	D	3	3	<0.1	0.3 ± 0.1	<0.1	<0.2	<0.1	<0.9	0.8 ± 0.4

TABLE 22 (Continued)

DIRECT RADIATION LEVELS AND RADIONUCLIDE CONCENTRATIONS
IN SURFACE SOIL FROM AREAS 1 - 12
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Area	Sample #[a]	Exposure Rate (μR/h) 1 m	contact	Radionuclide Concentrations (pCi/g) Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
7	A	5	4	0.1 ± 0.1	6.1 ± 0.4	<0.1	<0.3	<0.1	<0.8	<0.2
	B	4	4	<0.1	0.8 ± 0.2	<0.1	<0.4	<0.1	<0.7	0.5 ± 0.3
	C	4	4	<0.1	1.8 ± 0.3	<0.1	<0.3	<0.1	<0.8	0.5 ± 0.6
8	A	3	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.7	0.5 ± 0.4
	B	2	3	<0.1	0.3 ± 0.1	<0.1	<0.2	<0.1	<1.1	<0.3
	C	3	3	<0.1	0.3 ± 0.1	<0.1	<0.1	<0.1	1.0 ± 0.6	0.6 ± 0.3
	D	6	4	<0.1	0.3 ± 0.1	<0.1	<0.1	<0.1	<0.7	0.6 ± 0.4
	E	3	4	<0.1	0.1 ± 0.1	<0.1	<0.3	<0.1	<0.5	<0.2
	F	3	3	0.2 ± 0.1	0.4 ± 0.1	<0.1	<0.2	<0.2	<0.7	<0.2
	G	3	4	<0.1	0.8 ± 0.2	<0.1	<0.5	<0.2	1.8 ± 1.4	0.4 ± 0.4
9	A	8	10[d]	<0.1	<1.1	<0.1	<0.1	<0.1	1.5 ± 2.2	<0.4
	B	3	3	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1	<0.3	0.4 ± 0.3
	C	4	4	<0.1	0.3 ± 0.1	<0.1	<0.2	<0.1	<0.8	<0.2
	D	3	3	<0.1	0.3 ± 0.2	<0.1	<0.1	<0.1	0.9 ± 0.8	0.9 ± 0.4
	E	4	5	1.7 ± 0.2	2.0 ± 0.2	<0.1	<0.4	<0.1	<0.8	0.6 ± 0.6
	F	3	5	2.8 ± 0.4	0.5 ± 0.4	<0.1	<0.6	<0.1	<0.8	<0.3
	G	4	4	0.3 ± 0.1	2.0 ± 0.2	<0.1	<0.3	<0.1	<0.8	0.8 ± 0.4
10	A	3	3	<0.1	0.3 ± 0.1	<0.1	<0.1	<0.1	<0.7	0.8 ± 0.2
	B	2	2	<0.1	0.4 ± 0.1	<0.1	<0.1	<0.1	1.1 ± 0.5	0.6 ± 0.3

TABLE 22 (Continued)

DIRECT RADIATION LEVELS AND RADIONUCLIDE CONCENTRATIONS
IN SURFACE SOIL FROM AREAS 1 - 12
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
MAYAGUEZ, PUERTO RICO

Area	Sample #[a]	Exposure Rate (μR/h) 1 m	contact	Radionuclide Concentrations (pCi/g) Co-60	Cs-137	Ba-133	Eu-152	Eu-154	U-238	Th-232
11	A	3	3	<0.1	0.7 ± 0.1	<0.1	<0.2	<0.1	<1.1	0.8 ± 0.3
	B	3	3	<0.1	0.3 ± 0.1	<0.1	<0.1	<0.1	1.0 ± 1.0	0.9 ± 0.5
	C	3	3	<0.1	0.5 ± 0.1	<0.1	<0.1	<0.1	1.4 ± 0.6	0.5 ± 0.4
	D	3	3	<0.1	0.3 ± 0.1	<0.1	<0.1	<0.1	<0.9	<0.3
12	A	3	3	<0.1	0.5 ± 0.1	<0.1	<0.2	<0.1	<1.1	<0.3
	B	2	2	<0.1	0.5 ± 0.2	<0.1	<0.1	<0.1	0.3 ± 0.5	0.6 ± 0.4
	C	3	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.6	0.7 ± 0.5
	D	3	3	<0.1	0.3 ± 0.1	<0.1	<0.1	<0.1	<1.0	<0.2

[a]Refer to Figures 42 - 52.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of 6 to 10% have not been propagated in these data.
[c]Storage trucks with radioactive materials were parked in the area.
[d]Location near shack building. Radioactive materials were stored in the building.

REFERENCES

1. Black and Veatch, CEER Decontamination - Decontamination Tanks, 1979.

2. Bechtel National Inc., Work Plan for the CEER, Mayaguez Project, Oak Ridge, TN, May 1987.

3. Bechtel National Inc., Characterization Plan for the CEER, Mayaguez Project, Oak Ridge, TN, May 1987.

4. Bechtel National Inc., Final Report on Decontamination of the Center for Energy and Environment Research (CEER), Mayaguez Facility at the University of Puerto Rico, Oak Ridge, TN, Revision C, Vol. I, II, and III, February 1988.

5. Oak Ridge Associated Universities "Proposed Verification Plan for the Center for Energy and Environment Research, Mayaguez, Puerto Rico", Oak Ridge, TN, February 1987.

6. U.S. Department of Energy, "U.S. Department of Energy Guidelines for Residual Radioactivity at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites, Revision 2, March 1987.

7. Letter from J.D. Berger (ORAU) to P. Gross (DOE/OR), "Verification of Remedial Actions at the CEER Facility, University of Puerto Rico, Mayaguez, Puerto Rico," Oak Ridge, TN., June 1988.

APPENDIX A

U.S. DEPARTMENT OF ENERGY GUIDELINES FOR RESIDUAL CONTAMINATION AT THE CEER SITE

APPENDIX A

U.S. DEPARTMENT OF ENERGY
GUIDELINES FOR RESIDUAL
CONTAMINATION AT THE CEER SITE

INDOOR/OUTDOOR STRUCTURE SURFACE CONTAMINATION GUIDELINES
(Maximum Limits for Unrestricted Use)

Radionuclide[a,b]	Allowable Residual Surface Contamination[a] (dpm/100 cm^2)		
	Average[c,d]	Maximum[d,e]	Removable[d,f]
Transurancis, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100	300	20
Th-Natural, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000	3,000	200
U-Natural, U-235, U-238, and associated decay products	5,000	15,000	1,000
Beta-gamma emitters (radionuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above	5,000	15,000	1,000

[a]As used in this table, dpm (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.

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

[c]Measurements of average contamination should not be averaged over more than 1 m^2. For objects of less surface area, the average shall be derived for each such object.

[d]The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 marred/h and 1.0 mrad/h, respectively, at 1 cm.

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

[f]The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter of soft absorbent paper, applying moderate pressure, and measuring the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of surface area less than 100 cm^2 is determined, the activity per unit area should be based on the actual area and entire surface should be wiped. The numbers in this column are maximum amounts.

SOIL (LAND) GUIDELINES (Maximum Limits for Unrestricted Use)

Radionuclide	Soil Concentration (pCi/g) above background
Radium-226 Radium-228 Thorium-230 Thorium-232	5 pCi/g, averaged over the first 15 cm of soil below the surface; 15 pCi/g when averaged over any 15-cm-thick soil layer below the surface layer[a,b,c,d]
Na-22	45[e]
Co-60	20[e]
Sr-90	30[e]
Cs-137	30[e]
Fu-152	30[e]

[a]These guidelines take into account ingrowth of radium-226 from thorium-230 and of radium-228 from throrium-232, and assume secular equilibrium. If either thorium-230 and radium-226 or thorium-232 and radium-228 are both present, not in secular equilibrium, the guidelines apply to the higher concentration. If other mixtures of radionuclides occur, the concentrations of individual radionuclides shall be reduced so that the dose for the mixtures will not exceed the basic dose limit.

[b]These guidelines represent unrestricted-use residual concentrations above background averaged across any 15-cm-thick layer to any depth and over any contiguous 100 m^2 surface area.

[c]Localized concentrations in excess of these limits are allowable provided that the average concentration over a 100 m^2 area does not exceed these limits.

[d]From reference 6

[e]Based on site specific pathways analysis (Reference 2).

EXTERNAL GAMMA RADIATION FOR STRUCTURES

The average level of gamma radiation inside structures to be released for unrestricted must not exceed the background level by more than 20 μR/hr.

RESIDUAL WATER CONCENTRATION GUIDELINES FOR INDIVIDUAL RADIONUCLIDES
(Release Criteria)

Radionuclide	Concentration[a] pCi/l
Na-22	80
Co-60	80
Sr-90	8
Cs-137	50
Eu-152	200
Ra-226	3
H-3	20,000
C-14	2,000

[a]Per 40 CFR 141 and calculations based on information from EPA and committed dose equivalent of 4 mrem/yr.

APPENDIX B

MAJOR SURVEY AND ANALYTICAL EQUIPMENT

APPENDIX B

Major Survey and Analytical Equipment

The display or description of a specific product is not to be construed as an endorsement of that product or its manufacturer by the authors on their employer.

A. Direct Radiation Measurements

Eberline "RASCAL"
Portable Ratemeter-Scaler
Model PRS-1
(Eberline, Santa Fe, NM)

Eberline PRM-6
Portable Ratemeter
(Eberline, Santa Fe, NM)

Eberline Alpha Scintillation Detector
Model AC-3-7
(Eberline, Santa Fe, NM)

Ludlum Alpha-Beta Floor Monitor
Model 239-1
(Ludlum, Sweetwater, TX)

Ludlum Ratemeter-Scaler
Model 2220
(Ludlum, Sweetwater, TX)

Ludlum Scaler
Model 2200
(Ludlum, Sweetwater, TX)

Reuter-Stokes Pressurized Ionization Chamber
Model RSS-111
(Reuter-Stokes, Cleveland, OH)

Victoreen NaI Scintillation Detector
Model 489-55
(Victoreen, Cleveland, OH)

B. Laboratory Analyses

Low Background Alpha-Beta Counter
Model LB-5110
(Tennelec, Oak Ridge, TN)

High Purity Germanium Detector
Model GMX-23195-S, 23% Efficiency
(EG&G ORTEC, Oak Ridge, TN)

used in conjunction with:
Lead Shield Model G-16
(Gamma Products, Palos Hills, IL)

High Purity Germanium Coaxial Well Detector
Model GWL-110210-PWS-S, 23% Efficiency
(EG&G ORTEC, Oak Ridge, TN)

used in conjunction with:
Lead Shield Model G-16
(Applied Physical Technology, Atlanta, GA)

High Purity Germanium Detector
Model IGC25, 25% Efficiency
(Princeton Gamma-Tech, Princeton, NJ)

used in conjunction with:
Lead Shield
(Nuclear Data, Schaumburg, IL)

Multichannel Analyzer
ND66/680 System
(Nuclear Data, Schaumburg, IL)

APPENDIX C

MEASUREMENT AND ANALYTICAL PROCEDURES

APPENDIX C

Measurement and Analytical Procedures

Alpha and Beta-gamma Measurements

Measurements of total alpha radiation levels were performed using Eberline Model PRS-1 portable scaler/ratemeters with Model AC-3-7 alpha scintillation probes. Measurements of total beta-gamma radiation levels were performed using Eberline Model PRS-1 portable scaler/ratemeters with Model HP-260 thin-window "pancake" GM probes. Count rates (cpm) were converted to disintegration rates (dpm/100 cm^2) by dividing the net rate by the 4π efficiency and correcting for the active area of the detector. Effective window areas were 59 cm^2 for the ZnS detectors and 15 cm^2 for the GM detectors. The background count rate for ZnS alpha probes averaged approximately 2 cpm; the average background count rate was approximately 40 cpm for the GM detectors.

Surface Scans

Surface scans in the facility were performed by passing the probes slowly over the surface. The distance between the probe and the surface was maintained at a minimum - nominally about 1 cm. Identification of elevated levels was based on increases in the audible signal from the recording or indicating instrument. Alpha and beta-gamma scans of large surface areas on the floor of the facility were accomplished by use of a gas proportional floor monitor, with a 600 cm^2 sensitive area. The instrument was slowly moved in a systematic pattern to cover 100% of the accessible area. Combinations of detectors and instrument for the scans were:

Beta-Gamma	- Pancake GM probe with PRM-6 ratemeter.
Beta-Gamma	- Pancake GM probe with PRS-1 scaler/ratemeter.
Gamma	- NaI scintillation detector (3.2 cm x 3.8 cm crystal) with PRM-6 ratemeter.
Alpha	- ZnS probe with PRS-1 scaler/ratemeter.
Alpha/Beta	- Gas proportional floor monitor with Ludlum Model 2220 scaler/ratemeter.

Exposure Rate Measurement

Walkover surface scans and measurements of gamma exposure rates were performed using Eberline Model PRM-6 portable ratemeters with Victoreen Model 489-55 gamma scintillation probes, containing 3.2 cm x 3.8 cm NaI(Tl) scintillation probes. Count rates were converted to exposure rates (μR/h) by onsite cross-calibration with a Reuter-Stokes Model RSS-111 pressurized ionization chamber (PIC).

Borehole Logging

Borehole gamma radiation measurements were performed using a Victoreen Model 489-55 gamma scintillation probe, shielded by a 1.25 cm thick lead shield, with four 2.5 x 7 mm holes evenly spaced around the region of the scintillation detector. The probe was lowered into each hole using a tripod holder with a small winch. Gross gamma measurements were performed at 30 cm intervals between the surface and the bottom of the hole and recorded using a Ludlum Model 2200 portable scaler. At locations where the borehole had a tendency to cave in, the probe was lowered through the inside of the hollow stem auger.

Removable Contamination Measurements

Smear measurements were performed using numbered filter paper disks, 47 mm in diameter. Smears were sealed in labeled envelopes with the location and other pertinent information recorded. The smears were returned to Oak Ridge and evaluated using a low-background alpha-beta proportional system.

Soil and Miscellaneous Sample Analysis

Gamma Spectrometry

Soil and miscellaneous samples were dried, mixed, and a portion sealed in 0.5-liter Marinelli beaker. The quantities placed in each beaker were chosen to reproduce the calibrated counting geometry and typically ranged from 600 to 800 g of soil. Net soil weights were determined and the samples counted using

germanium detectors coupled to a Nuclear Data Model ND-680 pulse height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using the computer capabilities inherent in the analyzer system. The sample of tile was processed to a size proportions to a Marinelli beaker for gamma spectroscopy analysis. Energy peaks used for determining the radionuclides of concern were:

Co-60 - 1.173 MeV
Cs-137 - 0.662 MeV
Ba-133 - 0.356 MeV
Eu-152 - 0.344 MeV
Eu-154 - 0.123 MeV
U -238 - 0.094 MeV from Th-234 (Secular Equilibrium Assumed)
Th-232 - 0.911 MeV from Ac-228

Spectra were also reviewed for the presence of other radionuclides.

Strontium-90 Analysis

Aliquots of soil were dissolved by pyrosulfate fusion and the strontium precipitated as a sulfate. Successive treatments with EDTA preferentially removed lead and excess calcium and returned the strontium to solution. Ferric and other insoluble hydroxides were precipitated at a pH of 12 to 14. Strontium was reprecipitated as a sulfate. Barium was removed as a chromate using DTPA. The final precipitate of strontium carbonate was counted using a low-background Tennelec alpha-beta proportional counter.

Tritium Analysis

Aliquots of soil were refluxed with low tritium water. The distillate was collected and an aliquot analyzed in a Packard liquid scintillation counter.

Water Sample Analysis

Gross Alpha and Gross Beta

Water samples were rough-filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by subsequent filtration through 0.45 μm membrane filters. The filtrate was acidified by addition of 10 ml of concentrated nitric acid. A known volume of each sample was evaporated to dryness and counted for gross alpha and gross beta using a Tennelec Model LB-5100 low-background proportional counter.

Gamma Spectrometry

Water samples were also placed into 3.5 liter Marinelli beakers, and gamma spectrometry was performed using the same procedures as described above for soil samples.

Strontium-90 Analysis

Aliquots of water were mixed with carriers and sodium EDTA and passed through a cation exchange resin to remove strontium. Strontium was eluted from the cation resin using sodium chloride solution and precipitated as a carbonate; barium was removed by chromate precipitation. The resulting sample was counted in a low-background beta unit and the count rate corrected for yttrium ingrowth. Chemical yield was determine gravimetrically.

Tritium Analysis

Aliquots of water were distilled. Nine milliliters of the distillate was added to a liquid-scintillation solution and direct counted in a Packard Tri-Carb 300 liquid scintillation counter.

Uncertainties and Detection Limits

The uncertainties associated with the analytical data presented in the tables of this report, represent the 95% confidence levels for that data.

These uncertainties were calculated based on both the gross sample count levels and the associated background count levels. When the net sample count was less than the 95% statistical deviation of the background count, the sample concentration was reported as less than the detection capability of the measurement procedure. Because of variations in background levels and Compton contributions from other radionuclides in samples, the detection limits differ from sample to sample and instrument to instrument. Additional uncertainties of ± 6 to 10%, associated with sampling and laboratory procedures, have not been propagated into the data presented in this report.

Calibration and Quality Assurance

Laboratory and field survey procedures are documented in the following manuals, developed specifically for the Oak Ridge Associated Universities' Radiological Site Assessment Program: "Survey Procedures Manual", Revision 3, May 1987; "Laboratory Procedures Manual", Revision 3, May 1987 and "Quality Assurance Manual", Revision 1, June 1987.

With the exception of the portable gamma scintillation survey meters, field and laboratory instruments are calibrated with NBS-traceable standards. The calibration procedures for the portable gamma instruments are performed by comparison with an NBS-traceable pressurized ionization chamber.

Quality control procedures on all instruments included daily background and check-source measurements to confirm equipment operation within acceptable statistical fluctuations. The ORAU laboratory participates in the EPA Cross Check and EML Quality Assurance Programs.