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FORMERLY UTILIZED MED/AEC SITES REMEDIAL ACTION PROGRAM

REPORT OF
THE DECONTAMINATION OF JONES CHEMICAL LABORATORY, RYERSON PHYSICAL LABORATORY, AND ECKHART HALL
THE UNIVERSITY OF CHICAGO
CHICAGO, ILLINOIS

OCCUPATIONAL HEALTH AND SAFETY DIVISION
Health Physics Section
ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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DRAFT

ANL-OHS/HP-84-108

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FORMERLY UTILIZED MED/AEC SITES REMEDIAL ACTION PROGRAM REPORT OF THE DECONTAMINATION OF JONES CHEMICAL LABORATORY, RYERSON PHYSICAL LABORATORY AND ECKHART HALL THE UNIVERSITY OF CHICAGO CHICAGO, ILLINOIS

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EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) has implemented a program to decontaminate radioactively contaminted sites that were formerly utilized by the Manhattan Engineer District (MED) and/or the Atomic Energy Commission (AEC) for activities that included handling of radioactive material. This program is referred to as the "Formerly Utilized Sites Remedial Action Program" (FUSRAP). Among these sites are Jones Chemical Laboratory, Ryerson Physical Laboratory, Kent Chemical Laboratory, and Eckhart Hall of The University of Chicago, Chicago, Illinois.

From 1942 until 1952, portions of these buildings were used for nuclear research and development activities under MED/AEC contracts. Although it was reported that after use of radioactive materials ceased, the facilities were decontaminated to levels consistent with criteria then in force, a search of records conducted in the 1970s failed to reveal documentation pertinent to these earlier decontamination activities. Hence, the U.S. Atomic Energy Commission (AEC) (now DOE) directed the Argonne National Laboratory (ANL) Health Physics Radiological Survey Group (HP/RSG) to perform a radiological evaluation of these facilities. Radiological surveys were performed during the fall of 1976 and the summer of 1977. The surveys resulted in the documentation of specific areas of contamination above current guidelines remaining in these buildings.

Since 1977, the University of Chicago decontaminated Kent Chemical Laboratory as part of a facilities renovation program. The ANL-HP/RSG, per request of DOE, conducted a post-remedial-action survey of this decontamination effort in 1983. The post-remedial-action survey of Kent Chemical Laboratory has been documented in a separate report (ANL-OHS/HP-83-107). ANL was also requested to perform the necessary remedial action in the remaining three buildings (Eckhart Hall, Ryerson Physical Laboratory, and Jones Chemical Laboratory), as well as to perform a radiological assessment of the sewer systems servicing these facilities. These activities were accomplished during the 1984 fiscal year and the results form the basis for this report.

All areas of Eckhart Hall, Ryerson Physical Laboratory, and Jones Chemical Laboratory that had been identified as contaminated in excess of current guidelines in the 1976-1977 surveys (see Refs. 1, 3 and 4) were decontaminated to levels where no contamination could be detected relative

to natural backgrounds. All areas that required defacing to achieve this goal were restored to their original condition.

The radiological evaluation of the sewer system, based primarily on the radiochemical analyses of sludge and water samples, indicated that the entire sewer system is measurably contaminated. Decontamination of the sewer system was not included in the purview of this effort.

The documentation included in this report substantiates the judgment that all contaminated areas identified in the earlier reports (see Refs. 1, 3 and 4) in the three structures included in the decontamination effort (Eckhart Hall, Ryerson Physical Laboratory, and Jones Chemical Laboratory) were cleaned to levels commensurate with release for unrestricted use.

This activity was performed under the auspices of the Health Physics Section of the Occupational Health and Safety Division of Argonne National Laboratory, Agonne, Illinois. The following Health Physics personnel participated: R. A. Wynveen, W. H. Smith, K. F. Flynn, C. M. Sholeen, J. D. Thereon and D. W. Reilly. The following Waste Management personnel participated: C. P. Finch, L. Brooks and E. E. Armand II.

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INTRODUCTION

During 1939 and 1940, U.S. interest in nuclear physics increased as a result of scientific discoveries, the war in Europe, and the possibility for development of an atomic bomb. During that time, the National Defense Research Committee (NDRC) was interested in constructing uranium piles that would maintain self-sustaining nuclear chain reactions. In connection with this interest, the NDRC in January 1941 contracted for the University of Chicago to make measurements on beryllium as a moderator for a uranium pile. This was the beginning of the University of Chicago involvement in the U.S. nuclear research program.

When the United States entered World War-II in December 1941, the nation's nuclear physics research effort was reorganized. The Office of Scientific Research and Development (OSRD) became responsible for all work related to nuclear chain reactions, and all emphasis was centered on production of an atomic bomb. The OSRD established the S-1 Committee to assume responsibility for scientific studies and measurements necessary to develop such a bomb. Individual committee members accepted responsibility for various aspects of the project. Dr. Arthur Compton, a professor at the University of Chicago, was responsible for the theoretical studies and experimental measurements necessary to produce element 94 (plutonium) for the bomb. Pursuant to this responsibility, a contract was initiated between the University of Chicago and OSRD in January 1942. Between then and the end of May 1942, pile experiments from Columbia and Princeton Universities were transferred to the Metallurgical Laboratory (Met Lab), which was created on the University of Chicago campus.

To produce large quantities of plutonium that were needed for the bomb, an intense source of neutrons was needed. (Plutonium is produced when neutrons are absorbed by uranium.) Only uranium piles offered the possibility of creating this neutron source by producing a self-sustaining nuclear chain reaction. The first pile that was large enough to sustain a chain reaction was composed of uranium and graphite. It was constructed beneath the west stands of Stagg Field at the University of Chicago under the direction of Dr. Enrico Fermi. The self-sustaining condition was achieved on December 2, 1942.

During 1942, Dr. Compton also transferred all work on the development of methods for the purification of plutonium to the Met Lab. In April 1942, Dr. Glenn Seaborg arrived in Chicago with a group from the University of California at Berkeley to continue their chemical work on element 94 separation and purification. The work on plutonium chemistry and pile experiments, which involved use of the Kent Chemical Laboratory, the Ryerson Physical Laboratory, Eckhart Hall, and Jones Chemical Laboratory, was conducted exclusively at the University of Chicago. At that time, the Clinton Laboratories in Tennessee (now Oak Ridge National Laboratory) were organized to institute pilot plant operations.

By June 1942, the Army Corps of Engineers took over responsibility for atomic bomb development and production, forming the Manhattan Engineer District (MED) for this purpose. After the feasibility of producing plutonium had been demonstrated, the contract with the Met Lab at the University of Chicago was transferred from OSRD to MED on May 15, 1943. Experimental work at the Met Lab continued under MED until 1946, when the Atomic Energy Commission (AEC), a civilian organization, was created. At that time, the name of the laboratory was changed from the Metallurgical Laboratory to Argonne National Laboratory (ANL). Work under the AEC contract continued through 1952, when most of the activities were moved from the University of Chicago campus to the new site of Argonne National Laboratory in DuPage County.

A record search conducted in the 1970s did not reveal documentation relative to radiation surveys or decontamination efforts that had been conducted in the University of Chicago facilities after termination of MED/AEC activities. Therefore, the U.S. Atomic Energy Commission (AEC) directed the Argonne National Laboratory (ANL) Radiological Survey Group (RSG) to perform radiation surveys of the facilities of concern to determine if any radioactive contamination above current guidelines remained. The surveys were performed during the fall of 1976 and the summer of 1977. The results, as reported in earlier documents[1,2,3,4], indicated that, while the contamination was minimal, some remedial action was needed in order to meet current radioactive contamination guidelines.

Since 1977, the University has decontaminated Kent Chemical Laboratory prior to and concurrent with some facility renovations. In May 1983, DOE requested that the ANL Radiological Survey Group conduct a post-remedial-action survey of Kent Laboratory. The results are reported elsewhere.[5] DOE also has requested ANL to perform the necessary remedial action on the remaining three facilities of interest (Jones and Ryerson Laboratories and Eckhart Hall) and to conduct an assessment of the radiological conditions of the sewer system for all four buildings. In accordance with DOE program directives at that time, an assessment of the sewer system had not been accomplished during the 1976-1977 radiological survey activities. The results of these remedial action activities are reported in this document.

FACILITIES DESCRIPTION

The campus of the University of Chicago is on a 171-acre site in the City of Chicago, seven miles south of Chicago's Loop (see Fig. 1). It includes 127 buildings. As shown in the partial campus plan (see Fig. 2), Jones Chemical Laboratory, Ryerson Physical Laboratory, and Eckhart Hall are located in the approximate center of the campus, facing the central quadrangle. The three facilities currently are used for teaching and research purposes. From 1942 until 1952, the Metallurgical Laboratory-Argonne National Laboratory utilized portions of these buildings. As a consequence of nuclear research and development activities in the 1940s and 1950s, some small surface areas in the three facilities remained contaminated with low levels of radioactive material. Since the levels of contamination exceeded current guidelines, remedial action was specified.

During the early 1950s, operations were transferred from the University campus to the new Argonne National Laboratory site in DuPage County. Upon transfer of nuclear activities to the DuPage site, the University campus facilities that had been used by Argonne National Laboratory and its predecessor, the Metallurgical Laboratory, were decontaminated to levels consistent with guidelines then in force. These facilities included (among others) Jones Chemical Laboratory, Kent Chemical Laboratory, Ryerson

Physical Laboratory, and Eckhart Hall. All radiological measurements associated with the decontamination effort of that time were conducted using state-of-the-art instrumentation and techniques prevalent in the early 1950s.

Radioactive materials involved in the nuclear activities conducted on the campus ranged from activation and fission products through and including transuranic elements. Based on initial radiological observation made during the 1976-1977 surveys, the predominant contaminants were expected to be natural uranium and normal uranium.

The three buildings, Jones Chemical Laboratory, Ryerson Physical Laboratory, and Eckhart Hall were subjected to remedial action in accordance with the Project Management Plan.[6] These buildings are now, and have been in the past, used as normal academic laboratories, classrooms, and offices. Contaminated areas, as determined by the ANL Radiological Survey Group, had been identified in reports DOE/EV-0005/23[4], DOE/EV-0005/24[3], and DOE/EV-0005/26.[1]

Kent Chemical Laboratory, which also was used for nuclear research in the 1940s and 1950s, is being gutted as part of a complete remodeling of the interior. This effort will continue into 1985. The exterior portion of the building will remain the same as the initial construction in the late 1890s. Kent Chemical Laboratory was decontaminated by University of Chicago personnel, and verified by a post-remedial-action assessment conducted by the ANL Radiological Survey Group (ANL-RSG).[5] During that assessment, ANL-RSG personnel determined that the building's sewer lines contained radioactive contamination. However, these sewer lines were subsequently removed and replaced during the course of building reconstruction.

PROJECT OBJECTIVES

The objectives of the remedial action plan for Jones Chemical Laboratory, Ryerson Physical Laboratory, and Eckhart Hall remedial action were to (a) decontaminate (to levels commensurate with guidelines for unrestricted use) those areas that had been found to exceed the appropriate criteria during the 1976-1977 radiological assessment, (b) restore those areas defaced by decontamination efforts, and (c) disposal of generated radioactive waste.

The lead contractor for this remedial action was Argonne National Laboratory (ANL). The Health Physics Section of ANL's Occupational Health and Safety Division was responsible for all of the decontamination activities. Results of the radiological characterization surveys conducted during 1976 and 1977 by the ANL-RSG constituted the data base for these decontamination activities. In addition, an evaluation of the radiological conditions of the sewer system associated with the facilities was conducted.

DECONTAMINATION PROCEDURES

Experienced health physics and waste management operations specialists from ANL constituted the primary source of operating (working) personnel. When necessary, subcontractors mutually agreed upon by Argonne National Laboratory and the University of Chicago, were used. Certain restoration activities were conducted by tradesmen from Argonne National Laboratory and/or the University of Chicago as mutually agreed upon and as listed in the Two-Party Agreement.[7]

Remedial Action guidelines used for this project generally embody Draft American National Standard N13.12[10] and NRC Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source or Special Nuclear Material, July 1982.[11] The guidelines applied were at least as stringent as those specified in Rules and Regulations for Protection Against Radiation, Illinois Department of Public Health (as amended through July 1980).[12] "As Low As Reasonably Achievable" (ALARA) concepts were always applied.

All radioactive waste resulting from the decontamination activities was packaged in M-3 bins (see Fig. 3) and transported to Argonne National Laboratory for subsequent shipment to the waste site (EG&G, Idaho). These bins qualify as "Type A packaging" (49 CFR 171) and are acceptable at low-level waste disposal sites.

Decontamination of the residual radioactivity in Jones Chemical Laboratory, Ryerson Physical Laboratory, and Eckhart Hall was accomplished utilizing standard procedures such as the application of solvents for metals, scabbling for concrete, etc. Items and materials that could not be readily decontaminated (e.g. ductwork) were removed and replaced wherever possible. Areas and items that were decontaminated in these three buildings were those identified as contaminated in the previous radiological survey reports.[1,3,4] All items and areas identified in those reports as being contaminated were subject to an initial survey and as many follow-up surveys as needed during the course of decontamination to ensure that the appropriate criteria had been met.

Hoods and/or duct work suspected or known to be contaminated as a result of Met Lab-ANL activities were removed and disposed of as radioactive waste wherever possible. Decisions on such matters were made on a case-by-case basis.

The air in the vicinity of decontamination activities was constantly monitored for airborne radioactivity. No airborne contamination was detected during these operations.

The ductwork inside the walls of Jones Laboratory was inaccessible without extensive demolition within the building. Since these "potentially" contaminated ducts do not represent an immediate hazard, it was agreed that the ducts would remain until such time as the walls are demolished by the university. At that time, the duct materials may need to be treated as potentially contaminated waste.

Items and areas affected by decontamination operations were restored or replaced (as determined on a case-by-case basis) subject to agreement between DOE, ANL, and the University of Chicago.

Radiological assessments were made of sewer lines and drains associated with Kent Chemical Laboratory, Jones Chemical Laboratory, Ryerson Physical Laboratory, and Eckhart Hall. Sewers were surveyed at all available access points with portable survey instruments. Additionally, water and/or sludge samples were taken at these access points. These samples were radiochemically analyzed to ascertain the type and concentration of any radioactive contaminants. These lines and drains were not removed as a part of this operation, even though measurable levels of radioactive material were found in samples taken from available access points. Based on the results of these radiological assessments, the need for any immediate remedial action for the sewer lines is unnecessary.

Three types of portable survey instruments were used to conduct the direct radiological surveys. Gas-flow proportional detectors with window areas of 51 cm^2, 100 cm^2 and 325 cm^2 (using Eberline PAC-4G-3 electronics) were used to monitor for alpha and/or beta-gamma radiation. NaI crystal detectors, 2 in (5 cm) in diameter by 2 mm thick (Eberline PG-2 with

Eberline PRM-5-3 electronics), were used to monitor for low energy x-ray and gamma radiation. NaI crystal detectors, measuring 1 in (2.5 cm) in diameter by 1 in (2.5 cm) thick (Eberline PRM-7 μRmeter) and calibrated with a ^{137}Cs-^{137m}Ba standard source, were used to measure the ambient external penetrating radiation field. These instruments and associated calibration procedures are detailed in Appendices 1 and 2.

Decontamination efforts were continued until radiation levels, as determined by these three instruments, were indistinguishable from the general background radiation.

DECONTAMINATION RESULTS

- Eckhart Hall - The contaminated areas identified in the previous radiological survey of Eckhart Hall[3] are listed in Table 1 and the locations shown in Figure 4. The final condition of each contaminated area as a result of the decontamination effort is also reported in Table 1. Several of the spots previously identified as contaminated[3] no longer had detectable contamination. Some of the spots (e.g., #15 in Room 6 and #59 in Room 19) were attributable to natural radioactivity present in the materials identified. All contaminated areas were cleaned to the point no contamination was detectable, and the surfaces were restored to their original condition or equivalent (see Figs.. 19 and 20).

Cabinets that had been identified as containing radioactive material in the original report[3] (i.e., #25 in Room 8, #158 in Room 120, and #s 152 and 153 in Room 119) had been removed prior to this effort.

evidence of contamination?

A survey of the building for the presence of exhaust ducts revealed a duct through the window in Room 14 (possibly originally from a hood that was removed sometime in the past) and a duct that extended from a relatively new hood in Room 130, up the elevator shaft, and out through the chimney. The duct through the window in Room 14 was removed and disposed of as radioactive waste. The adjacent areas were surveyed and no contamination was detected. This latter hood and duct (in Room 130) were reportedly installed during the 1950s and are currently in use. No action was taken regarding this system.

A sample of debris (EH-S-12) was taken from a window well adjacent to where a hood duct vented from a basement window of Eckhart Hall (see Fig. 4). This hood duct was removed and disposed of as possibly contaminated waste. The debris sample indicated an elevated level for ^{137}Cs (14 pCi/g) but levels considered to be normal background for the other isotopes (see Table 5).

The decontamination effort in Eckhart Hall was restricted to the basement area. No surface contamination was found on the upper floors (1st through 4th) during the initial survey.

- Ryerson Physical Laboratory - The contaminated areas identified in the radiological survey of Ryerson Physical Laboratory[4] are listed in Table 2 and the locations shown in Figures 5 through 9. The final status of each contaminated area as a result of the decontamination effort is also included in Table 2. Several of the spots previously identified[4] as contaminated had no detectable contamination at the time of the decontamination project. Some of the spots were found to be attributable to natural radioactivity present in the materials identified. All areas indicating contamination were cleaned to "no contamination detectable" level, and the surfaces were restored to their original condition or equivalent.

A small area of contamination located on the floor at the entrance to Room 255 (see Fig. 7 and Table 2) was removed and the floor was resurfaced. This contamination was identified as ^{226}Ra. The adjacent area, including the second floor hallway and Room 255C, were surveyed in their entirety. No additional contamination was detected. Radioactive sources that had been identified on the second and third floors had been removed subsequent to the original survey. However, a ^{60}Co source and two radium-beryllium sources located on the fourth floor (locations 310, 326, and 328, respecitively, in Fig. 8), are still in use. Additionally, several pieces of contaminated material (e.g. depleted uranium foils, thorium tubes, radioactive electron tubes, etc.) found in the fourth floor attic were disposed of as solid radioactive waste.

Was contamination actually identified in the hood duct removed

A survey of the building for exhaust ducts revealed a single duct extending from the first floor (Room 161) through the wall of the second floor (Room 256A) and third floor (Room 359) and then out through the roof adjacent to Room 450 and the fourth floor (see Figures 6 through 9). This duct was removed and disposed of as SRW. All defaced areas were restored to their original condition (see Figs. 21-27). All adjacent areas were surveyed and no contamination was detected.

- <u>Jones Chemical Laboratory</u> - The contaminated areas identified in the radiological survey of Jones Chemical Laboratory Report[2] are listed in Tables 3 and 4 and the locations are shown in Figures 10 through 17. The final status of each of these areas following the decontamination effort is also noted in Tables 3 and 4.

Several of the spots previously identified[1] as being contaminated had no detectable contamination at this time. Paramount among these was the complex of Rooms 19, 20, 22, 23 and 23A in the basement and the complex of Rooms 120, 121, 122, 123, 124, and 125 on the first floor. Both areas had undergone extensive remodeling, including the removal of walls and the replacement of floor coverings (e.g. tiles, etc.), and as a result, no contamination was detectable. Additionally, the contamination previously identified in Room 104 was no longer present. However, Rooms 104, 105, and 106 represent a complex of laboratories currently in use as radiochemical laboratories. Contamination in these rooms is usually from short-lived activities and either decays away or is cleaned up by the university personnel.

The first, second, and third floors of the building had no detectable contamination at this time. The basement had a few relatively small areas of contamination that were readily cleaned by removal of the surface or, in one case (Room 10), by removal of a junction box and attached conduit. The fourth floor had substantial contamination in Rooms 404D and 404E. Some piping and a significant amount of floor material were removed from Room 404D. Large quantities of yellow uranium salts were found to have been grouted over. These areas of the concrete floor were completely removed. A large fraction of one wall and a small section of floor material were removed from Room 404E. Both rooms were restored to their original condition after the contamination was removed (see Figs. 28-33).

The fourth floor attic section (see Fig. 16) had substantial floor contamination scattered throughout. It was necessary to completely clear this area of stored equipment and furniture prior to the initiation of decontamination activity. The material was surveyed for radioactive contamination and then temporarily stored in two large tractor trailers for the duration of the decontamination and restoration.

Much of the contaminated area was cleaned by scrubbing with suitable solvents and scabbling some small areas of concrete. However, a large area of contamination in the northeast corner of the attic floor (see Fig. 16) was severely contaminated with visible deposits of yellow uranium salts (primarily nitrate) penetrating deep into the concrete. It was necessary to remove concrete from this area (~ 400 ft^2) with a jackhammer penetrating completely through the floor at three spots. The contamination in this area was identified as normal uranium (i.e., uranium that had been separated from its natural daughters).

All attic areas were cleaned until contamination could not be detected above the ambient background. The floor, having been certified free from contamination, was restored to its original condition and the equipment and furniture were returned from storage (see Figs. 34-36).

The building was surveyed in its entirety for exhaust ducts that were or had been connected to hoods. All remaining hoods in the building (see Figs. 10 through 14), as well as exposed duct work, were of recent origin (see Fig. 37). However, the ductwork within the walls and exhausts through the attic (see Fig. 14) and chimneys were from the original discharge system. These ducts were inside interior walls and, hence, inaccessible without extensive demolition of those walls. Since potential contamination within these ducts does not represent an immediate hazard, it was agreed[13] that the ducts would remain until such time as the walls are demolished by the university as part of renovation or building removal. At that time, the duct material may need to be handled as contaminated waste.

SEWER EVALUATION

A systematic evaluation of the radiological condition of the sewer systems exiting from the four University of Chicago buildings associated with these decontamination activities (see Fig. 2) was conducted. Instrument surveys were made at all available access points to the sewer system, and whereever possible, water and sludge samples were taken for radiochemical analysis. No contamination was detected using the survey instruments; however, contamination was detected by radiochemical analysis of several of the samples. All samples containing water were divided into dissolved solids (DS) and suspended solids (SS) fractions prior to analysis. Samples with insufficient water to identify a separate phase were dried and treated as a single sample.

- Eckhart Hall - Sewer access points in the Eckhart Hall basement are identified in Figure 4 (also see Fig. 38). A total of nine samples (EH-SS-3 through EH-SS-11) were taken from eight locations. The results of the analyses of these samples are given in Tables 5, 6 and 7. Access points EH-SS-7 through EH-SS-11 seemed to follow a single drain line proceeding from west to east along the southern end of the building. An additional access point north of the transverse corridor (EH-SS-6, see Fig. 4) seemed to be part of this same drainage system. Samples taken from these access points were dry, indicating infrequent use. Normal background concentrations of ^{232}Th and ^{226}Ra decay chains were found. However, elevated levels of uranium were found in all samples, reaching as high as 179 pCi/g in sample EH-SS-8. Mass spectrometric analysis of this sample (see Table 6) indicated normal abundances for the isotopes, as expected. Since the ^{226}Ra decay chain was at background levels, this contamination is normal uranium (i.e. uranium that has been separated from its natural daughters). This sample was further analyzed for plutonium contamination, and slightly elevated levels (i.e., 68 fCi/g, see Table 7) of this isotope were also found. General background levels for plutonium range between 15 and 20 fCi/g in surface soil.

Additional sewer samples were taken from a pit (EHSS-5) and a sump (EHSS-3 and EHSS-4) located in the eastern side of the building (see Fig. 4) where the main building drain exits eastward to the sewer along University Avenue (see Fig. 2). The sample from the pit (EHSS-5) had background levels for all isotopes; however, the water samples from the sump indicated elevated levels for ^{226}Ra decay chain (104 pCi/g), ^{232}Th decay chain (101 pCi/ℓ), and ^{137}Cs (~~42~~ 57 pCi/g), as well as slightly elevated levels (8 pCi/g) for uranium (see Table 5). One of the samples (EHSS-3) also indicated a slightly elevated level (23 fCi/g) for plutonium (see Table 7). There were no accessible access points to the sewer lines exterior to this building (Eckhart Hall) prior to discharge into the main sewer line under University Avenue. The main sewer lines were not investigated since they are City of Chicago property.

- Ryerson Physical Laboratory - Sewer access points in the Ryerson Physical Laboratory basement are identified in Figure 5 (also see Fig. 40). A total of 12 samples (RL-SS-4 through RL-SS-15) were taken from 10 access points in the interior of the building, and one sample (RL-SS-3) was taken from a catch basin just west of the building. The main building drain exits westward to the sewer under Greenwood Avenue. The results of the analyses of these samples are given in Tables 5, 6, and 7.

Substantially elevated levels of ^{137}Cs contamination were found in two locations (RL-SS-8 and RL-SS-13). Significant ^{232}Th decay chain contamination was also found in two locations (RL-SS-5 and RL-SS-13). Significant ^{226}Ra decay chain contamination was also found in two locations (RL-SS-3 and RL-SS-11). An elevated level of uranium contamination was found at one location (RL-SS-4). At this latter location, the ^{226}Ra decay chain concentration was not elevated, indicating that the uranium contamination was from normal uranium (i.e.,

Quantify as for Eckhart above

uranium that had been separated from its daughters). Mass spectrometric analysis of this sample showed that the uranium isotopes were in their normal abundances (see Table 6). Plutonium contamination was also found in sample RL-SS-5 (see Table 7).

- Jones Chemical Laboratory - Sewer access points in the Jones Chemical Laboratory basement are identified in Figure 10 (also see Fig. 39). A total of nine samples (JC-SS-2 through JC-SS-10) were taken from seven access points in the interior of the building, and one sample (JC-SS-11) was taken from a sewer manhole exterior to the southwest corner of the building (see Fig. 10). The sewer system from this building exits west into the main drain under the street along Ellis Avenue. The results of the analyses of these samples are given in Tables 5, 6, and 7. No significant ^{137}Cs contamination was found in these samples. However, elevated levels of the ^{232}Th decay chain (274 pCi/g) were found in JC-SS-11, and elevated levels of the ^{226}Ra decay chain (60 pCi/ℓ) were found in JC-SS-6. Elevated levels of uranium contamination was found in three samples (JC-SS-3, JC-SS-5 and JC-SS-6). Mass spectrometric analysis of sample JC-SS-6 showed normal abundances for the isotopes (see Table 6). The lack of equilibrium with ^{226}Ra daughters (see Table 5) indicated that the contamination is normal uranium (i.e., uranium that has been separated from its natural daughters). Some plutonium contamination (see Table 7) was found in ~~five~~ some of the samples (JC-SS-2, JC-SS-3, JC-SS-5, 6 + 10 JC-SS-11 and JC-SS-14). Contamination levels, confinement, and inaccessibility reduce the need for any further remedial action at this time.

exterior

note some Th in I-5

quantify as for Eckhart area

exterior

14 is external - discuss on p.1

- Kent Chemical Laboratory - An analysis of the status of the sewers in Kent Chemical Laboratory was conducted as part of the post-remedial-action radiological survey of that facility. The results were documented in a separate report.[5] Subsequent to this survey[5], the sewer lines under Kent Laboratory (main building) were removed and replaced. The sewer lines under the auditorium adjunct to the building were not removed but these lines are not part of the Laboratory sewer system.

not a sewer Ra cont. already discussed on p. 12.

- **Exterior Lines** - Samples were taken from the sewer lines exterior to these buildings at all available access points on University of ~~Chicago~~ property. A total of 20 samples (JC-SS-11 through JC-SS-14, RL-SS-3, and RL-SS-16 through RL-SS-30) were taken from 13 locations. These locations are identified in Figure 18 (also see Figs. 41-44). The results of the analyses of these samples are given in Tables 5, 6, and 7. Elevated levels of ^{137}Cs contamination were found at three locations (JC-SS-12, RL-SS-20 and RL-SS-26). ^{232}Th decay chain contamination was found at four locations (JC-SS-11, JC-SS-12, RL-SS-20 and RL-SS-26). ^{226}Ra decay chain contamination was found at four locations (JC-SS-11, JC-SS-13, RL-SS-16, and RL-SS-28). Slightly elevated levels of uranium were found at one location (RL-SS-19). Plutonium contamination was found at two locations (JC-SS-11 and JC-SS-14).

The contamination found in the sewer system samples was sufficiently extensive that the entire sewer system should be considered contaminated. However, the level, confinement and inaccessibility reduce the need for any further remedial action at this time.

FINAL CONDITION

Upon completion of these decontamination activities, all contaminated areas in the interiors of Eckhart Hall, Ryerson Physical Laboratory, and Jones Chemical Laboratory that were identified in the 1976-1977 radiological surveys had been cleaned to the level that contamination could no longer be detected. Additional areas of contamination that were detected during the course of these activities were also cleaned to the level that contamination could no longer be detected. The entire buildings were not resurveyed at this time. Moreover, at the time of the 1976-1977 radiological survey, it was not possible to survey every square foot of surface because of the presence of immovable objects (e.g. plumbing fixtures, cabinets, permanently installed carpeting, etc.) Nevertheless, within the framework of these limits, the interior of these buildings are deemed to be generally free from measurable contamination. All decontaminated areas were restored to their original condition.

Areas of Eckhart Hall requiring significant defacing to remove the contamination were restricted to the basement (see Fig. 4). Photographs of the principal area before and after restoration are shown in Figure 19.

Areas of Ryerson Physical Laboratory requiring restoration after decontamination included all levels, basement through fifth floor (see Figures 5 through 9). The most extensive decontamination and restoration effort was associated with the removal of the hood exhaust duct and the companion roof vent. Photographs showing the various stages in the removal of the roof vent are presented in Figure 20. Photographs showing the removal of the exhaust duct and the restored wall are reproduced in Figure 21.

Areas of Jones Chemical Laboratory requiring extensive defacing and associated restoration were restricted to the fourth floor (see Fig. 14) and the attic (see Fig. 16). A large section of the wall in Room 404E was removed and replaced. Photographs of this operation are shown in Figure 22. In Room 404D, a large section of floor (about 30 ft^2) that was visibly contaminated with uranium salts to about a 2-in depth was removed. Photographs of this operation are shown in Figure 23. A very large section of the northeastern section of the concrete attic floor (see Fig. 16) was removed with jackhammers. The floor beneath the surface was visibly contaminated with uranium salts. This contamination covered a large area (~ 400 ft^2) and penetrated about 3 in deep. Photographs of the area during decontamination and after restoration are shown in Figure 24.

Hoods and duct work remaining from the MED/AEC era were removed from Eckhart Hall and Ryerson Physical Laboratory. All of the hoods, as well as the exposed duct work in Jones Chemical Laboratory, were of recent vintage. A typical hood and exposed duct complex is shown in Figure ~~25~~ 37. The locations of all existing hoods in Jones Chemical Laboratory are shown in Figures 10 through 17. All duct work within the walls are from the original discharge system that was present during the MED/AEC era. These ducts were not removed (per agreement, Reference 13) and will remain in place until such time as the walls are demolished by the university. At that time, these duct materials may need to be treated as contaminated waste.

[illegible]
1 hood
removed
(Ryerson
2 ducts
(1 Eckhart
1 Ryerson)

A total volume of about 300 ft^3 of radioactively contaminated solid waste and three 55-gallon drums of liquid waste were produced as a result of decontamination efforts. The solid waste was returned to ANL for shipment to the radioactive waste disposal site (EG&G, Idaho). The liquid waste was returned to ANL for processing and disposal according to accepted ANL procedures. The contamination present in this waste material was primarily normal uranium as established by gamma spectrometric, uranium fluorometric, and mass spectrometric techniques.

Decontamination of the sewer system was not included in the purview of this effort. Nevertheless, a comprehensive evaluation of the radiological condition of the sewer system was attempted, and the results are included in the "Sewer Evaluation" section of this report. The condition of the sewer system remains as reported in that section. Photographs of typical sewer access points in Eckhart Hall, Ryerson Physical Laboratory, and Jones Chemical Laboratory are shown in Figure 26. Photographs of typical sewer access points exterior to the building are shown in Figure 27.

CONCLUSIONS

The three structures associated with this decontamination effort (Eckhart Hall, Ryerson Physical Laboratory, and Jones Chemical Laboratory) can be certified free from significant contamination and released for unrestricted use.

The duct work remaining inside the interior walls of Jones Chemical Laboratory remains suspect and may need to be treated as contaminated with both MED/AEC and university deryied radioactivity whenever these walls are removed by the university.

The sewer systems and drains beneath and exiting from these buildings had sufficiently extensive contamination for the entire sewer system to be considered contaminated. This contamination does not pose an immediate hazard. Appropriate safeguards should be taken into consideration whenever these sewers are intruded upon or removed.

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2. Radiological Survey of Kent Chemical Laboratory, The University of Chicago, Chicago, Illinois, September 7-13, 1977. DOE/EV-0005/25 (ANL-OHS/HP-82-101), Occupational Health and Safety Division, Argonne National Laboratory, May 1982.

3. Radiological Survey of Eckhart Hall, The University of Chicago, Chicago, Illinois, September 14, 1976, March 22, 1977. DOE/EV-0005/24 (ANL-OHS/HP-82-102), Occupational Health and Safety Division, Argonne National Laboratory, May 1982.

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(cont'd.)

12. Rules and Regulations for Protection Against Radiation. Illinois Department of Public Health (as amended through July 1980).

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TABLE 1. ECKHART HALL - CONTAMINATION LOCATIONS[a]

Room Number	Location Number	Estimated Area of Contamination (cm^2)	Maximum PAC Reading ($dis/min-100\ cm^2$) Beta-Gamma	Alpha	Final Status
3	7	500	1.2×10^3	BKGD[b]	NCD[c] Tile removed
	8	500	2.5×10^3	BKGD	NCD Tile removed
6	15	500	7.8×10^2	BKGD	NCD[c] (high natural background from brick wall)
8	25	-	6.5×10^4	BKGD	Cabinet removed
9	30	500	9.0×10^3	BKGD	NCD[c] Tile removed
12	39	500	5.6×10^4	1.7×10^3	NCD[c] Tile removed
19	59	500	4.2×10^4	6.4×10^3	Soapstone bench cleaned to NCD (this material has high natural background)
	60	500	6.2×10^3	BKGD	Floor decontaminated to NCD and repaired
25	71	500	3.1×10^4	6.6×10^2	NCD[c] Tile removed
27	78	500	2.0×10^3	BKGD	NCD[c] - wall had been repaired
Basement Corridor	88	500	-	BKGD	Removed tile and decontaminated subflooring to NCD by scabbling; subfloor resurfaced and tile replaced
	89	500	-	BKGD	
Main Stairs	90	200	2.0×10^4	BKGD	Decontaminated to NCD by abrasion of stone surface; no resurfacing required
	91	1000	3.5×10^5	3.9×10^4	

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[a] Locations are shown in Figure 4.

[b] BKGD = Background.

[c] NCD = No Contamination Detected at the time of decontamination activity.

TABLE 2. RYERSON PHYSICAL LABORATORY - CONTAMINATION LOCATIONS[a]

Room Number	Location Number	Estimated Area of Contamination (cm^2)	Maximum PAC Reading (dis/min-100 cm^2) Beta-Gamma	Alpha	Final Status
Basement Corridor	7	500	3.2×10^5	BKGD[b]	NCD[c]
50	9	500	4.6×10^4	BKGD	Decontaminated to NCD
	11	500	1.6×10^3	BKGD	Decontaminated to NCD
55	29	500	1.6×10^3	BKGD	Cleaned to NCD (this material has high natural background)
56	32	200	1.1×10^5	BKGD	Instrument chassis disposed of (SRW)[d]
	33	200	1.1×10^5	BKGD	Metal box - gone
	34	200	1.9×10^5	BKGD	Metal box - gone
	35	200	7.8×10^4	BKGD	Metal chassis - gone
	36	200	1.6×10^3	BKGD	Contaminated tube - gone
59B	45	100	2.7×10^3	BKGD	NCD[c]
	46	-	1.5×10^4	BKGD	Sources removed
	47	-	6.3×10^4	BKGD	Sources removed
	48	-	4.3×10^3	BKGD	Sources removed
	49	200	4.3×10^3	BKGD	NCD[c]
	50	-	4.6×10^4	BKGD	Sources removed
60	53	500	4.5×10^3	BKGD	NCD[c]
	54	500	4.5×10^3	BKGD	NCD[c]
61	57	500	5.9×10^3	BKGD	Cleaned to NCD (this material has high natural background)
62	61	1000	1.5×10^5	1.2×10^4	Decontaminated to NCD
	62	500	7.8×10^3	BKGD	NCD[c]
63	65	300	1.8×10^4	BKGD	Decontaminated to NCD
N-001	76	100	5.1×10^3	BKGD	NCD[c]

TABLE 2. - (cont'd.)

Room Number	Location Number	Estimated Area of Contamination (cm^2)	Maximum PAC Reading (dis/min-100 cm^2)		Final Status
			Beta-Gamma	Alpha	
N-76	83	500	3.5×10^3	BKGD	NCD[c]
	84	1000	1.5×10^4	BKGD	NCD[c]
Stairway	106	100	7.8×10^4	1.3×10^4	Wooden cart had been removed; was located in Jones basement and disposed of as SRW
	107	100	-	-	
155	(new)	300	4×10^3	BKGD	Decontaminated to NCD
158	128	300	1.2×10^4	3.0×10^3	Decontaminated to NCD above background of natural material in stone
Loading Dock	129	500	BKGD	3.0×10^3	NCD[c]
161	137	500	1.5×10^4	BKGD	Hood removed; then NCD
162	141	500	1×10^6	1.5×10^5	Removed oak floor and subfloor to NCD
253	202	200	7.2×10^3	BKGD	Cleaned to NCD
	203	200	4.8×10^3	BKGD	Cleaned to NCD
255	212	-	-	-	Check sources removed
255	e	100	1.2×10^4	2.0×10^3	Floor removed to NCD
256A	218	200	1.6×10^4	BKGD	Window sill cleaned to NCD
256	221	200	1.4×10^4	BKGD	Window sill cleaned to NCD

TABLE 2. - (cont'd.)

Room Number	Location Number	Estimated Area of Contamination (cm^2)	Maximum PAC Reading ($dis/min-100\ cm^2$) Beta-Gamma	Alpha	Final Status
257	224	200	9.5×10^4	BKGD	Cleaned to NCD
	225	-	-	-	Standard source removed
258A	232	500	4.7×10^4	BKGD	Cleaned to NCD
	233	500	7.2×10^3	BKGD	Cleaned to NCD
	(new)	200	4×10^4	2×10^3	Cleaned to NCD
259	242	500	3.1×10^4	BKGD	NCD
M-200U	191	-	-	-	Bench samples removed
350	265	-	NRR[f]	BKGD	Source removed
351	266	-	1.5×10^4	BKGD	Source removed
361A	294	500	1.3×10^4	BKGD	Cleaned to NCD
	295	200	1.6×10^5	BKGD	Cleaned to NCD
361B	296	-	1.6×10^5	BKGD	Photo lense removed
450	309	300	1.9×10^5	9.6×10^4	Wooden bench had been removed
	310	-	2.2×10^3	BKGD	Source removed
453	326	-	2.2×10^4	BKGD	Source removed
	328	-	NRR	BKGD	Source removed
454	330	100	BKGD	8.0×10^4	Rheostat had been removed
	331	100	5.0×10^4	BKGD	Chassis had been removed
455	336	300	6.3×10^4	BKGD	Wooden bench had been removed
550	340	300	9.5×10^4	BKGD	Steel bench cleaned to NCD

TABLE 2. - (cont'd.)

[a] Locations are indicated in Figures 5 through 9.

[b] BKGD = Background.

[c] NCD = No Contaminatin Detectable at the time of decontamination activity.

[d] SRW = Solid Radioactive Waste.

[e] Contaminated area not previously identified.

[f] NRR = No Reading Recorded.

TABLE 3. JONES CHEMICAL LABORATORY - CONTAMINATION LOCATIONS[a]

Room Number	Location Number	Estimated Area of Contamination (cm^2)	Maximum PAC Reading ($dis/min-100\ cm^2$)		Final Status
			Beta-Gamma	Alpha	
Stairs by 17	6	200	1.2×10^3	BKGD[b]	NCD[c]
	7	200	6.2×10^2	BKGD	NCD[c]
	8	200	9.2×10^2	BKGD	NCD[c]
7E	31	200	2.0×10^3	BKGD	These floor areas were decontaminated to NCD
	32	20,000	2.3×10^3	BKGD	
10	36	100	3.9×10^5	BKGD	Contaminated junction box and conduit removed (SAW)[d] and replaced
16	41	200	6.2×10^2	BKGD	NCD[c]
17 and 17A	44	300	1.5×10^3	BKGD	Decontaminated to NCD
	45	300	2.0×10^3	BKGD	Decontaminated to NCD
	46	300	2.0×10^3	BKGD	NCD[c]
	47	300	3.0×10^3	BKGD	Decontaminated to NCD
19	51	300	3.0×10^2	BKGD	These rooms (19, 20, 23, and 23A) completely remodeled and all floors replaced; no remaining contamination detected.
	52	300	6.0×10^2	BKGD	
	53	300	1.2×10^4	9.6×10^2	
20	54	300	9.0×10^2	BKGD	
23 and 23A	59	300	3.0×10^2	BKGD	
	61	300	1.2×10^3	BKGD	

TABLE 3. - (cont'd.)

Room Number	Location Number	Estimated Area of Contamination (cm^2)	Maximum PAC Reading ($dis/min\text{-}100\ cm^2$)		Final Status
			Beta-Gamma	Alpha	
104	81	100	3.0×10^4	3.2×10^4	NCD[c]
	82	100	2.4×10^3	3.1×10^1	NCD[c]
	84	100	2.3×10^4	1.6×10^4	NCD[c]
	85	100	BKGD	1.6×10^5	NCD[c]
122	108	300	6.0×10^2	BKGD	These rooms (122, 124 and 125) completely remodeled and all floors replaced; no remaining contamination detected.
124	113	200	5.9×10^3	BKGD	
	114	300	1.6×10^3	BKGD	
	115	200	2.5×10^3	BKGD	
	116	200	5.9×10^3	BKGD	
	117	200	7.5×10^3	BKGD	
125	118	300	5.4×10^3	5.0×10^2	
	119	200	1.4×10^4	9.6×10^3	
213	141	-	1.4×10^4	BKGD	Source removed
222	158	100	9.5×10^4	BKGD	These three hoods have been replaced since the initial survey
	159	100	1.4×10^3	BKGD	
	160	100	1.0×10^5	BKGD	
316	192	300	5.6×10^3	BKGD	NCD[c](Floor was replaced)
404B	214	100	1.1×10^3	BKGD	NCD[c]
404D	217	300	2.1×10^4	BKGD	Decontaminated to NCD
	218	200	1.1×10^4	BKGD	Decontaminated to NCD

TABLE 3. - (cont'd.)

Room Number	Location Number	Estimated Area of Contamination (cm^2)	Maximum PAC Reading ($dis/min-100\ cm^2$)		Final Status
			Beta-Gamma	Alpha	
404E	220	300	2.8×10^3	BKGD	Floor decontaminated to NCD
	221	500	6.1×10^3	BKGD	Contaminated wall removed and replaced
	222	500	4.8×10^4	BKGD	
5th Floor	306	10,000	3.0×10^4	5.0×10^2	NCD (wooden floor had been removed)

[a] Locations are shown in Figures 10 through 14 and 17.

[b] BKGD = Background

[c] NCD = No Contamination Detectable at the time of decontamination activity.

[d] SAW = Solid Active Waste.

TABLE 4. JONES CHEMICAL LABORATORY ATTIC - CONTAMINATION LOCATIONS[a]

Room Number	Location Number	Estimated Area of Contamination (cm^2)	Maximum PAC Reading (dis/min-100 cm^2)		Final Status
			Beta-Gamma	Alpha	
IA	260	100,000	$3.0x10^5$	$8.5x10^4$	Floor removed with jackhammer until NCD
IB	261	100,000	$1.9x10^5$	$1.5x10^4$	
IE	264	1,000	$6.5x10^4$	$2.9x10^3$	Floor cleaned with solvent to NCD
IIA	259	50,000	$7.0x10^3$	$3.6x10^4$	Floor scabbled to NCD
IIB	258	50,000	$5.5x10^3$	BKGD[b]	Floor cleaned with solvent to NCD
IIC	257	50,000	$7.5x10^4$	$2.6x10^3$	Floor cleaned with solvent to NCD
IID	256	1,000	$1.5x10^4$	$3.5x10^3$	Floor cleaned with solvent to NCD
IIE	255	1,000	$2.5x10^3$	BKGD	Floor cleaned with solvent to NCD
IIIA	263	1,000	$1.3x10^5$	$7.3x10^3$	Floor cleaned with solvent to NCD
IIIB	262	1,000	$5.5x10^4$	$7.3x10^3$	Floor cleaned with solvent to NCD
IIIC	265	-	$6.4x10^3$	$1.6x10^3$	Source removed
	276	-	$2.9x10^3$	$7.3x10^2$	Source removed

[a] Locations are shown in Figure 16.

[b] BKGD = Background

[c] NCD = No Contamination Detected

TABLE 5. GAMMA SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SEWER SAMPLES

Sample Number	Gamma Spectra (pCi/g ± σ[a]) or (pCi/ℓ ± σ[a])			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	(μg/g±10%)	(pCi/g±10%)[b]
EH-SS[c]-3(DS)[d]	✓42 ±4	✓18 ± 2	✓80 ± 8	0.11± 0.01	0.1 ± 0.1
EH-SS-3(SS)[e]	0.14±0.04	0.60± 0.06	1.08± 0.11	11.8 ± 1.2	✓8.1 ± 0.8
EH-SS-4(DS)	< 0.02	✓101 ±10	< 0.02	0.15± 0.02	0.1 ± 0.1
EH-SS-4(SS)	✓57 ±6	< 0.04	✓104 ±10	8.2 ± 0.8	5.6 ± 0.6
EH-SS-5	0.08±0.03	0.24± 0.07	0.44± 0.04	2.7 ± 0.3	1.8 ± 0.2
EH-SS-6	< 0.02	0.97± 0.10	0.86± 0.09	14.7 ± 1.5	✓10.0 ± 1.0
EH-SS-7	0.28±0.04	0.65± 0.07	1.09± 0.11	8.0 ± 0.8	✓5.5 ± 0.6
EH-SS-8	0.03±0.02	0.07± 0.03	0.43± 0.04	262 ±26	✓179 ±18
EH-SS-9	0.10±0.03	0.36± 0.07	0.86± 0.09	7.8 ± 0.8	✓5.3 ± 0.5
EH-SS-10	0.13±0.04	0.11± 0.04	2.72± 0.27	16.3 ± 1.6	✓11.1 ± 1.1
EH-SS-11	0.07±0.03	0.23± 0.06	1.07± 0.11	11.8 ± 1.2	✓8.1 ± 0.8
EH-SS-12	✓14 ±1	0.45± 0.05	1.01± 0.10	5.3 ± 0.5	3.6 ± 0.4
RL-SS[f]-3(DS)[d]	< 0.02	< 0.04	✓121 ±12	0.51± 0.05	0.4 ± 0.1
RL-SS-3(SS)[e]	0.05±0.02	0.32± 0.06	0.38± 0.04	3.3 ± 0.3	2.3 ± 0.2
RL-SS-4	0.18±0.04	0.40± 0.06	0.47± 0.05	35.7 ± 3.6	✓24.4 ± 2.4
RL-SS-5(DS)	< 0.02	✓53 ± 5	< 0.02	0.32± 0.03	0.2 ± 0.1
RL-SS-5(SS)	0.77±0.08	0.34± 0.06	1.35± 0.14	4.1 ± 0.4	2.8 ± 0.3
RL-SS-6	< 0.02	0.17± 0.05	0.62± 0.06	1.9 ± 0.2	1.3 ± 0.1
RL-SS-7(DS)	< 0.02	< 0.04	< 0.02	0.21± 0.02	0.1 ± 0.1
RL-SS-7(SS)	< 0.02	< 0.04	4.67± 0.47	1.8 ± 0.2	1.2 ± 0.1
RL-SS-8(DS)	✓30.0 ±3.0	< 0.04	< 0.02	0.12± 0.01	0.1 ± 0.1
RL-SS-8(SS)	< 0.02	< 0.04	2.71± 0.27	1.8 ± 0.2	1.2 ± 0.1
RL-SS-9(DS)	< 0.02	< 0.04	< 0.02	0.17± 0.02	0.1 ± 0.1
RL-SS-9(SS)	< 0.02	< 0.04	< 0.02	4.5 ± 0.5	3.1 ± 0.3
RL-SS-10(DS)	< 0.02	< 0.04	< 0.02	0.11± 0.01	0.1 ± 0.1
RL-SS-10(SS)	0.69±0.07	< 0.04	0.81± 0.08	1.1 ± 0.1	0.8 ± 0.1
RL-SS-11(DS)	< 0.02	< 0.04	✓220 ±22	0.53± 0.05	0.4 ± 0.1
RL-SS-11(SS)	< 0.02	2.10± 0.21	4.82± 0.48	1.2 ± 0.1	0.8 ± 0.1

TABLE 5 - (cont'd.)

Sample Number	Gamma Spectra (pCi/g±σ[a]) or (pCi/ℓ ± σ[a]) ^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	Uranium Fluorometric (μg/g±10%)	(pCi/g±10%)[b]
RL-SS-12(DS)	< 0.02	< 0.04	< 0.02	3.43± 0.34	2.3 ± 0.2
RL-SS-12(SS)	< 0.02	1.82± 0.18	2.58± 0.26	2.4 ± 0.2	1.6 ± 0.2
RL-SS-13(DS)	✓ 10 ±1	✓ 25 ± 3	< 0.02	0.91± 0.09	0.6 ± 0.1
RL-SS-13(SS)	< 0.02	0.46± 0.05	0.51± 0.05	0.9 ± 0.1	0.6 ± 0.1
RL-SS-14(DS)	< 0.02	< 0.04	< 0.02	0.21± 0.02	0.2 ± 0.1
RL-SS-14(SS)	< 0.02	1.13± 0.11	1.62± 0.16	0.7 ± 0.1	0.5 ± 0.1
RL-SS-15(DS)	< 0.02	< 0.04	< 0.02	0.64± 0.06	0.4 ± 0.1
RL-SS-15(SS)	0.88±0.09	0.56± 0.06	0.88± 0.09	0.8 ± 0.1	0.5 ± 0.1
JC-SS[g]-2	0.11±0.03	0.52± 0.06	0.35± 0.04	5.9 ± 0.6	4.0 ± 0.4
JC-SS-3	0.38±0.04	0.45± 0.06	0.72± 0.07	26.1 ± 2.6	✓ 18 ± 1.8
JC-SS-4	< 0.02	0.11± 0.04	0.23± 0.02	3.4 ± 0.4	2.3 ± 0.2
JC-SS-5	0.50±0.05	0.84± 0.08	2.48± 0.25	31.1 ± 3.0	✓ 21 ± 2.1
JC-SS-6(DS)[d]	< 0.02	< 0.04	✓ 60 ± 6	2.2 ± 0.2	1.5 ± 0.2
JC-SS-6(SS)[e]	0.29±0.04	? 5.48± 0.55	✓ 7.07± 0.71	64 ± 6	✓ 44 ± 4.4
JC-SS-7	0.11±0.03	0.52± 0.05	0.35± 0.04	5.6 ± 0.6	3.8 ± 0.4
JC-SS-8(DS)	< 0.02	< 0.04	< 0.02	0.2 ± 0.1	0.1 ± 0.1
JC-SS-8(SS)	< 0.02	< 0.04	1.27± 0.13	1.2 ± 0.1	0.8 ± 0.1
JC-SS-9	0.38±0.04	0.30± 0.06	0.50± 0.05	2.3 ± 0.2	1.6 ± 0.2
JC-SS-10	0.60±0.06	0.38± 0.04	0.89± 0.09	4.6 ± 0.5	3.1 ± 0.3
EXTERIOR SEWER SAMPLES					
JC-SS-11(DS)	< 0.02	✓ 274 ±27	✓ 8 ± 1	0.1 ± 0.1	0.1 ± 0.1
JC-SS-11(SS)	2.29±0.23	0.47± 0.07	0.69± 0.07	1.5 ± 0.2	1.0 ± 0.1
JC-SS-12(DS)	✓ 10 ±1	✓ 171 ±17	< 0.02	0.5 ± 0.1	0.3 ± 0.1
JC-SS-12(SS)	0.06±0.02	0.26± 0.08	0.54± 0.05	1.3 ± 0.1	0.9 ± 0.1
JC-SS-13(DS)	< 0.02	< 0.04	✓ 70 ± 7	0.5 ± 0.1	0.3 ± 0.1
JC-SS-13(SS)	0.17±0.03	0.27± 0.07	0.55± 0.06	1.2 ± 0.1	0.8 ± 0.1
JC-SS-14	0.22±0.04	0.18± 0.05	0.18± 0.03	0.8 ± 0.1	0.5 ± 0.1

TABLE 5 - (cont'd.)

Sample Number	Gamma Spectra (pCi/g±σ^a) OR (pCi/ℓ ± σ^a)			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	(µg/g±10%)	(pCi/g±10%)^b
RL-SS-16(DS)	< 0.02	< 0.04	✓53 ± 5	2.80± 0.28	1.9 ± 0.2
RL-SS-16(SS)	< 0.02	< 0.04	0.27± 0.03	1.3 ± 0.1	0.9 ± 0.1
RL-SS-17(SS)	2.03±0.20	0.24± 0.04	0.75± 0.08	2.6 ± 0.3	1.8 ± 0.2
RL-SS-18(DS)	< 0.02	< 0.04	< 0.02	2.0 ± 0.2	1.4 ± 0.2
RL-SS-18(SS)	1.84±0.18	2.34± 0.23	2.63± 0.26	5.0 ± 0.5	3.4 ± 0.3
RL-SS-19(SS)	1.70±0.17	1.09± 0.11	2.41± 0.24	12.6 ± 1.3	✓8.6 ± 0.9
RL-SS-20(DS)	✓32 ±3	✓31 ± 3	< 0.02	0.12± 0.01	0.1 ± 0.1
RL-SS-20(SS)	< 0.02	< 0.04	< 0.02	3.2 ± 0.3	2.2 ± 0.2
RL-SS-21(SS)	0.26±0.02	0.14± 0.04	0.20± 0.02	5.9 ± 0.6	?4.0 ± 0.4
RL-SS-22(SS)	1.01±0.10	0.40± 0.03	0.73± 0.07	2.5 ± 0.3	1.7 ± 0.2
RL-SS-23(SS)	2.08±0.21	< 0.04	0.62± 0.06	2.5 ± 0.3	1.7 ± 0.2
RL-SS-24(SS)	0.72±0.07	0.21± 0.06	0.24± 0.02	1.2 ± 0.1	0.8 ± 0.1
RL-SS-25(SS)	2.75±0.08	< 0.04	1.22± 0.12	2.7 ± 0.3	1.8 ± 0.2
RL-SS-26(DS)	✓26 ±3	✓18 ± 2	< 0.02	0.5 ± 0.1	0.3 ± 0.1
RL-SS-26(SS)	0.64±0.06	< 0.04	< 0.02	2.7 ± 0.3	1.8 ± 0.2
RL-SS-27(SS)	0.79±0.08	0.33± 0.07	0.83± 0.08	3.1 ± 0.3	2.1 ± 0.2
RL-SS-28(DS)	< 0.02	< 0.04	< 0.02	0.4 ± 0.1	0.3 ± 0.1
RL-SS-28(SS)	< 0.02	3.87± 0.39	✓18 ± 2	3.1 ± 0.3	2.1 ± 0.2
RL-SS-29(SS)	0.09±0.04	0.50± 0.06	0.51± 0.05	1.0 ± 0.1	0.7 ± 0.1
RL-SS-30(DS)	< 0.02	< 0.04	< 0.02	0.5 ± 0.1	0.3 ± 0.1
RL-SS-30(SS)	0.67±0.07	1.80± 0.18	2.33± 0.23	1.9 ± 0.2	1.3 ± 0.2

TABLE 5 - (cont'd.)

[a] One standard deviation due to counting statistics.

[b] ANL conversion factor from Appendix 5.

[c] EH-SS identifies Eckhart Hall-Sewer Sample.

[d] (DS) identifies dissolved solids in a water sample - (units pCi/ℓ).

[e] (SS) identifies suspended solids in a water sample - (units pCi/g solids).

[f] RL-SS identifies Ryerson Physical Laboratory-Sewer Sample.

[g] JC-SS identifies Jones Chemical Laboratory-Sewer Sample.

TABLE 6. URANIUM MASS SPECTROMETRIC ANALYSES OF SELECTED SAMPLES

	U Isotopes, Atom%				
Sample Number	233	234	235	236	238
EH-SS-8	< 5ppm	0.0057±0.0005	0.7204±0.002	< 5ppm	99.273±0.003
RL-SS-4	< 5ppm	0.0055±0.0005	0.7203±0.002	< 5ppm	99.274±0.003
JC-SS-6	< 5ppm	0.0052±0.0005	0.7204±0.002	< 5ppm	99.274±0.003

TABLE 7. PLUTONIUM SEPARATION AND ALPHA SPECTROMETRIC ANALYSIS OF SELECTED SAMPLES (fCi/g±σ)

Sample Number	^{239}Pu	^{238}Pu
EH-SS-3(DS)[a]	BDL[b]	BDL
EH-SS-3(SS)[c]	23 ± 5[d]	BDL
EH-SS-8	✓ 68 ± 10	BDL
RL-SS-3(DS)	BDL	BDL
RL-SS-3(SS)	14 ± 3	BDL
RL-SS-5(DS)	BDL	BDL
RL-SS-5(SS)	✓ 57 ± 5	BDL
RL-SS-13(DS)	BDL	BDL
RL-SS-13(SS)	7 ± 3	BDL
JC-SS-2	✓ 13,000 ± 1,000	350 ± 40
JC-SS-3	✓ 350 ± 30	BDL
JC-SS-4	15 ± 4	BDL
JC-SS-5	✓ 46 ± 5	BDL
JC-SS-6(SS)	✓ 27 ± 5	BDL
JC-SS-7	7 ± 3	BDL
JC-SS-8(DS)	BDL	BDL
JC-SS-8(SS)	13 ± 4	BDL
JC-SS-9	19 ± 5	BDL
JC-SS-10	✓ 31 ± 5	BDL
JC-SS-11(DS)	BDL	BDL
JC-SS-11(SS)	✓ 76 ± 8	BDL
JC-SS-12(DS)	BDL	BDL
JC-SS-12(SS)	2 ± 1	BDL
JC-SS-13(DS)	BDL	BDL
JC-SS-13(SS)	16 ± 4	BDL
JC-SS-14	✓ 96 ± 15	74 ± 10

TABLE 7 - (cont'd.)

[a] (DS) identifies dissolved solids in a water sample - (units fCi/ℓ).

[b] BDL equates to "Below Detectable Limits" for the analysis method.

[c] (SS) identifies suspended solids in a water sample - (units fCi/g).

[d] Background levels from fallout are 15 to 20 fCi/g.

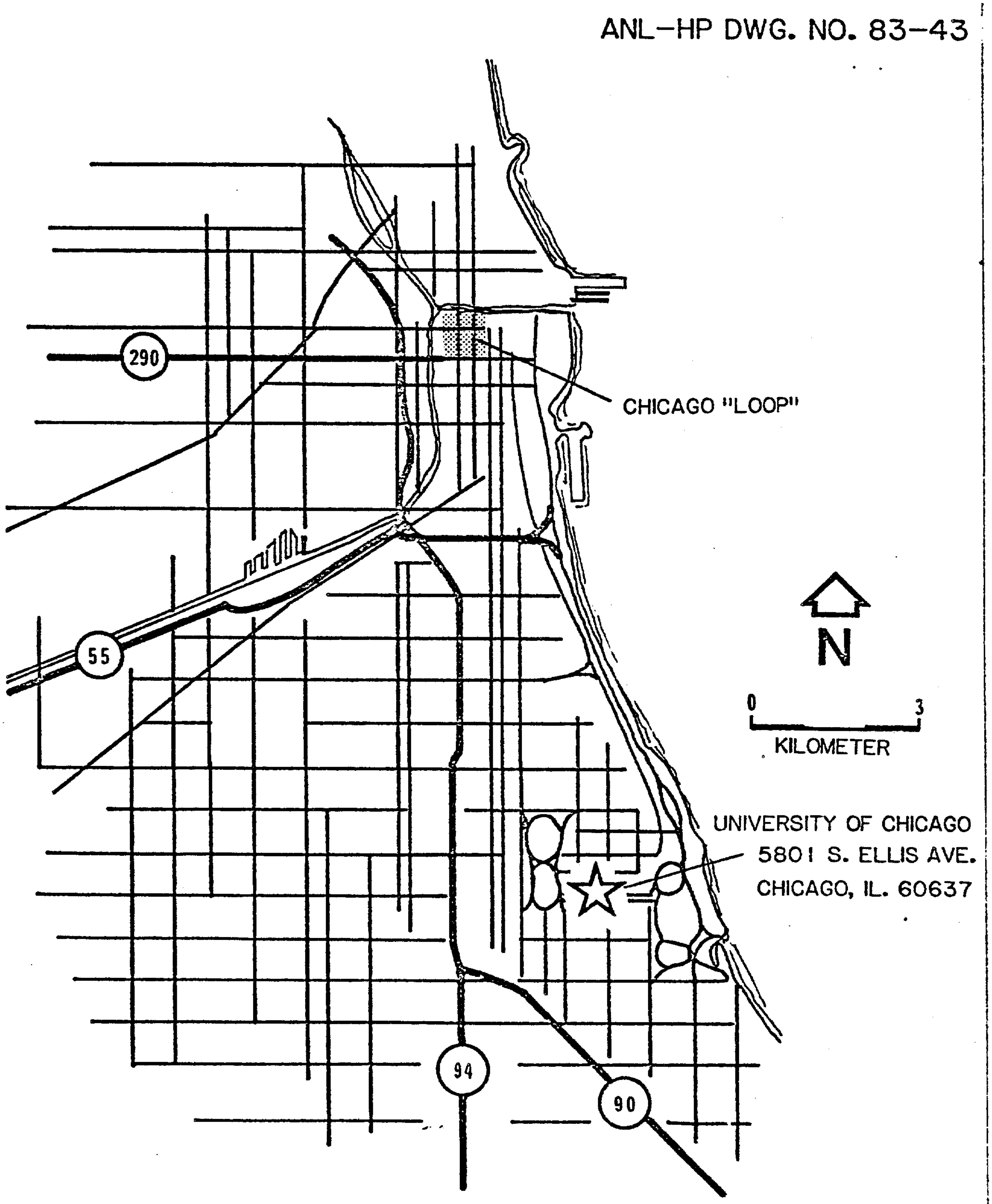

Figure 1. Site Location of The University of Chicago

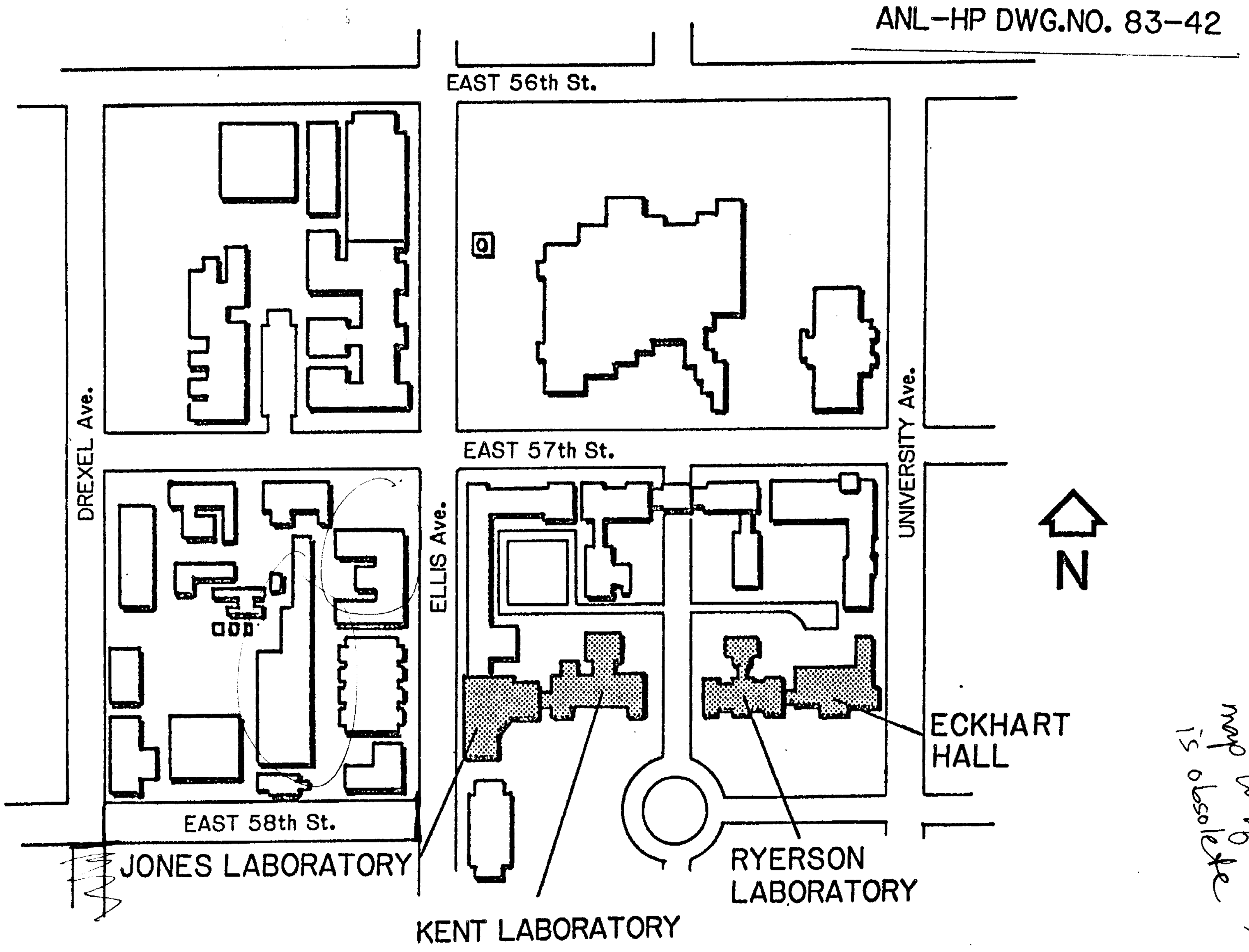

Figure 2. The University of Chicago Campus

Trivial comment: map W of Ellis, S of 57th is obsolete

ANL–HP DWG. NO. 84–3

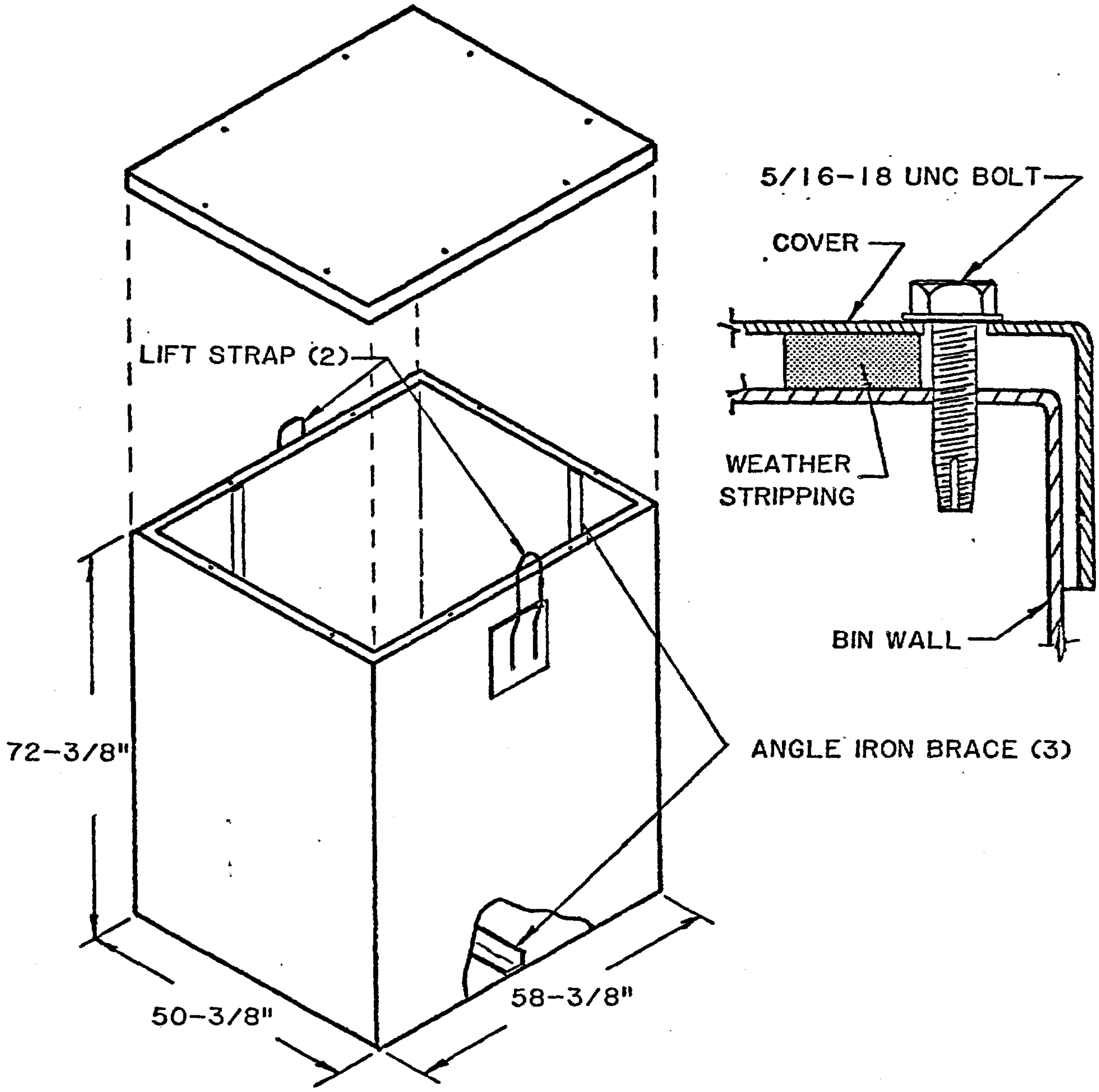

Figure 3. Waste Storage Bin M-III.

ANL-HP DWG. NO. 84-16

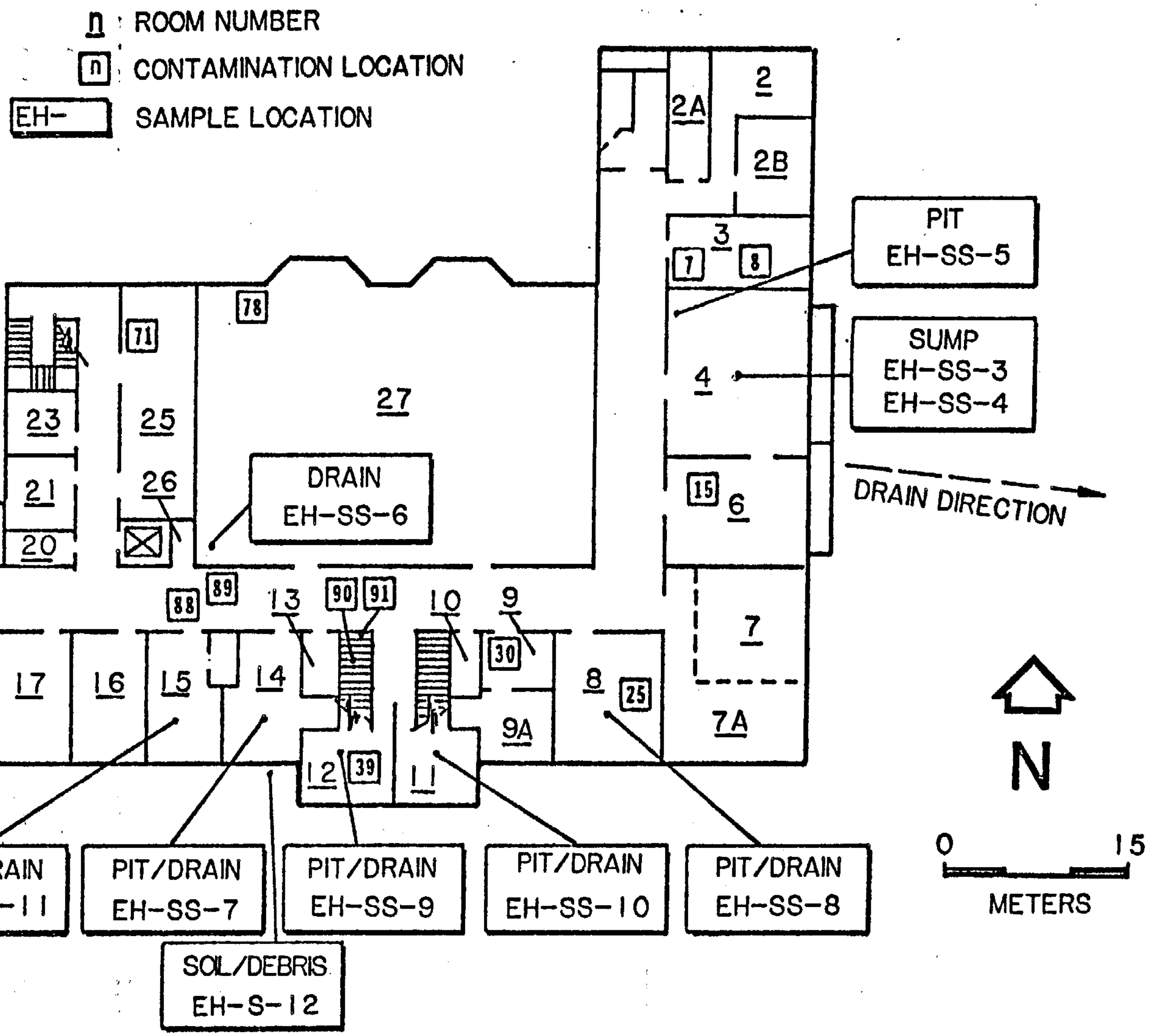

Figure 4. Eckhart Hall Basement.

ANL-HP DWG. NO. 84-17

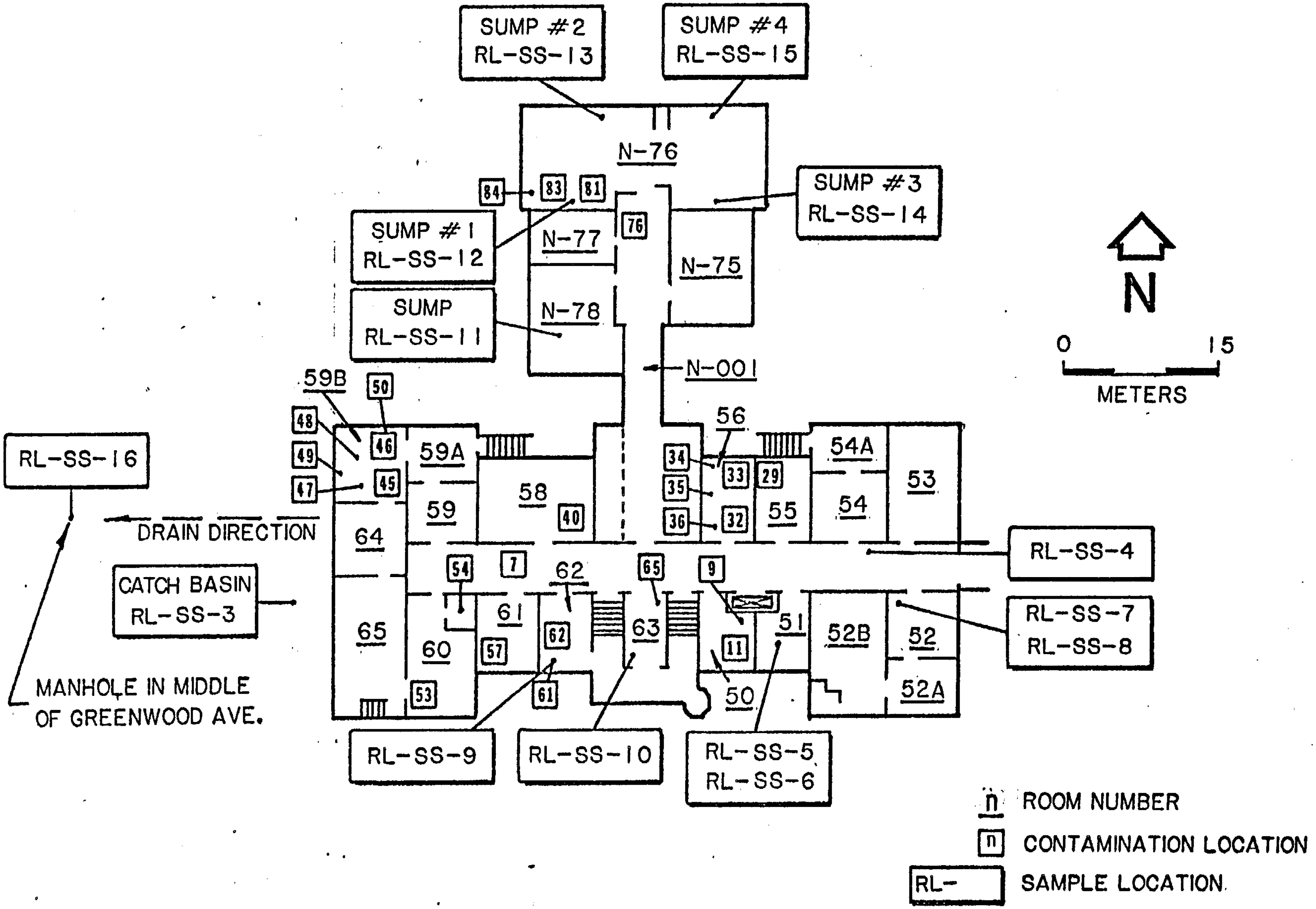

Figure 5. Ryerson Laboratory Basement.

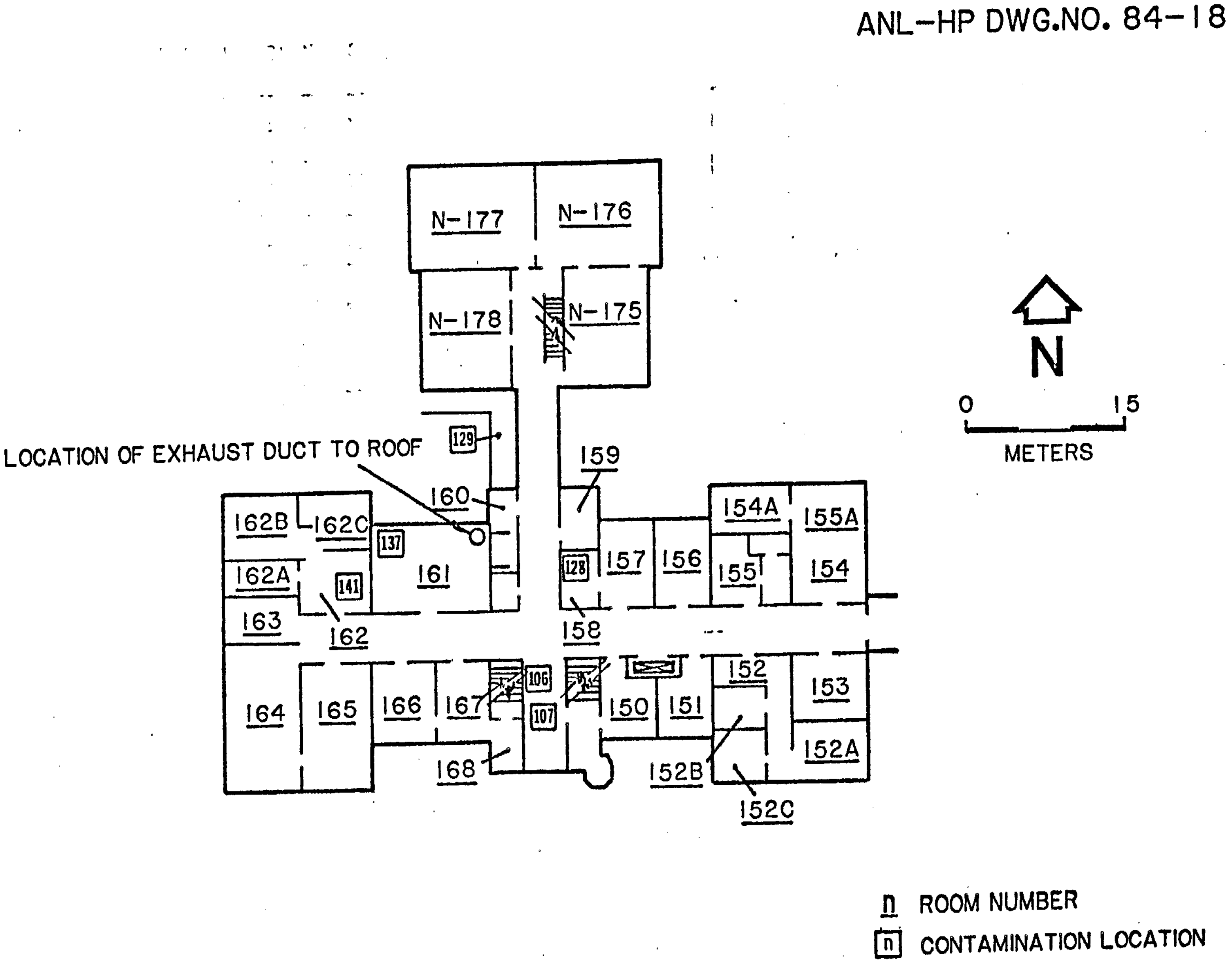

Figure 6. Ryerson Laboratory First Floor.

ANL-HP DWG. NO. 84-19

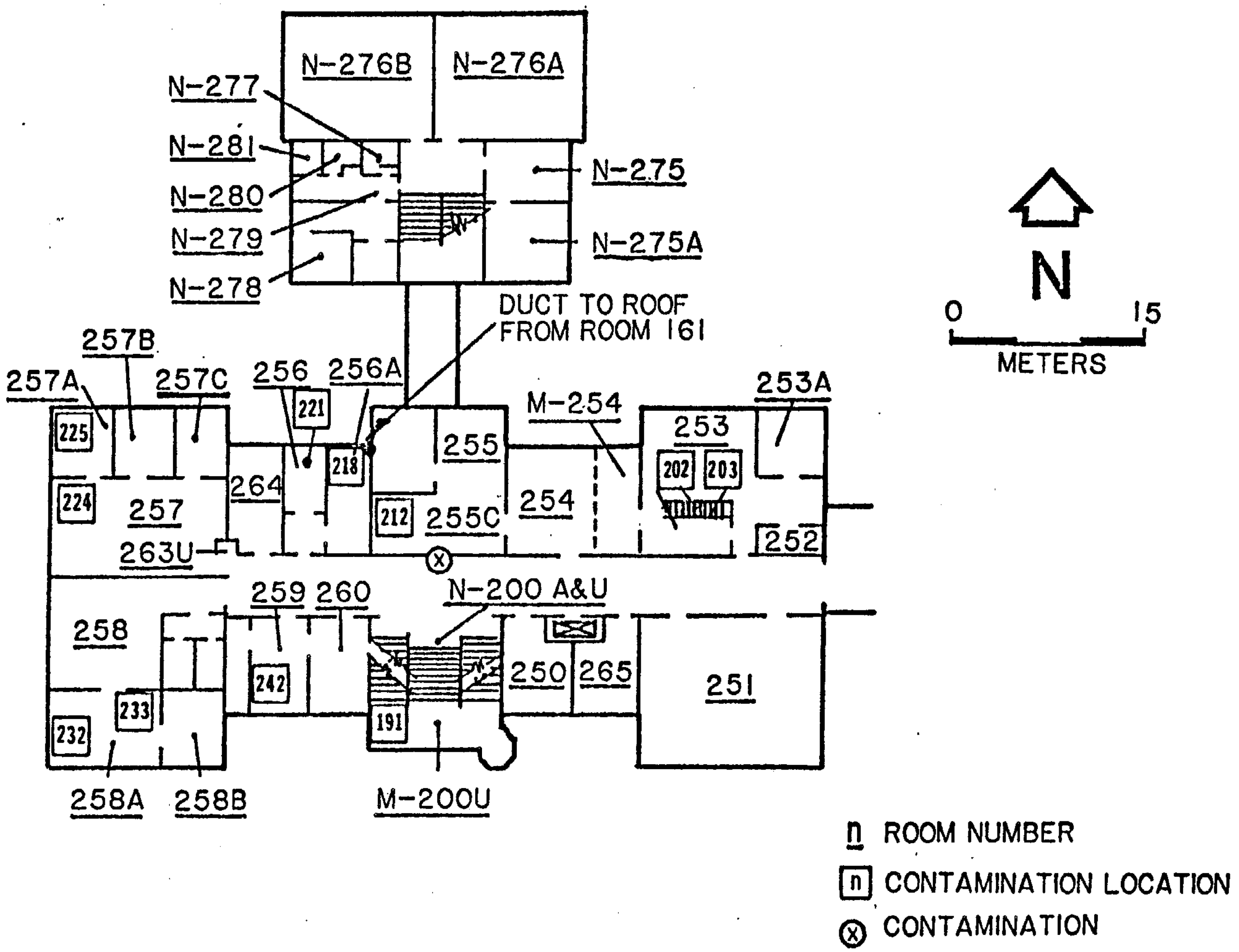

Figure 7. Ryerson Laboratory Second Floor.

ANL-HP DWG. NO. 84-20

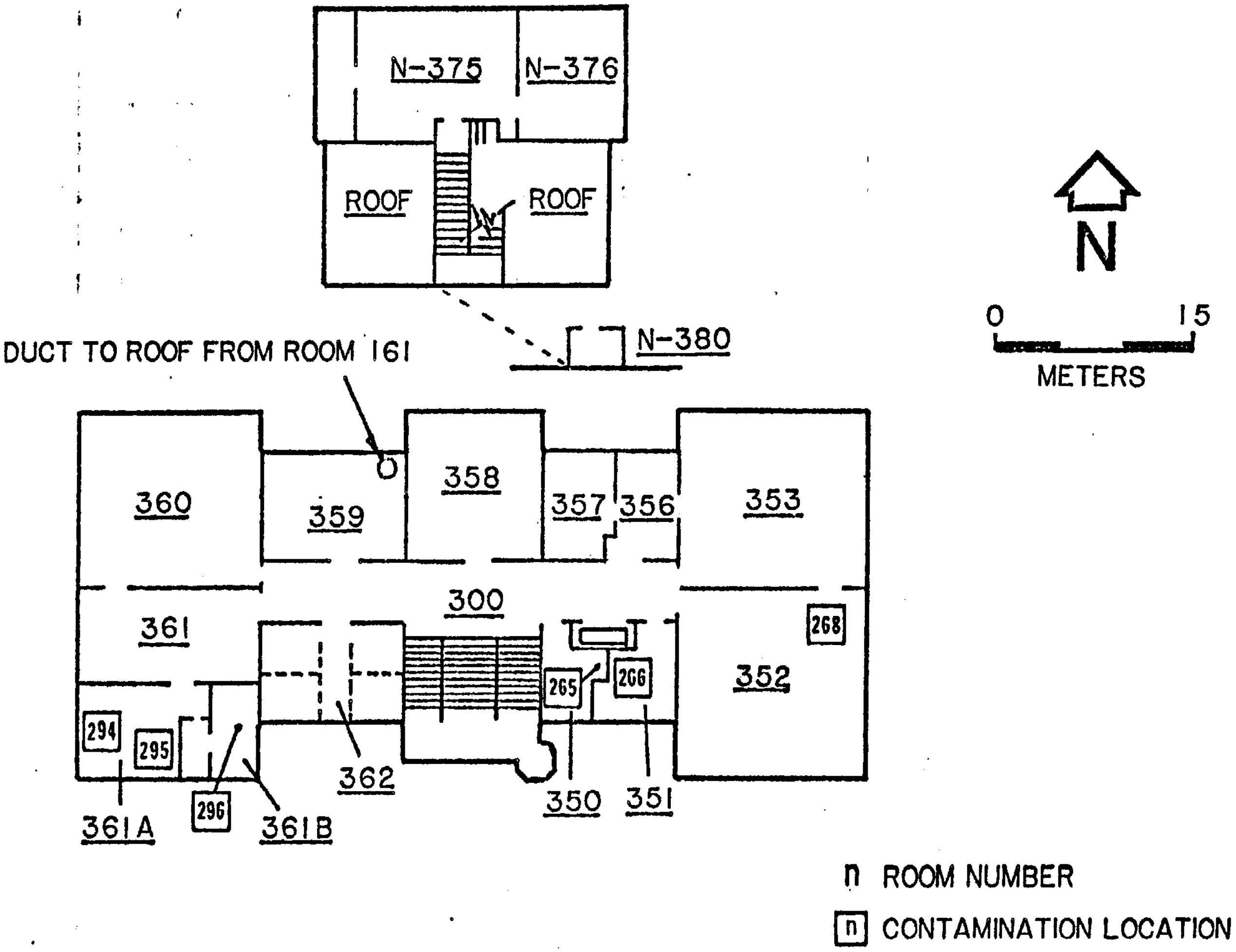

Figure 8. Ryerson Laboratory Third Floor.

ANL-HP DWG. NO. 84-21

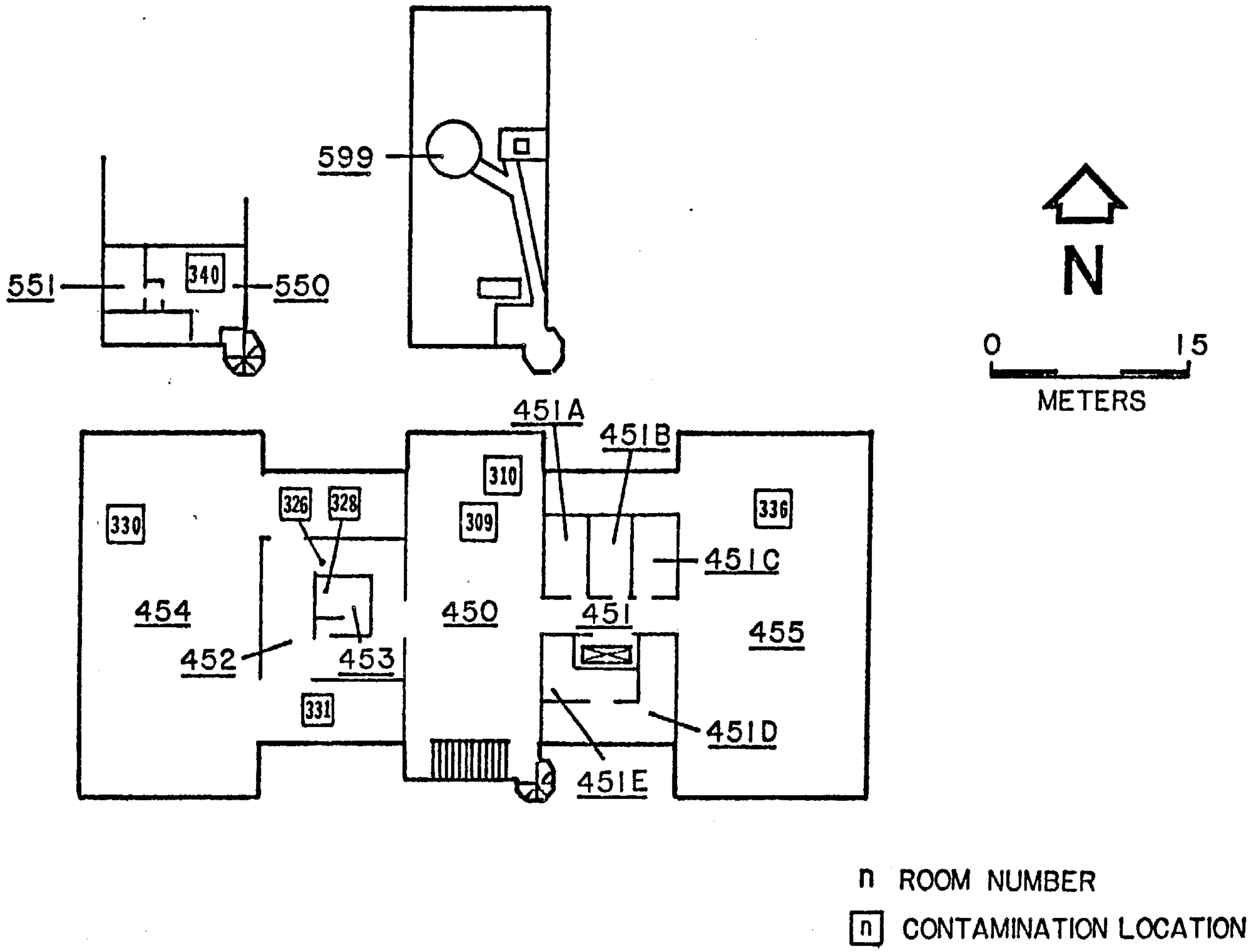

Figure 9. Ryerson Laboratory Fourth and Fifth Floors.

ANL-HP DWG. NO. 84-22

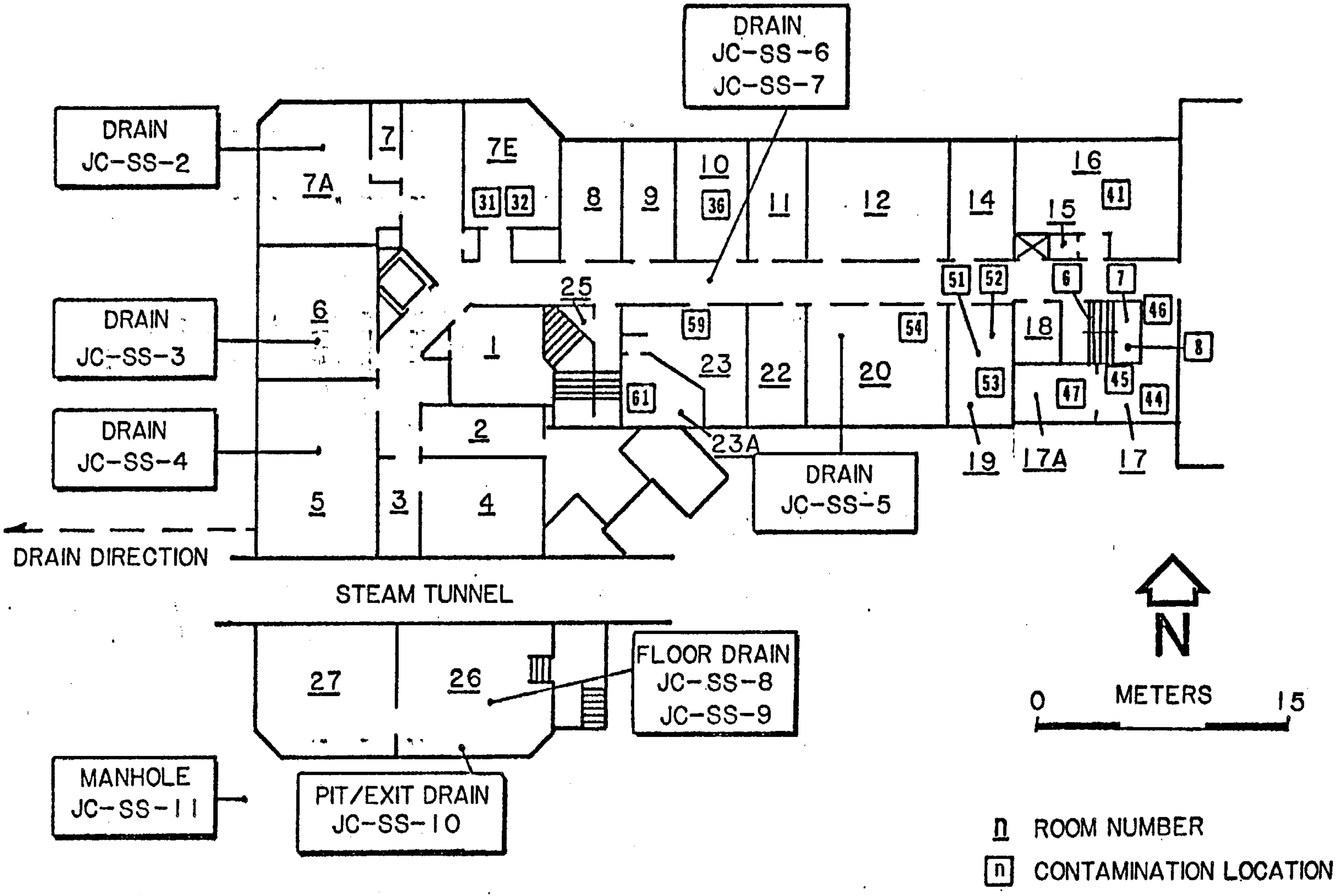

Figure 10. Jones Laboratory Basement.

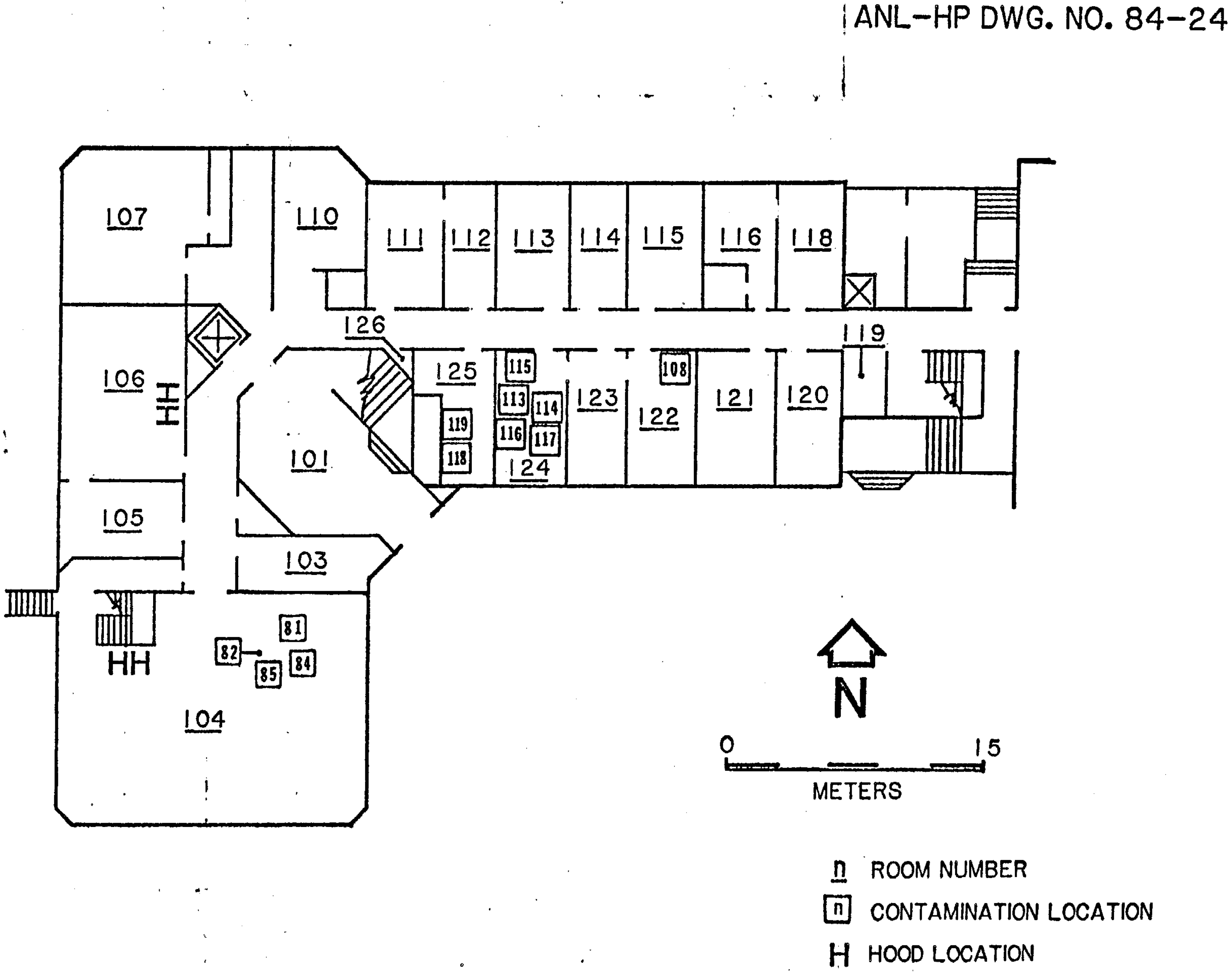

Figure 11. Jones Laboratory First Floor.

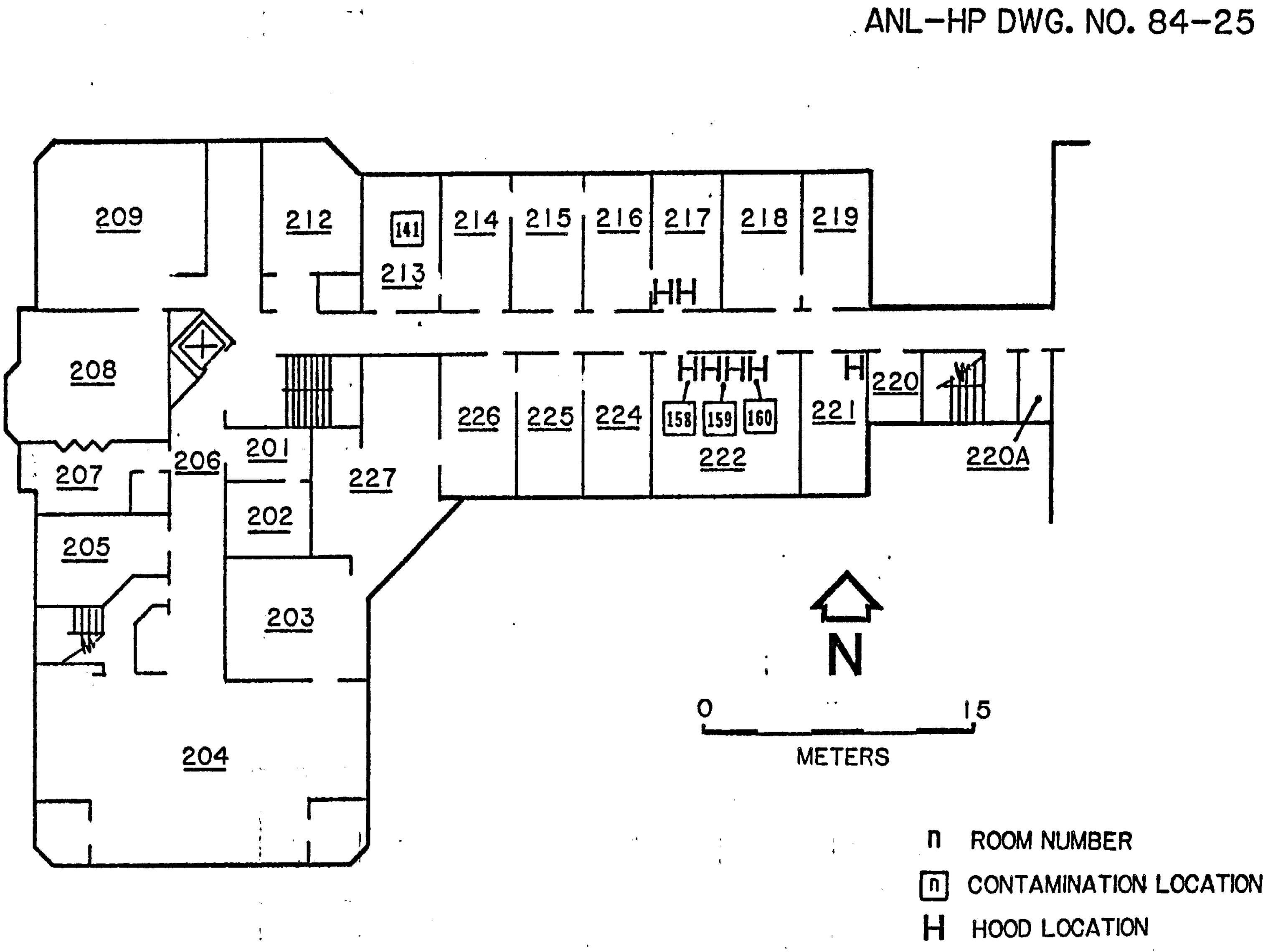

Figure 12. Jones Laboratory Second Floor.

ANL-HP DWG. NO. 84-26

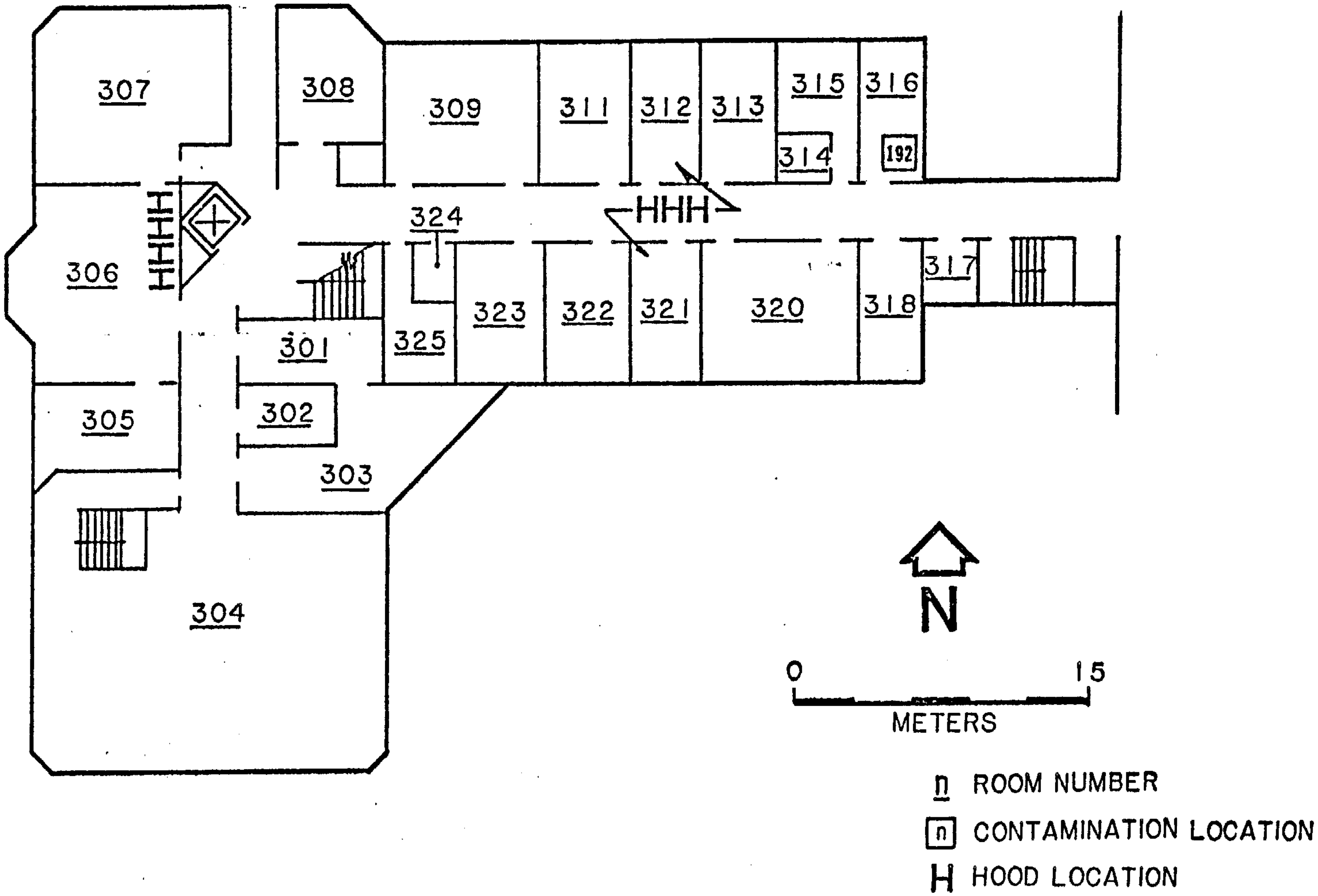

Figure 13. Jones Laboratory Third Floor.

ANL-HP DWG. NO. 84-27

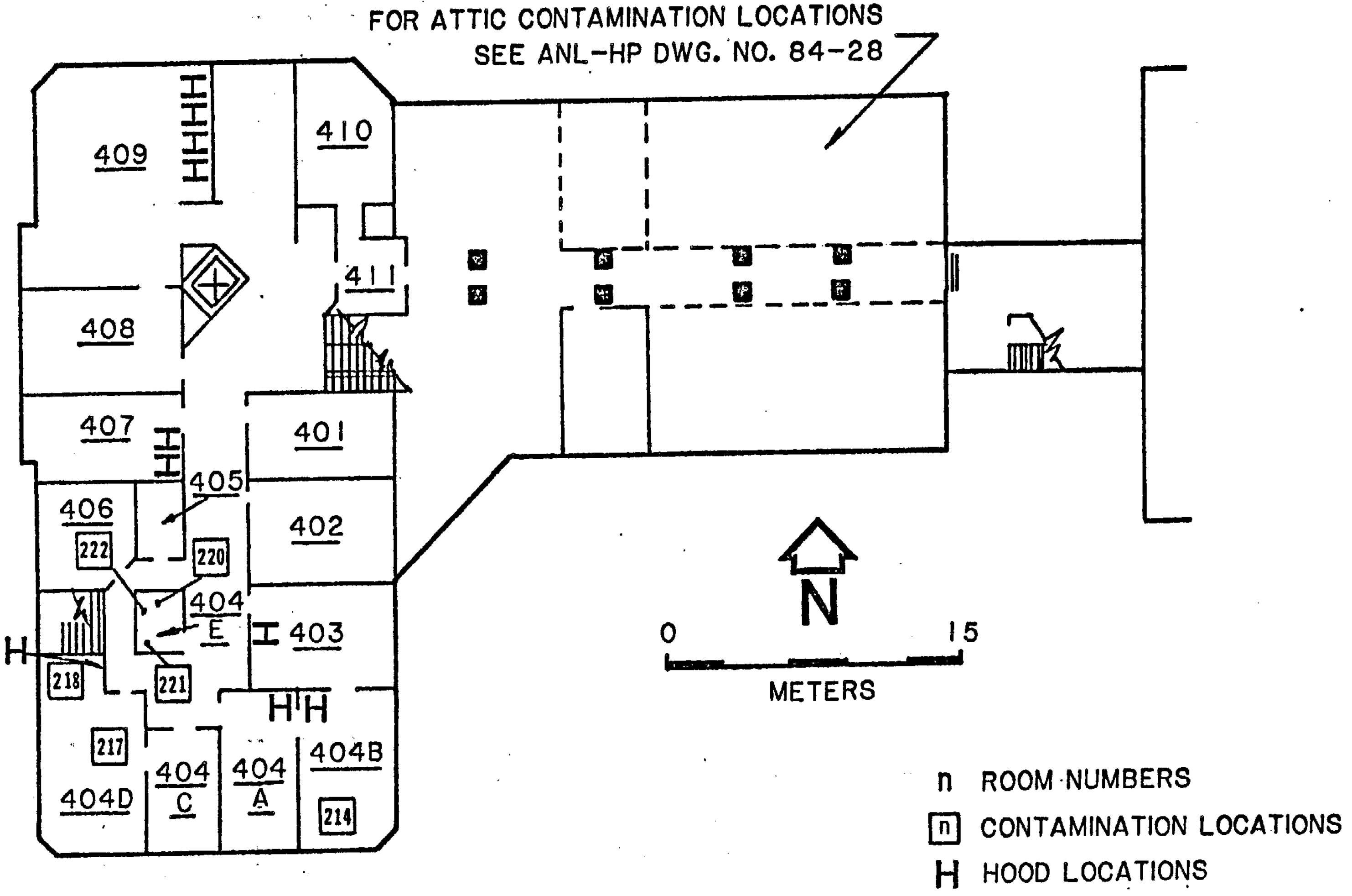

Figure 14. Jones Laboratory Fourth Floor.

ANL-HP DWG. NO. 84-30

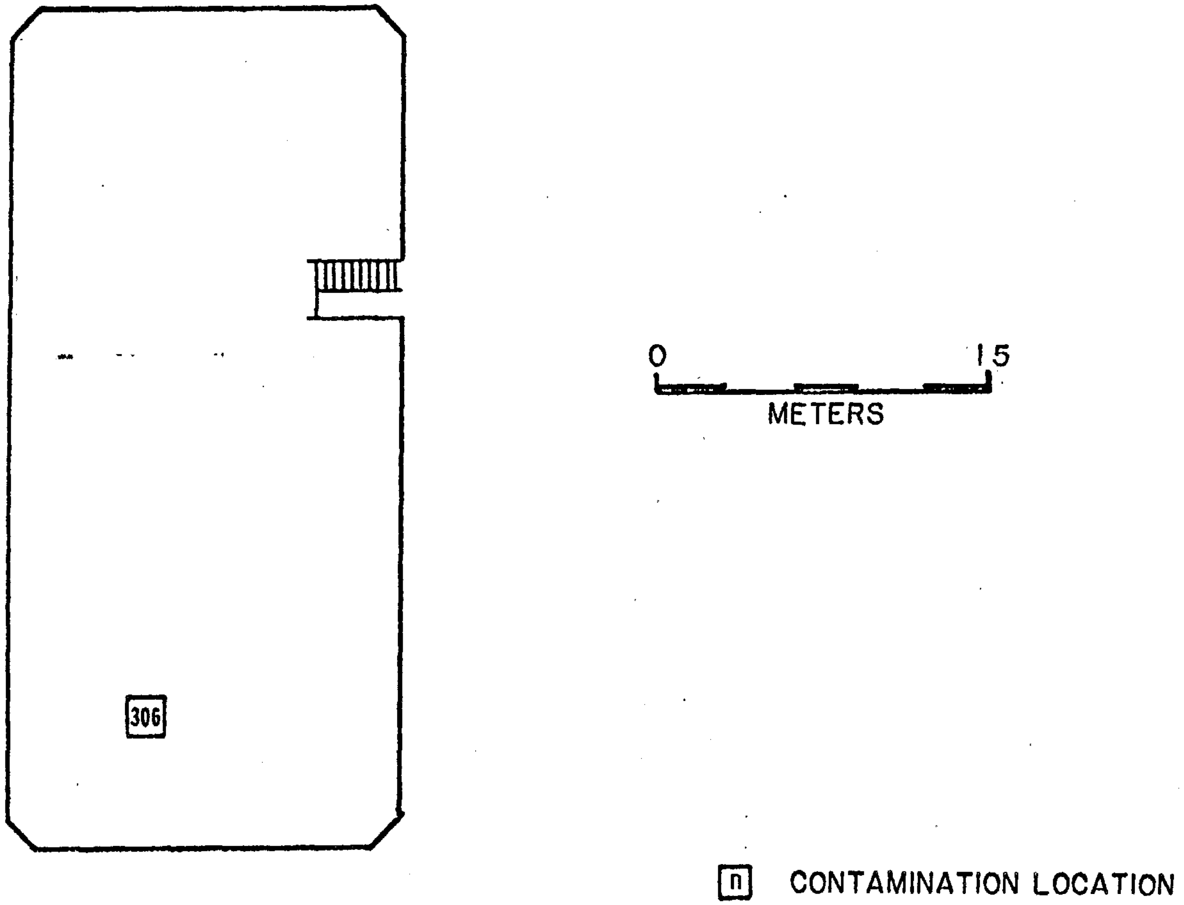

Figure 15. Jones Laboratory Fifth Floor Fan Loft.

ANL-HP DWG. NO. 84-28

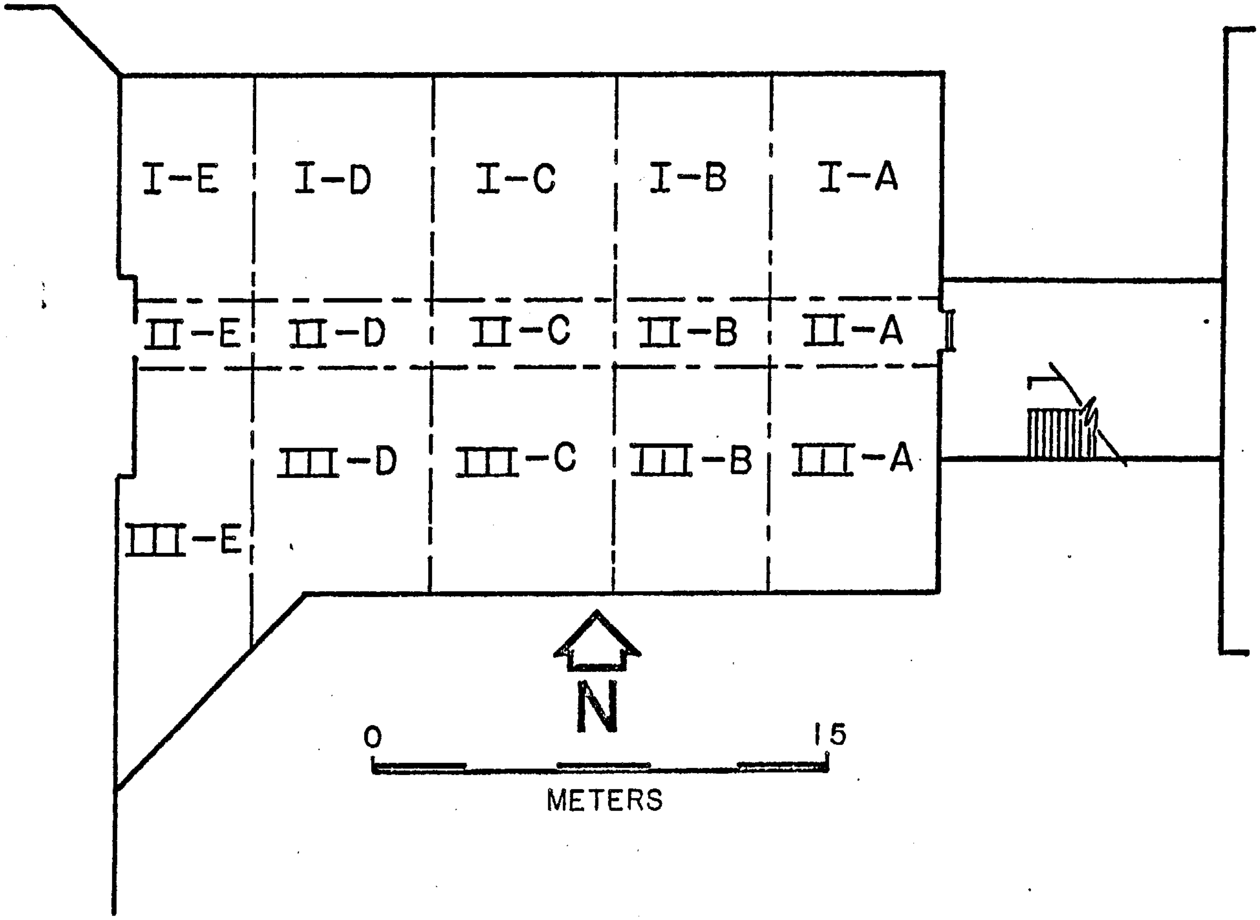

Figure 16. Jones Laboratory Fourth Floor Attic Sections.

ANL-HP DWG. NO. 84-29

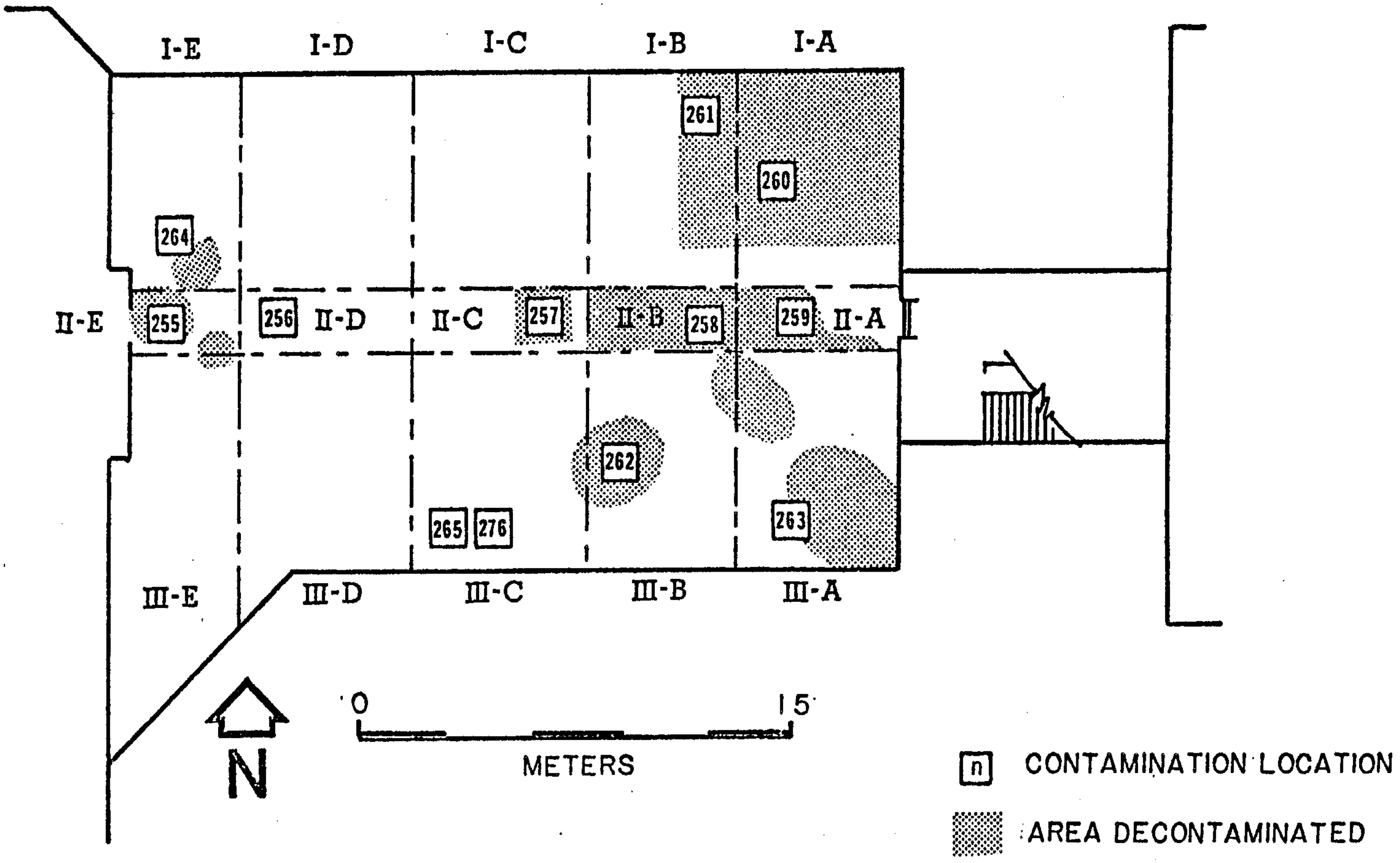

Figure 17. Jones Laboratory Attic Decontaminated Areas.

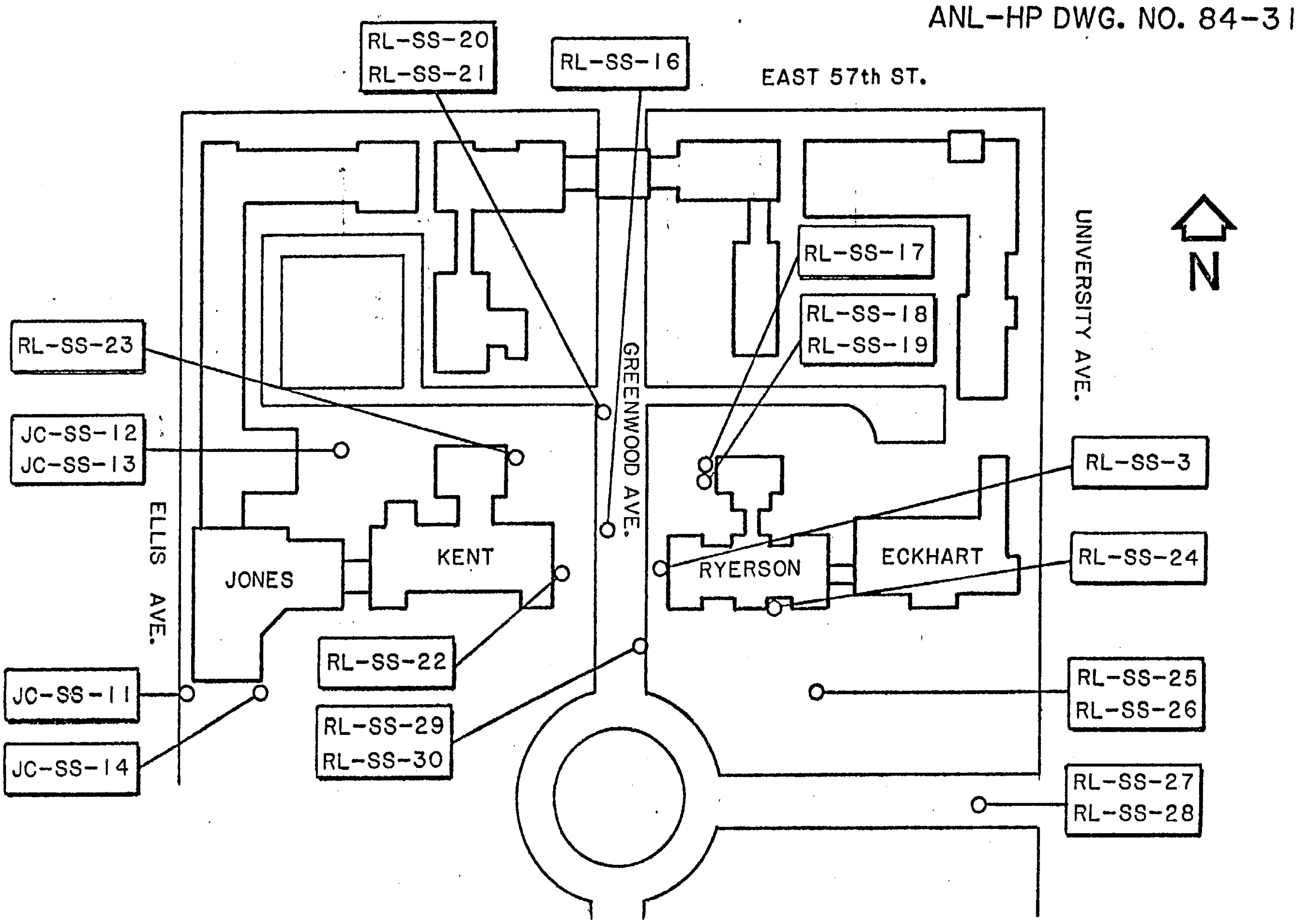

Figure 18. Outside Sewer Sample Locations.

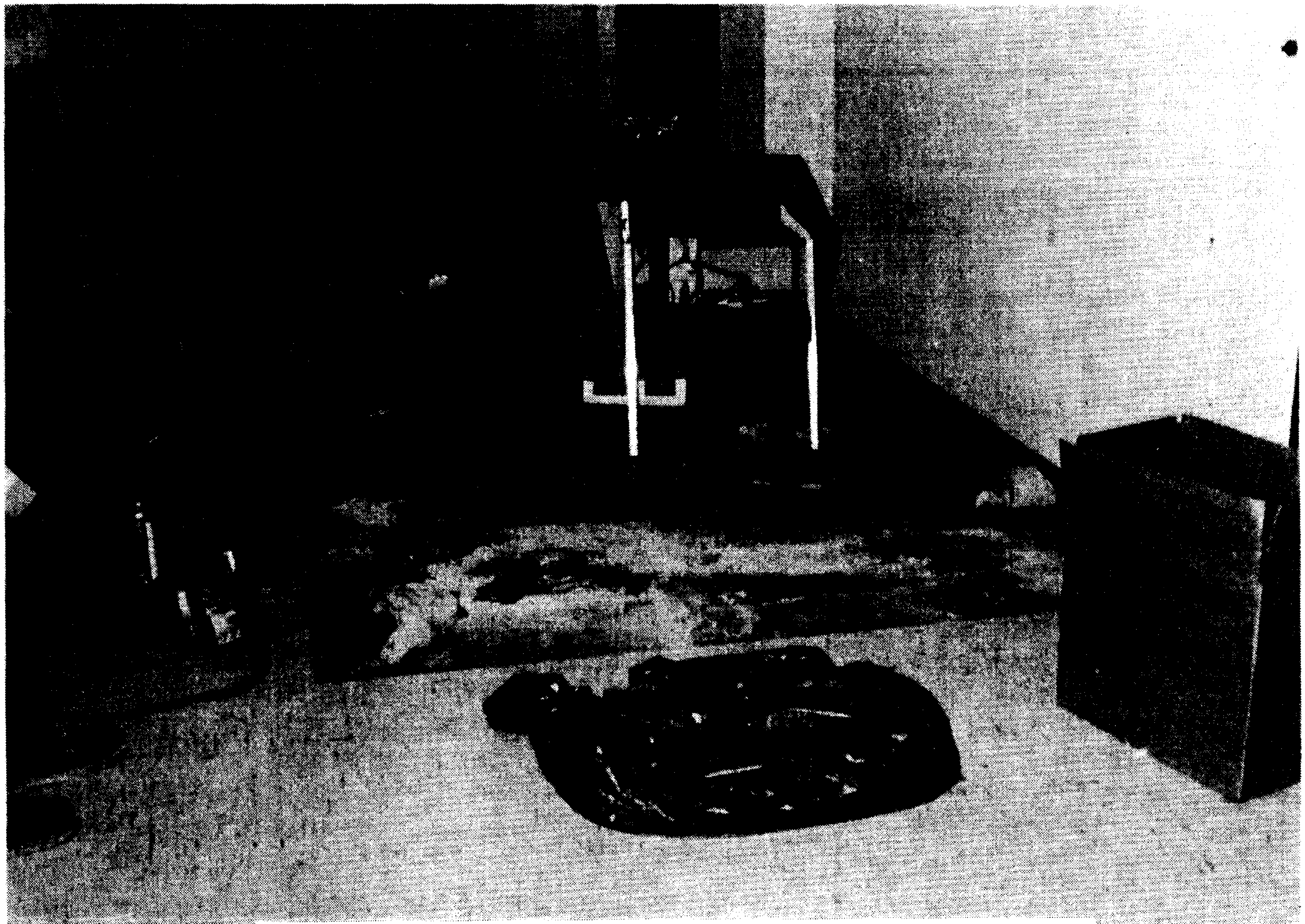

Figure 19. Eckhart Hall Basement After Decontamination

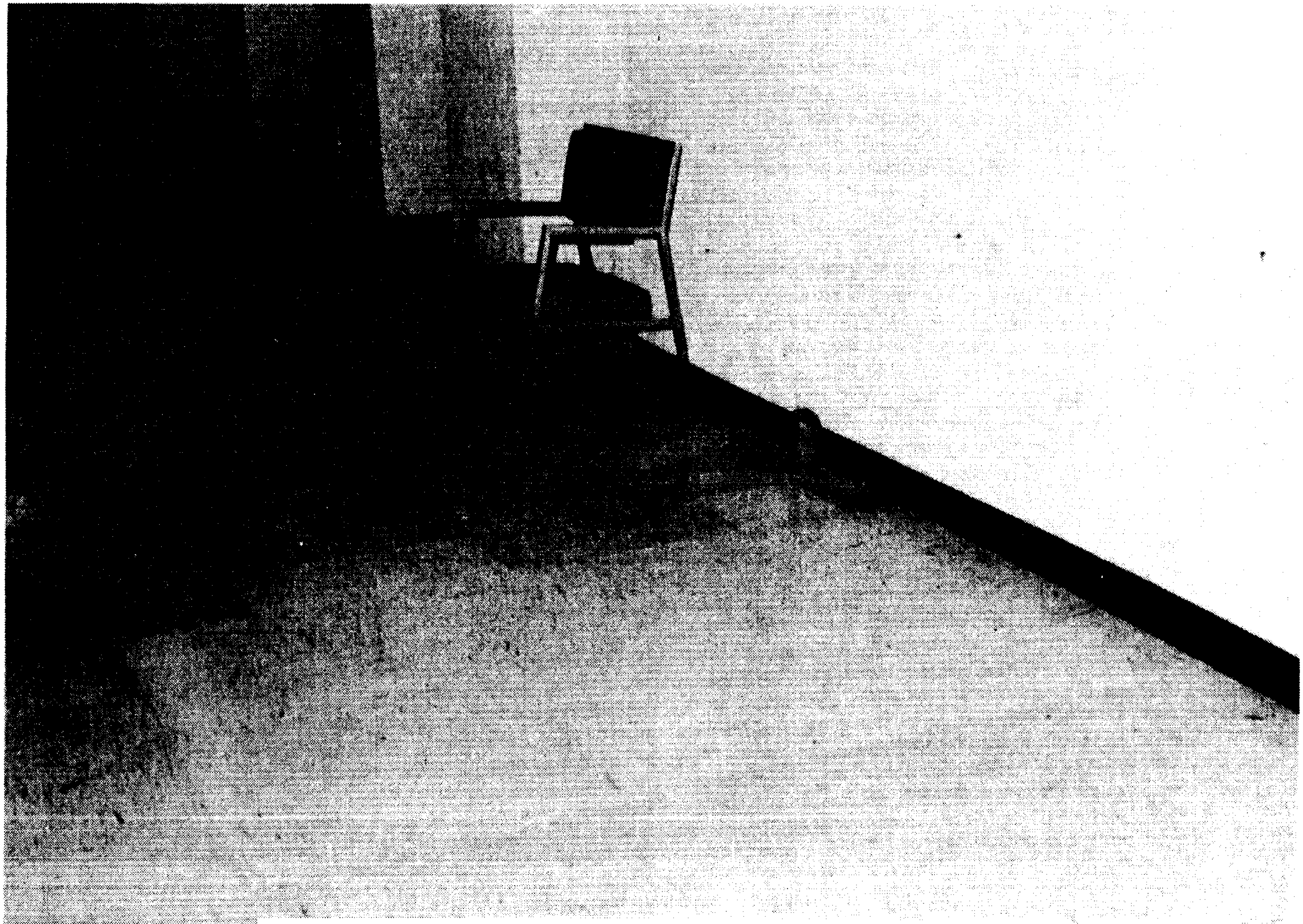

Figure 20. Eckhart Hall Basement After Restoration

Figure 21. Ryerson Laboratory Roof Vent Before Removal

Figure 22. Ryerson Laboratory Roof Vent After Removal

Figure 23. Ryerson Laboratory Roof Vent After Restoration

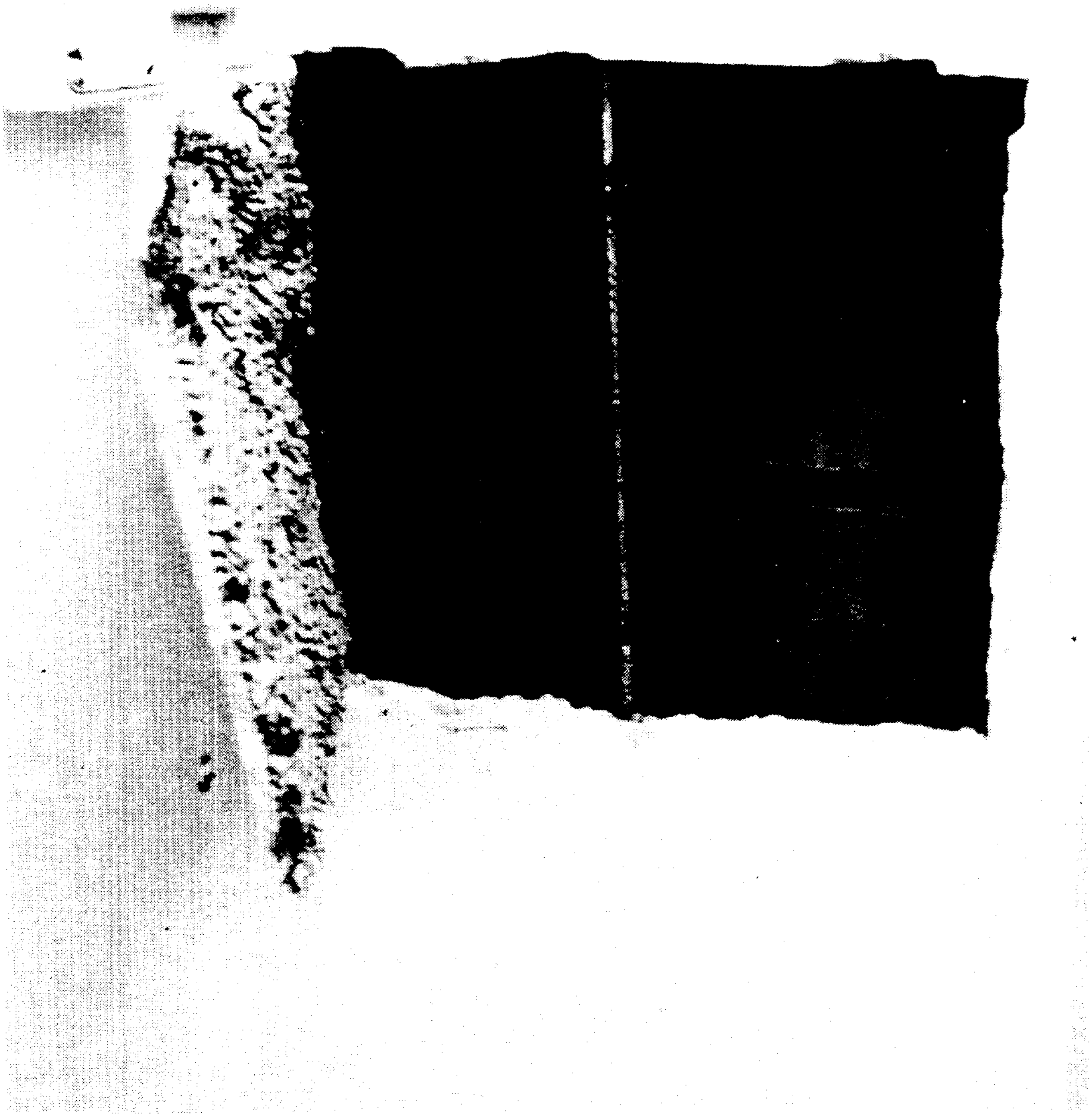

Figure 24. Ryerson Laboratory Exhaust Duct Before Removal

Figure 25. Ryerson Laboratory Exhaust Duct During Removal

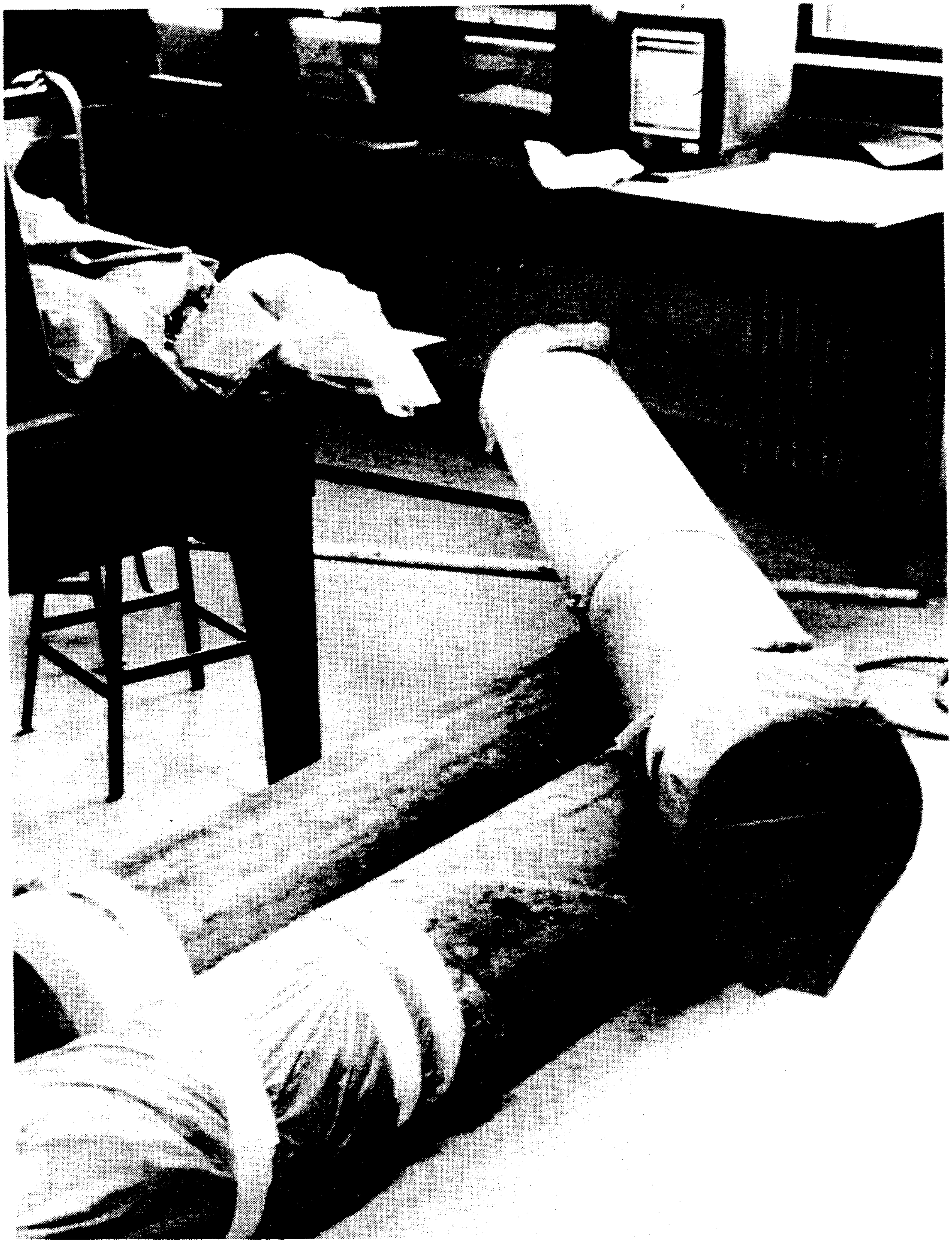

Figure 26. Ryerson Laboratory Exhaust Duct Removed Pipe

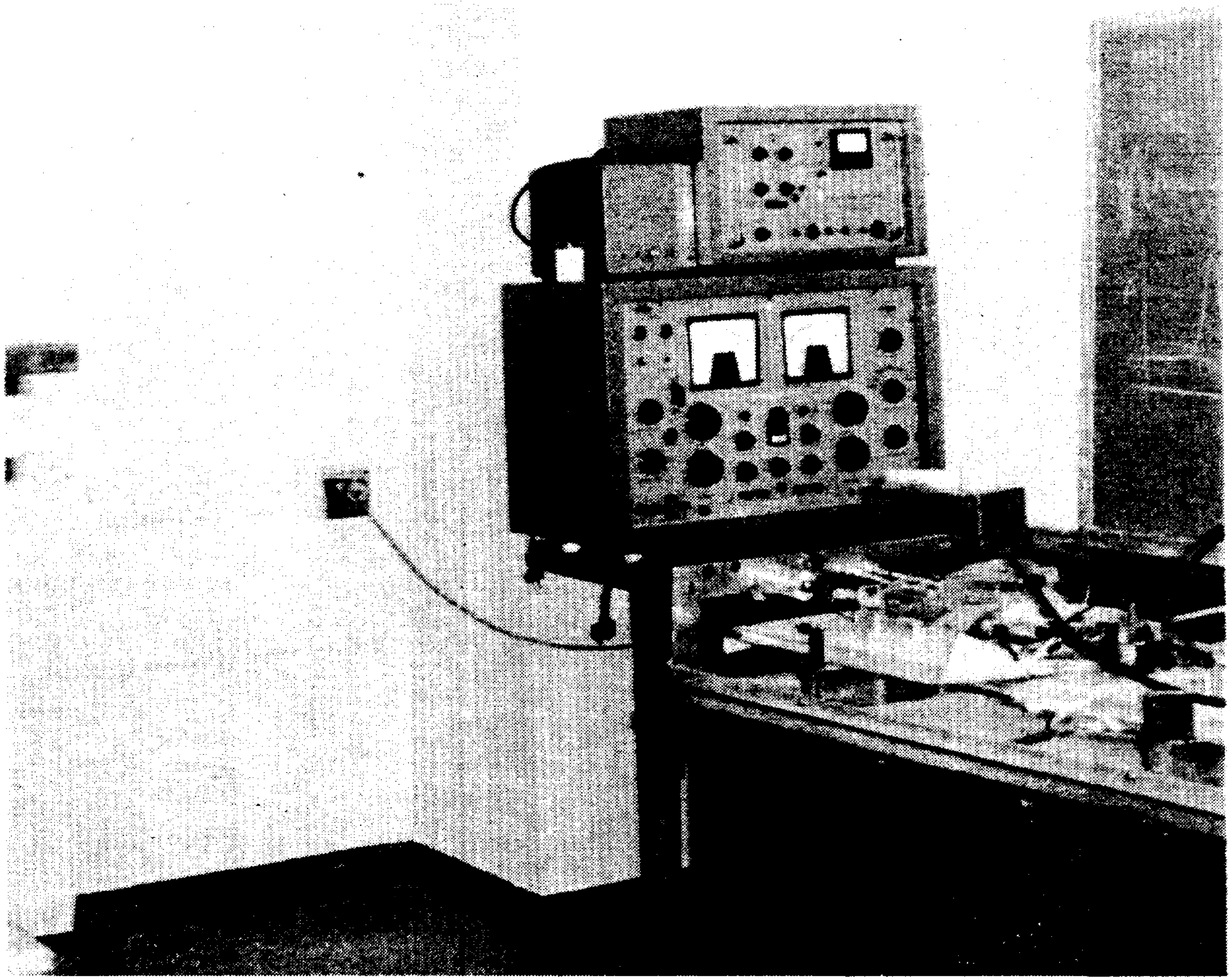

Figure 27. Ryerson Laboratory Exhaust Duct Restored Wall

Figure 28. Jones Laboratory Room 404E Initiation Of Wall Removal

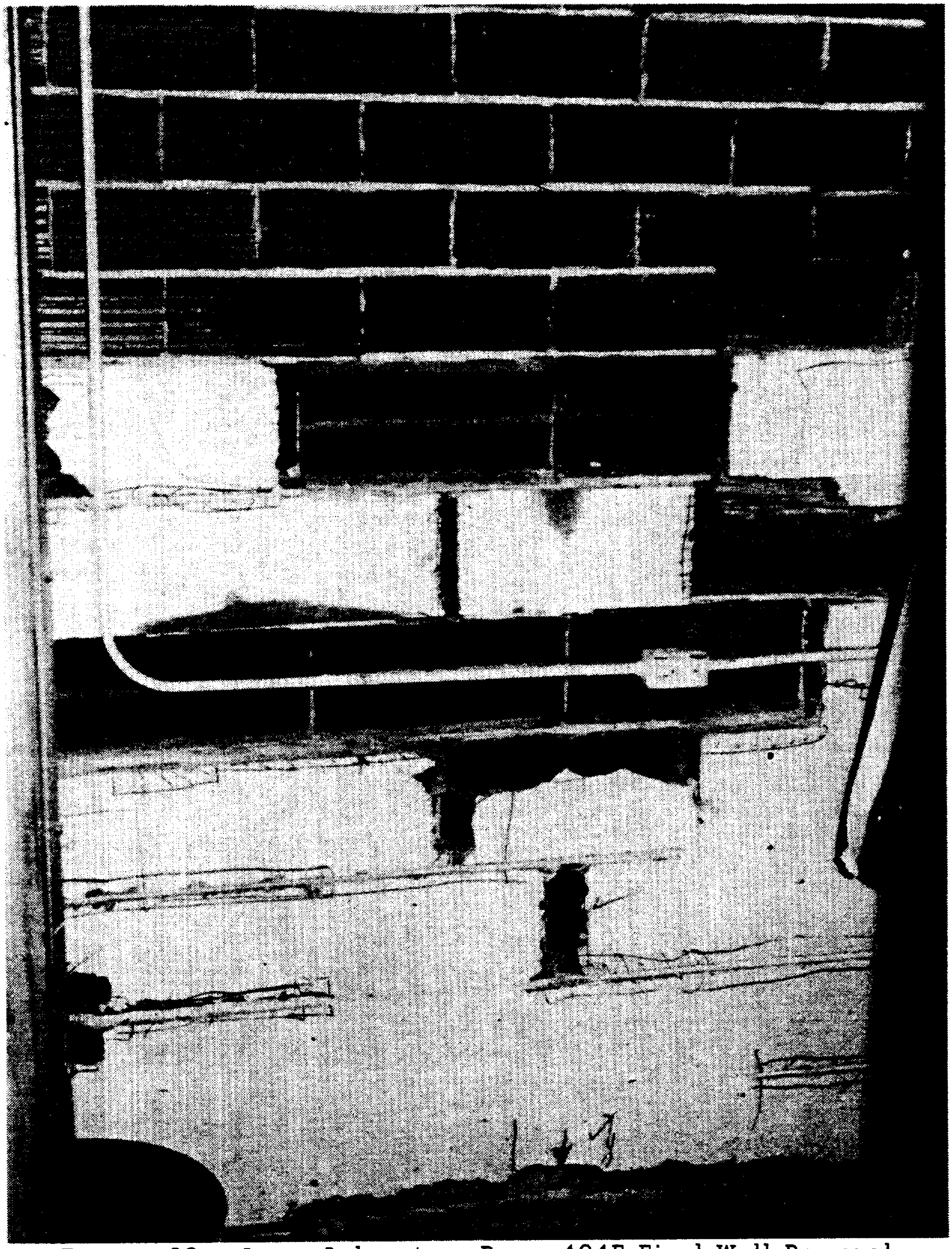

Figure 29. Jones Laboratory Room 404E Final Wall Removal

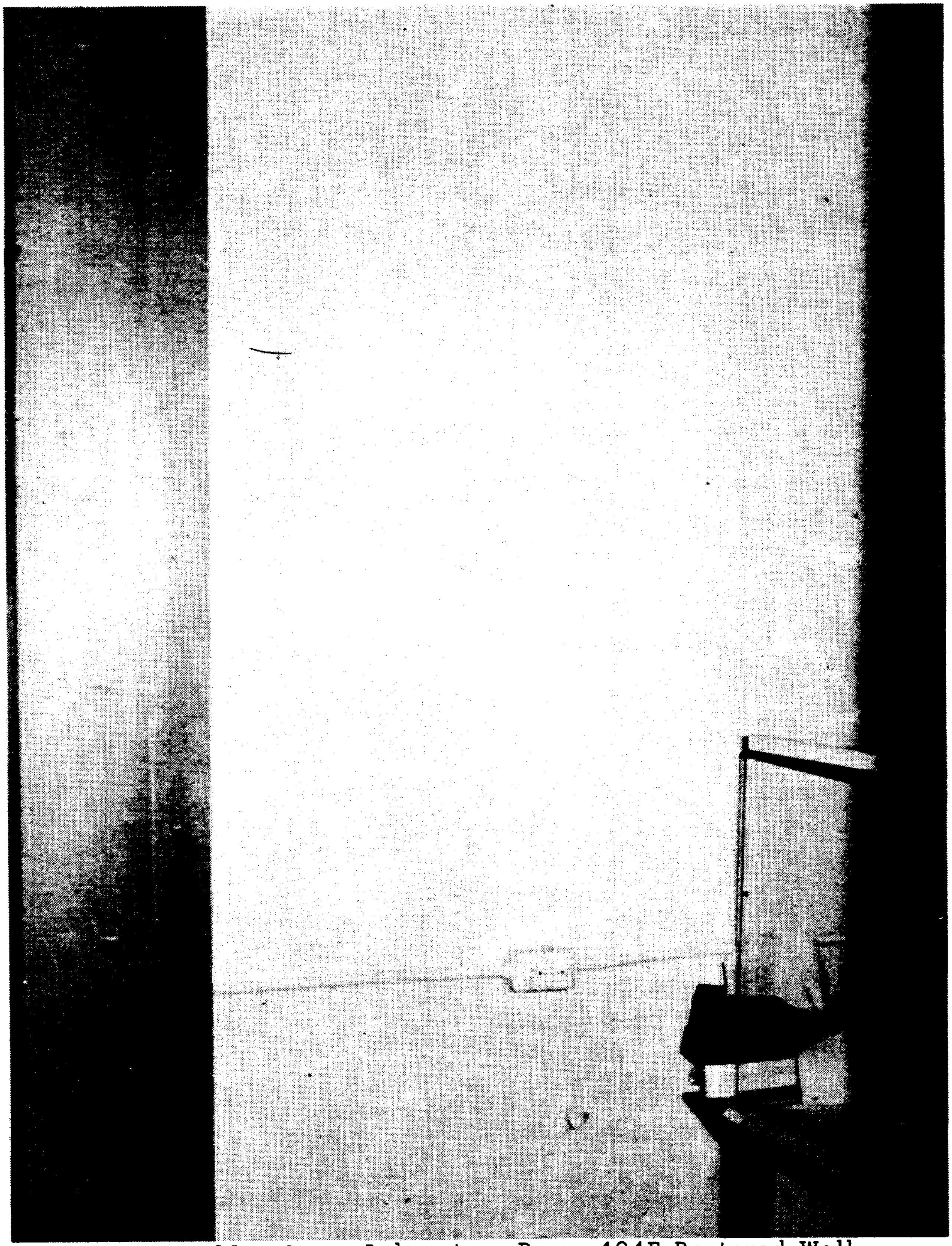

Figure 30. Jones Laboratory Room 404E Restored Wall

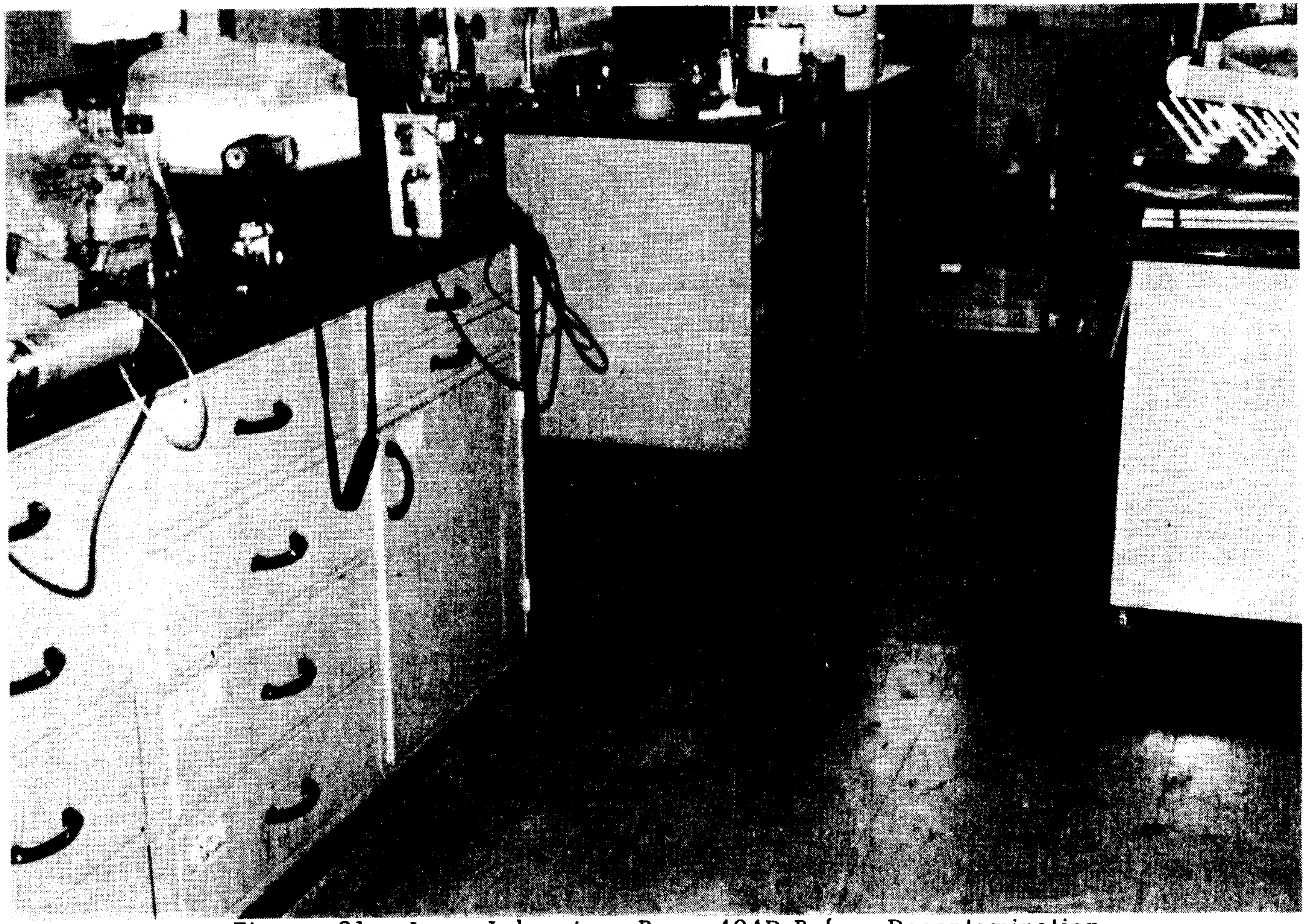

Figure 31. Jones Laboratory Room 404D Before Decontamination

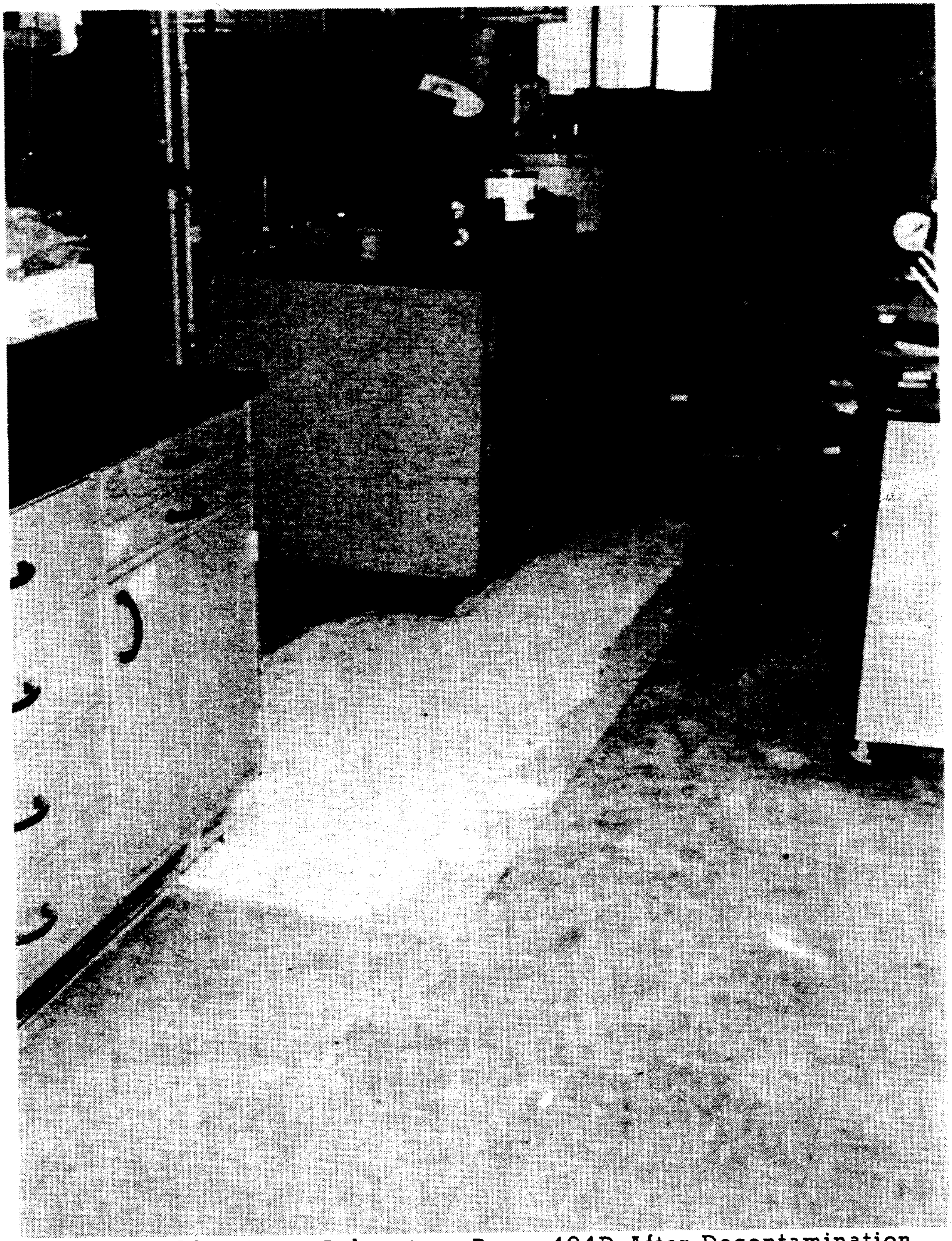

Figure 32. Jones Laboratory Room 404D After Decontamination

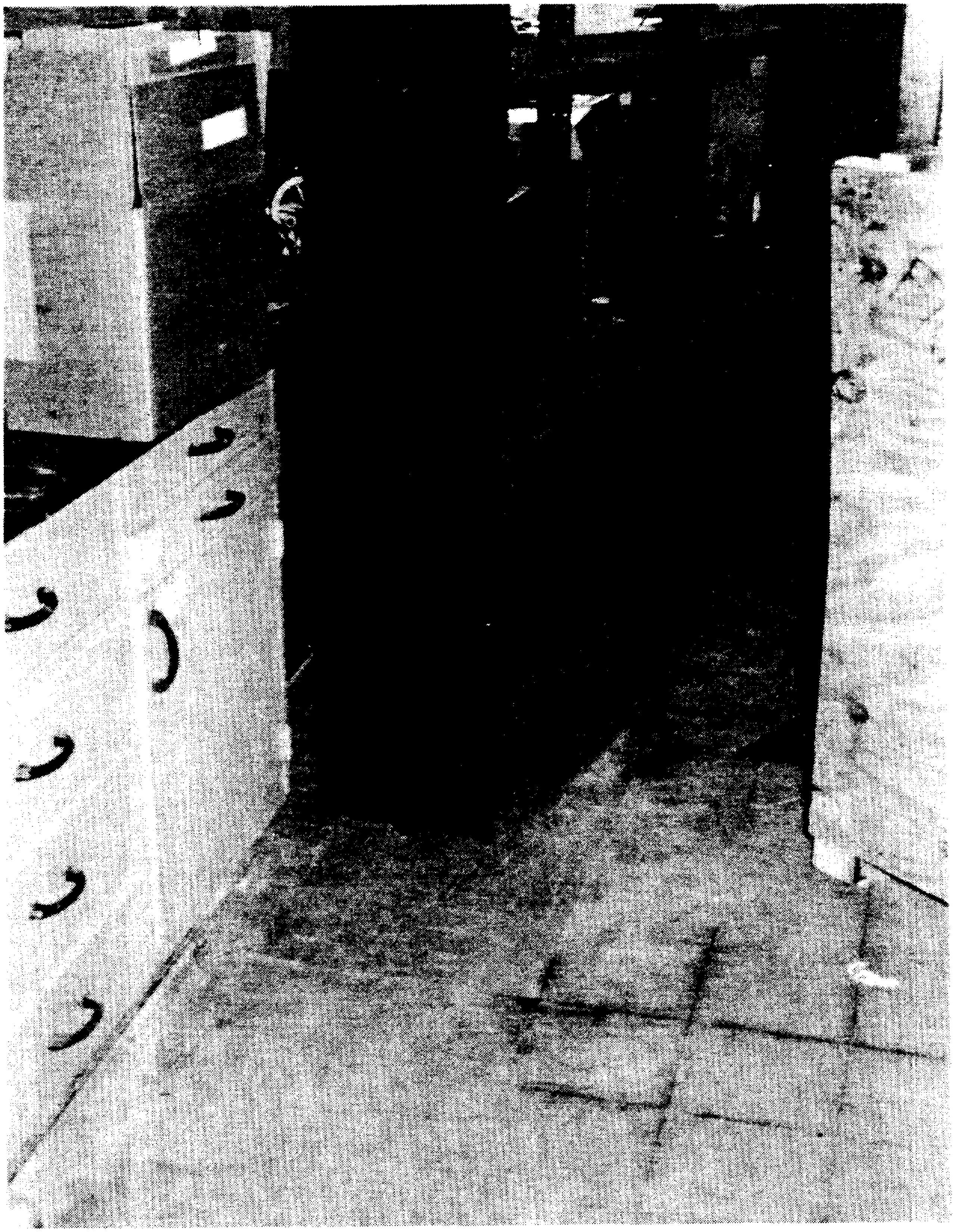

Figure 33. Jones Laboratory Room 404D After Restoration

Figure 34. Jones Laboratory Attic Before Decontamination

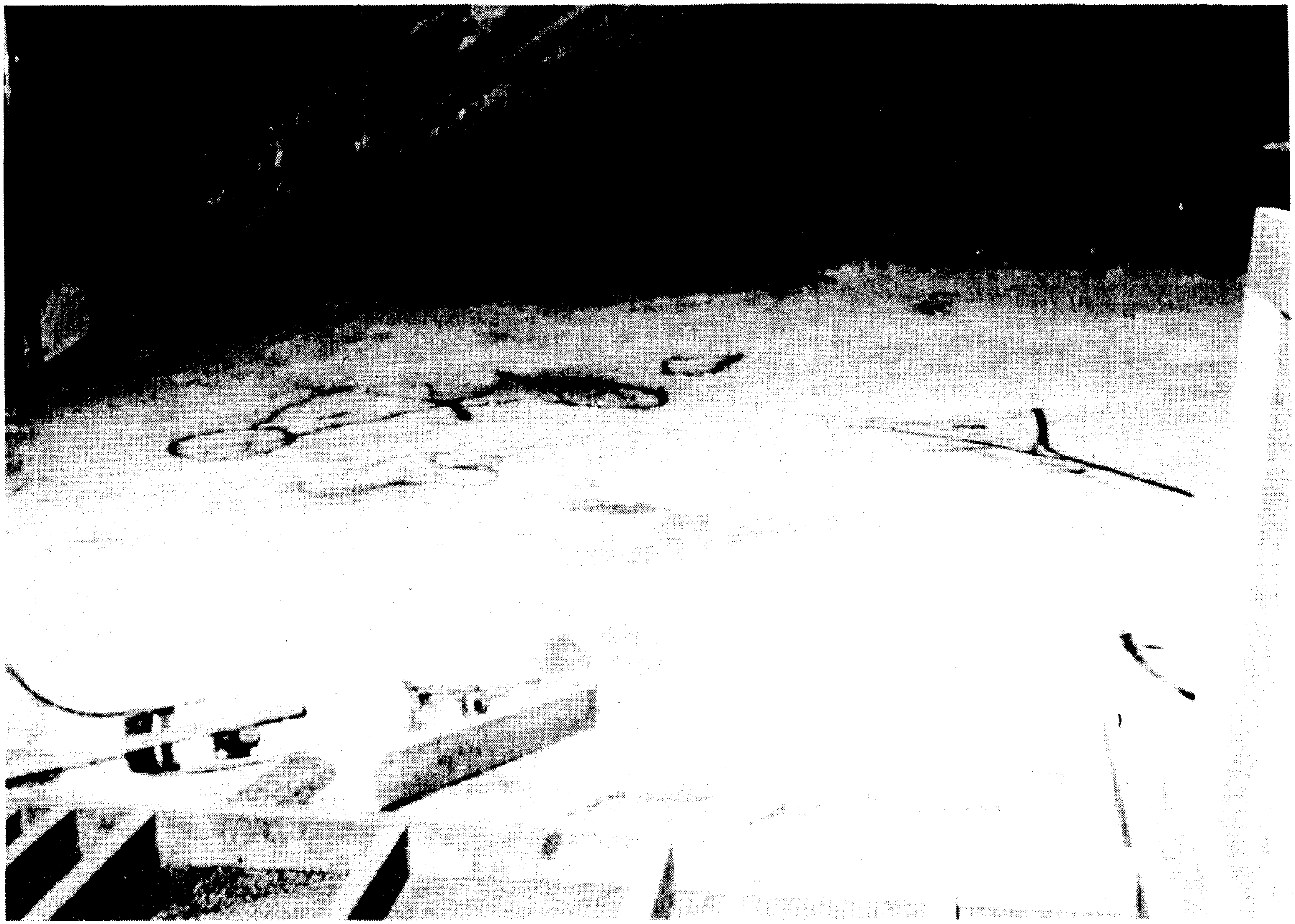

Figure 35. Jones Laboratory Attic After Decontamination

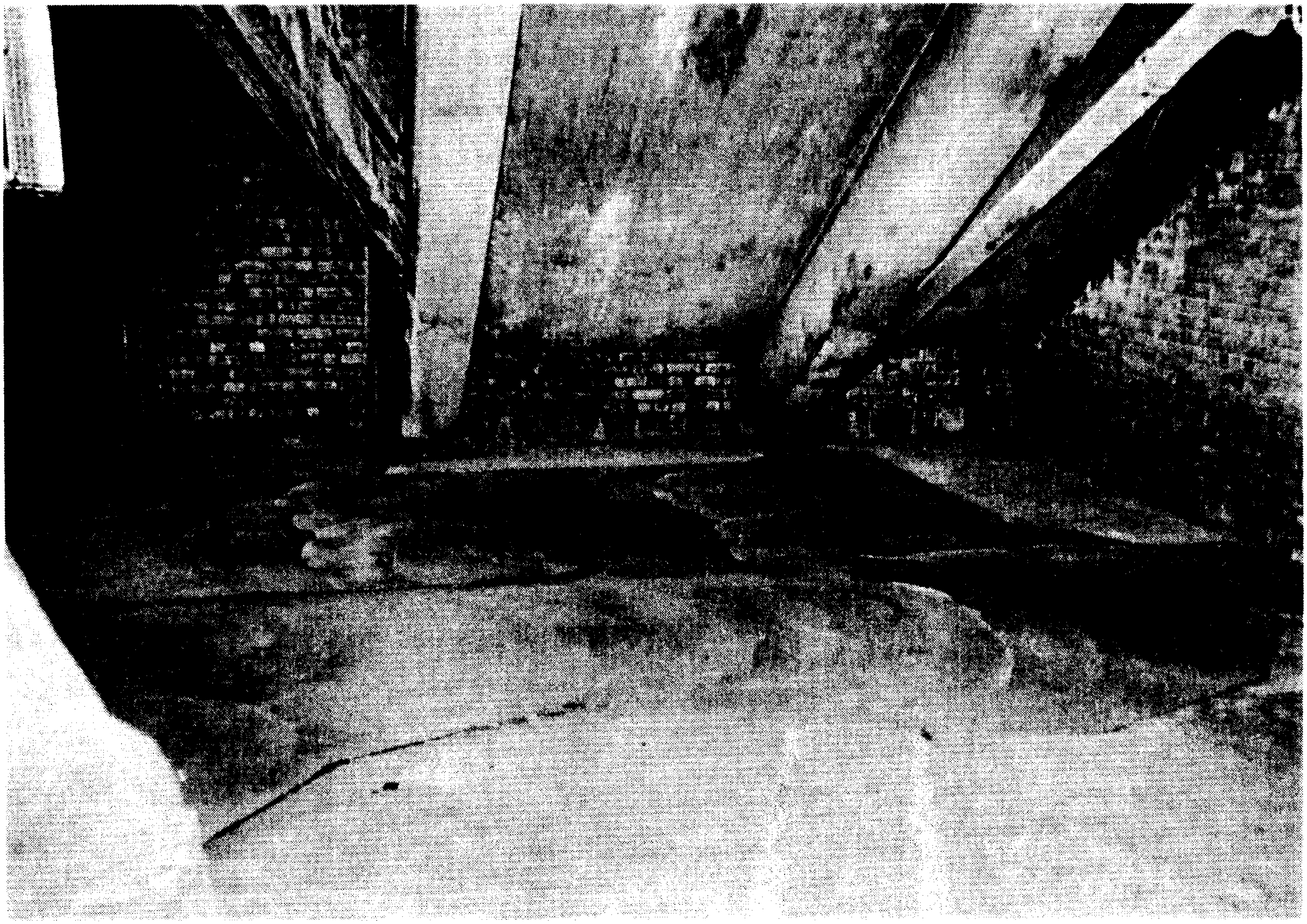

Figure 36. Jones Laboratory Attic After Restoration

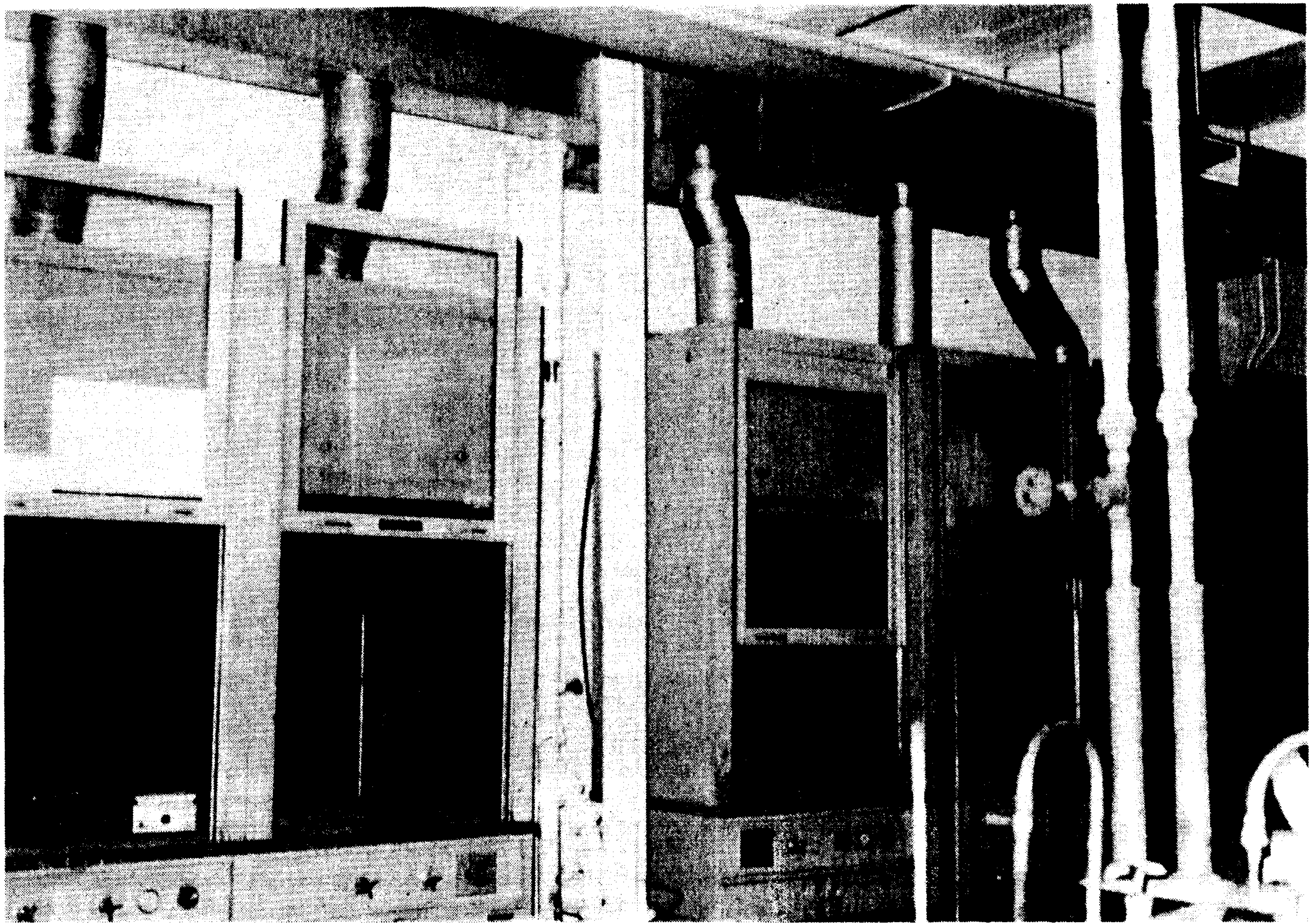

Figure 37. Typical Hood Complex With Exposed Ductwork in Jones

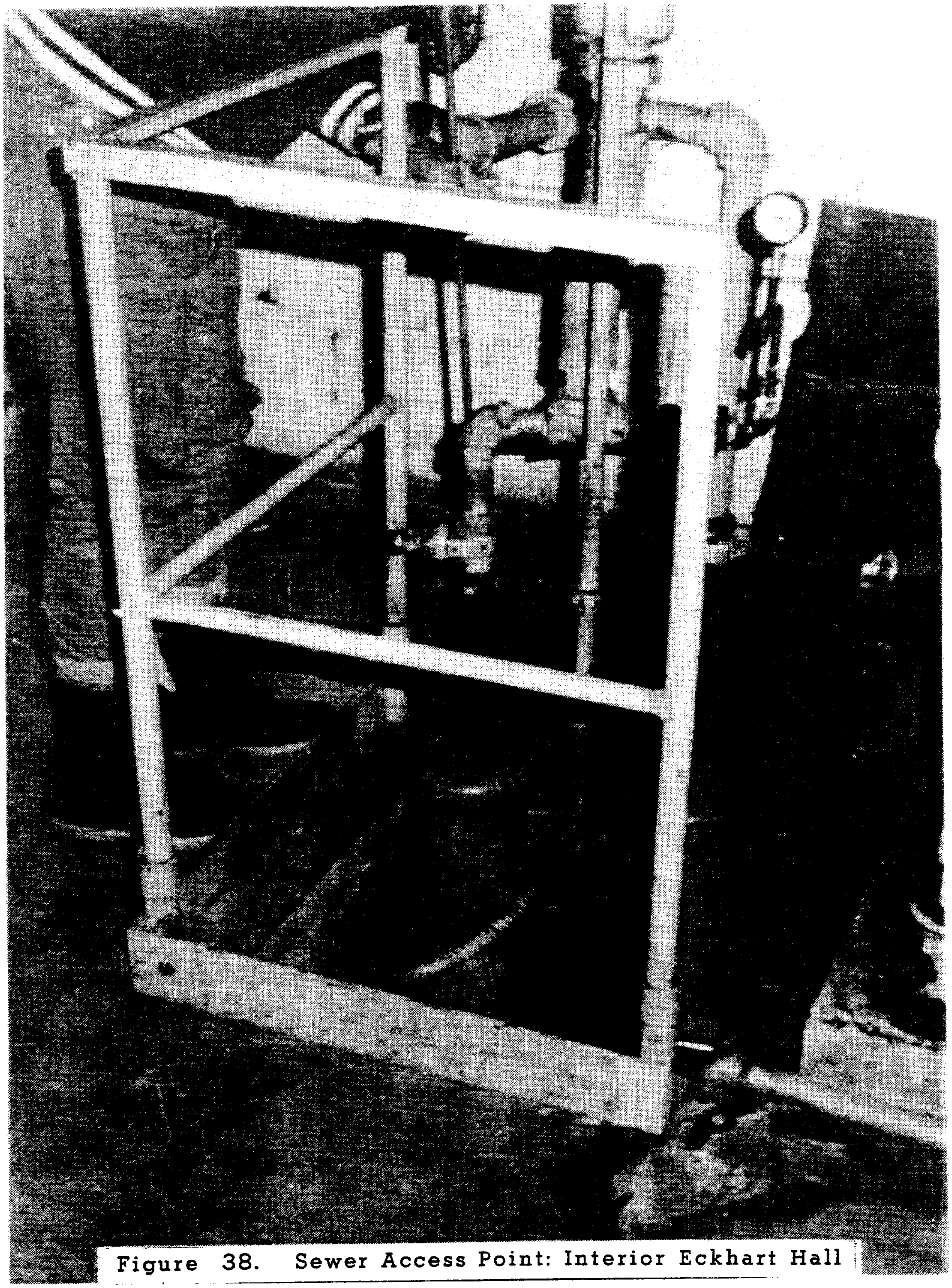

Figure 38. Sewer Access Point: Interior Eckhart Hall

Figure 39. Sewer Access Point: Interior Jones Laboratory

Figure 40. Sewer Access Point: Interior Ryerson Laboratory

Figure 41. Sewer Access Point: Exterior Greenwood Avenue

Figure 42. Sewer Access Point: Exterior South Of Jones Laboratory

Figure 43. Sewer Access Point: Exterior West Of Ryerson Laboratory

Figure 44. Sewer Access Point: Exterior East Of Kent Laboratory

APPENDICES

Appendices 1 through 5 contain detailed descriptions of the array of instruments and computational and analytical procedures typically employed by ANL's Radiological Survey Group in its comprehensive radiological assessments. Although the specific instruments and techniques used in a given survey depend on the conditions encountered and the information sought, descriptions of the entire array have been included here for completeness. The exact instruments and methods used in the survey reported in this document are specified in appropriate discussions in the text.

or convenience of author!

Appendix 6 contains excerpts from numerous regulations, standards, and guidelines relative to radiological conditions and exposure to radiation. Not all these necessarily apply at each site surveyed. Again, however, all have been included for completeness. The pertinent regulations, standards, and guidelines for this survey are cited in the text.

Appendix 8 contains a generic discussion of the nature and sources of radiation, its potential danger to humans, and methods utilized to evaluate radiation exposures.

APPENDIX 1

INSTRUMENTATION

I. PORTABLE RADIATION SURVEY METERS

A. Gas-Flow Proportional Survey Meters

The Eberline PAC-4G-3 was the primary instrument used for surveying. This instrument is a gas-flow proportional counter which utilizes a propane gas-proportional detector, 51 cm^2 (AC-21), 100 cm^2, or 325 cm^2 (AC-22) in area, with a thin double-aluminized Mylar window (~ 0.85 mg/cm^2).

Since this instrument has multiple high-voltage settings, it can be used to distinguish between alpha and beta-gamma contamination. This instrument was initially used in the beta mode. In that mode, the detector responds to alpha and beta paticles and x- and gamma-rays. When areas indicated a higher count rate than the average instrument background, the beta-mode reading was recorded, and the instrument was then switched to the alpha mode to determine any alpha contribution. In the alpha mode, the instrument responds only to particles with high-specific ionization. The alpha voltage is set to 1600 V, and the input discriminator is set to 1.5 mV. The instrument is then calibrated in the alpha mode with four flat-plate, infinitely-thin NBS-traceable ^{239}Pu standards, and in the beta mode with a flat-plate, infinitely-thin NBS-traceable ^{90}Sr-^{90}Y standard. The PAC-4G-3 instruments are calibrated to an apparent 50% detection efficiency.

B. Beta-Gamma End Window Survey Meter

not used

When an area of contamination was found with a PAC instrument, a reading was taken with an Eberline Beta-gamma Geiger-Mueller Counter, Model E-530, with a HP-190 probe. This probe has a thin mica end window and is, therefore, sensitive to alpha and beta particles and x- and gamma-rays. A thin piece of aluminum is added to the mica, making the window density approximately 7 mg/cm^2. At this density, the instrument is not sensitive to the majority of alpha emissions. A maximum reading is obtained with the probe placed in contact with the area of contamination. In this position, the response (in mR/h) to gamma radiation is generally conservative relative to a determination of mrad/h at 1 cm. This instrument is calibrated in mR/h with a ^{226}Ra standard.

C. Low-Energy Gamma Scintillation Survey Meter

An Eberline Model PRM-5-3 with a PG-2 gamma scintillation detector was used to determine low-energy x and gamma radiation. The PG-2 detector consists of a thin NaI(Tℓ) scintillation crystal 5 cm (2 in.) in diameter by 2 mm thick. This instrument is calibrated on three separate discriminators for three energy regions using ^{239}Pu (17 keV), ^{241}Am (59.5 keV), and ^{235}U (185.7 keV) sources. This instrument can be operated in either a differential (to discriminate between different energy regions) or integral mode.

APPENDIX 1
(cont'd.)

D. High-Energy Micro "R" Scintillation Survey Meter

An Eberline Micro "R" meter model PRM-7 was used to detect high-energy gamma radiation. This instrument contains an internally mounted NaI(Tℓ) scintillation crystal 2.5 cm (1 in.) in diameter by 2.5 cm (1 in.) thick and can be used to measure fields of low-level radiation between 10 μR/h and 5000 μR/h. This instrument is used to survey ambient background radiation. It is held 1 m (3 ft.) from the surface during the survey. This instrument is also calibrated with a standard ^{226}Ra source.

not used

E. Integrating Radiation Meter

In addition to the PRM-7, a pressurized ion chamber (Reuter Stokes Model RSS-111) was used at selected locations to determine the ambient radiation field. The RSS-111 has three output modes: (1) instantaneous exposure rate, (2) strip chart differential readout, and (3) integrated exposure. The chamber is mounted on a tripod, 3 ft (~ 1 m) above the surface and has a uniform energy response from about 0.2 MeV to about 4 MeV. A 3-h period of operation is usually sufficient to obtain significant data.

II. SMEAR-COUNTING INSTRUMENTATION

An ANL-designed gas-flow proportional detector connected to an Eberline Mini Scaler Model MS-2 was used to count multiple smears simultaneously. This detector has a double-aluminized Mylar window (400 cm^2) and uses P-10 (90% argon and 10% methane) as the counting gas. The metal sample holder for this detector has been machined to hold ten smear papers. This particular system consists of two Mini Scalers and two detectors. One is used to count in the alpha mode; the other is used in the beta mode. Up to ten samples can be counted simultaneously.

Any smear taken from a contaminated area was counted individually in a Nuclear Measurements Corporation gas-flow proportional counter (PC-5 or PC-3A). These instruments have been modified to contain a double-aluminized Mylar spun top window. This top is placed over non-conducting media (e.g. paper smears) to negate the dielectric effect on the counter. This counter also uses P-10 counting gas. Smears are counted in both the alpha and beta modes.

The PC counters are calibrated by adjusting the input discriminator with the high voltage set at 700 V until it begins to count an alpha source. The plateaus are run to establish the operating voltages for alpha and beta-gamma. The MS-2 input discriminator is set to 2 mV and again plateaus are run to establish the operating voltages.

III. AIR-SAMPLING DEVICE

Air samples were collected using a commercially available (ANL-modified Filter Queen) vacuum cleaner identified as the "Princess Model."

APPENDIX 1
(cont'd.)

Air was drawn through a filter medium at a flow rate of 40 m^3/h. The filters consist of 200-cm^2 sheets of Hollingsworth-Vose (HV-70) or LB5211-9 mil filter paper. The collection efficiency at these flow rates for 0.3-μm particles is about 99.9%.

A separate air sample can be taken with a positive displacement pump drawing about 20 liters/min through a Millipore membrane (0.5 to 0.8 μm) filter paper for about one hour. An alpha spectrum can be measured from a section of this filter paper. The ratio of actinon (^{219}Rn) daughters (6.62 MeV α, AcC) to radon (^{222}Rn) daughters (7.69 MeV α, RaC') can be determined from this spectrum.

IV. GAMMA SPECTRAL INSTRUMENTATION

A. Contamination Identification

A Nuclear Data Multichannel Analyzer Model ND-100, utilizing a 7.6-cm (3-in.) diameter by 7.6-cm (3-in.) thick NaI(Tℓ) lead shielded scintillation crystal is commonly used for determining a gamma spectrum. The crystal and lead shielding are located inside the radiological survey vehicle. This instrument is calibrated with NBS-traceable gamma sources. This system can be used to identify contaminant radionuclides by analyzing the gamma-rays emitted by samples from contaminated areas.

Hyperpure Germanium detectors (ORTEC - 17% efficiency right-circular cylinders) can be used when more sophisticated gamma-ray analyses are required. These detectors are coupled to Nuclear Data Multichannel Analyzers (Models ND-60, ND-66 or ND-100).

B. Borehole Logging

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The gamma-ray spectrum of a borehole is logged using the Bicron 5.1 cm (2 in) by 5.1 cm (2 in) NaI crystal and either the ND-66 or the ND-100. This crystal is specially designed to withstand the temperature changes that can be encountered in boreholes. Permanent records of the spectrum are produced by the teletype printer and paper tape punch or the Centronix Printer and Magnetic Tape Drive.

APPENDIX 2

CONVERSION FACTORS

I. INSTRUMENTATION

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

A. Conversion Factors

	PAC-4G-3		Floor Monitor (FM-4G)	
	Alpha	Beta	Alpha	Beta
To 100 cm^2	1.96	1.96	0.31	0.31
cts/min to dis/min for $^{90}Sr-^{90}Y$	-	2	-	2
cts/min to dis/min for ^{239}Pu	2	-	2	-
cts/min to dis/min for normal U	3.5	2.7	3.0	2.5
cts/min to dis/min ^{226}Ra plus daughters	1.7	1.7	1.7	1.8

B. Derivation of Conversion Factors

- Floor Monitor

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

- PAC-4G-3

Window Area: ~ 51 cm^2
Conversion to 100 cm^2 = 1.96 times PAC reading

- 2π Internal Gas-Flow Counter, PC counter

Geometry: Solid Steel Spun Top - 0.50

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

APPENDIX 2
(cont'd.)

The PAC-4G-3 and PC counters were calibrated as described in Appendix 1. With a flat-plate, infinitely thin ^{226}Ra plus short-lived daughters standard used as a source of alpha emissions, the plate was counted in a 2π Internal Gas-Flow Counter (PC counter) with the source leveled to an apparent 2π geometry. The alpha counts per minute (cts/min) reading was found to be 1.86 x 10^4 cts/min, or 1.86x 10^4 ÷ 0.51* = 3.65 x 10^4 disintegrations per minute (dis/min) alpha. Since the source was infinitely-thin, the alpha component was used as the total alpha dis/min of the source.

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

The same source was covered with two layers of conducting paper, each 6.31 mg/cm^2, to absorb the alpha emissions. With the PC counter in the beta mode and the paper in good contact with the chamber, the count was found to be 1.17 x 10^4 cts/min or 1.17 x 10^4 ÷ 0.50 = 2.35 x 10^4 dis/min beta. With the PAC-4G-3 in the beta mode and in contact with the covered source in the center of the probe, the count was found to be 1.36 x 10^4 cts/min. This indicates a conversion factor of 2.35 x 10^4 ÷ 1.36 x 10^4 = 1.7 dis/min per cts/min beta-gamma. All three detectors (51 cm^2, 100 cm^2, and 325 cm^2) gave readings similar to those reported above for the alpha and beta-gamma modes.

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

The normal uranium source was also counted with the PAC instruments using all three detector areas in the alpha mode and covered with two layers of conducting paper in the beta mode. The conversion factors were calculated as for ^{226}Ra.

Irrelevant

II. SMEAR COUNT

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

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

APPENDIX 2
(cont'd.)

A. Conversion Equation (Alpha)

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

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

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

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

If the energies of the isotope are known, the appropriate window air factor (waf) is used; if the energies of the isotopes are not known, the (waf) of ^{239}Pu (0.713) is used.

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

B. Conversion Equation (Beta)

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

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

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

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

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

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

APPENDIX 3

RADON-DETERMINATION CALCULATIONS

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

I. RADON CONCENTRATIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

APPENDIX 3
(cont'd.)

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

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

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

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

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

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

S. AcA, AcB and AcC are in equilibrium.

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

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

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

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

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

Y. 84% of the AcC decays by 6.62 MeV α emissions and 16% decays by 6.28 MeV α emissions.

The following postulate is assumed in deriving the long-lived concentration:

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

APPENDIX 3
(cont'd.)

II. EQUATIONS USED TO DERIVE AIR CONCENTRATIONS

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

where: A_o = activity (dis/min) present at the end of the sampling period (usually 40 minutes)

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

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

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

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

Concentration is determined by the equation:

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

where: C = concentration (dis/min-m^3)

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

f = sampling rate (m^3/min = m^3/h x 1 h/60 minutes)

t_s = length of sampling time (minutes)

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

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

III. ACTINON CORRECTION

Since the actinon (^{219}Rn) progeny (AcA, AcB & AcC) decays at the AcB half-life of 36 minutes, it cannot be distinguished from the radon (^{222}Rn) progeny using standard air sampling with HV-70 or LB5211 filter media and standard alpha-counting techniques. A positive displacement pump is used to collect a sample on Millipore membrane (0.5 to 0.8 µm) filter media. The sample rate is approximately 20 liters/minute for a sampling time of at least 90 minutes. The center portion of the sample is removed and counted

APPENDIX 3
(cont'd.)

in an alpha spectrometer which exhibits the 6.62 MeV AcC alpha emissions and the 7.69 MeV RaC' alpha emissions. If these two peaks are observed in the spectrum, then the following calculations are performed:

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

where: B_j = summation of the counts in n channels under peak j

b_{ij} = the number of counts in channel i of peak j

j = 1 for the 6.62 MeV peak of actinon; 2 for the 7.69 MeV peak of radon

n = total number of channels in the summation.

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

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

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

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

IV. EXAMPLE CALCULATION

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

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

For long-lived activity:

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

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

APPENDIX 3
(cont'd.)

For thoron:

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

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

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

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

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

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

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

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

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

For 6.62 MeV peak:	44 in 10 channels, where the 6.62 alpha emissions are 84% of the total.
For 7.69 MeV peak:	601 counts in 10 channels, where the 7.69 MeV alpha emissions are 100% of the total.

APPENDIX 3
(cont'd.)

$B_1 = 44$

$B_1/0.84 = 52$ counts

$B_2 = 601$ counts

Actinon = 52/653 = 0.08

Radon = 601/653 = 0.92

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

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

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

C actual = C measured x progeny correction factor

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

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

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

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

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

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

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

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

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

APPENDIX 4

SAMPLE PREPARATION AND ANALYSIS, GENERIC PROTOCOL

Delete I, II, IV, V, Edit VII, as required

I. SOIL-SAMPLE PREPARATION

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

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

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

After milling, each sample is sieved through a number 30 standard testing sieve (600 μ mesh) and transferred to a 12" x 12" ziplock bag. Rocks and dross are bagged separately from the sieved material. The bags are marked with the sample number, the sieve number and R(rocks) or S(soil). The balance is tared and the weights of the soil (or rocks) are measured and recorded in the soil-sample book. A 100-g sample of the sieved material is transferred to a 4-oz. Nalgene bottle. These samples are analyzed by suitable analytical techniques, including, as a minimum, gamma spectroscopy (GeLi). A 5-g sample of the sieved material is transferred to a 1-oz Nalgene bottle. One gram of this sample is used for the determination of uranium by laser fluorometry; 100 grams of this are needed for radiochemical analysis for Pu, Am, and Th if these analyses are required. The bottles containing these weighed samples are marked with sample number and date, and

APPENDIX 4
(cont'd.)

this information is recorded in the soil-sample book. The rocks (and dross) and remaining soil are placed in storage.

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

II. EQUIPMENT DECONTAMINATION

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

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

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

III. WATER AND SLUDGE

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

APPENDIX 4
(cont'd.)

pended and dissolved solids are analyzed by appropriate radiochemical analytical techniques.

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

IV. VEGETATION, TRASH AND RUBBLE

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

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

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

V. TRITIUM FROM SOLID MATERIALS

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

VI. ANALYSIS PROCEDURES

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

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

Thorium analysis consists of an acid leach of the soil (using a ^{234}Th spike for yield determination) followed by plating a thin source of the

APPENDIX 4
(cont'd.)

radiochemically separated thorium and determining the thorium isotopes (^{228}Th and ^{232}Th) by alpha spectroscopy.

The results of the above measurements allow for quantitative determination of the relative amounts of normal uranium, natural uranium, tailings (i.e., ^{226}Ra decay chain), thorium (^{232}Th), mesothorium (^{228}Ra decay chain), radiothorium (^{228}Th decay chain), plutonium (^{238}Pu, ^{239,240}Pu), and americium (^{241}Am) present in the contaminated material.

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

APPENDIX 5

CALCULATION OF URANIUM SPECIFIC ACTIVITY

The specific activity for normal uranium was obtained by summing the measured specific activities for the individual isotopes weighted according to their normal abundances. Best values for these specific activities were taken from A. H. Jaffey et al., Phys. Rev.C 4 1889 (1971). The half-life for each isotope was taken from David C. Kocher, "Radioactive Decay Tables - A Handbook of Decay Data for Application to Radiation Dosimetry and Radiological Assessments" (1981). The percent abundances were taken from N. E. Holden, BNL-NCS-50605 (1977). Atomic weights were taken from the Handbook of Chemistry and Physics, 52nd Edition (1971). The specific activity of ^{234}U was calculated from the half-life.

Isotope	Specific Activity (dis/min-μg)	Half-life (years)	Abundance (atom %)	Atomic Weight (grams)	Abundance (wt %)
^{234}U	1.387×10^{4}	2.446×10^{5}	0.0054	234.0409	0.0053
^{235}U	4.798	7.038×10^{8}	0.720	235.0439	0.7110
^{238}U	0.746	4.4683×10^{9}	99.2746	238.0508	99.2837
			100.0000		100.0000

where $(\text{wt }\%)_i =$

$$\frac{(\text{atom }\%)_i \ (\text{atomic weight})_i}{\sum_{\text{all } j} (\text{atom }\%)_j \ (\text{atomic weight})_j} = \frac{(\text{atom }\%)_i \ (\text{atomic weight})_i}{238.0289}$$

Specific activity for normal uranium:

$0.746 \times 0.99284 \times 2 = 1.481$ dis/min-μg from ^{234}U & ^{238}U
$4.798 \times 0.00711 = \underline{0.034}$ dis/min-μg from ^{235}U
1.515 dis/min-μg for normal U

or (1.515 dis/min-μg)/(2.22 dis/min-pCi) = 0.683 pCi/μg

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

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

Calculation of the specific activity of other than normal mixtures of uranium isotopes are performed in a similar manner. For example, uranium having the isotopic composition (atom %) 238(0.99268), 236(0.000007), 235 (0.007233), 234(0.000064) and 233(0.000012) as determined by mass spectrometry would have the composition (weight %) of 238(.99278), 236(0.000007), 235(0.007142), 234(0.000063), and 233 (0.000012) and the following specific activity:

APPENDIX 5
(cont'd.)

$$\begin{array}{llll}
0.99278 \times 0.746 & = 0.7406 & \text{dis/min-}\mu\text{g from} & {}^{238}\text{U} \\
0.000007 \times 1.436 \times 10^{2} & = 0.0010 & \text{dis/min-}\mu\text{g from} & {}^{236}\text{U}^{*} \\
0.007142 \times 4.798 & = 0.0343 & \text{dis/min-}\mu\text{g from} & {}^{235}\text{U} \\
0.000063 \times 1.387 \times 10^{4} & = 0.8738 & \text{dis/min-}\mu\text{g from} & {}^{234}\text{U} \\
0.000012 \times 2.140 \times 10^{4} & = \underline{0.2568} & \text{dis/min-}\mu\text{g from} & {}^{233}\text{U}^{**} \\
 & \ 1.9065 & \text{dis/min-}\mu\text{g U total} &
\end{array}$$

corresponding to:

$$(1.9065 \text{ dis/min-}\mu\text{g})/(2.22 \text{ dis/min-pCi}) = 0.859 \text{ pCi}/\mu\text{g U}$$

*The half-life for ^{236}U (2.342×10^{7} yr) and the corresponding specific activity (1.436×10^{2} dis/min-μg) were taken from K. F. Flynn, et. al. J. Inorg. Nucl. Chem. <u>34</u> 1121 (1972).

**The half-life for ^{233}U (1.5911×10^{5} yr) and the corresponding specific activity (2.140×10^{4} dis/min-μg) were taken from A. H. Jaffey, K. F. Flynn, et. al. Phys. Rev. C <u>9</u> 1991 (1974).

Should recent interim criteria ~~stds~~ + guidelines for FUSRAP + remote SFMP sites be included?

APPENDIX 6

PERTINENT RADIOLOGICAL REGULATIONS STANDARDS, AND GUIDELINES

Excerpts From

I. DRAFT AMERICAN NATIONAL STANDARD

N13.12

Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use

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

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

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

APPENDIX 6
(cont'd.)

TABLE 1

SURFACE CONTAMINATION LIMITS*

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

APPENDIX 6
(cont'd.)

SURFACE CONTAMINATION LIMITS

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

[+] Disintegrations per minute per square decimeter.

NOTES:

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

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

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

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

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

APPENDIX 6
(cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

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

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

APPENDIX 6
(cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

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

[+] Disintegrations per minute per square decimeter.

NOTES:

(1) U_{nat} and decay products.

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

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

APPENDIX 6
(Cont'd.)

II.

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

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

(These have been retyped for
purposes of this report)

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

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

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

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

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

APPENDIX 6
(cont'd.)

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

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

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

a. Identify the premises.

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

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

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

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

APPENDIX 6
(cont'd.)

TABLE 1

ACCEPTABLE SURFACE CONTAMINATION LIMITS

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

APPENDIX 6
(cont'd.)

TABLE 1

ACCEPTABLE SURFACE CONTAMINATION LEVELS

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

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

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

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

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

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

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(cont'd.)

III.

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

712.1 Purpose

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

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

712.2 Scope

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

712.3 Definitions

As used in this part:

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

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

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

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

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

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

APPENDIX 6
(cont'd.)

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

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

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

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

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

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

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

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

712.4 Interpretations

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

712.5 Communications

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director,

APPENDIX 6
(cont'd.)

Division of Safety, Standards, and Compliance, U.S. Department of Energy, Washington, D.C. 20545.

712.6 General radiation exposure level criteria for remedial action.

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

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

712.7 Criteria for determination of possible need for remedial action

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

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

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

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

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

(1) For dwellings and schoolrooms:

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(cont'd.)

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

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

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

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

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

(2) For other structures:

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

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

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

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

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

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

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

APPENDIX 6
(cont'd.)

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

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

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

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

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

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

712.10 Selection of appropriate remedial action.

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

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

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IV.

40 CFR Part 192
HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS FOR URANIUM MILL TAILINGS

(Excerpts have been retyped for purposes of this report)

SUBPART B--Standards for Cleanup of Open Lands and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.10 Applicability

This subpart applies to land and buildings which are part of any processing site designated by the Secretary of Energy under Pub. L. 95-604, Section 102. Section 101 of Pub. L. 95-604, states that "processing site" means--

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

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

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

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

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

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

192.11 Definitions

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

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

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

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(cont'd.)

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

192.12 Standards

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

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

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

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

(b) in any occupied or habitable building---

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

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

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V

EXCERPTS FROM LA-UR-79-1865-Rev., "Interim Soil Limits for D&D Projects"

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

	Inhalation	Ingestion		External Radiation	All Pathways[c]
		Home Gardener	Full Diet		
^{231}Pa	50	740	150	250	40
^{227}Ac	200[d]	4,900	1,000	300	120[d]
^{232}Th	45	670	140	40	20
^{228}Th	1,000	37,000	7,800	55	50
^{230}Th (No Daught.)	300	4,400	940	36,000	280
^{238}U-^{234}U	750	44	8	6,000	40
^{90}Sr	2×10^6	100	19	-	100
^{137}Cs	7×10^6	800	1	90	80

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

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

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

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

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VI. DOE 5480.1 Chg. 6, Chapter XI

REQUIREMENTS FOR RADIATION PROTECTION

(Excerpts have been retyped for purposes of this report. Table XI-1 has been modified to reflect the fundamental definition of the Curie as a unit of radioactivity. The designation of uranium is changed to reflect the original usage of the terms normal and natural.)

1. PURPOSE This chapter establishes radiation protection standards and requirements for Department of Energy and Department of Energy contractor operations based upon the recommendations of the Environmental Protection Agency and the National Council on Radiation Protection and Measurement.

2. DEFINITIONS

   a. Controlled Area. Any area to which access is controlled in order to protect individuals from exposure to radiation and radioactive materials.

   b. Dose Commitment. The dose equivalent (rem) received by specific organs during a period of one calendar year, that was the result of uptakes of radionuclides by a person occupationally exposed.

4. REQUIREMENTS.

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

      (1) Radiation Protection Standards for External and Internal Exposure.

	Annual Dose Equivalent or Dose Commitment[1]	
Type of Exposure	Based on Dose to Individuals at Points of Maximum Probable Exposure	Based on Average Dose to a Suitable Sample of the Exposed Population[2]
Whole body, gonads, or bone marrow	0.5 rem (or 500 mrem)	0.17 rem (or 170 mrem)
Other organs	1.5 rem (or 1500 mrem)	0.5 rem (or 500 mrem)

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(cont'd.)

1/ In keeping with Department of Energy policy on lowest practicable exposures, exposures to the public shall be limited to as small a fraction of the respective annual dose limits as is reasonably achievable.

2/ See Paragraph 5.4, Federal Radiation Council Report No. 1, for discussion on concept of suitable sample of exposed population.

(2) Monitoring Requirements. To assure that doses to the public are maintained as low as reasonably achievable consistent with dose standards set forth in paragraph 4b(1) above, effluents to the environment, and other parameters shall be monitored and documented in accordance with DOE 5484.1.

(3) Concentration Guides.

(a) Concentration Guides in Attachment XI-1, Table II, were derived for the most part from the dose standards for individuals in paragraph 4b(1) above (assume 168 hours of exposure per week). These guides shall be reduced by a factor of three when applied to a suitable sample of the population. Where transient exposures can be calculated, the concentration guides other than those in Attachment XI-1, Table II, may be used to evaluate compliance with the dose commitment standard.

(b) There may be situations where it is not feasible or desirable to evaluate the exposure of individuals and samples of exposed populations to effluents to assure compliance with standards in paragraph 4b(1) above. In those cases, effluent releases to uncontrolled areas shall be such that average concentrations of radioactivity at the point of release are within the concentration guides and are as low as reasonably achievable. The point of release shall be considered to be the point at which the effluents pass beyond the site boundary. Radioactivity concentrations may be averaged over periods up to 1 year.

(4) Further Limitations on Effluent Discharges. In any situation in which the effluents discharged by one or more activities of the Department, Department contractors, or others cause exposure to approach the standards specified in subparagraph b(1) above, appropriate effluent discharge limits may be set for these operations. In such cases, the manager of the field organization may take the necessary corrective action if all activities concerned are within his or her area of responsibility. Otherwise, each case will be referred to EP-30 for

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(cont'd.)

appropriate action including, where appropriate, coordination with actions taken by the Nuclear Regulatory Commission under the Code of Federal Regulations, Title 10, Part 20.106(e).

(5) <u>Discharge to Sanitary Sewage Systems</u>.

(a) Effluents may be discharged to public sanitary sewage systems provided:

<u>1</u> The quantity of radioactivity released in any one month, if diluted by the average monthly quantity of water released by the installation, will not result in an average concentration exceeding the concentration guide in Attachment 1, Table I, Column 2.

<u>2</u> The radiation protection standards in paragraph (1), above, are not exceeded.

(b) Concentrations or quantities of radioactive materials greater than those specified in paragraphs 4(b) and (5)(a)1 and <u>2</u>, above, may be released to chemical or sanitary sewage systems owned by the Federal Government provided the standards in paragraph 4b(1) above are not exceeded in uncontrolled areas.

Attachment XI-1

CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND

		Table I Controlled Area		Table II Uncontrolled Area	
Element (atomic number)	Isotope soluble (S) insolube (I)	Column 1 Air (pCi/ℓ)	Column 2 Water (pCi/ℓ)	Column 1 Air (pCi/ℓ)	Column 2 Water (pCi/ℓ)
Silver (47)	Ag 110m S	200	$9x10^5$	7	$3x10^4$
	I	10	$9x10^5$	0.3	$3x10^4$
Cesium (55)	Cs 137 S	60	$4x10^5$	2	$2x10^4$
	I	10	$1x10^6$	0.5	$4x10^4$
Radon (86)	Rn 220 S	300		10	
	Rn 222 I	100		3	
Radium (88)	Ra 226 S	0.05	400	0.003	30
	I	0.05	$9x10^5$	0.002	$3x10^4$

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(cont'd.)

Thorium (90)[1] natural	S	0.06	$2x10^4$	0.002	2000
	I	0.06	$6x10^5$	0.002	$2x10^4$
Uranium (92)[2] normal	S	0.14	$4x10^4$	0.006	1200
	I	0.12	$1x10^6$	0.004	$4x10^4$

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[1] The Curie is the activity of that quantity of radioactive material in which the number of disintegrations per second is 3.7×10^{10}. In DOE Order 5480.1, Change 6, the Curie was redefined to 3.7×10^{10} dis/sec from Th-232 plus 3.7×10^{10} dis/sec from Th-228. In order to make the above table consistent with the real definition of Curie, the concentrations for natural thorium were mutiplied by a factor of 2.

[2] In this report, the terms natural uranium and normal uranium are used as they were commonly used in the early days of MED work. Natural uranium is uranium as found in nature in equilibrium with all its daughter products. Normal uranium is uranium that has been processed to separate it from its long-lived daughter products (i.e., the daughter products Th-230 through Pb-206).

In Doe Order 5480.1, Change 6, the Curie is redefined as 3.7×10^{10} dis/sec from U-238 plus 3.7×10^{10} dis/sec from U-234 plus 1.7×10^9 dis/sec from U-235. This is also called natural uranium in these regulations. In order to make the above table consistent with the real definition of Curie, the concentrations for uranium were multiplied by a factor of 2.046. Also, the uranium is called normal uranium as the term is used elsewhere in this report and since the regulation implies that the uranium has been separated from its long-lived daughter products. This is consistent with the earliest use of these terms.

Irrelevant

APPENDIX 7

ESTIMATED EXTENT OF CONTAMINATION

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

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

Estimates of the extent of contamination are usually determined for averaged (Option 1) and maximum or worst-case (Option 2) conditions. Sample calculations for the extent of contamination in the Back Forty area of the Albany, Oregon Bureau of Mines Site are as follows:

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

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

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

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

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

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

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

APPENDIX 8

EVALUATION OF RADIATION EXPOSURES

INTRODUCTION

A. Types of Radiation

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

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

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

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

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

B. Sources of Radiation

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

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

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(cont'd.)

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

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

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

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(cont'd.)

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

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

BACKGROUND RADIATION DOSES

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

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

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

The external penetrating radiation dose to man derives from both terrestrial radioactivity and cosmic radiation. The terrestrial component is due primarily to the gamma dose from potassium-40 and the radioactive decay products of thorium-232 and uranium-238 in soil, as well as from the beta-gamma dose from radon daughters in the atmosphere. Radon is a gaseous member of the uranium-238 chain. The population-weighted external dose to an individual's whole body from terrestrial sources in the United States has been estimated as 15 mrem per year for the Atlantic and Gulf Coastal Plain, 57 mrem per year for an indeterminate area along the Rocky Mountains, and 29 mrem per year for the majority of the rest of the United States. The

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(cont'd.)

overall population-weighted external dose for the U.S. population as a whole has been estimated to be 26 mrem per year.

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

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

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

The total natural background radiation dose is the sum of the external and internal components. The population-weighted dose for the U.S. population as a whole is about 82 mrem per year to the gonads or whole body,

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about 179 mrem per year to the lung, about 79 mrem per year to the bone marrow, and about 171 mrem per year to the bone (osteocytes).

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

EVALUATION OF RADIATION DOSE AND POTENTIAL HAZARD

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

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

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

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

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

Besides estimation of risks and comparisons to natural background, doses may be compared to standards and regulations. The appropriate standards, the Department of Energy's "Requirements for Radiation Protection," give limits for external and internal exposures for the whole body and specified organs which are expressed as the permissible dose or dose commitment annually in addition to natural background and medical exposures. There are, in general, two sets of limits, one applicable to occupationally exposed persons and the second applicable to individuals and population groups of the general public. The limits for individuals of the public are one-tenth of those permitted for occupationally exposed individuals. The set of limits important to this report are those applicable to individuals and population groups of the public. The limits for individuals of the public are 500 mrem per year to the whole body, gonads, or bone marrow and 1500 mrem per year to other organs. The limits for population groups of the public are 170 mrem to the whole body, gonads, or bone marrow and 500 mrem per year to other organs, averaged over the group. In either case, exposures are to be limited to the lowest levels reasonably achievable within the given limits.

DOSE DETERMINATION CALCULATION

External Exposure

External penetrating radiation dose rates are measured on contact with an end-window beta-gamma Geiger-Mueller (GM) detector (7 mg/cm^2 window), and at 1 meter with a NaI crystal detector (1 in diameter by 1 in thick) manufactured by Eberline Corporation (PRM-7 μR Meter). For the purpose of these calculations, the following conservative assumptions are made. First, it is assumed that the half-life of the contaminant is long and, therefore, the dose rate is constant with respect to time. Second, it is assumed that a person is stationary at the location of maximum dose for 40 hours per week for 50 weeks per year. For such a situation, the annual dose (A) for a 0.3 mR/h radiation field (about ten times normal background) would be:

$$A = 40 \text{ hr/week} \times 50 \text{ weeks/yr} \times 0.3 \text{ mR/h} = 600 \text{ mR/yr}$$

For the purposes of this example it is assumed that one milliRoentgen of penetrating radiation is equivalent to one millirem of dose. Hence, the maximum dose for this case would be 600 mrem. This value is then compared with the allowable limit of 500 mrem per year for a person non-occupationally exposed.(1)

Internal Exposure

The internal radiological hazard from inhalation/ingestion of contamination is assessed by postulating hypothetical "worst case" scenarios. To this end two cases are considered. The first case is based on the situation whereby a child would eat 100 g per year of the contaminated soil. The second case assumes a home gardener would rototill the contaminated soil (dry) to a 1-ft depth for a working day (eight hours) once a year. For this latter case, a resuspension factor of 10^{-6} m^{-1}, a breathing rate of 9.6 m^3/working day and a soil density of 1.5 g/cm^3, are used. This means 4.39 g (1 ft x 0.305 m/ft x 1.5 g/cm^3 x 10^6 cm^3/m^3 x 10^{-6} m^{-1} x 9.6 m^3) of soil are inhaled each year. In both cases it is assumed that the average concentration of contaminants in the soil is equal to the maximum measured value (a conservative assumption). All calculations are based on methods outlined in ORNL/NUREG/ TM-190, Vol. 3.(2) These calculations approximate the ICRP-30 guidelines for hazard analysis.

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(cont'd.)

The adult inhalation and ingestion dose commitment factors for the bone, lung and total body from ^{238}U, ^{235}U, ^{234}U and ^{232}Th (and all their significant daughters), as determined in Reference 2, are given in Table 1. For calculation purposes, normal uranium is assumed to be composed of 2.26% ^{235}U, and 97.74% ^{234}U and ^{238}U (in equilibrium) by activity.

An example calculation is given below that is based on the above scenarios assuming a soil contamination level of 5 pCi/g of radium-226 EPA limit. This gives the following dose levels (50-year dose commitment):

Ingestion (consumption of 100 g/yr of soil):

Bone: 6.5×10^{-2} mrem/pCi x 5 pCi/g x 100 g = 32.5 mrem
Total Body: 5.5×10^{-3} mrem/pCi x 5 pCi/g x 100 g = 2.75 mrem.

Inhalation (rototilling and breathing ensuing aerosol):

Lung: 1.1×10^{-1} mrem/pCi x 5 pCi/g x 4.39 g = 2.4 mrem
Bone: 9.2×10^{-2} mrem/pCi x 5 pCi/g x 4.39 g = 2.0 mrem
Total Body: 9.5×10^{-3} mrem/pCi x 5 pCi/g x 4.39 g = 0.2 mrem.

There is no regulation setting an allowable limit for radionuclides with both a long radiological half-life and a long biological half-life such as radium.

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TABLE 1

FIFTY-YEAR DOSE COMMITMENT FACTORS (Inhalation/Ingestion)[a]
(mrem/pCi assimilated)

Nuclide[b]	Inhalation			Ingestion	
	Bone	Lung	Total Body	Bone	Total Body
^{238}U	$7.1x10^{-3}$	$4.8x10^{-1}$	$1.5x10^{-2}$	$2.8x10^{-4}$	$2.1x10^{-5}$
^{234}U	$7.9x10^{-3}$	$5.4x10^{-1}$	$1.6x10^{-2}$	$3.1x10^{-4}$	$2.4x10^{-5}$
^{230}Th	$3.1x10^{-1}$	$5.3x10^{-1}$	$3.8x10^{-2}$	$1.2x10^{-3}$	$9.2x10^{-5}$
^{226}Ra	$4.9x10^{-2}$	$5.6x10^{-2}$	$4.7x10^{-3}$	$4.3x10^{-2}$	$3.4x10^{-3}$
^{210}Po	$8.1x10^{-4}$	$4.6x10^{-2}$	$1.3x10^{-3}$	$5.2x10^{-4}$	$4.1x10^{-4}$
^{210}Pb	$4.2x10^{-2}$	$6.2x10^{-3}$	$3.5x10^{-3}$	$2.1x10^{-2}$	$1.7x10^{-3}$
Total Chain	$4.2x10^{-1}$	1.7	$7.9x10^{-2}$	$6.6x10^{-2}$	$5.6x10^{-3}$
^{226}Ra Chain	$9.2x10^{-2}$	$1.1x10^{-1}$	$9.5x10^{-3}$	$6.5x10^{-2}$	$5.5x10^{-3}$
^{238}U+^{234}U	$1.5x10^{-2}$	1.0	$3.1x10^{-2}$	$5.9x10^{-4}$	$4.5x10^{-5}$
^{235}U	$7.2x10^{-3}$	$4.8x10^{-1}$	$1.5x10^{-2}$	$2.8x10^{-4}$	$2.2x10^{-5}$
^{231}Pa	$9.6x10^{-1}$	$5.9x10^{-1}$	$1.4x10^{-1}$	$1.8x10^{-2}$	$2.1x10^{-3}$
^{227}Ac	$5.4x10^{-1}$	1.0	$1.0x10^{-1}$	$1.2x10^{-2}$	$1.3x10^{-3}$
^{223}Ra	$9.6x10^{-4}$	$4.6x10^{-2}$	$8.6x10^{-4}$	$1.2x10^{-3}$	$2.3x10^{-4}$
^{227}Th	$4.8x10^{-4}$	$6.9x10^{-2}$	$1.1x10^{-3}$	$2.7x10^{-5}$	$5.1x10^{-6}$
Total Chain	1.5	2.2	$2.6x10^{-1}$	$3.2x10^{-2}$	$3.7x10^{-3}$
^{232}Th	$3.3x10^{-1}$	$4.5x10^{-1}$	$3.8x10^{-2}$	$1.3x10^{-3}$	$9.6x10^{-5}$
^{228}Th	$4.4x10^{-2}$	$7.2x10^{-1}$	$1.9x10^{-2}$	$4.5x10^{-4}$	$3.8x10^{-5}$
^{228}Ra	$2.9x10^{-2}$	$4.8x10^{-3}$	$2.5x10^{-3}$	$2.1x10^{-2}$	$1.7x10^{-3}$
^{224}Ra	$3.0x10^{-4}$	$8.8x10^{-3}$	$1.8x10^{-4}$	$4.0x10^{-4}$	$7.5x10^{-5}$
^{212}Pb	$2.6x10^{-5}$	$1.8x10^{-3}$	$2.9x10^{-5}$	$1.8x10^{-5}$	$2.6x10^{-6}$
Total Chain	$4.0x10^{-1}$	1.2	$6.0x10^{-2}$	$2.3x10^{-2}$	$1.9x10^{-3}$

[a] Data taken from Reference 2.

[b] Nuclides in the chain that contribute negligibly (e.g., $<10^{-6}$ mrem) have not been included.

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(cont'd.)

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