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OAK RIDGE NATIONAL LABORATORY

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UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Radiological Survey of the Mallinckrodt Chemical Works, St. Louis, Missouri

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ABSTRACT

The results of a radiological survey of part of the Mallinckrodt Chemical Works (former Destrehan and Broadway Street plants), St. Louis, Missouri, are presented in this report. During the period 1942 through 1957, this site was used for various projects involving the production of purified uranium from pitchblende concentrates. The survey included measurements of the following: residual alpha and beta-gamma contamination levels in the existing buildings that were used in the uranium projects; external gamma radiation levels at 1 m above the surface in these buildings and outdoors around these buildings; radon and radon daughter concentrations in the air in these buildings; uranium, radium, actinium, and thorium concentrations in surface and subsurface soil on the site; concentrations of radionuclides in water and sediment found in drains both inside and outside the buildings; and concentrations of radionuclides in ground and surface water on the site and in river water taken near the site. Alpha and beta-gamma contamination levels inside and outside some of the buildings were above limits set by current federal guidelines concerning the release of property for unrestricted use. Elevated external gamma radiation levels were measured at some outdoor locations and in some of the buildings. Licensable concentrations of uranium were found in soil at some places, and the concentration of uranium in a water sample taken from a core hole between Buildings 100 and 101 was in excess of limits set by current federal standards. Radon and radon daughter concentrations in three buildings were in excess of current federal guidelines for nonoccupational radiation exposure.

*Former ORNL employee.

INTRODUCTION

A radiological survey of parts of the Mallinckrodt Chemical Works used in pre-1960 uranium processing was conducted at the request of the Department of Energy (DOE, then the Energy Research and Development Administration [ERDA]) during July, August, and September, 1977. A brief history of the Mallinckrodt uranium processing program follows. This history is based on information given in refs. 1 through 3. Descriptions of earlier surveys performed at this plant are given in refs. 4 and 5. The general plant layout is representative of the area utilized during work performed under an Atomic Energy Commission (AEC) contract (Fig. 1).

These properties were formerly used in the fabrication of purified uranium compounds and metals from uranium feed materials. All work was carried out under contract with the U.S. Government.

Mallinckrodt's work at plants in St. Louis began in 1942 and continued through 1957, at which time the facilities were shut down for decontamination. This history includes only the work carried out at plants in the St. Louis, Missouri, area and as such does not cover work at Weldon Springs or at other facilities.

The initial contract work consisted of the production of uranium trioxide (UO_3) and uranium dioxide (UO_2) to be used in the nuclear pile that was currently being constructed in Chicago. Impure natural feed material containing low levels of uranium was processed to yield a concentrate of uranium trioxide that could be used for a reactor core. In addition, extra steps allowed the production of uranium dioxide (UO_2) and uranium tetrafluoride (UF_4). Uranium derby metal also was produced and then vacuum recast to form ingot metal. All of the initial contract work appears to involve ^{238}U, with no process existing for the purification and working of ^{232}Th, highly enriched uranium, UF_6, fission products, or by-product material (Fig. 2).

A variety of work processes was carried on at various times during the period 1942 to 1966 including: (1) machining of natural uranium metal rods to make reactor fuel slugs, (2) reverting UF_4 to UO_2 or to

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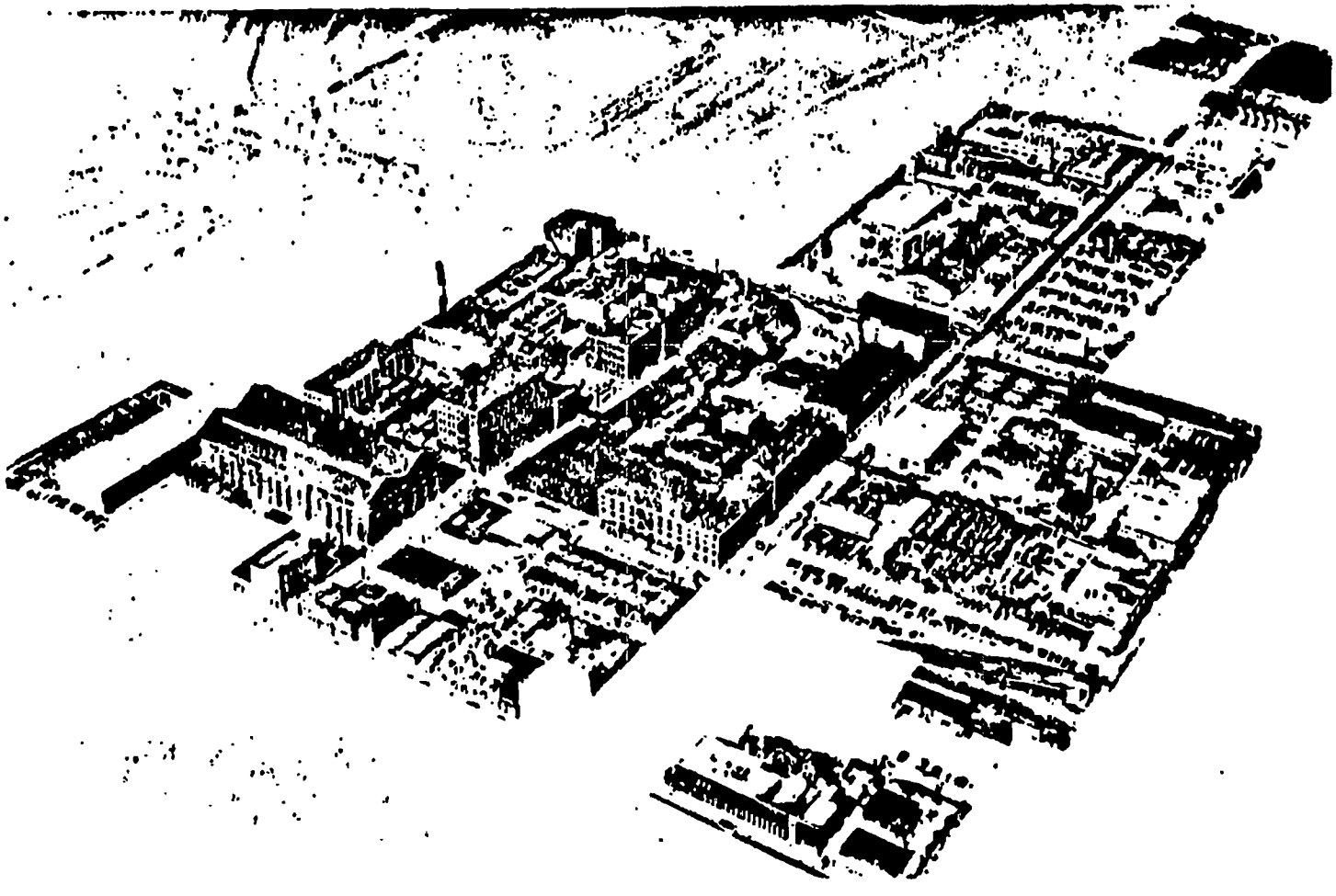

Fig. 1. Aerial view of the Mallinckrodt Chemical Works during AEC-contracted operations.

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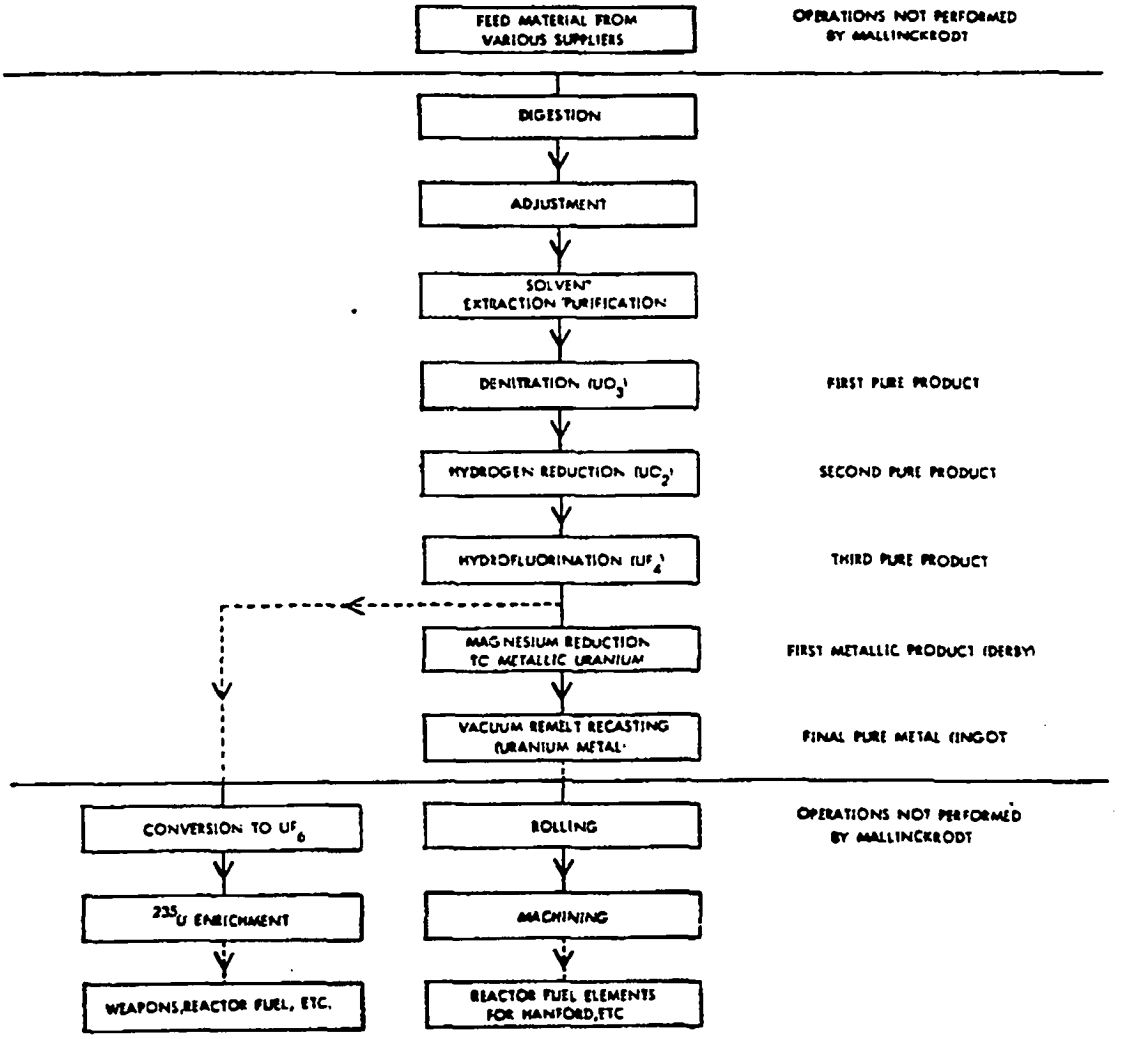

Fig. 2. Flow diagram of uranium refining process conducted at Mallinckrodt.

U_3O_8, (3) recovering scrap uranium metal, (4) producing UO_2F_2, (5) extracting and concentrating ^{230}Th from pitchblende raffinate, and (6) experimentally purifying or reworking very low enrichment UF_4.[1]

Work was carried on to extract uranium from pitchblende ore and to concentrate this extract. In addition, ^{226}Ra and its daughters were extracted, along with the lead content, since the African Metals Company retained ownership of the radium content of the ore. The radium and lead were precipitated when the pitchblende after dissolution in nitric acid was combined with sulfuric acid. This precipitate was sent to the Lake Ontario Ordnance Works, Lewiston, New York, for storage. Much of this material was moved to facilities operated by National Lead of Ohio, Ferhold, Ohio in 1952. Beginning about 1945, process wastes and residues were taken from the St. Louis plants and stored at a government storage site near the St. Louis Airport.

During the 24-year period (1942 to 1966), the company designed and operated feed materials facilities in St. Louis and St. Charles County, Missouri, which employed a total of about 3,300 individuals and produced more than 100,000 tons of purified natural uranium materials. The plants in St. Louis, Missouri, were constructed and operated on Mallinckrodt land. In St. Charles County, the land, buildings, and all equipment belonged to the U.S. Government.

The contractual work from 1942 to 1947 was carried out under the Manhattan Engineer District (MED) project. This contract was transferred in 1947 to the newly formed AEC and remained under the AEC New York Operations until 1954. At this time, the contract was transferred to the AEC Oak Ridge Operations and remained there until 1966, at which time the contract was terminated.

Four plants were in existence during the history of Mallinckrodt's government contracts. All of the work from 1942 to 1945 was carried out in previously existing structures at the Main Plant and at Plant 4 in the city of St. Louis. The Main Plant was used as a refinery for U_3O_8 feed and pitchblende until 1945, at which time these operations were closed. A new refinery called Plant 6 and located at 65 Destrehan in St. Louis began operations in 1946 to process pitchblende ore and produce UO_2.

Additional plants began operating at the Destrehan Street location in the period 1950-51 and went under the names Plant 6E and Plant 7. Plant 6E produced uranium metal while Plant 7 was designed to produce green salt (UF_4). Plant 4 operations ended at this time, and its facilities were modified to be used as a metallurgical pilot plant for development work with uranium metal. This operation continued until 1956.

Decontamination surveys were carried out at the Main Plant from 1948 to 1950. This work was performed and supervised by Mallinckrodt personnel according to existing AEC criteria. The property has been returned to Mallinckrodt for unrestricted use since 1951. Plant 4 was closed during 1955-56, with all operations at Destrehan closing in 1957 and being transferred to the new AEC feed material processing center at Weldon Springs, Missouri, which Mallinckrodt operated for the AEC. The results of the radiological survey conducted at the Plant 4 site in 1958 are given in ref. 4.

The Plant 4 and Destrehan properties were released to Mallinckrodt for unrestricted use in 1961-62 following decontamination work by an AEC subcontractor and subsequent monitoring surveys performed by Mallinckrodt personnel.[5] All contaminated buildings were removed from Plant 4, with some production buildings being left at Destrehan. Contaminated earth was removed and backfilled by the AEC.

Since 1962, Mallinckrodt has used this property for various purposes related to its commercial chemical operations. Tables 1 through 4 are provided to give a brief description of the status of buildings which existed at the time of uranium work at Mallinckrodt. Some buildings have been torn down, some are being used as warehouses, and new buildings have been constructed at Plant 4 and at Destrehan. Parts of the Destrehan site have been used for storage of columbium-tantalum ore, which is a Nuclear Regulatory Commission (NRC) licensed material. This ore may contribute to the background radioactivity in Plants 6, 7N, and 7W. These plants are also used for storage of potassium compounds which will contain natural isotopic abundances of ^{40}K, a gamma emitter.

Table 1. Identification of buildings used for uranium project work (name commonly used by project people versus current designation)

Common usage	Current designation
Main plant	Plants 1 and 2
Building 51	The complex at Plant 2: 50, 51, 51A, 52, 52A, 55
Plant 1	Same as main plant
Project 89	Plants 1 and 2
Project 90	(Green salt) Plant 10 (Building 400)
Project 91	(Derby) Plant 10 (Building 400)
Project 92	(Recast) Plant 10 (Building 400)
Plant 6	All of Destrehan site
Plant 6E	Building 116 at Plant 6
Plant 7	Buildings 704, 705, 706, 707, 708 at Plant 7N and 7W
Plant 4	Part of Plant 10

Table 2. Identification of existing buildings used for uranium project work

Plant	Building	Use
1	25-1	Lab, R&D, control
	25-2	Lab, G.C. spectrophotometry
	Alley	R&D extraction
	K1-E	Pilot plant, semiworks (pitchblende)
	A	General plant mechanical
2	50	General storage, utility, UF_4 experiment
	51	Digest and treat U_3O_8 feeds
	51A	Denitrate and hydrogen reduce
	52	Ether extraction
	51X	Outside for extraction of pitchblende liquor
	38	Personnel change house
	40	Temporary storage of residues
10	None, except part of RR dock	Movement of materials
6	100	Electric substation
	116-1	Manufacturing U metal, warehouse
	116-2	Warehouse, office, graphite machining
	116-B	Electric substation
	117-1	Security, change house (trace pitchblendes)
	117-2	Lunchroom, laundry, contractor change room (trace pitchblendes)
7N	704	HF off gas treatment
	705	Manufacturing UO_2, UF_4
	706	Storage UO_2, UO_3, UF_4
	707	Manufacturing $H_2 + N_2$ from NH_3
7W	70B	Magnesium storage, packaging
	700	Warehouse, safety office, some core machining

Table 3. Identification of removed buildings used for uranium project work

Plant	Building	Function
1	None	
2	55	Shotgun laboratory - temporary structure
	52X	Canopy enclosures - temporary structure
10	400	Main manufacturing building for UF_4 and metal slag handling, maintenance, laboratory, offices, change house
	401	Maintenance, metal process and storage, UF_4 pilot plant
	406	Magnesium storage
	408	Slag, dolomite, KOH, NH_3, HF, and other storage; processing
6[a]	101	Offices, R&D lab, receiving decontamination (trace pitchblende)
	102	Main control lab, R&D lab, lab offices (minor pitchblende)
	103	Air conditioning for 102
	104	Main refinery building - ore to UO_3 to UO_2 (pitchblende)
	104A and AA	Main refinery - ore handling and milling (pitchblende)
	104B	Main refinery - pilot plant area (pitchblende)
	105	Main refinery - ether house (extraction) (trace pitchblende)
	106, 106A	Nitric acid recovery
	107	Tank farm pump house
	108	Shotgun sample prep lab
	110	Main warehouse for bag goods, ore, concentrate (pitchblende)
	110A	Main warehouse - part used as Ledoux lab (pitchblende)
	110B	Automobile repair
	111	North - Ledoux lab (pitchblende); south - maintenance shop
	112-1	Maintenance shop, maintenance stores, health lab, dispensary
	112-2	MCW and AEC administration offices
	114	Scale house; temporary storage of residues (pitchblendes)
	115 and 119	Steam plant
	120 and 121	U metal dissolver, miscellaneous digest and recovery (pitchblendes)
	123	Ammonia and disassociator
	116C	Slag grinding and packaging

Table 3. (continued)

Plant	Building	Function
7N[a]	703	HF tank farm
	709	HF refrigeration and pump house
	710	NH_3 tank farm and pump house
7W[a]	711	Mechanical storage
	712	Thorium-230 extraction (temporary)
	701	Slag treatment for U metal recovery

[a] Only major buildings are listed for Plants 6, 7N, and 7W.

Table 4. New construction and its orientation to old buildings

Plant	New building	Location
1	None	
2	None	
10	81	Covers approximately the north half of old Building 400, which was the UF_4 manufacturing area
	101	Covers approximately: Ore room, digestors, radium filters of 104 (SW corner 101) 114 scale house (SW of center 101) Storage bays of Warehouse 110 (NW corner 101) Ledoux Lab 111 (NE corner of 101) Maintenance shop 112 North edge of lab 102 (SW corner 101)

SURVEY METHODS

Instrumentation

Direct alpha measurements

Direct alpha measurements were made with alpha scintillation survey meters described in Appendix I. These meters are equipped with scalers which allow integration of counts over 15, 30, or 60 s, permitting direct alpha measurements on surfaces with low-level alpha contamination. If counts are integrated over a period of 60 s, the count-rate error* associated with an alpha contamination level (by direct reading) of N dpm/100 cm^2 is approximately 5 $N^{-1/2}$ x 100%. For example, the count-rate error associated with an alpha contamination level by direct measurement of 100 dpm/100 cm^2 is approximately ±50%.

Direct beta-gamma measurements

Beta-gamma dose rates were measured with Geiger-Mueller (G-M) survey meters described in Appendix I. The meters were calibrated at Oak Ridge National Laboratory (ORNL) using sealed sources and by comparison with a Victoreen Model 440 ionization chamber (Appendix I). It was determined that, for surfaces contaminated with ^{226}Ra in equilibrium with ^{238}U and other radionuclides from the ^{238}U chain, an open-window reading of 2,000 cpm on the G-M meter is equivalent to approximately 1 mrad/h. For surfaces contaminated with initially ^{226}Ra-free uranium, the proper conversion factor is 2,300 cpm = 1 mrad/h. In most areas surveyed on this site, the radioactive material which had been handled was ^{226}Ra-free uranium; and in these areas, the conversion factor 2,300 cpm = 1 mrad/h was applied to open-window G-M meter readings. In areas where uranium ore was handled, the conversion factor was 2,000 cpm = 1 mrad/h. It appears that in extreme cases the absolute error involved in using these conversion factors may be as high as 60%

*Errors stated in this report refer to the 68% confidence level unless otherwise specified.

for individual measurements; however, the absolute error involved in determining an average beta-gamma dose rate for a large contaminated surface such as a floor or wall appears to be no higher than 15%.

Beta radiation cannot penetrate the closed window on the G-M probe; hence, gamma radiation levels can be measured with the window closed. The conversion factor for gamma radiation and its associated error is 3,200 cpm = 1 ± 0.3 mrad/h. This factor was determined at ORNL using a ^{226}Ra source. A significant difference in the open- and closed-window readings on the G-M meter at any location indicates the presence of beta-emitting surface contamination (since most beta particles can penetrate only a few millimeters of dense materials).

Measurements of transferable alpha and beta contamination

Transferable alpha and beta contamination levels were measured using the standard smear techniques described in NRC guidelines (Appendix II). The smears were counted using the alpha and beta smear counters shown in Appendix I. The count-rate error (for a 60-s count) associated with a transferable alpha measurement of N dpm/100 cm^2 is approximately 2.2 $N^{-1/2}$ x 100%. For example, the count-rate error associated with a transferable alpha contamination level of 100 dpm/100 cm^2 is approximately 22%. Similarly, the count-rate error associated with a transferable beta measurement of N dpm/100 cm^2 can be estimated from the expression

$$\frac{16}{N}\left(20 + \frac{N}{16}\right)^{1/2} \times 100\% .$$

Hence, the count-rate error associated with a transferable beta level of 1,000 dpm/100 cm^2 is approximately ±15%. Indeterminable errors are introduced in taking smear samples because of some variation in pressure applied, in the condition of the surface, and in surface area covered.

Measurement of external gamma radiation levels

Three types of instruments were used to measure external gamma radiation levels at 1 m above the surface on this site: (1) portable

NaI scintillation survey meters described in Appendix I, (2) G-M meters with the probe window closed, and (3) a scaler-equipped energy-compensated (Phil) G-M counter.[6] The G-M meters are equipped with rate meters which show instantaneous gamma radiation levels when the probe window is closed. Since these rate meters are unreliable for near-background radiation levels such as those encountered in most areas on this site, most external gamma measurements reported in this document were made with the scaler-equipped G-M counters. The NaI scintillation meters are extremely sensitive and were used on this site principally to locate contaminated areas. Also, measurements of gamma radiation levels made with NaI detectors were normalized to the Phil detector mentioned above in order to estimate the exposure rate in units of microroentgens per hour.

Measurement of radon and radon daughters in air in the buildings

Continuous 24-h measurements of radon concentrations in air were made in some buildings using an instrument developed by Wrenn, Spitz, and Cohn[7] and referred to as a Wrenn chamber. This instrument, described in Appendix III, was equipped with a printer which permitted the automatic recording of radon concentrations at intervals of 2,000 s. Because some radon and progeny from previous 2,000-s intervals remain in the Wrenn chamber, each reading actually represents a concentration which has, effectively, been integrated over a period of 2 to 4 h.

For the measurement of radon daughter concentrations in air in the buildings, air was pumped for 5 to 10 min at approximately 12 l/min through a membrane filter with a maximum pore size of 0.4 μm. The filter was counted using an alpha spectrometry technique described in Appendix III.

Methods Used to Analyze Samples

Samples of soil and other solid materials collected on the site were packed in plastic bags and returned to ORNL where they were dried for 24 h at 110°C and pulverized to a particle size no greater than

500 μm in diameter (-35 mesh). Next, aliquots from each sample were transferred to plastic bottles or petri dishes, weighed, and counted using a Ge(Li) detector and a multichannel analyzer. The spectra obtained were analyzed by computer techniques. A description of the Ge(Li) detector and soil counting techniques is given in Appendix IV. Concentrations* of ^{226}Ra, ^{238}U, ^{227}Ac, ^{232}Th, and ^{230}Th (selected samples around the ionium pad) were estimated in this way. A more accurate method of determining the ^{238}U concentration in soil samples is normally used and employs neutron absorption techniques and the subsequent fission of ^{235}U in the sample.[8]

Water samples collected on and near the site and sediment filtered from these water samples were analyzed by the Analytical Chemistry Division of ORNL for ^{210}Pb, ^{226}Ra, and ^{230}Th using radiochemical techniques described in appendices to the ORNL Master Manual. The water samples were analyzed for natural uranium using the neutron absorption techniques previously mentioned. The activity reported for each radionuclide in the water sediment samples represent only that percentage of the activity (normally between 50 and 100%) available by hot HNO_3 leaching.

Survey Schemes for Indoor and Outdoor Measurements

Throughout this report, the term "lower walls" refers to wall surfaces up to a height of 6 ft. A "survey block" is a rectangular subsection of some large area to be surveyed, either indoors or outdoors. The division of large areas into small survey blocks is convenient for reporting purposes. In addition, the measurement of radiation levels in numerous equally "weighted" areas allows statistically meaningful estimates of average contamination levels on the site. Finally, the reporting of both representative and maximum contamination levels for

*Whenever the accuracy of a concentration determined in this way appears questionable, the concentration is listed in the tables as ND (not determined) unless the concentration is more accurately determined by some other method. The appearance of ND in a table usually means that the concentration of the radionuclide is so low that poor counting statistics result, although this is not always the case.

individual survey squares serves to define the degree of nonuniformity of contamination.

Indoor survey methods

Whenever practical, floors and lower walls were divided into survey blocks defined by natural boundaries such as building supports. The size of the survey blocks generally varied with the size of the building, with side lengths of the blocks varying from 6 to 20 ft.

Unless otherwise stated in the section on survey results, each block was surveyed in the following manner. The entire block was scanned with an open-window G-M meter, and an area-weighted average of the measured beta-gamma dose rates was recorded. Next, one or more alpha measurements were taken at the surface near the center of the block, and the measurement or average of the measurements was recorded. Then a smear sample was taken at randomly chosen locations in the block for the measurement of transferable alpha and beta contamination levels, and the external gamma radiation level was measured at 1 m above the surface near the center of the block. The measurements just described are referred to throughout this document as representative measurements in order to distinguish them from a second set of measurements in the block which were made in an attempt to determine highest contamination levels. In particular, if the beta-gamma scan of the block revealed areas with much higher-than-average beta-gamma dose rates, then the locations of these areas were noted, the beta-gamma dose rates measured in these areas were recorded, closed-window G-M meter measurements and direct alpha measurements were made in these areas and recorded, and smear samples were usually taken in these areas for the measurement of transferable alpha and beta contamination levels. For the survey of overhead surfaces (including walls above 6 ft), direct measurements of alpha and beta-gamma contamination levels and measurements of transferable alpha and beta contamination levels were made at several randomly selected points as uniformly spaced as practicable.

In some buildings, scale or other materials showing elevated alpha and beta-gamma contamination levels were found in drains, on overhead

ledges, on window ledges, or in cracks. Samples of some of the materials were removed and returned to ORNL for analysis of ^{238}U, ^{226}Ra, ^{227}Ac, and ^{232}Th. Also, water samples were taken from many of the building drains and were analyzed for ^{238}U, ^{226}Ra, ^{230}Th, and ^{210}Pb. In all buildings surveyed except 38, 40, 100, and 116B, concentrations of ^{222}Rn and/or ^{222}Rn daughters in air were measured. In Buildings K1E, 25, 51, 51A, 52A, and 101, holes were drilled through the floors to depths of 10 ft or more, and soil samples were taken at intervals of approximately 1 ft. The samples were analyzed for ^{238}U, ^{226}Ra, ^{227}Ac, and ^{232}Th.

Outdoor survey methods

The areas surveyed outdoors included the alleyway between Buildings K1E and 25; the ionium pad adjacent to Building 708; pads adjacent to Buildings 116, 117, 705, 706, and 708; an 0.5-acre area in the vicinity of Buildings 50, 51, 51A, 52, and 52A; a 1.5-acre area in the vicinity of Building 81; a 4-acre area in the vicinity of Buildings 100, 101, 116, and 117; and a 3.5-acre area in the vicinity of Buildings 700, 704, 705, 706, 707, and 708.

The alleyway between Buildings K1E and 25 and all building pads were divided into survey blocks and were surveyed in the same manner as were the floors and lower walls inside the buildings.

The other areas described above were divided into survey blocks with side length typically near 50 ft. Measurements of the external gamma radiation level at 1 m above the ground were made at randomly chosen locations in each survey block (in alternate survey blocks in some areas), and the measurement or average of the measurements was recorded. Accessible areas in each survey block were scanned with a NaI scintillation survey meter. At the point of maximum gamma within each block the beta-gamma dose rate was measured at 1 cm above the surface with a G-M survey meter. Also, at many points showing elevated beta-gamma dose rates, surface soil samples were taken for the determination of ^{238}U, ^{226}Ra, ^{227}Ac, and ^{232}Th content. In large areas showing no elevated beta-gamma dose rates, surface samples were taken

at randomly selected locations for analysis of these four radionuclides.

For the determination of the extent of subsurface soil contamination on the site, holes were augered to depths of 12 ft or more in areas of suspected subsurface contamination. The spacing of the auger holes was as uniform as was practicable. A plastic pipe was placed in each hole, and a NaI scintillation probe was lowered inside the pipe. The probe was encased in a lead shield with a narrow opening on the side. This arrangement allowed measurement of gamma radiation intensities resulting from contamination within small fractions of the hole depth. Measurements were usually made at 6-in or 1-ft intervals. This logging of the core holes was done as a first step in determining the extent of subsurface contamination at each location. Whenever practical, if the gamma readings in the hole were not uniform, a soil sample was scraped from the wall of the auger hole at the point showing the highest gamma radiation level. These samples were analyzed for ^{238}U, ^{226}Ra, ^{227}Ac, and ^{232}Th. The auger hole loggings were used to select locations where further soil sampling would be useful. At points as close as practical to several selected auger holes, a split-spoon sampler was used to collect soil samples, usually at 1-ft intervals, from the surface through the contaminated zone. These core holes were also logged with a NaI scintillation meter.

Water samples were taken from all auger holes in which water was found. Additional water samples were taken at points along the Mississippi River where drainage from the site flows into the river. The samples were analyzed for ^{238}U, ^{230}Th, ^{226}Ra, and ^{210}Pb.

Background Measurements

Background external gamma radiation levels at 1 m above the ground were measured at four points within 15 miles of the site. The measurements ranged from 7 to 9 μR/h and averaged 8 μR/h. Since the error in measurement is approximately ±30%, only those external gamma measurements of 11 μR/h or higher on the site are considered above background. Soil samples taken at the same points at which background external gamma measurements were taken showed concentrations of ^{238}U,

^{226}Ra, and ^{232}Th averaging 1.25 pCi/g, 1.18 pCi/g, and 1.15 pCi/g, respectively.

Background beta-gamma dose rates as measured at 1-cm distance from surfaces with the G-M survey meters used on the site generally ranged from 0.01 to 0.04 mrad/h and typically averaged 0.02 mrad/h. However, readings at the background level cannot be reproduced accurately on the G-M survey meter. Background direct alpha readings for the type of alpha survey meter used on this site are negligible.

All direct meter readings reported in this document represent gross readings;. background radiation levels have not been subtracted. Similarly, background levels have not been subtracted from radionuclide concentrations measured in environmental samples and building materials. For the measurement of transferable alpha and beta contamination levels, average background counts were determined for the smear counters (at the place of counting), and these background counts were subtracted from gross counts.

Background radon and radon daughter concentrations typically averaged less than 1.0 pCi/l and 0.01 working level*, respectively. Measurements of the radon concentration in air near the St. Louis Airport averaged approximately 0.35 pCi/l with a maximum concentration of 0.99 pCi/l.[9]

GUIDELINES USED TO EVALUATE RESULTS

Guidelines used in this document to evaluate data from the survey can be found in Appendix II of this report and in 10 CFR 20. Some of the guidelines are discussed briefly in this section.

Surface contamination levels measured on the site are compared in this report with NRC guidelines for release of property for unrestricted use. For surfaces contaminated with alpha emitters, strictest limits apply to a group of radionuclides including ^{226}Ra and ^{230}Th.

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*A working level (WL) is defined as any combination of short-lived radon daughters in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy.

The average and maximum* limits for direct measurements of alpha contamination levels on surfaces contaminated with these radionuclides are 100 dpm/100 cm^2 and 300 dpm/100 cm^2, respectively, and transferable alpha contamination should not exceed 20 dpm/100 cm^2. Alpha measurements taken on this site in areas where uranium ore was handled are compared with these limits. Measurements taken in areas where initially ^{226}Ra-free uranium was handled are compared with the less stringent guidelines for surfaces contaminated with natural uranium. These guidelines specify that average and maximum direct alpha measurements should not exceed 5,000 dpm/100 cm^2 and 15,000 dpm/100 cm^2, respectively, and transferable alpha contamination should not exceed 1,000 dpm/100 cm^2. In both cases mentioned above, the NRC guidelines specify that transferable beta contamination should not exceed 1,000 dpm/100 cm^2. Furthermore, regardless of the contaminant, average and maximum beta-gamma dose rates should not exceed 0.20 mrad/h and 1.0 mrad/h, respectively. Unless otherwise stated, beta-gamma dose rates between 0.20 mrad/h and 1.0 mrad/h reported in this document are average measurements over an area of not more than 1 m^2 and hence are considered to be above NRC guidelines.

SURVEY RESULTS

Interpretation of Data

Wherever practical, data from the survey are displayed in figures rather than tables. Whenever survey blocks are shown in a figure, it should be assumed that measurements were taken in each survey block as described in the section "Survey Methods," unless stated otherwise in the text. The absence of data for a particular type of measurement in a survey block on any given figure should be interpreted as meaning that that particular measurement was at the background level. Blocks which were completely inaccessible are labeled "no reading." The following notation is used in many of the figures in this report:

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*Measurements may not be brought below limits by averaging over more than 1 m^2. The maximum level applies to an area of not more than 100 cm^2.

$d\alpha$ = direct alpha measurements in dpm/100 cm^2,

$d\beta$-γ = directly measured beta-gamma dose rates in mrad/h measured at 1 cm distance from surfaces,

$t\alpha$ = transferable alpha contamination level in dpm/100 cm^2,

$t\beta$ = transferable beta contamination level in dpm/100 cm^2,

exγ = external gamma radiation level at 1 m above the surface in μR/h.

Unless otherwise indicated by arrows or by areas enclosed by broken lines (or both), measurements shown in indoor survey blocks refer to representative measurements as defined in the section "Survey Methods." Any small oval, circular, or rectangular area shown in the figures and associated with an elevated beta-gamma or alpha measurement is intended only as a first approximation of the extent of the contaminated area and is not drawn to scale.

Measurement of Alpha and Beta-Gamma Contamination and External Gamma Radiation Levels in Buildings and Contamination in Building Drains

Building K1E

This building served as a pilot plant during uranium operations. The more restrictive NRC guidelines for alpha contamination of surfaces (those for ^{226}Ra) are applicable because pitchblende ore was handled in this building.

Directly measured beta-gamma dose rates exceeded the NRC guideline of 0.20 mrad/h in several areas of Building K1E as indicated in Fig. 3. The highest beta-gamma dose rate observed was 1.3 mrad/h and was measured in block B3. Alpha contamination levels exceeded the maximum NRC guideline (300 dpm/100 cm^2) for radium in several spots. In fact, the average alpha contamination level for the entire area surveyed was 500 dpm/100 cm^2. The highest measured alpha contamination level was 2,900 dpm/100 cm^2 and was measured in block B5. Measurements of direct and transferable alpha and beta-gamma contamination were made at 16 randomly selected locations on overhead surfaces; no contamination was found.

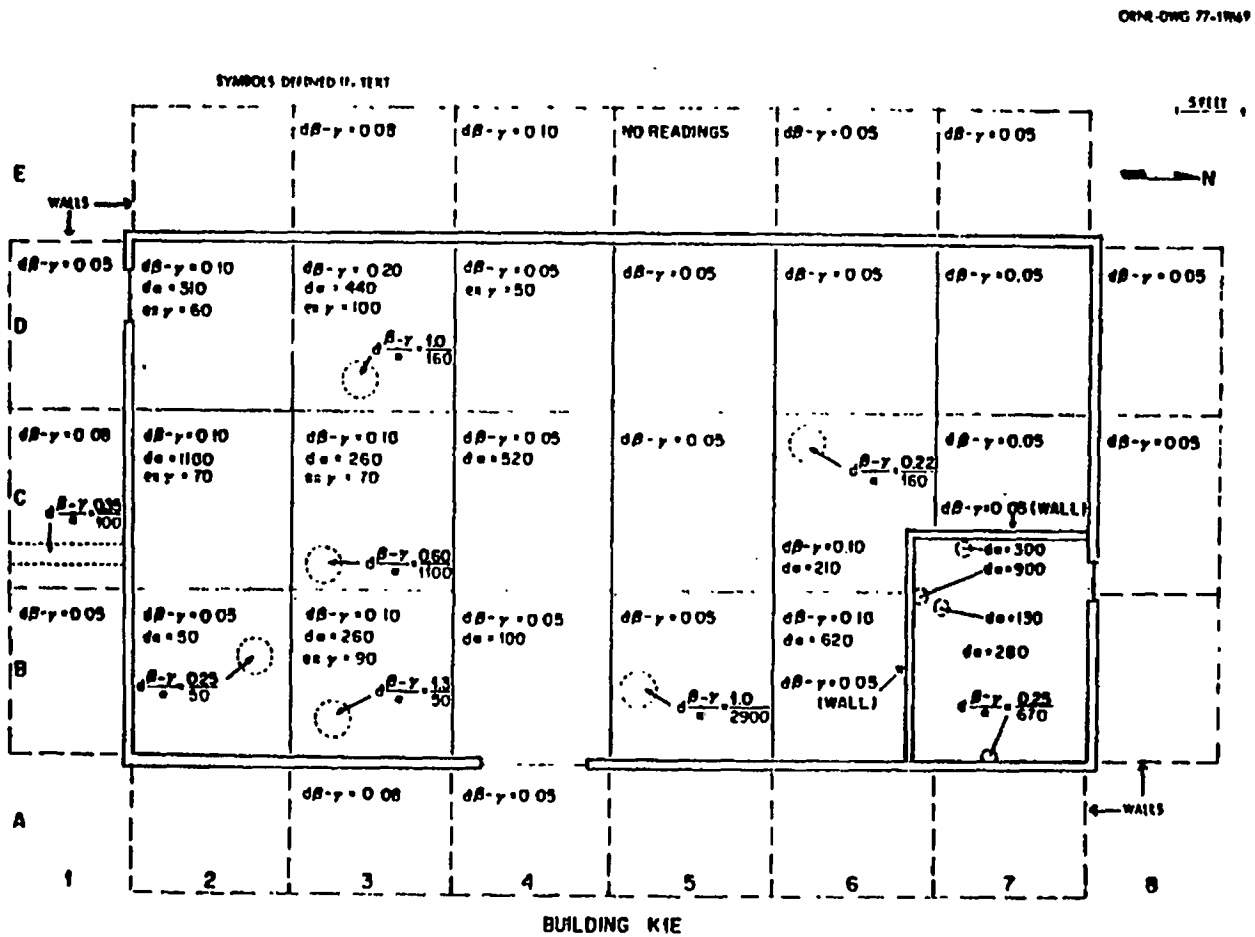


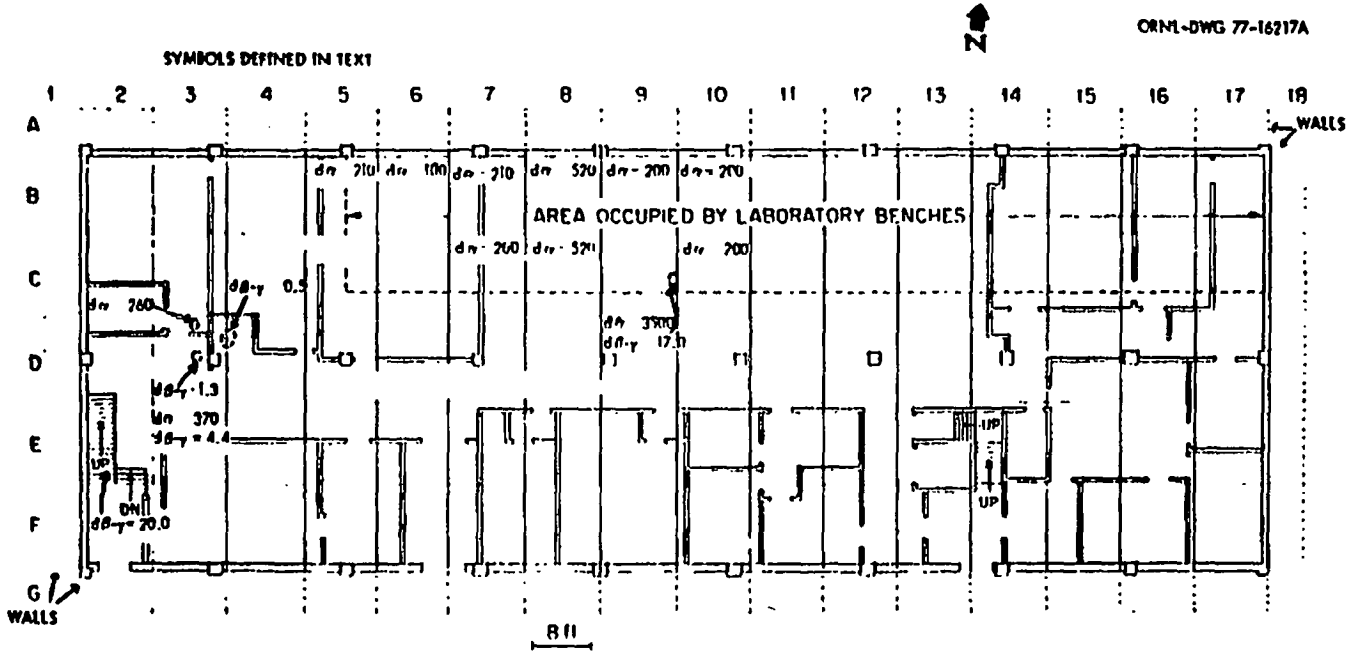
Fig. 3. Radiological measurements in survey blocks in Building K1E. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Analysis of a dirt sample taken from a trench in the north end of the building indicated concentrations of ^{226}Ra and ^{238}U of 23 and 5.1 pCi/g, respectively. This elevated ^{226}Ra concentration confirms the propriety of comparisons with the more restrictive surface alpha guidelines.

Building 25

The radioactive materials which were handled in Building 25 include U_3O_8 and pitchblende ore, the latter containing approximately 0.3 Ci/ton of ^{226}Ra.[1] Hence, it appears that the more restrictive NRC guidelines for alpha contamination (those for ^{226}Ra) are applicable to this building. The radiological survey of Building 25 included all areas which may have come in contact with radioactive materials, namely, the first level, the laboratory at the west end of the second level where early uranium processing was performed (and nearby areas), and the roof.

The floor and lower walls of the first level of Building 25 were divided into survey blocks with side length 10 ft or less. Maximum observed measurements of alpha and beta-gamma contamination on surfaces are shown in the appropriate survey blocks in Fig. 4. Although most measurements were at the background level, some spots on lab benches indicated alpha contamination ranging from 100 to 3,500 dpm/100 cm^2 by direct reading (rows B and C and 5 through 10 in Fig. 4). One spot on a lab bench in block C9 showed a beta-gamma dose rate of 17 mrad/h. The other principal contaminated spots were in survey blocks E2, D3, and D4. A contaminated spot beneath the stairway in block E2 showed a beta-gamma dose rate of 4.4 mrad/h, and a black pipe removed from a cabinet under the stairs in E2 showed a beta-gamma dose rate of 20 mrad/h. External gamma radiation levels measured at 1 m above the centers of the survey blocks were all at the background level. Overhead alpha and beta-gamma measurements made at randomly chosen overhead locations indicated only background radiation levels. Smear samples were taken in each of the survey blocks and at randomly chosen overhead locations; these samples indicated that all transferable alpha or beta contamination was at or near the background level.



BUILDING 25 1st LEVEL

Fig. 4. Radiological measurements in survey blocks in Building 25, first level. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

On the second level of Building 25, the survey was focused on the laboratory at the west end of the building, and spot checks were made in nearby office and lab areas. The floor and lower walls of the laboratory were divided into survey blocks with side length 10 ft or less. Maximum observed measurements of alpha and beta-gamma contamination levels on surfaces and external gamma radiation levels at 1 m above the floor are shown in the appropriate survey block in Fig. 5. Most measurements were at the background level, although there were some contaminated spots found on lab benches, cabinets, sinks, hoods, and the floor. Beta-gamma dose rates at these spots were as high as 11 mrad/h, and directly measured alpha levels were as high as 6,900 dpm/100 cm^2. On the landing at the top of the stairs, a beta-gamma dose rate of 1.5 mrad/h and a direct alpha measurement of 3,800 dpm/100 cm^2 were observed. Transferable alpha contamination levels did not exceed 20 dpm/100 cm^2, and transferable beta contamination levels did not exceed 180 dpm/100 cm^2. An external gamma radiation level of 18 μR/h was measured at 1 m above the center of survey block B2; all other external gamma measurements were at the background level.

The area east of the laboratory (Fig. 5) was checked at randomly selected points for alpha and beta-gamma contamination. All beta-gamma dose rates observed were at the background level, but alpha contamination in the range 100 to 780 dpm/100 cm^2 (by direct reading) was observed on bench tops. The transferable surface contamination was at or near the background level at all points.

Building 38

This building was used as a change room during the uranium processing period at Mallinckrodt. The floor and lower walls were surveyed using grid blocks shown in Fig. 6. Alpha and beta-gamma contamination levels on surfaces and external gamma radiation levels at 1 m were measured in each of the accessible blocks, and measurements of alpha and beta-gamma contamination were made at randomly chosen points on overhead surfaces. Because all measurements were at the background level, it may be concluded that no contamination was found in this building.

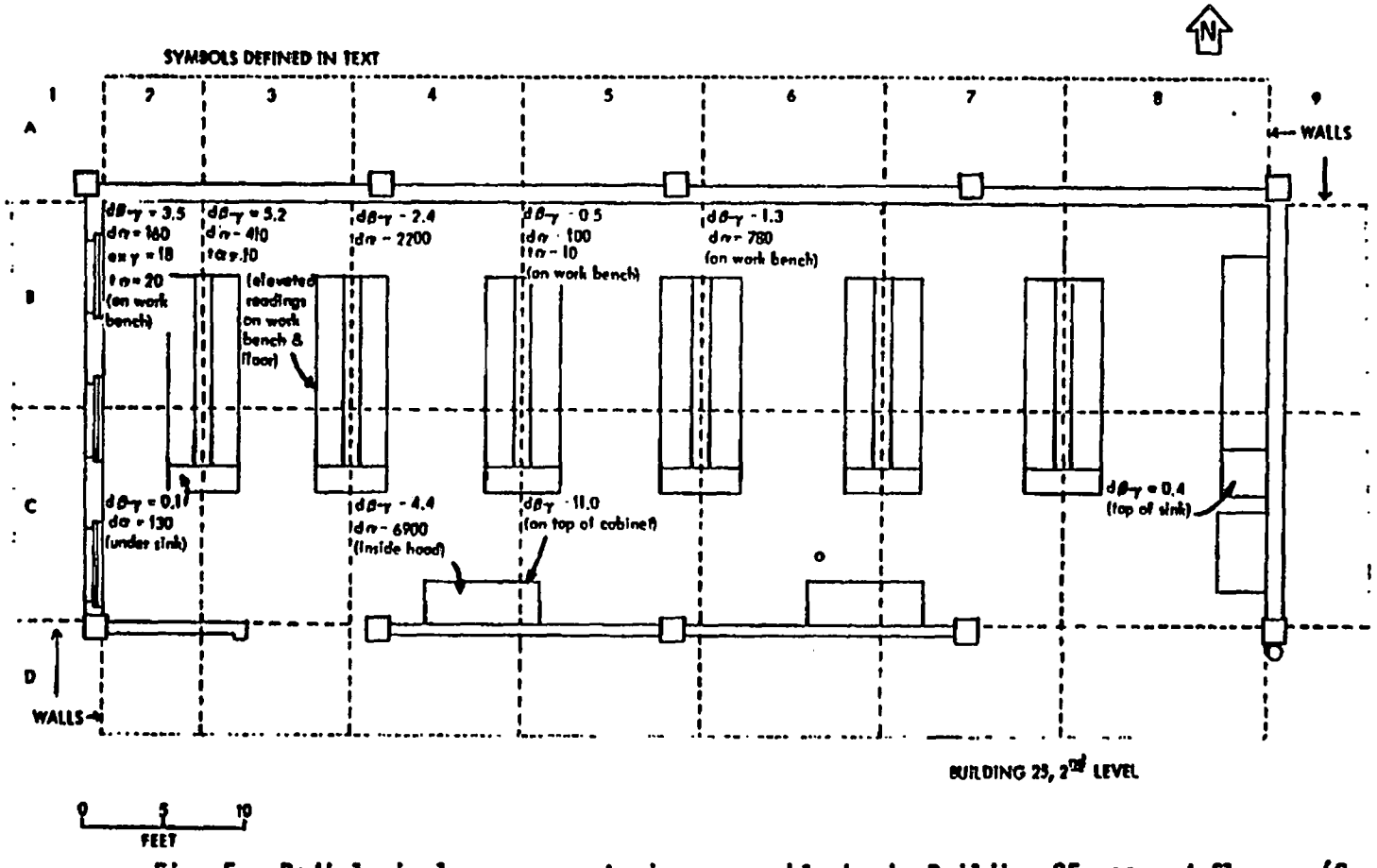


Fig. 5. Radiological measurements in survey blocks in Building 25, second floor. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

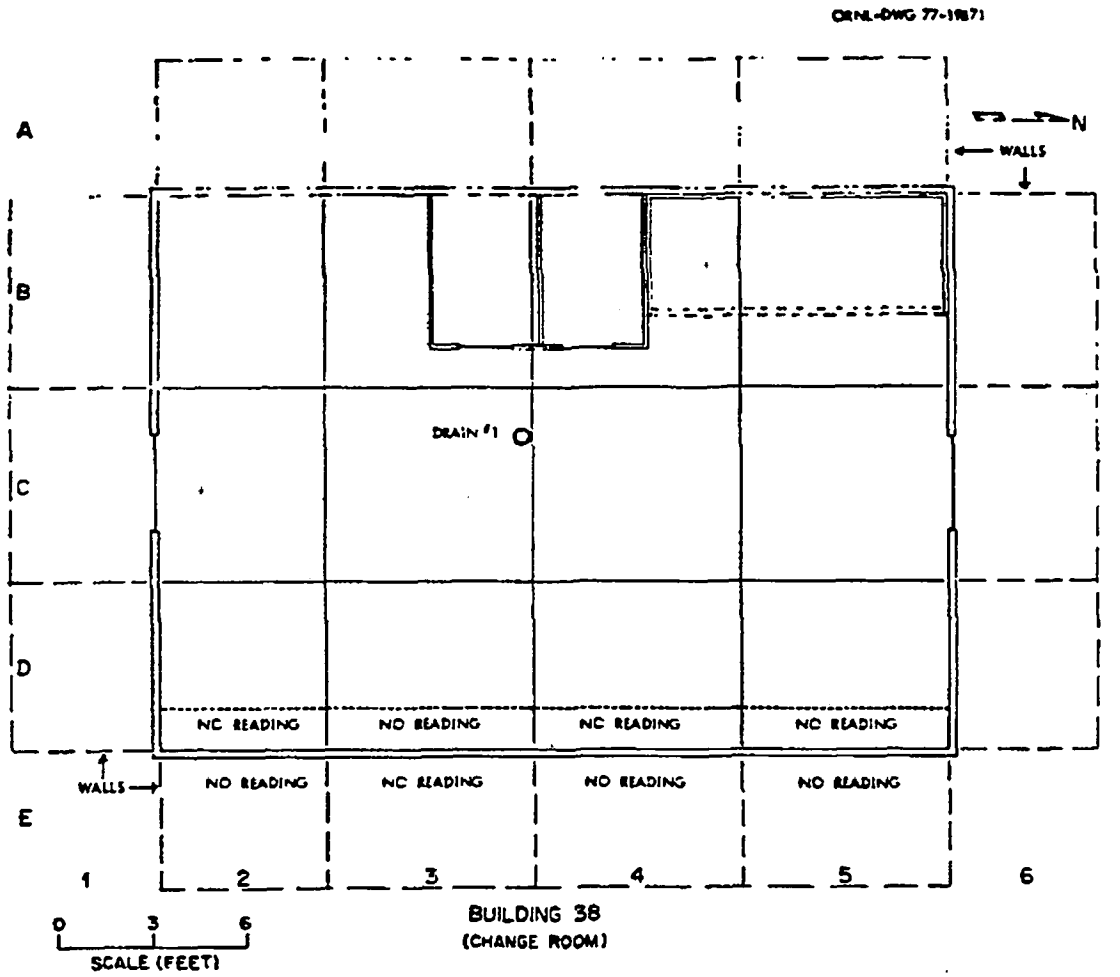


Fig. 6. Survey blocks used in survey of lower surfaces of Building 38 (measurements made in drain are given in Table 7).

Building 40

This structure was used during the uranium extraction operation for the temporary storage of residues. Thus, the NRC guidelines for ^{226}Ra are applicable to this building.

The floor and lower walls were divided into survey blocks as indicated in Fig. 7; several of the blocks were inaccessible. A scan of each accessible block with the G-M survey meter revealed several points with beta-gamma dose rates greater than the background level. These points are indicated with lower case letters in dotted circles in Fig. 7, and the direct alpha and beta-gamma measurements at these points are listed in Table 5. Alpha contamination levels as high as 25,000 dpm/100 cm^2 (by direct reading) and beta-gamma dose rates as high as 7.5 mrad/h were measured at these points. At point "e" (Fig. 7), transferable alpha and beta contamination levels were 260 dpm/100 cm^2 and 240 dpm/100 cm^2, respectively. At point "a", a transferable alpha contamination level of 15 dpm/100 cm^2 was found. Results of counts from smear samples for the remainder of the area indicated no transferable contamination. Direct alpha and beta-gamma measurements at 14 randomly selected overhead points indicated background radiation levels, except for alpha contamination levels of 100 dpm/100 cm^2 above survey block F2 and 310 dpm/100 cm^2 above block D4.

Building 50

This two-story building was used for general storage and UF_4 experiments during the uranium project work. Hence, the NRC guidelines for natural uranium are considered appropriate.

The floor and lower walls of the first level were divided into survey blocks (Fig. 8). In most survey blocks, direct readings were at the background level. However, several spots on the floor and lower walls in the north end of the first level indicated elevated beta-gamma dose rates (up to 1.0 mrad/h) and/or alpha contamination levels (up to 520 dpm/100 cm^2 by direct reading). No significant transferable contamination was found on smear samples taken on the floor and lower walls. However, analysis of a dirt sample (RC3) scraped from the floor

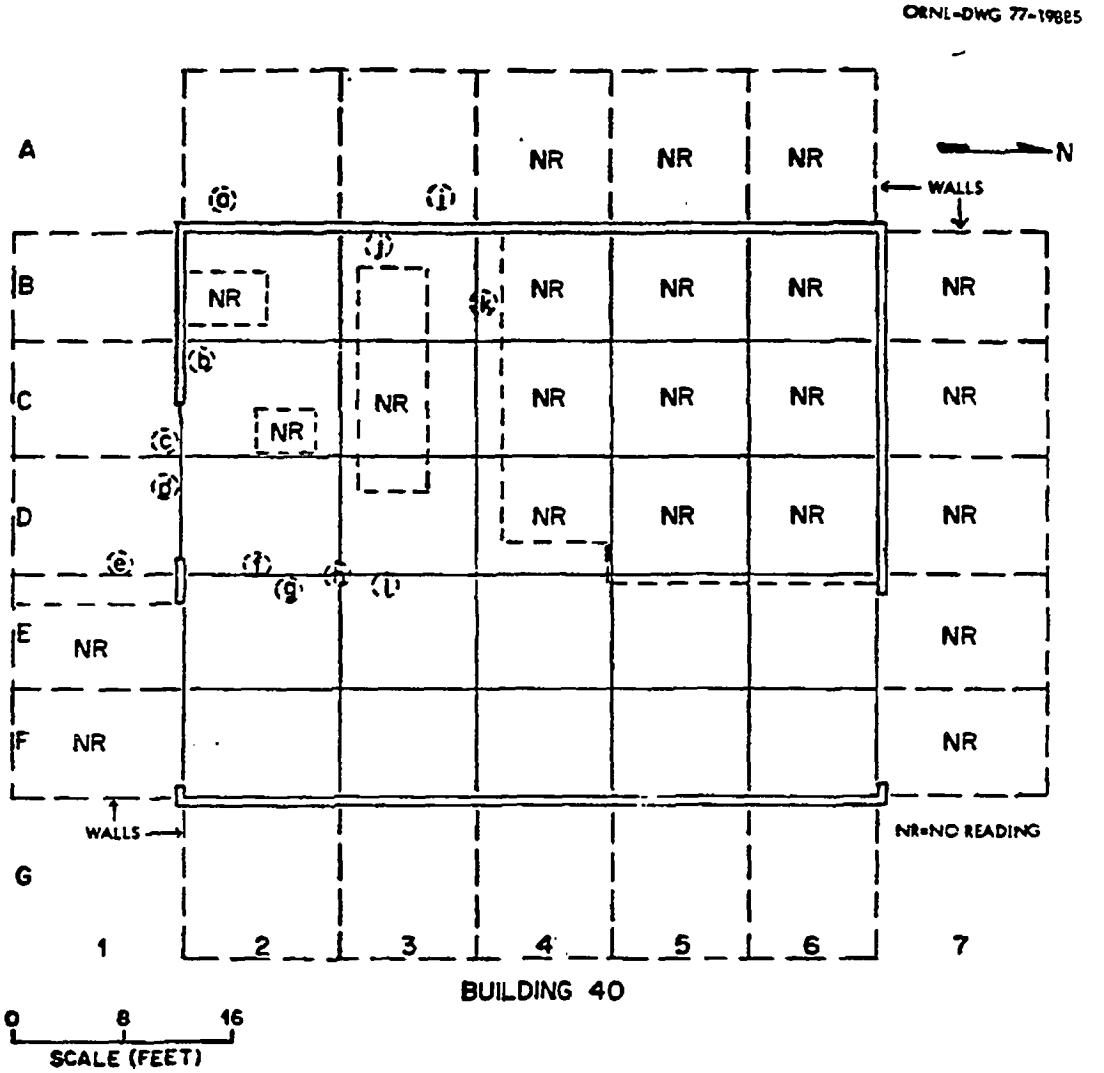


Fig. 7. Points on floor and lower walls in Building 40 where directly measured beta-gamma dose rates or alpha contamination levels exceeded background values (readings obtained at points "a" through "l" are given in Table 5).

Table 5. Alpha and beta-gamma measurements on contaminated spots in Building 40, floor and lower walls

Block shown in Fig. 7	Contaminated spot shown in Fig. 7	Directly measured contamination	
		Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/h)
A2	a	160	0.15
C2	b	2,600	2.5
C1	c	310	0.5
D1	d	NR[a]	1.0
D1	e	25,000	0.5
D2	f	260	1.0
E2	g	100	0.4
E2	h	100	0.25
A3	i	310	0.15
B3	j	NR	0.15
B4	k	210	7.5
E3	l	2,600	5.0

[a]NR = No reading.

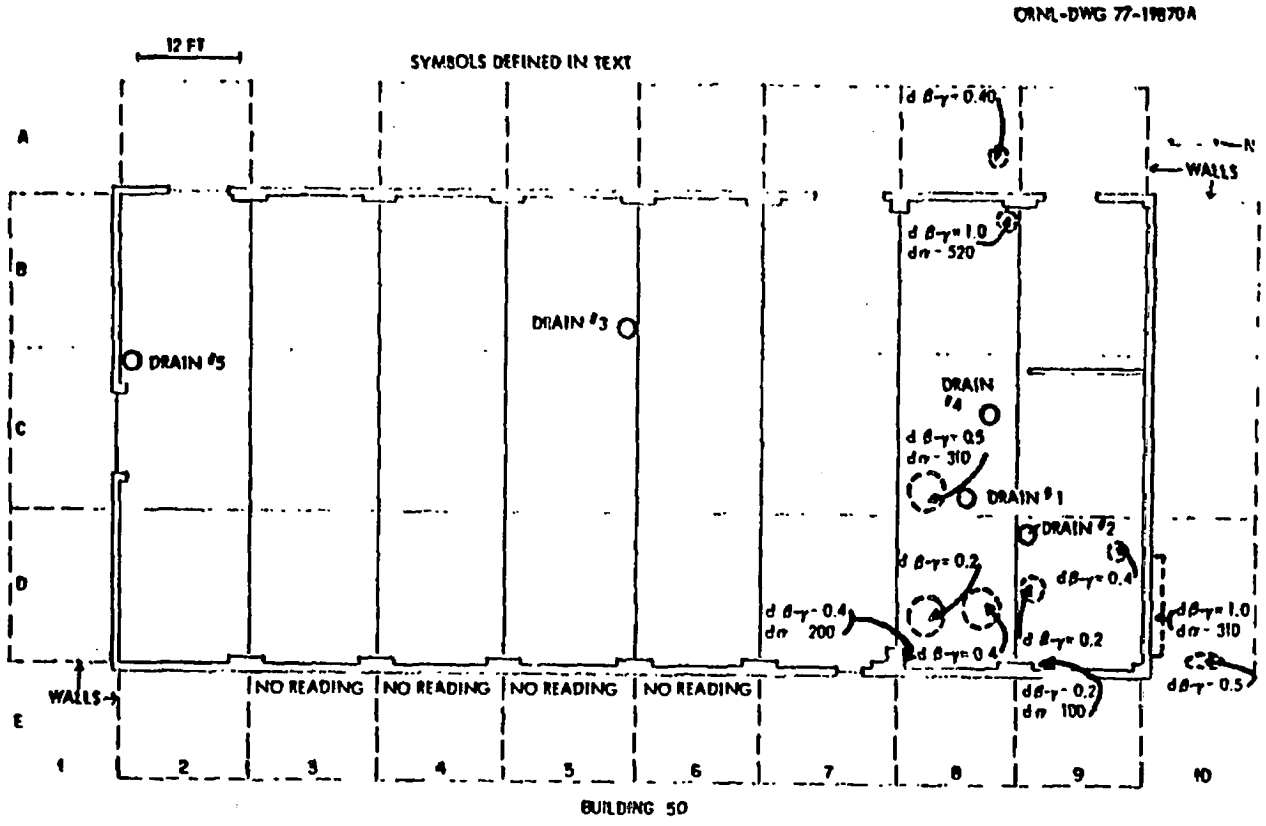


Fig. 8. Radiological measurements in survey blocks in Building 50 (measurements made in drains are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

and lower walls in the northeast corner of the first floor indicated a ^{238}U concentration of 1,400 pCi/g (Table 6). Elevated gamma radiation levels (up to 100 μR/h) were measured in some of the drains (Table 7). Concentrations of ^{238}U, ^{226}Ra, ^{230}Th, and ^{210}Pb in water samples taken from the building drains were well below the concentration guides for water (CG_w) for these radionuclides stated in 10 CFR 20 (Table 8). Several survey points were chosen at random on overhead surfaces of the first level; survey results are reported in Table 9. As on the lower surfaces, several elevated direct measurements of alpha and/or beta-gamma contamination were observed, principally in the north end of the building. Also, two overhead spots indicated some transferable contamination (Table 9).

Most areas on the second level (mezzanine) of Building 50 were not accessible to surveyors. All measurements in the accessible areas were at the background level.

Direct measurements of alpha and beta-gamma contamination levels and measurements of transferable alpha and beta contamination levels were made at randomly selected points on the roof of Building 50. No contamination was found on this surface.

Building 51

This building was used for digestion and treatment of U_3O_8. Hence, the NRC guidelines for natural uranium are applicable.

The floor and lower walls of the first level of Building 51 were divided into survey blocks (Fig. 9). It can be seen from Fig. 9 that some large areas (greater than 1 m^2) on the lower walls indicated beta-gamma dose rates exceeding the NRC guideline of 0.20 mrad/h. Direct alpha measurements were as high as 1,700 dpm/100 cm^2, and external gamma radiation levels at 1 m were above background in several survey blocks and at the tops of some drains (Table 7). Concentrations of ^{238}U, ^{226}Ra, ^{230}Th, and ^{210}Pb in drain water were well below the concentration guide for water (CG_w) for these radionuclides stated in 10 CFR 20 (Table 8).

Measurements taken at randomly selected overhead points on the first level are reported in Table 10. Direct alpha measurements up to

Table 6. Analyses of special samples

Sample code	Sample description and location	Radionuclide concentrations (pCi/g)			
		^{238}U	^{226}Ra	^{227}Ac	^{232}Th
RC1	Rust and dirt from overhead beam, Bldg. 708	180	ND[a]	ND	ND
RC2	Dirt from floor and lower wall, SW corner, Bldg. 50	3.1	ND	ND	ND
RC3	Dirt from floor and wall, NE corner, Bldg. 50	1,400	ND	ND	ND
RC4	Dirt from floor, second level of Bldg. 117, block F4	6,100	86	ND	ND
RC5	Dirt from Bldg. 52, floor, block D1	90	ND	ND	ND
SP1	Gravel and dirt from roof of Bldg. 116	16,000	ND	ND	ND
SP3	Dirt from floor, Bldg. 51A, block D3	14,000	480	ND	ND
SP4	Dirt from ionium pad, block A4	85	67	37	220
SP5	Dirt from ionium pad, block D8	170	160	ND	ND
SP7	Concrete and dirt from McKesson and Robbins Building (due east of Plant No. 6)	79	66	ND	ND

[a]ND = Not determined.

Table 7. Measurements of radioactivity in drains

Building or outdoor location	Figure	Drain code	Gamma radiation level (μR/h)		Beta-gamma dose rate at 1 cm above drain (mrad/h)	Direct alpha reading at 5 cm above drain (dpm/100 cm²)
			Top of drain	15 to 100 cm below surface		
38	6	1	NR[a]	13	NR	NR
50	8	1	NR	100	0.08	NR
50	8	2	NR	26	NR	NR
50	8	3	10	NR	NR	50
50	8	4	15	NR	NR	NR
50	8	5	10	NR	NR	50
51	9	1	15	NR	NR	50
51	9	2	27	NR	NR	50
51	9	3	10	NR	NR	50
51A	11	1	22	NR	NR	50
51A	11	2	NR	33	NR	100
51A	11	3	NR	10	NR	50
51A	11	4	NA[b]	NA	NA	NA
51A	11	5	NA	NA	NA	NA
51A	11	6	10	NR	NR	100
51A	11	7	NA	NA	NA	NA
51A	11	8	NA	NA	NA	NA
51A	11	9	22	NR	NR	50
52	12	1	22	NR	NR	NR
52	12	2	12	NR	NR	NR
117-2	22	3	NR	NR	0.35	3,100
117-2	22	4	NR	NR	0.13	310
117-1	21	1-3	NR	NR	0.43	1,200
117-1	21	4	NR	NR	5.2	3,000
117-2	22	1	NR	NR	0.43	100
117-2	22	2	NR	NR	0.43	50
700	23	1	NR	NR	20	NR
704	25	1	NR	NR	0.04	<10
704	25	2	NR	NR	0.04	<10
705	27	1	NR	NR	0.04	50
705	27	2	NR	NR	0.04	50
705	27	3	NR	NR	0.04	50
705	27	4	NR	NR	0.04	50
Ionium pad	44	5	44	NA	0.09	50
Ionium pad	44	4	NR	NA	0.26	1,400
Ionium pad	44	1	NR	NR	0.26	600
Ionium pad	44	2	NR	NR	0.26	400
Ionium pad	44	3	NR	NA	0.17	500
N of 101	48	D16	9	15	NR	NR
W of 101	47	D19	330	NR	0.65	<10
W of 101	47	D20	17	NR	0.13	310
W of 101	47	D21	NR	180	0.09[c]	160
S of 101	47	D22	NR	15	NR	160
N of 101	47	D23	NR	56	NR	50
SE of 101	47	D24	NR	33	NR	50
SE of 101	48	D25	56	NR	NR	NR
SE of 52	49	D26	6	NR	NR	50

[a] NR = No reading.

[b] NA = Measurement is not applicable; drain was plugged.

[c] Measurement taken at a depth of 5 ft in hole.

Table 8. Analyses of water samples taken from drains

Building or outdoor drain	Drain	Sample code	Water (pCi/ml)				Sediment (pCi/g)		
			^{210}Pb	^{230}Th	^{226}Ra	^{238}U	^{210}Pb	^{230}Th	^{226}Ra
38	1	DW17	ND[a]	ND	ND	0.009	ND	ND	ND
50	1	DW6	0.008 ± 35%	0.0005 ± 200%	0.0005 ± 100%	0.01	3.6 ± 25%	2.6 ± 3%	2.6 ± 18%
50	2	DW7	0.004 ± 75%	0.003 ± 110%	<0.0005	0.2	1.8 ± 25%	2.4 ± 4%	1.1 ± 42%
51	1	DW10	0.004 ± 110%	0.0003 ± 143%	0.0005 ± 100%	0.01	5.0 ± 73%	6.4 ± 7%	0.9 ± 50%
51	2	DW11	<0.004	0.0002 ± 200%	<0.0005	0.01	0.4 ± 200%	1.8 ± 25%	0.9 ± 50%
51	3	DW15	<0.0005	0.0005 ± 100%	<0.0005	0.01	2.0 ± 150%	0.7 ± 31%	0.2 ± 130%
51A	2	DW12	0.002 ± 180%	0.0009 ± 100%	0.0005 ± 100%	0.1	4.0 ± 78%	0.9 ± 20%	1.4 ± 33%
51A	3	DW13	<0.0005	0.0004 ± 130%	0.0005 ± 100%	0.01	2.0 ± 75%	2.3 ± 20%	0.4 ± 100%
52	1	DW8	0.004 ± 130%	0.009 ± 100%	0.0009 ± 100%	0.02	15 ± 110%	9.9 ± 90%	0.9 ± 100%
52	2	DW9	<0.003	0.00009 ± 250%	0.0005 ± 100%	0.01	1.4 ± 100%	0.45 ± 10%	0.2 ± 60%
700	1	DW3	<0.003	<0.003	0.0009 ± 100%	3.5	10 ± 43%	11.3 ± 4%	3.2 ± 43%
704	Block B3	DW1	0.01 ± 33%	0.0009 ± 50%	0.0009 ± 50%	<0.0003	1.4 ± 33%	1.5 ± 12%	0.9 ± 50%
704	Block B3	DW2	0.002 ± 150%	0.0001 ± 230%	0.001 ± 67%	0.006	46 ± 200%	12 ± 100%	110 ± 42%
705	Manhole 1	DW4	0.009 ± 50%	0.0014 ± 67%	<0.0005	0.08	18 ± 62%	9.5 ± 10%	3.6 ± 75%
705	Manhole 2	DW5	0.004 ± 110%	0.0009 ± 50%	0.0005 ± 100%	0.08	3.6 ± 75%	2.7 ± 8%	2.7 ± 50%
705		DW14	0.001 ± 67%	0.001 ± 100%	<0.0005	0.1	<23	4.1 ± 78%	2.3 ± 100%
O16[b]	16	DW16	ND	ND	ND	0.4	ND	ND	ND
O19[b]	19	DW19	ND	ND	ND	0.08	ND	ND	ND
O21[b]	21	DW21	ND	ND	ND	0.9	ND	ND	ND
O26[b]	26	DW26	ND	ND	ND	0.01	ND	ND	ND
CG_w			0.10	2	0.03	40			

[a]ND = Not determined.

[b]Outdoor drain.

Table 9. Alpha and beta-gamma contamination on overhead surfaces in Building 50, first level

Block shown in Fig. 8	Surface	Surface alignment	Directly measured contamination		Transferable contamination	
			Alpha (dpm/100 cm^2)	Beta-gamma dose rate (mrad/h)	Alpha (dpm/100 cm^2)	Beta (dpm/100 cm^2)
B7	Beam	Vertical	BG[a]	0.05	BG	BG
B7	Beam	Horizontal	BG	0.30	BG	BG
B9	Beam	Vertical	BG	BG	BG	BG
B9	Beam	Horizontal	BG	BG	BG	BG
C4	Beam	Vertical	BG	BG	BG	BG
C4	Beam	Horizontal	BG	0.13	BG	BG
C6	Beam	Vertical	BG	BG	BG	BG
C6	Beam	Horizontal	BG	BG	BG	BG
C8	Beam	Vertical	BG	BG	BG	BG
C8	Beam	Horizontal	BG	BG	BG	BG
C8	Bridge support	Horizontal	NR[b]	0.7	BG	BG
C9	Beam	Vertical	BG	BG	BG	BG
C9	Beam	Horizontal	BG	BG	BG	BG
D8	Beam	Vertical	260	0.23	30	180
D8	Beam	Horizontal	BG	BG	30	180
D9	Beam	Vertical	520	0.9	10	200
D9	Beam	Horizontal	BG	0.15	10	200
D9	Bridge	Horizontal	NR	2.5	NR	NR

[a]BG = Measurement could not be distinguished from background.

[b]NR = No reading.

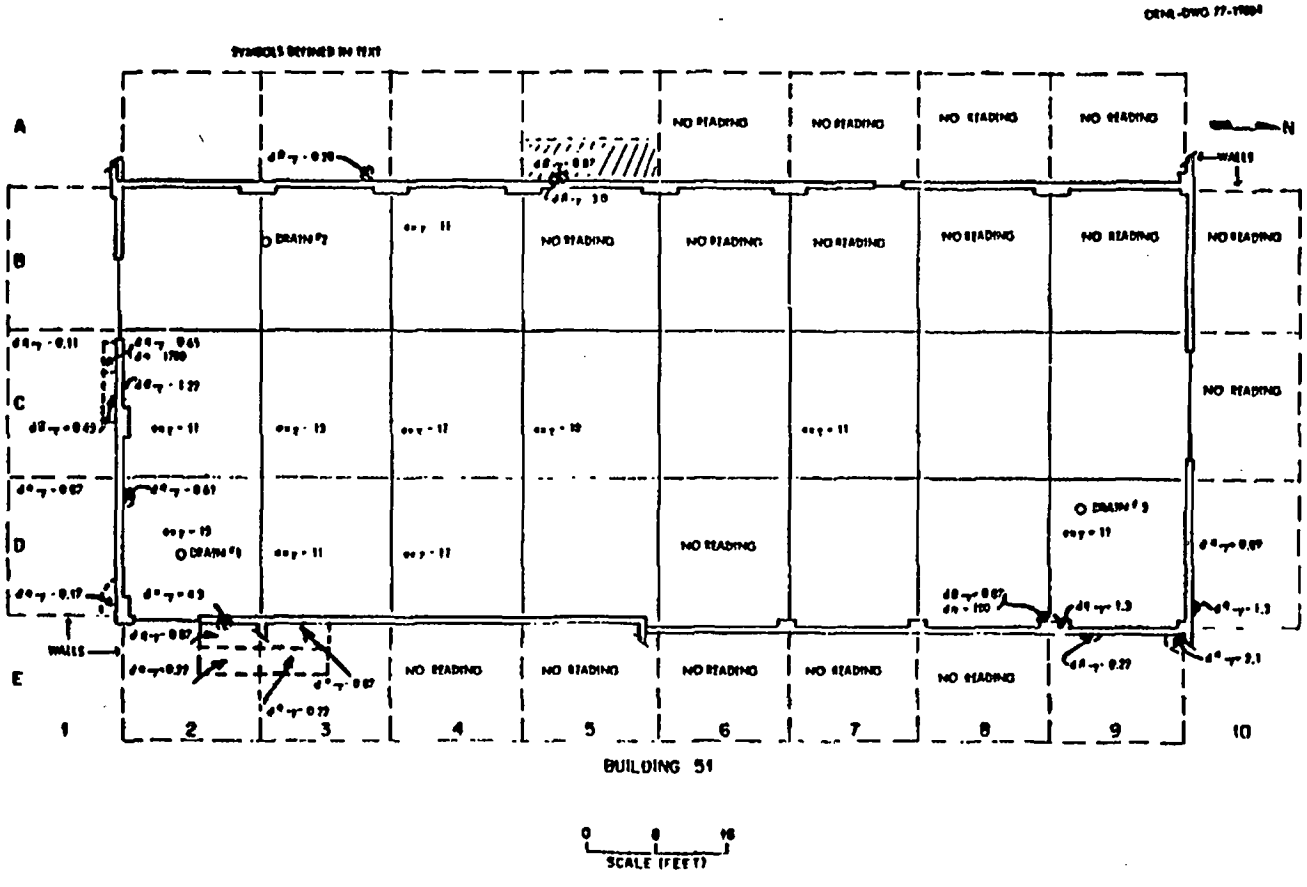


Fig. 9. Radiological measurements in survey blocks in Building 51 (measurements made in drains are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Table 10. Alpha and beta-gamma contamination on overhead surfaces in Building 51, first level

Block shown in Fig. 9	Surface	Surface alignment	Directly measured contamination		Transferable contamination	
			Alpha (dpm/100 cm²)	Beta-gamma dose rate at 1 cm (mrad/h)	Alpha (dpm/100 cm²)	Beta (dpm/100 cm²)
B2	Beam	Vertical	BG[a]	BG	BG	BG
B2	Beam	Horizontal	BG	BG	BG	BG
C2	Beam	Horizontal	BG	BG	BG	BG
C3	Beam	Vertical	BG	BG	BG	120
C3	Beam	Horizontal	BG	BG	BG	120
C4	Beam	Vertical	BG	BG	BG	BG
C4	Beam	Horizontal	BG	BG	BG	BG
C4	Bridge support	Horizontal	NR[b]	0.5	NR	NR
C8	Beam	Vertical	360	0.15	10	BG
C8	Beam	Horizontal	BG	0.1	10	BG
C9	Beam	Vertical	1,000	0.4	40	BG
C9	Beam	Horizontal	BG	0.05	NR	NR
C9	Bridge support	Horizontal	NR	0.3	NR	NR
D3	Bridge support	Horizontal	NR	0.3	NR	NR
D4	Beam	Vertical	BG	BG	BG	BG
D4	Beam	Horizontal	BG	BG	BG	NR
D9	Vent	Vertical	310	0.4	NR	NR

[a]BG = Measurement could not be distinguished from background.

[b]NR = No reading.

1,000 dpm/100 cm^2 were recorded for beams and supports overhead. However, most overhead readings were at the background level.

The accessible areas and measurements for the second level of Building 51 are shown in Fig. 10. The measurements given in Fig. 10 are average measurements for the areas indicated, except for the direct alpha reading of 100 dpm/100 cm^2, which applies to a 100 cm^2 area in survey block A5.

Several direct alpha and beta-gamma measurements were made on the roof of Building 51. No contamination was found.

Building 51A

Building 51A was used for denitration and hydrogen reduction of U_3O_8. Analysis of a dirt sample (SP3) taken from block D3 (Fig. 11) on the floor of Building 51A indicated the ^{238}U and ^{226}Ra concentrations to be 14,000 pCi/g and 480 pCi/g, respectively (Table 6). Since NRC guidelines for alpha contamination on surfaces are 50 times more restrictive for ^{226}Ra than for ^{238}U, it appears that the ^{226}Ra guidelines should be applied to this building.

The floor and lower walls of Building 51A were divided into survey blocks as shown in Fig. 11. It is evident that low-level contamination is widespread in this building. Spots in Building 51A indicating contamination levels significantly higher than average for the same survey block are given a number designation in Fig. 11, and data for these points are reported in Table 11. Direct alpha measurements at four of these points exceeded 15,000 dpm/100 cm^2, and one of these points (point 7 in block E3) indicated transferable alpha and beta contamination levels exceeding 1,000 dpm/100 cm^2.

Drain locations are also shown in Fig. 11, and survey data obtained at the drains in Building 51A are reported in Table 7. Concentrations of ^{238}U as high as 110 pCi/g were measured in dirt taken from these drains (Table 12). Concentrations of ^{238}U, ^{226}Ra, ^{230}Th, and ^{210}Pb in drain water were below the CG_w for these radionuclides as stated in 10 CFR 20.

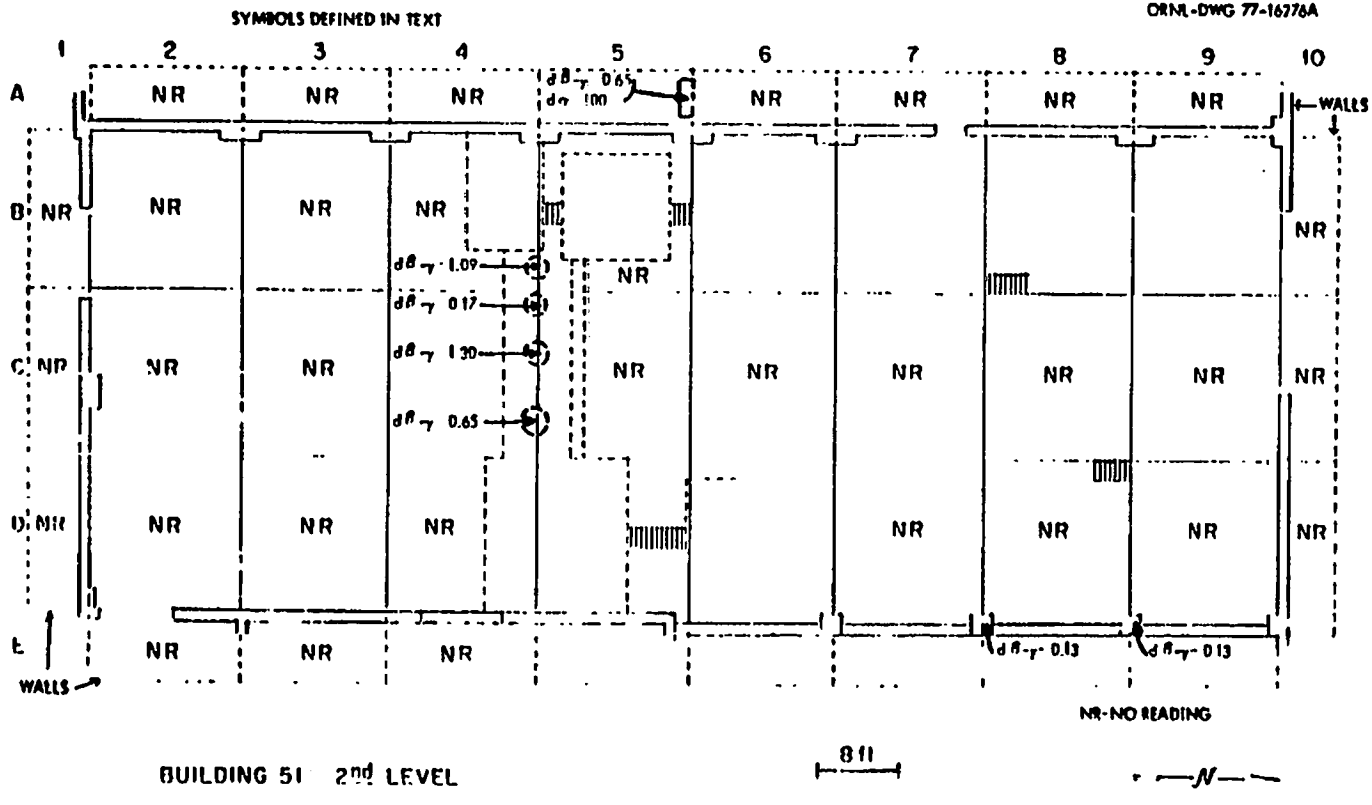
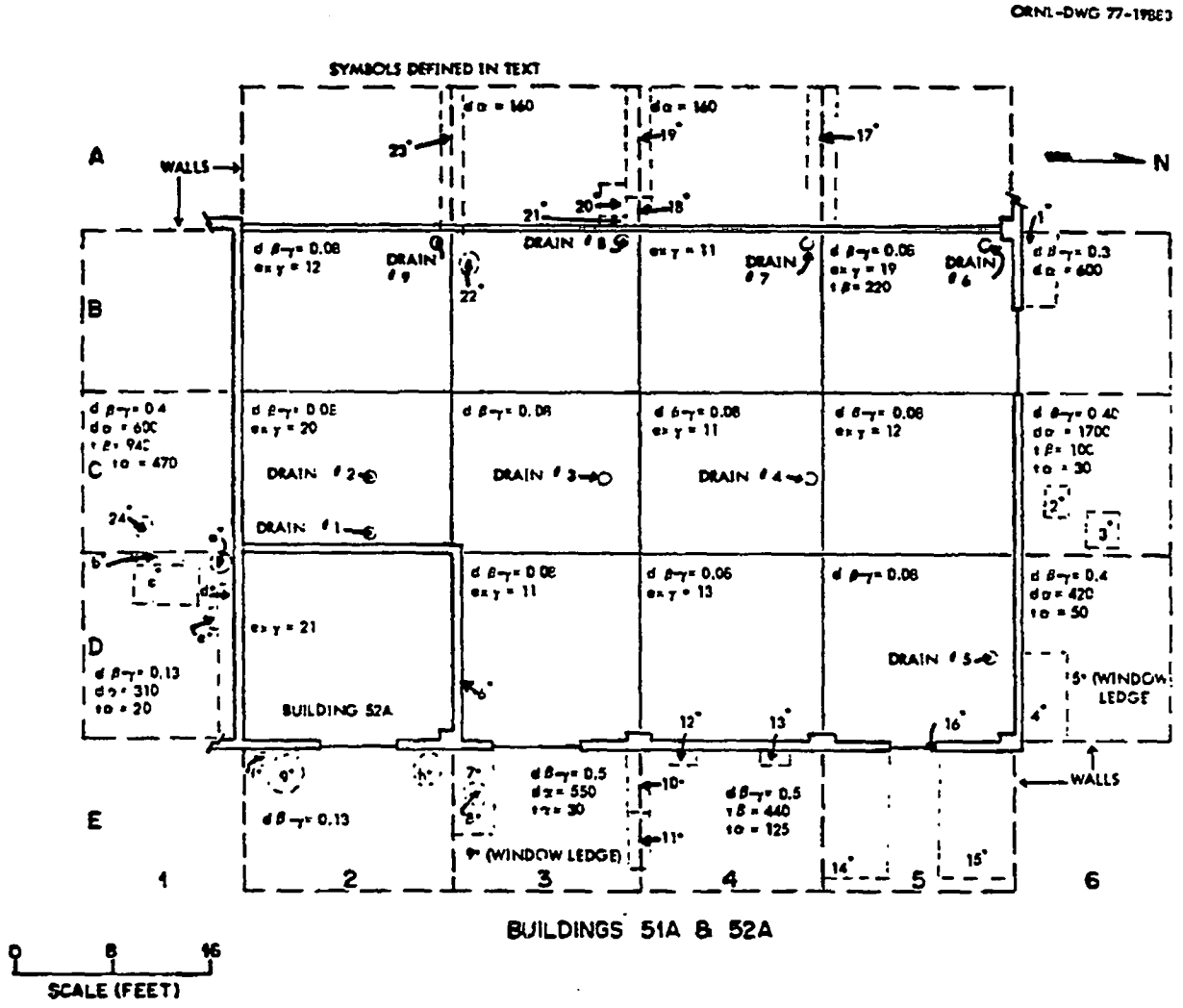


Fig. 10. Radiological measurements on second level of Building 51. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)



BUILDINGS 51A & 52A

Fig. 11. Radiological measurements in survey blocks in Buildings 51A and 52A (measurements in areas marked with asterisks are given in Tables 11 and 14; measurements made in drains are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Table 11. Alpha and beta-gamma measurements on contaminated spots in Building 51A

Block shown in Fig. 11	Contaminated spots shown in Fig. 11	Directly measured contamination		Transferable contamination	
		Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/h)	Alpha (dpm/100 cm^2)	Beta (dpm/100 cm^2)
B6	1	1,200	0.5	NR[a]	NR
C6	2	7,200	NR	380	800
C6	3	1,000	0.6	NR	NR
D6	4	2,400	1.7	NR	NR
D6	5	780	1.8	NR	NR
D3	6	25,000	5.0	NR	NR
E3	7	25,000	3.5	1,200	1,400
E3	8	48,000	10.0	NR	NR
E3	9	1,200	1.0	30	BG[b]
E4	10	12,000	1.8	NR	NR
E4	11	48,000	5.0	NR	NR
E4	12	2,400	4.0	NR	NR
E4	13	480	0.5	NR	NR
E5	14	720	0.5	NR	NR
E5	15	500	0.4	100	140
E5	16	NR	3.0	NR	NR
E5	17	1,500	NR	NR	NR
A4	18	1,400	NR	NR	NR
A4	19	600	NR	NR	NR
A3	20	NR	1.0	20	160
A3	21	NR	14.0	NR	NR
A3	22	NR	0.5	NR	NR
A2	23	1,200	NR	NR	NR
C1	24	1,200	NR	270	700

[a]NR = No reading.

[b]BG = Measurement could not be distinguished from background.

Table 12. Concentrations of ^{226}Ra, ^{238}U, ^{227}Ac, and ^{232}Th (pCi/g) in dirt samples taken from drains inside buildings

Location	Drain designation	Sample code	^{226}Ra	^{238}U	^{227}Ac	^{232}Th
K-1E	North trench	DS6	23	5.1	2.3	5.3
51A	Drain 9	DS10	1.7	64	ND[a]	1.1
51A	Drain 6	DS11	1.2	110	ND	ND
117, 2nd level	Drain 1 (in drain basket)	DS2	2.2	25	ND	2.2
117, 2nd level	Drain 1 (below drain basket)	DS3	30	1,800	ND	ND
117, 2nd level	Drain 2	DS4	2.9	34	ND	2.0
117, 1st level	Drain 4	DS5	100	12,000	ND	ND
700	Drain 1	DS8	ND	56,000	ND	ND
705	Drain 4	DS7	7.3	ND	ND	17
705	Manhole 3	DS9	2.2	31	1.8	4.0

[a]ND = Not determined.

Measurements at randomly selected overhead points are reported in Table 13. Most of these points indicated radiation levels greater than background. In fact, at several points, the beta-gamma dose rates at 1 cm from the surface ranged from 1 to 11 mrad/h.

Building 52A

This building occupies a corner of Building 51A (Fig. 11). It is presently used to store sodium. Its use during the uranium processing is not indicated in the historical summary; however, analyses of samples taken from beneath the floor indicate that natural uranium is the most significant contaminant.

Little contamination was found on the floor of Building 52A; however, beta-gamma dose rates exceeding 1.0 mrad/h were observed in several areas on the lower walls. The location and extent of these areas are indicated with lower case letters in Fig. 11, and the measurements are reported in Table 14.

The common roof of Buildings 51A and 52A was scanned to determine alpha and beta-gamma contamination levels. External gamma-ray measurements were also made over the entire roof surface. The roof scan indicated background beta-gamma and alpha readings everywhere except on the sides of the cupola. The external gamma-ray level at 1 m above the surface varied between 13 and 22 μR/h over most of the roof but jumped to approximately 44 to 56 μR/h near the cupola. The top foot of the cupola is wood, painted on the side, with tar covering the top. An average beta-gamma dose rate of 0.35 mrad/h was measured at 1 cm above the surface of the painted side. Measurements on the cupola roof indicated only background levels of beta-gamma and alpha contamination. Below the wooden part of the cupola wall, an average alpha contamination level of 260 dpm/100 cm^2 was found. The highest alpha level (1,100 dpm/100 cm^2) was measured over a crack in the south side of the cupola, and the highest beta-gamma surface dose rate, 1.5 mrad/h, was found near the point of maximum alpha contamination.

Table 13. Alpha and beta-gamma contamination on overhead beam surfaces in Building 51A

Block shown in Fig. 11	Surface alignment	Directly measured contamination		Transferable contamination	
		Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/h)	Alpha (dph/100 cm^2)	Beta (dpm/100 cm^2)
B2	Horizontal	100	0.05	BG[a]	BG
B2	Vertical	250	0.08	BG	BG
B3	Horizontal	BG	0.05	BG	BG
B3	Vertical	500	0.05	BG	BG
B4	Horizontal	BG	5.0	60	BG
B4	Vertical	1,300	4.5	60	BG
C2	Horizontal	BG	BG	BG	140
C2	Vertical	150	0.08	BG	140
C3	Horizontal	100	3.5	15	BG
C3	Vertical	BG	0.05	15	BG
D3	Horizontal	BG	3.0	BG	BG
D3	Vertical	100	1.0	BG	BG
D4	Horizontal	BG	10	50	180
D4	Vertical	3,900	4.5	50	180
D5	Horizontal	BG	9.0	20	BG
D5	Vertical	3,900	2.0	20	BG
C4	Horizontal	3,300	11	110	80
C4	Vertical	2,600	5.0	110	80
C5	Horizontal	BG	5.5	30	BG
C5	Vertical	550	0.6	30	BG

[a] BG = Measurements could not be distinguished from background.

Table 14. Alpha and beta-gamma measurements on contaminated spots in Building 52A

Block shown in Fig. 11	Contaminated spot shown in Fig. 11	Directly measured contamination	
		Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/h)
D1	a	2,100	5.0
	b	5,000	9.0
	c	1,600	1.0
	d	570	1.5
	e	2,500	3.3
E2	f	2,200	1.5
	g	1,100	0.35
	h	1,300	1.3

Building 52

This building was used for ether extraction of uranyl nitrate. The starting material in this process was U_3O_8. Hence, the NRC guidelines for natural uranium are applicable to this building.

The data in Fig. 12 and Table 15 indicate that while most of the total surface area of Building 52 has only background radiation levels, there are several contaminated spots, principally on lower walls, with beta-gamma dose rates higher than 1.0 mrad/h. Direct measurements of alpha contamination levels in the building did not exceed the guideline value of 5,000 dpm/100 cm^2. A dirt sample taken from a small area on the floor contained 90 pCi/g of ^{238}U. Overhead measurements made at randomly selected points indicated only background radiation levels. External gamma-ray measurements taken a few centimeters above the two drains shown in Fig. 12 indicated slightly elevated gamma radiation levels (22 μR/h above drain 1 and 12 μR/h above drain 2). Water samples taken from these drains had concentrations of ^{238}U, ^{226}Ra, ^{230}Th, and ^{210}Pb below the CG_w for these radionuclides stated in 10 CFR 20 (Table 8).

Building 81

This building was constructed recently in an area where radioactive materials had been handled. Although a formal survey was considered unnecessary, it appeared plausible that radon could be diffusing through the floor if the soil beneath the floor had been contaminated with radium-bearing materials. Hence, radon and radon daughter measurements were taken; the results are reported in a separate section along with radon and radon daughter measurements for the other buildings.

Building 100

This building was reportedly used as an electric substation during the uranium project work. Since the building is in an area where pitchblende ore was handled, it appears that the NRC guidelines for ^{226}Ra should be applied in this case.

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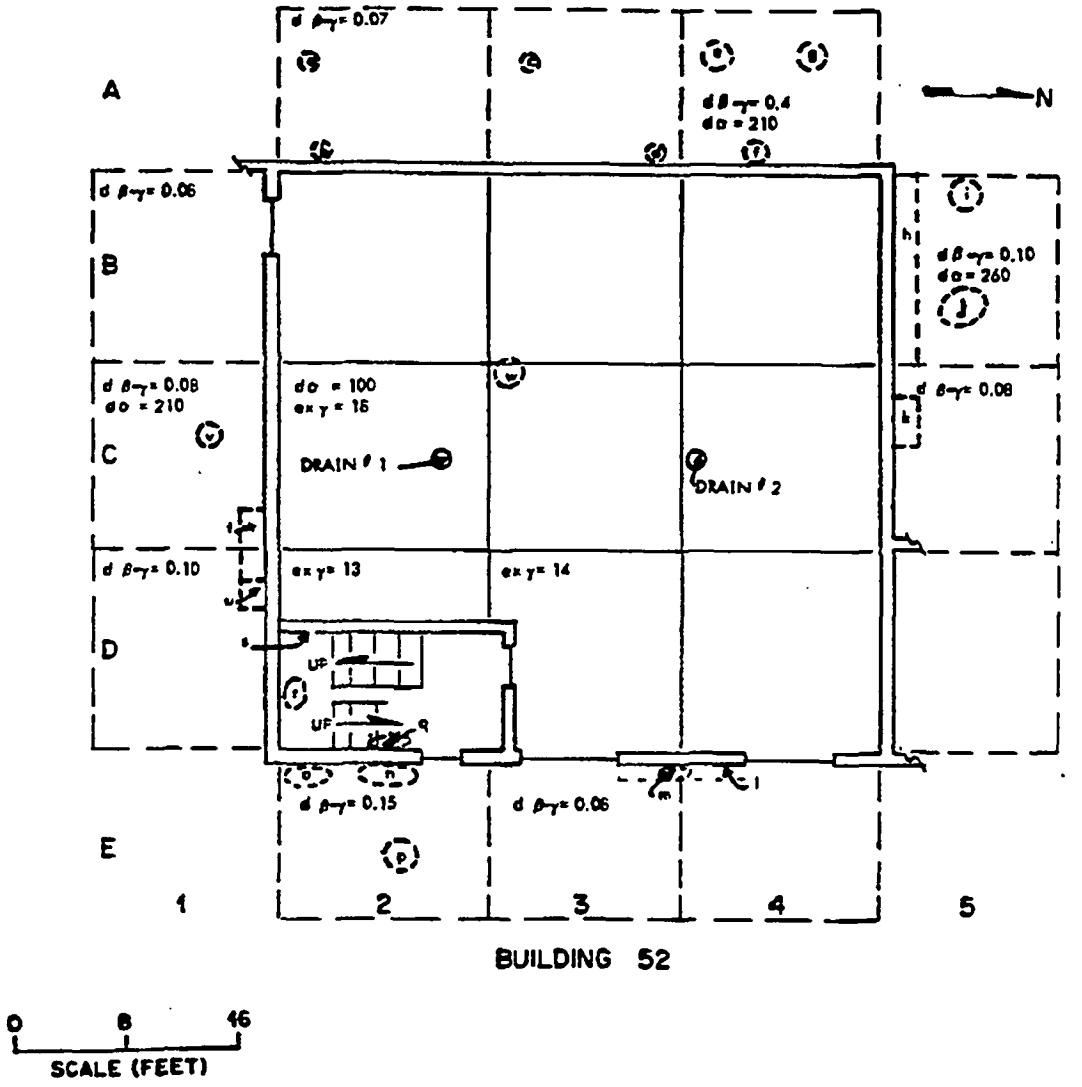


Fig. 12. Radiological measurements in survey blocks in Building 52 (measurements in areas indicated by lower-case letters are given in Table 15; measurements made in drains are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Table 15. Alpha and beta-gamma contamination in Building 52

Block shown in Fig. 12	Contaminated spot shown in Fig. 12	Directly measured contamination	
		Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/h)
A2	a	420	0.5
A2	b	620	2.1
A3	c	1,300[a]	2.3[b]
A4	d	680	0.7
A4	e	2,500	0.5
A4	f	680	17
A4	g	530	0.3
B5	h	100	1.5
B5	i	1,000	0.3
B5	j	520	0.4
C5	k	NR[c]	1.8
E4	l	NR	4
E3	m	3,100	7
E2	n	4,000	5
E2	o	1,700	5
E2	p	NR	0.3
D2	q	210	0.1
D2	r	5,000	0.8
D2	s	1,500	0.6
D1	t	NR	1.0
D1	u	360	3
C1	v	360	1.5
C3	w	NR	0.1

[a]This area showed a transferable alpha contamination level of 30 dpm/100 cm^2.

[b]This area showed a transferable beta contamination level of 240 dpm/100 cm^2.

[c]NR = No reading.

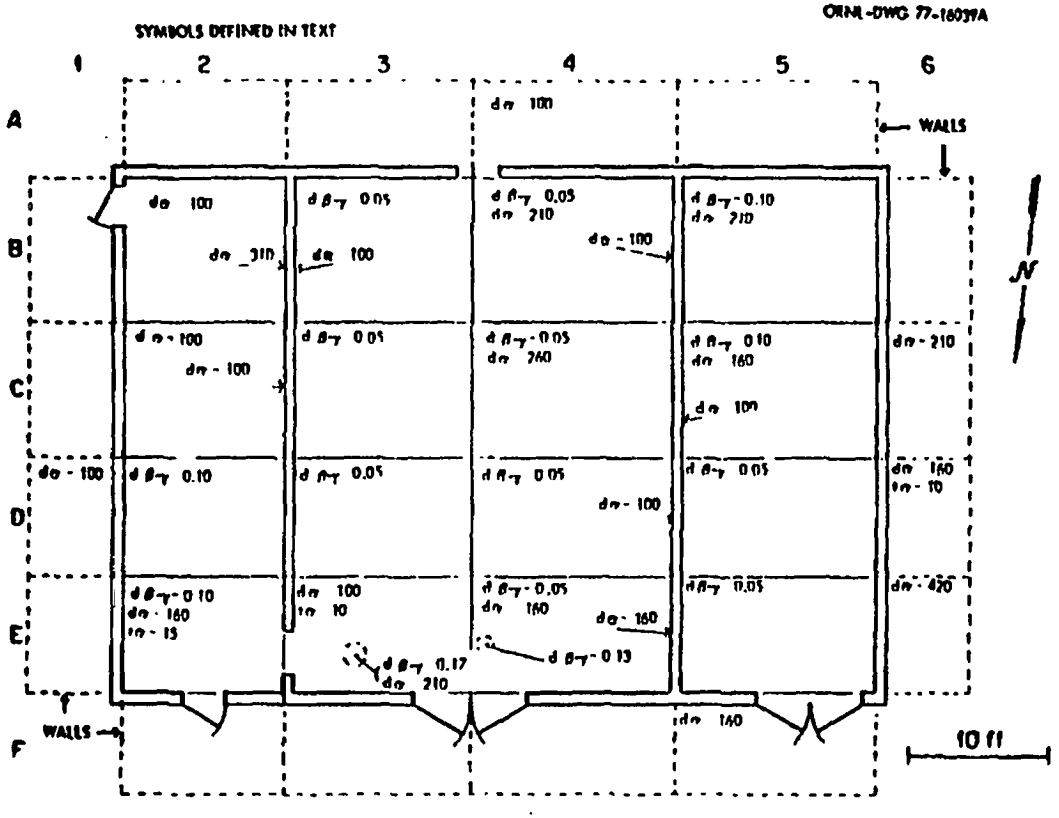
The floor and lower walls of Building 100 were divided into survey blocks, as shown in Fig. 13. All observed beta-gamma dose rates were below NRC guidelines. Measurements made in two small areas (in survey blocks E3 and E4, Fig. 13) indicated beta-gamma dose rates higher than the rest of the building (up to 0.17 mrad/h). It appears that over a large fraction of the floor and lower wall surfaces of this building, the alpha contamination level is 100 dpm/100 cm^2 or higher by direct reading and hence exceeds average NRC guidelines. No contamination was found on overhead surfaces.

Alpha and beta-gamma measurements were taken at several points on the roof. All readings were at the background level except on the clay tile around the edge of the roof and over the partitions of the building. Measurements taken on these clay tiles indicated beta-gamma dose rates from background to 0.15 mrad/h (principally beta radiation) and direct reading alpha contamination levels which ranged from 160 to 25,000 dpm/100 cm^2. Five smear samples were taken on the tiles. The maximum transferable alpha contamination level found was 80 dpm/100 cm^2. These measurements indicate that the glaze used on the tile contains thorium.

Building 101

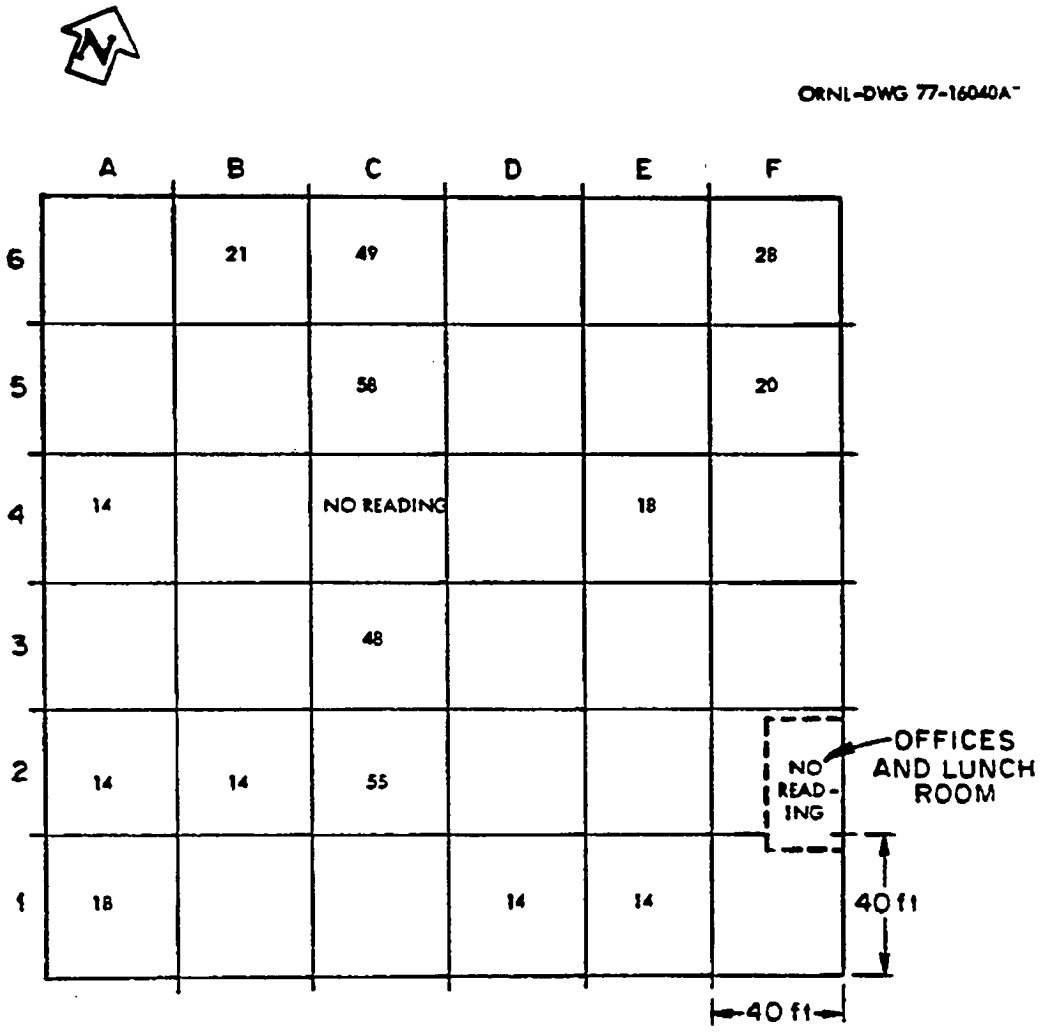
This is a relatively new building used as a warehouse, and surface contamination was not expected to be present. It is built; however, on the site of several demolished buildings where pitchblende ore was processed. Hence, a limited survey was conducted to check whether elevated external gamma-ray levels or elevated radon levels exist. As shown in Fig. 14, the maximum observed external gamma radiation level was 58 μR/h; the average of the external gamma-ray levels measured in all 35 accessible survey blocks was 15 μR/h.

The radon measurements made in this building are reported in a separate section along with radon measurements in the other buildings.



BUILDING 100

Fig. 13. Radiological measurements in survey blocks in Building 100. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)



BUILDING 101

Fig. 14. External gamma radiation levels (μR/h) at 1 m in survey blocks in Building 101. (The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Building 116

This building was used in the uranium project and apparently came in contact with uranium metal. Hence, the NRC guidelines for uranium are applicable.

For purposes of reporting, the building has been divided into several sections. These include the main section of Building 116, two levels of the north section (116N), a small addition at the southwest corner designated 116B, a stairwell in the southeast corner of Building 116, and a shed adjacent to Building 116.

It is evident from Fig. 15 and Table 16 that there is low-level alpha contamination over much of the floor and lower wall surfaces of this portion of Building 116. The lower-case letters in Fig. 15 denote points where elevated direct beta-gamma dose rates were observed. However, the direct alpha measurements in this section did not exceed 1,600 dpm/100 cm^2 and hence were below NRC guidelines for natural uranium. Alpha and beta-gamma measurements were taken at 17 randomly selected overhead points in this section of the building. Direct alpha readings on ceiling vents over survey blocks D4, D6, and D8 averaged 570 dpm/100 cm^2. These surfaces indicated a maximum transferable alpha contamination level of 30 dpm/100 cm^2 (over block D8). Also, a horizontal beam surface over block C2 indicated a beta-gamma dose rate of 0.10 mrad/h and alpha contamination of 100 dpm/100 cm^2 by direct reading. Overhead measurements taken at the other points were at the background level.

For the floor and lower walls of the first level of the north end, all measurements were below NRC guidelines for surfaces contaminated with natural uranium even though alpha, beta-gamma, and/or external gamma measurements were above the background level in several of the survey blocks (Fig. 16). No contamination was found on overhead surfaces.

The floor and lower walls of the second level of the north end are shown in Fig. 17. Except for a small area on the floor in block B3 and a screen on the lower wall in block G4 that had beta-gamma dose rates exceeding 0.20 mrad/h, all other measurements were below NRC guidelines for uranium contamination. Overhead measurements at randomly

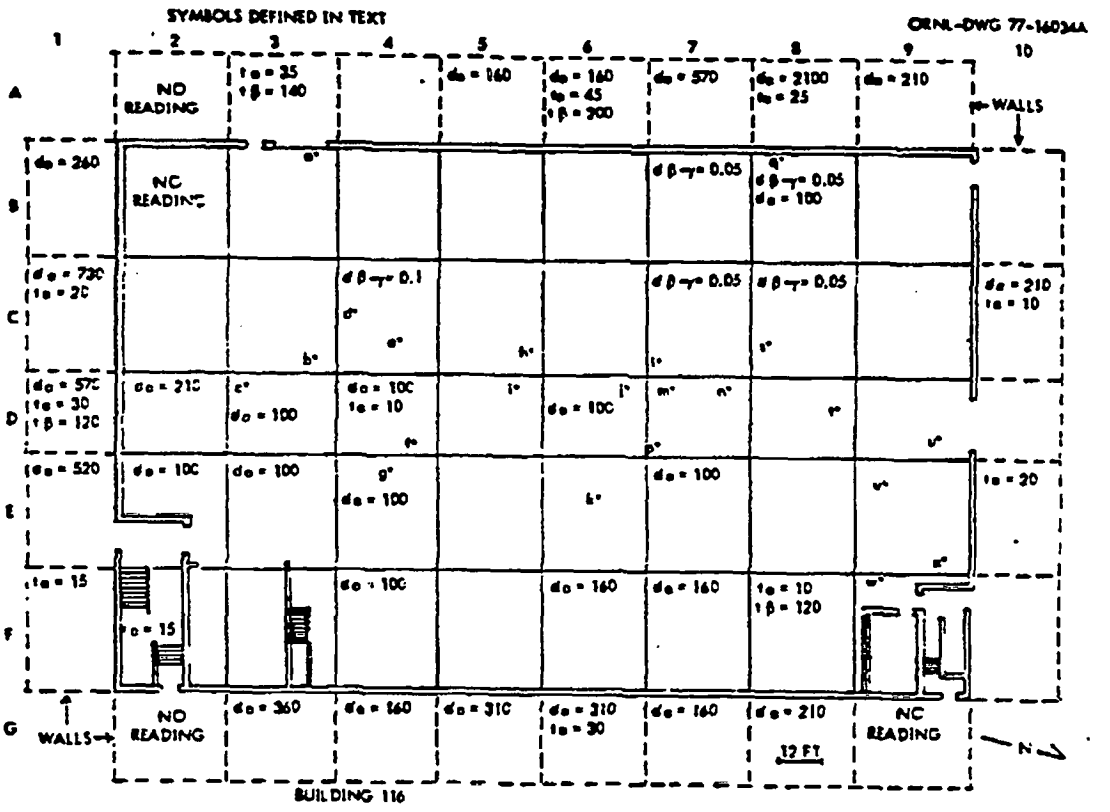


Fig. 15. Radiological measurements in survey blocks in main part of Building 116 (measurements at points indicated by lower-case letters are given in Table 16). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Table 16. Alpha and beta-gamma measurements on contaminated spots in Building 116

Block shown in Fig. 15	Contaminated spot shown in Fig. 15	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/h)
B3	a	1,600	1.5
C3	b	260	0.6
D3	c	100	0.18
C4	d	210	0.5
C4	e	420	1.3
D4	f	BG[a]	0.08
E4	g	NR[b]	0.1
C5	h	NR	0.18
D5	i	310	0.18
D6	j	BG	0.15
E6	k	360	1.5
C7	l	BG	0.15
D7	m	NR	0.15
D7	n	BG	0.15
E7	p	NR	1.0
B8	q	BG	0.18
B8	r	210	1.0
C8	s	BG	0.8
D8	t	100	0.05
D9	u	210	0.4
E9	v	BG	0.25
F9	w	260	NR
F9	x	260	NR

[a] BG = Measurement could not be distinguished from background.

[b] NR = No reading.

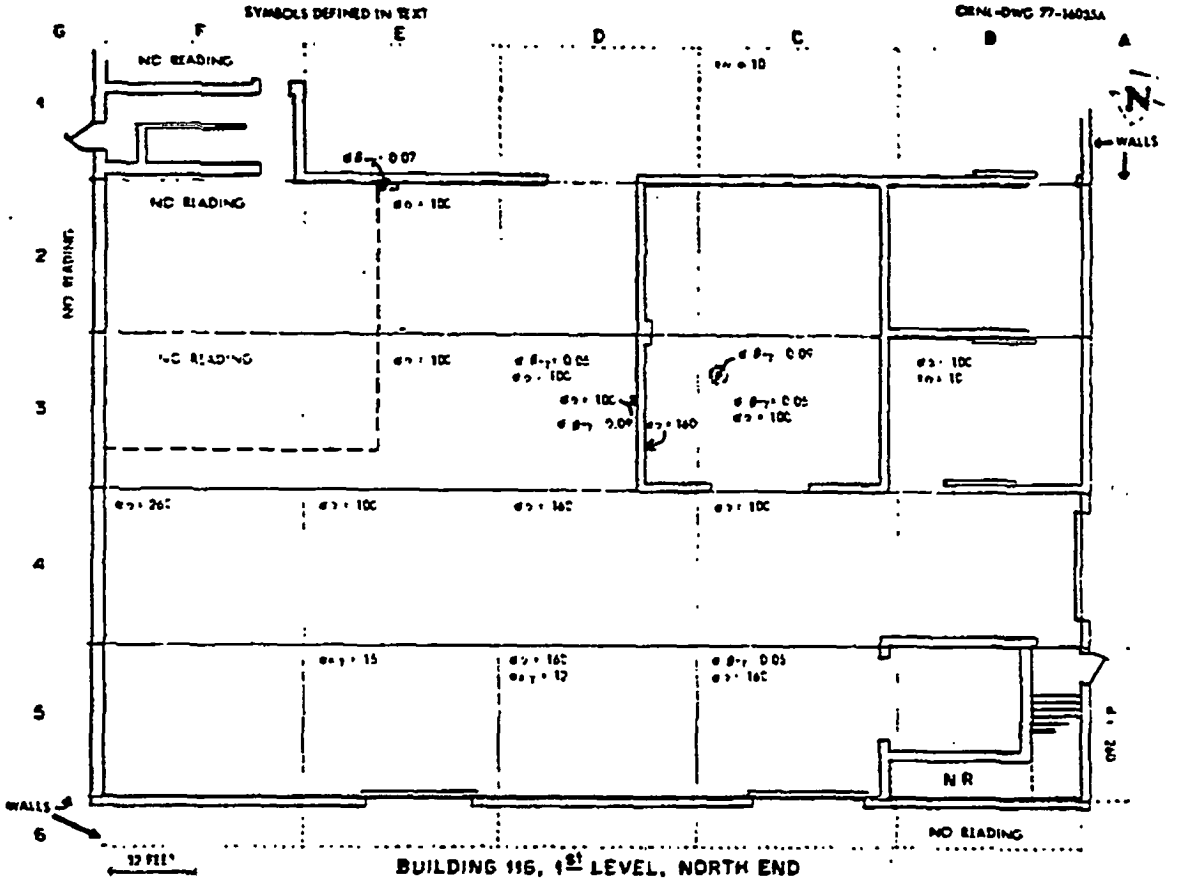
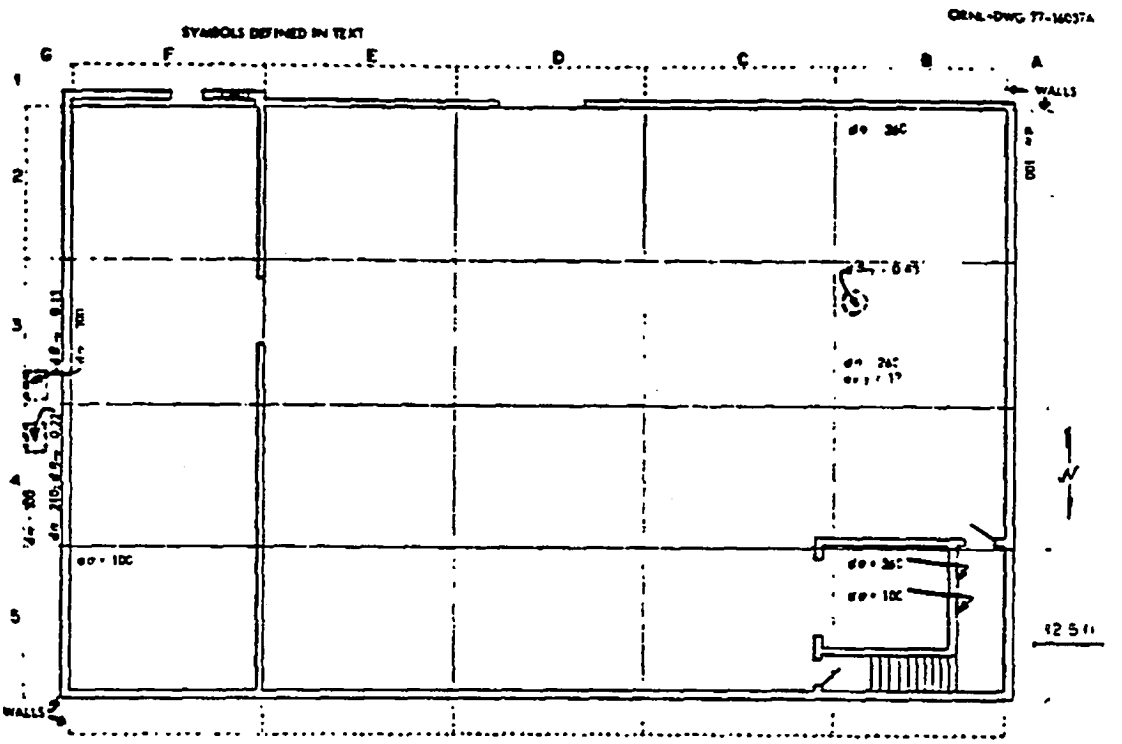


Fig. 16. Radiological measurements in survey blocks on the first level of the north end of Building 116. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)



BUILDING 116, 2ND LEVEL, NORTH END

Fig. 17. Radiological measurements in survey blocks on the second level of the north end of Building 116. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

selected points revealed alpha contamination levels of approximately 100 dpm/100 cm^2 by direct reading at some points over rows B and D. All other alpha and beta-gamma measurements made overhead were at the background level.

Divisions used in the survey of the upper level of the stairwell in the southeast corner of Building 116 are shown in Fig. 18. Measurements given in Fig. 18 are averages of observed measurements for the areas indicated. All surfaces were scanned for the determination of beta-gamma dose rates, and the other types of measurements were taken at randomly selected points. Hence the data shown in Fig. 18 indicate that, although NRC guidelines are not exceeded in this area, there is low-level contamination over a large fraction of the floor and lower walls.

Beta-gamma dose rates and direct alpha contamination levels on the roof of Building 116 were at the background level, with the exception of the measurements made at the southeast corner near the stairwell. Here the beta-gamma dose rates were in the range of 0.75 to 4 mrad/h. The maximum beta-gamma dose rate (4 mrad/h) was measured throughout an area of more than 4 m^2. Direct alpha measurements in this area ranged from 50 to 680 dpm/100 cm^2. Analysis of a sample (SP1, Table 6) of gravel and dirt from the roof indicated 16,000 pCi/g of ^{238}U.

Inside Building 116B (Fig. 19), all measurements were at the background level. On the roof of this building there were two large areas where beta-gamma dose rates averaged more than 0.20 mrad/h. Direct alpha measurements on the roof were as high as 1,500 dpm/100 cm^2 (on cap tiles on the edge of the roof). The measurements shown in the four sections of the roof are average measurements observed in those sections.

In the shed attached to Building 116 (Fig. 20), some contamination was found on the floor and at the base of one wall. Unless otherwise indicated, measurements shown in Fig. 20 are averages of observed measurements in the area specified. Three points at the base of the west wall indicated beta-gamma dose rates ranging from 0.35 to 0.61 mrad/h. The contaminated areas in all three cases were less than 100 cm^2, and

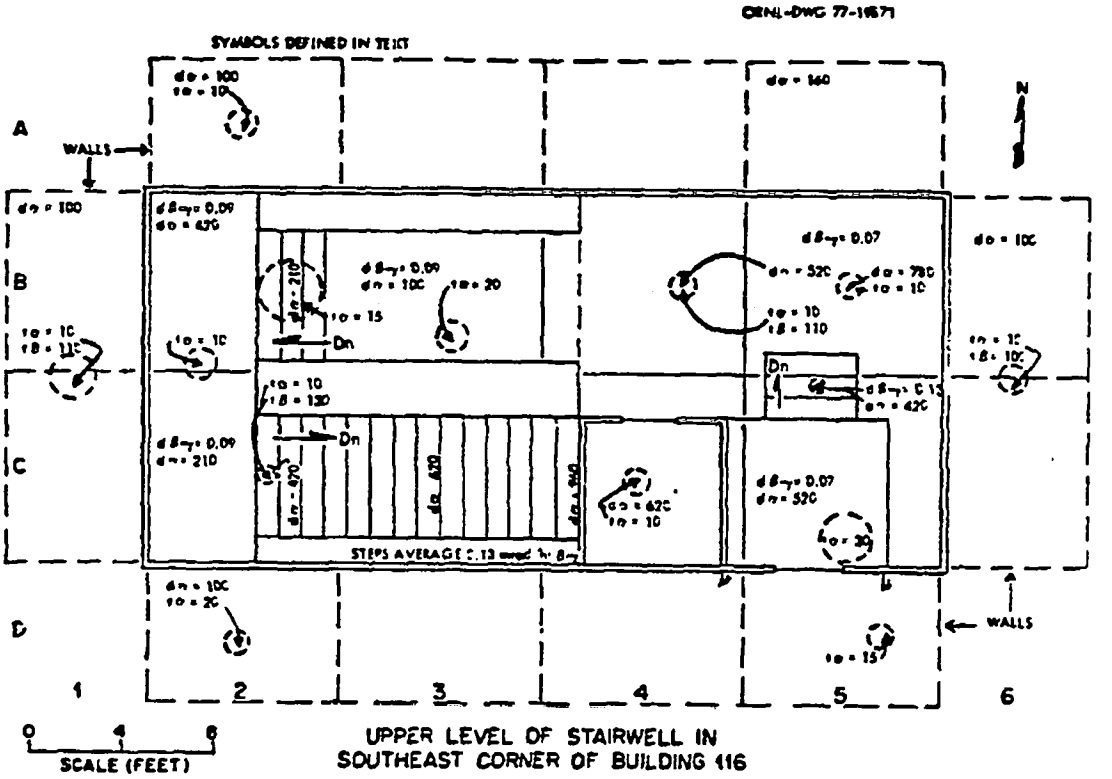


Fig. 18. Radiological measurements in survey blocks on the upper level of the stairwell in the southeast corner of Building 116. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

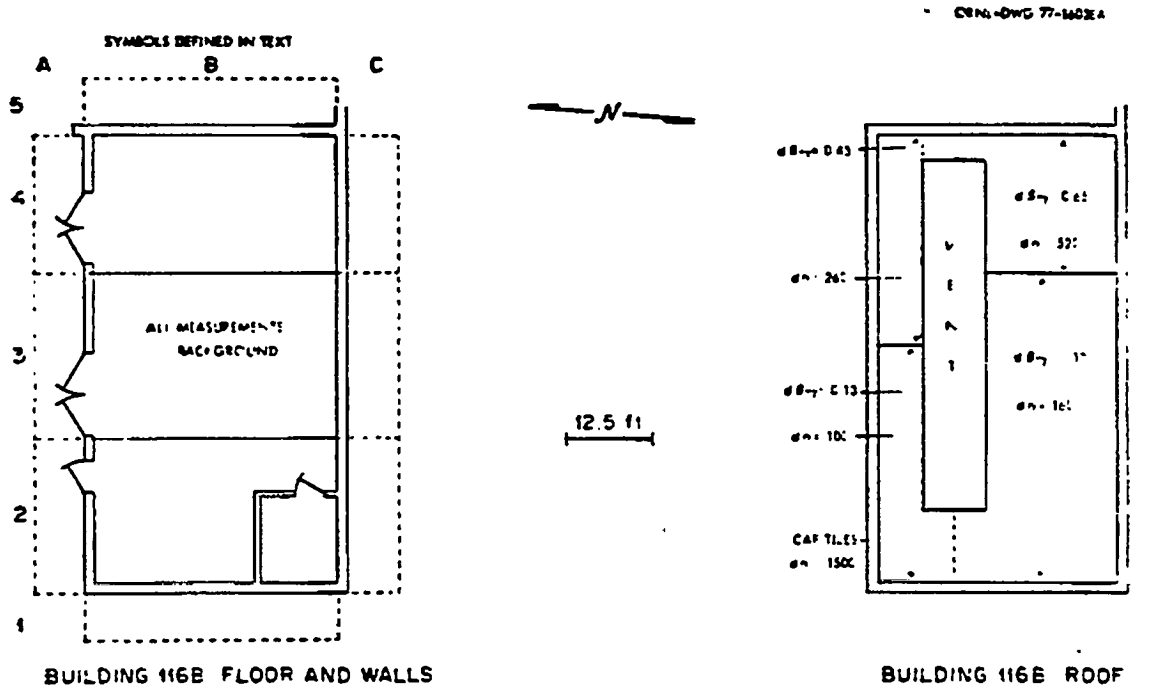


Fig. 19. Survey blocks used inside Building 116B and radiological measurements on the roof of Building 116B. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

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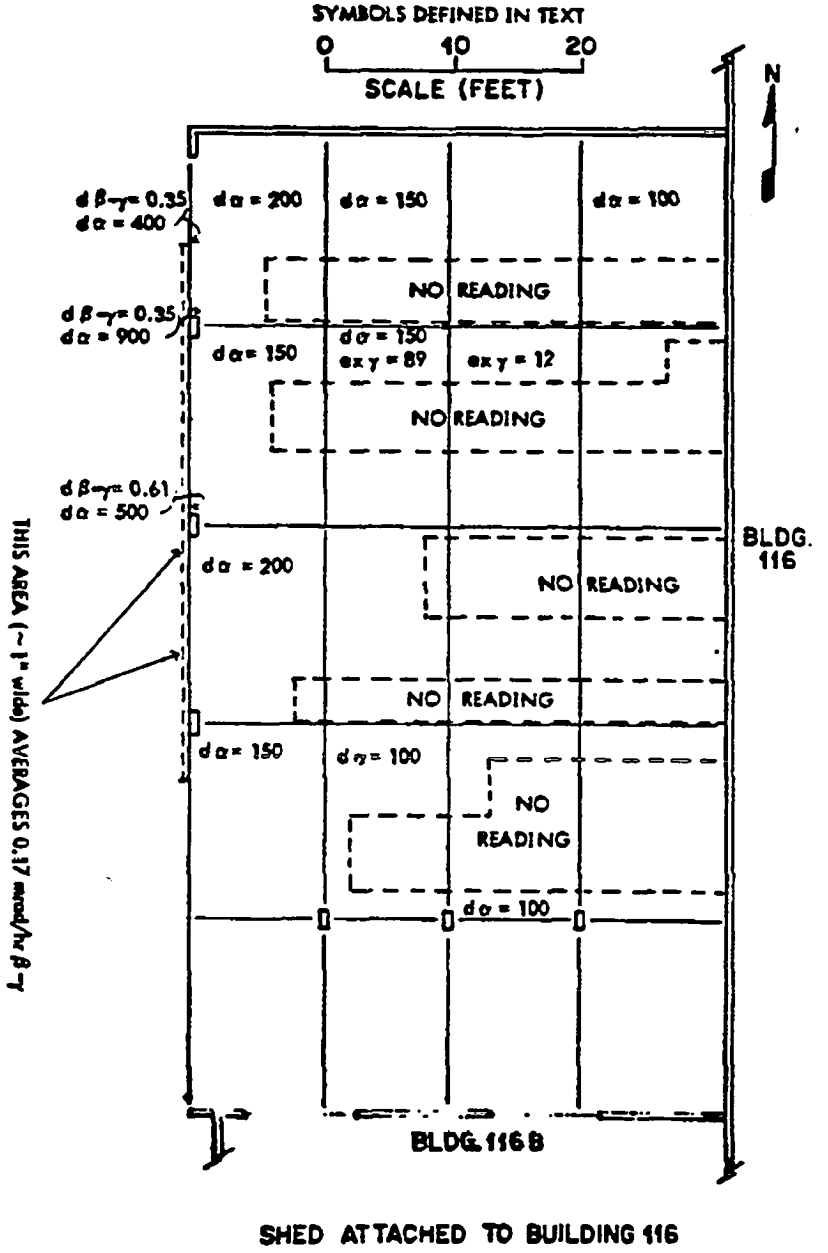


SHED ATTACHED TO BUILDING 116

Fig. 20. Radiological measurements in survey blocks in shed attached to Building 116 and 116B. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

averaging over 1 m^2 yielded average measurements below 0.20 mrad/h; hence, NRC guidelines were not exceeded.

Building 117

This building served as a security and change house, lunchroom, and laundry during uranium operations. Small traces of pitchblende ore were probably brought into the building on clothes and shoes; hence, the NRC guidelines for radium should probably be applied. However, a dirt sample taken from the floor of the second level of Building 117 had a ^{238}U concentration of 6,100 pCi/g and a ^{226}Ra concentration of only 86 pCi/g (Table 6).

Measurements of the floor and lower walls of the first level of Building 117 are shown in Fig. 21.

It appears from the survey results that alpha contamination of at least 100 dpm/100 cm^2 by direct reading is present over a large fraction of the floor and on the north wall; hence, average NRC guidelines for radium contamination are exceeded. Also, there are two blocks where NRC guidelines for beta-gamma contamination are exceeded at some points, since the beta-gamma dose rate in D4 exceeds 1.0 mrad/h, and the beta-gamma dose rate in one corner of G4 averages 0.52 mrad/h. Beta-gamma dose rates and alpha contamination levels were measured at 28 randomly selected overhead points. All beta-gamma dose rates were at the background level; however, alpha contamination levels of 100 to 150 dpm/100 cm^2 were measured over blocks E4, G2, and G4.

For the floor and lower walls of the second level of Building 117, direct alpha measurements at several randomly selected points are 100 dpm/100 cm^2 or greater; hence, it appears that average NRC guidelines for radium are exceeded in these areas (Fig. 22). Beta-gamma dose rates exceed the average NRC guidelines of 0.20 mrad/h in several areas on the floor and inside drains. The highest observed beta-gamma dose rate on the second level was 1.1 mrad/h and was found in the entrance to a shower in block F4. Beta-gamma dose rates and alpha contamination levels were measured at 18 randomly selected overhead points. All beta-gamma dose rates were at the background level; however, alpha

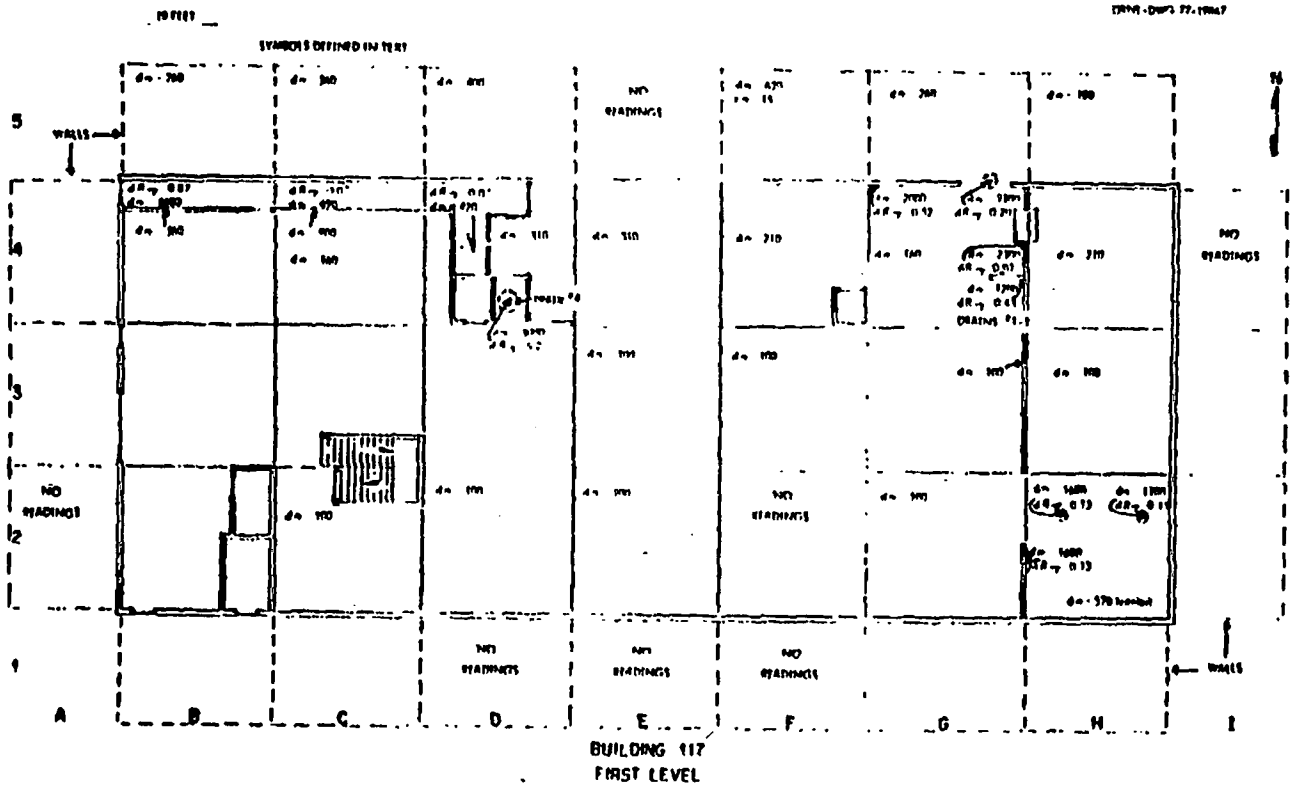


Fig. 21. Radiological measurements in survey blocks on first level of Building 117 (measurements made in drains are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

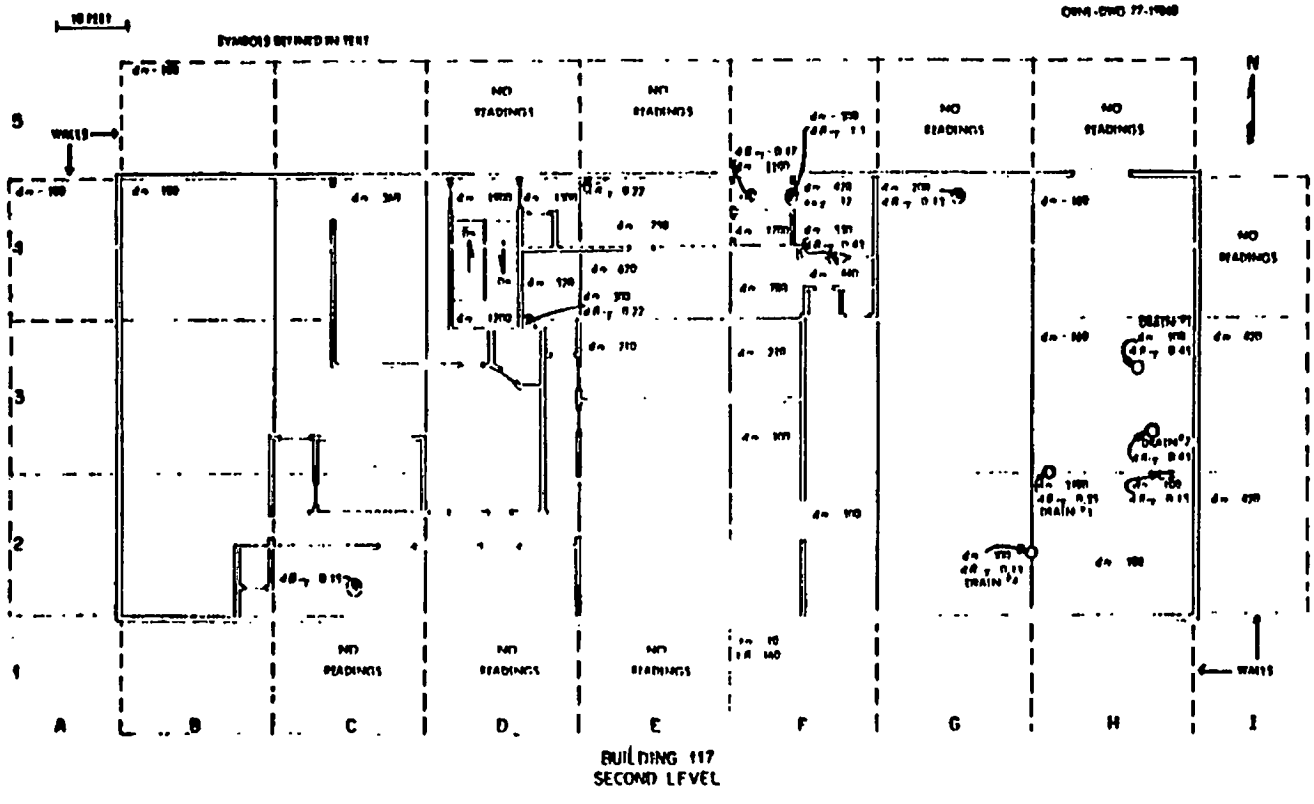


Fig. 22. Radiological measurements in survey blocks on second level of Building 117 (measurements made in drains are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

contamination levels of 100 to 2,000 dpm/100 cm^2 were measured over blocks E3 and F3 and over the stairs in block D4.

Direct measurements of alpha contamination levels and beta-gamma dose rates were made on the roof of Building 117. The only measurements above background were those made in a blower vent where a direct alpha contamination level of 100 dpm/100 cm^2 and a beta-gamma dose rate of 0.09 mrad/h were measured. Some moisture was present between the concrete roof surface and the tar paper covering the surface; the direct alpha readings could have been affected by this moisture.

There are five drains in Building 117 (Figs. 21 and 22). The direct alpha, beta-gamma, and external gamma-ray measurements made at the tops of the drains are shown in Table 7. Dirt samples taken from drains 1 and 4 (on the second and first levels of Building 117, respectively) contained ^{238}U concentrations of 1,800 and 12,000 pCi/g, respectively (Table 12).

Building 700

This building served as a warehouse, safety office, and core machining facility during uranium operations. There is no evidence that radium-bearing materials were brought into the building, and the NRC guidelines for natural uranium appear to be applicable.

The highest beta-gamma dose rate observed in Building 700 (20 mrad/h) was measured at 1 cm above a drain inside a small room in block D10 (Fig. 23). Beta-gamma dose rates exceeding 0.20 mrad/h were observed in five additional areas, all on the floor. Direct alpha measurements at these five locations on the floor were less than 100 dpm/100 cm^2, with the exception of one point in block A6 which measures 2,000 dpm/100 cm^2. The above-mentioned beta-gamma dose rates were the only measurements observed in Building 700 which exceeded the NRC guidelines.

Alpha contamination levels and beta-gamma dose rates were measured directly at nine randomly selected overhead locations, over survey blocks C6, C4, C2, and D2. Smear samples were taken at each of the nine locations. The only above-background measurements were those

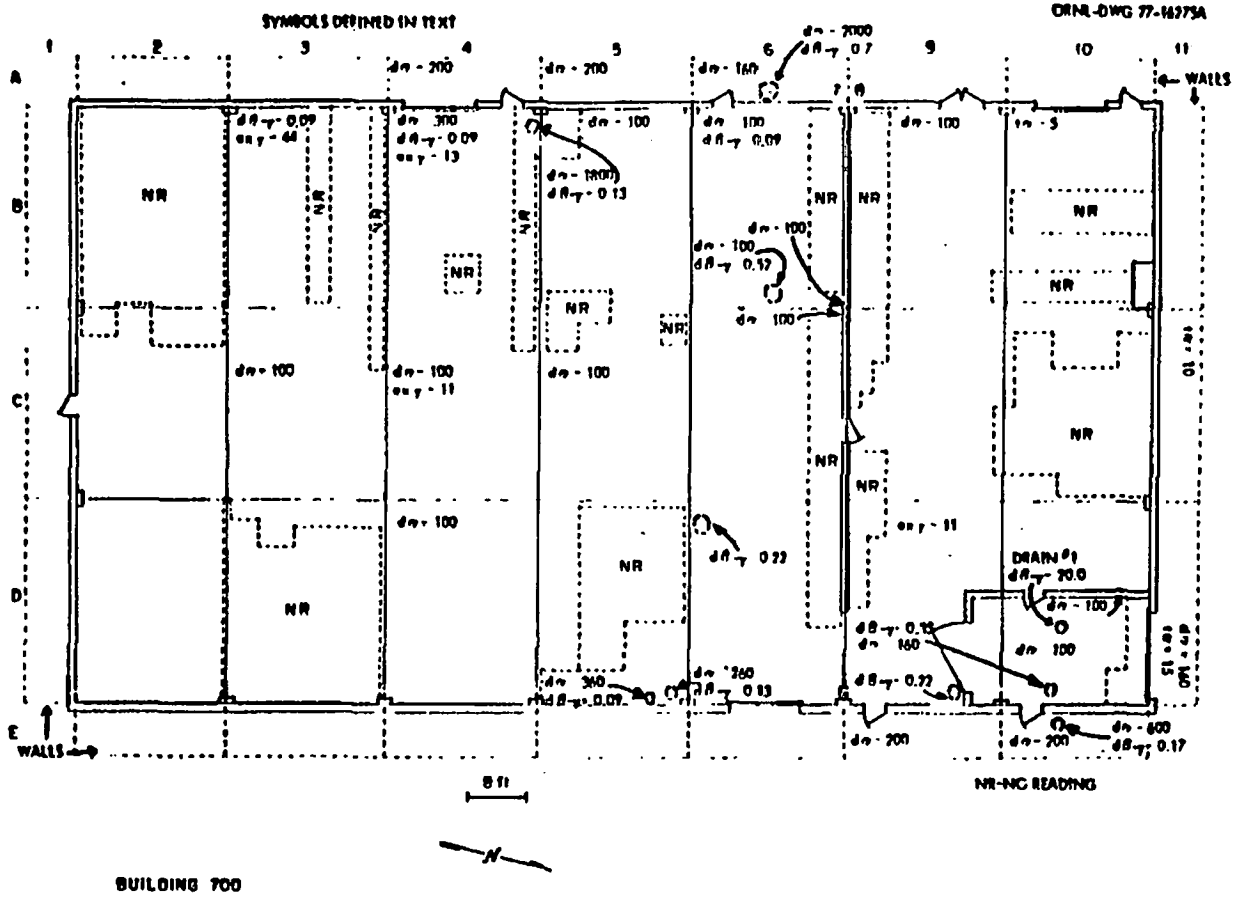


Fig. 23. Radiological measurements in survey blocks in Building 700 (measurements made in drains are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

observed on a horizontal beam above survey block C6. Here the beta-gamma dose measured 0.09 mrad/h, the direct alpha contamination level was 100 dpm/100 cm^2, and the transferable alpha contamination level was 30 dpm/100 cm^2.

There is only one drain inside Building 700 (Fig. 23). As noted earlier, the beta-gamma dose rate at 1 cm above the drain measured 20 mrad/h. A water sample (DW3, Table 8) taken from this drain contained a ^{238}U concentration of 3.5 pCi/ml, which is approximately 9% of the CG_w stated in 10 CFR 20. A dirt sample (DS8, Table 12) taken from this drain had a ^{238}U concentration of 56,000 pCi/g (16%-wt. uranium).

Beta-gamma dose rates and alpha contamination levels were measured at randomly selected points on the roof of Building 700 (Fig. 24). All beta-gamma measurements were at the background level. The highest alpha contamination level measured on the roof was 800 dpm/100 cm^2 on a roof cap on the northeast side. All other direct alpha measurements made on the roof were between 100 and 520 dpm/100 cm^2.

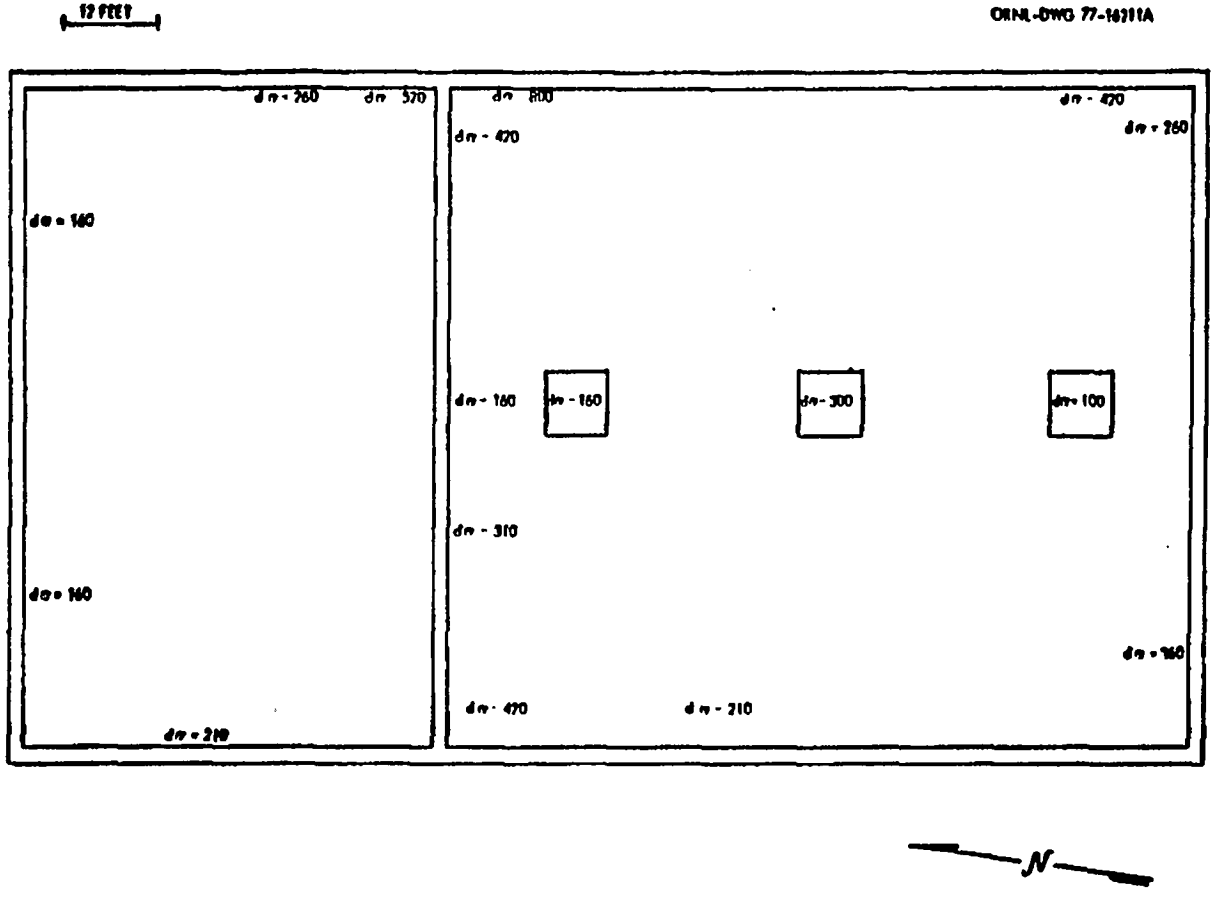
Building 704

This building was used for HF feed and recovery during uranium operations. It appears that the NRC guidelines for natural uranium are applicable.

On the floor and lower walls of Building 704, the only measurements which exceed the NRC guidelines are the beta-gamma dose rates in two separate areas in block B5, both 0.22 mrad/h (Fig. 25).

Direct alpha contamination levels and beta-gamma dose rates were measured at six randomly selected overhead locations above four survey blocks. Smear samples were taken at each location. Direct measurements made in a vent in the ceiling over block B3 indicated a beta-gamma dose rate of 0.09 mrad/h. All other measurements were at the background level.

Water samples DW1 and DW2 (Table 8) were taken from drains 1 and 2, respectively (Fig. 25). Concentrations of ^{238}U, ^{230}Th, ^{226}Ra, and ^{210}Pb in the water were below concentration guides for water (CG_w) stated in 10 CFR 20. However, concentrations of ^{230}Th, ^{226}Ra, and



BUILDING 700 ROOF

Fig. 24. Directly measured alpha contamination levels (dpm/100 cm^2) at randomly selected points on roof of Building 700.

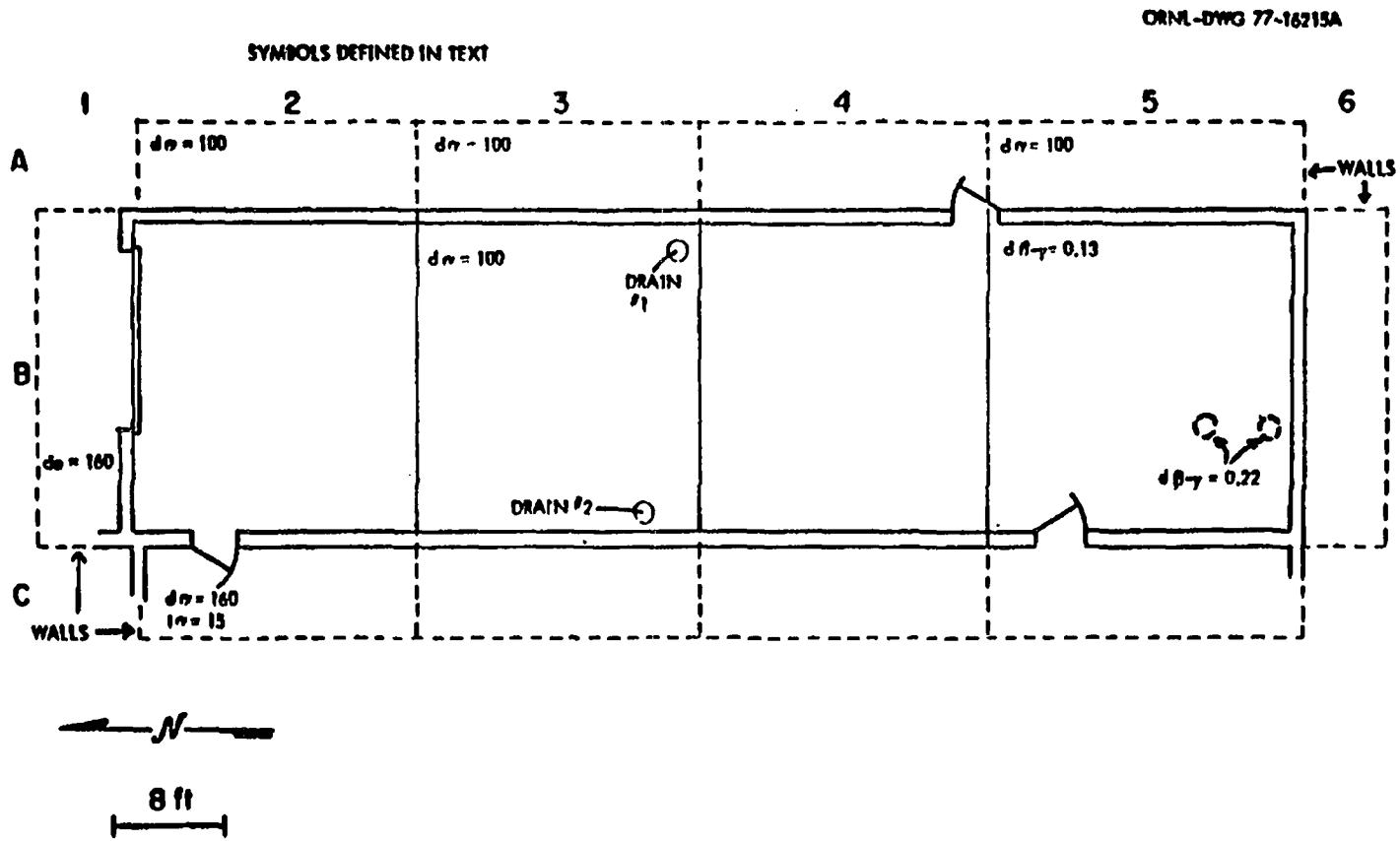


Fig. 25. Radiological measurements in survey blocks in Building 704 (measurements made in drains are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

^{210}Pb in sediment taken from the water sample from drain 2 were 12, 110, and 46 pCi/g, respectively, as compared with average background concentrations of near 1 pCi/g for these radionuclides.

Direct alpha and beta-gamma measurements were made on the roof of Building 704 as indicated in Fig. 26. All beta-gamma dose rates were at the background level. Alpha contamination levels on the roof ranged from 360 to 7,200 dpm/100 cm^2.

Building 705

This building was the main processing area during uranium operations. Manufacturing of UO_2 and UF_4 was carried out in various parts of the building. The NRC guidelines for natural uranium appear to be applicable. There are four main floors remaining in this building; results of the survey of each level will be presented separately.

First level. The highest beta-gamma dose rate measured on the first level of Building 705 was approximately 2.0 mrad/h at 1 cm from a surface (Fig. 27 and Table 17). Beta-gamma dose rates of this magnitude were observed at three points in three separate blocks: D3, F2, and D4. Several direct measurements of alpha contamination levels on the first level floor and walls were between 100 and 1,000 dpm/100 cm^2. None of the direct or transferable alpha measurements on the first floor exceeded the NRC guidelines for natural uranium. Approximately 35 overhead locations were selected at random for measurement of direct alpha contamination levels and beta-gamma dose rates. A beta-gamma dose rate of 1.3 mrad/h was measured at 1 cm from a small (~2-cm-diam) opening in the upper north wall above block B3. Five areas were found which indicated beta-gamma dose rates greater than 0.20 mrad/h. Alpha contamination levels on the overhead surfaces were in the range of 100 to 1,900 dpm/100 cm^2. The average direct alpha reading on overhead surfaces was 200 dpm/100 cm^2. Transferable alpha contamination levels in the range of 10 to 20 dpm/100 cm^2 were found at 13 of the overhead locations.

The first level of Building 705 has four drains (Fig. 27). The observed beta-gamma dose rates and alpha contamination levels above all

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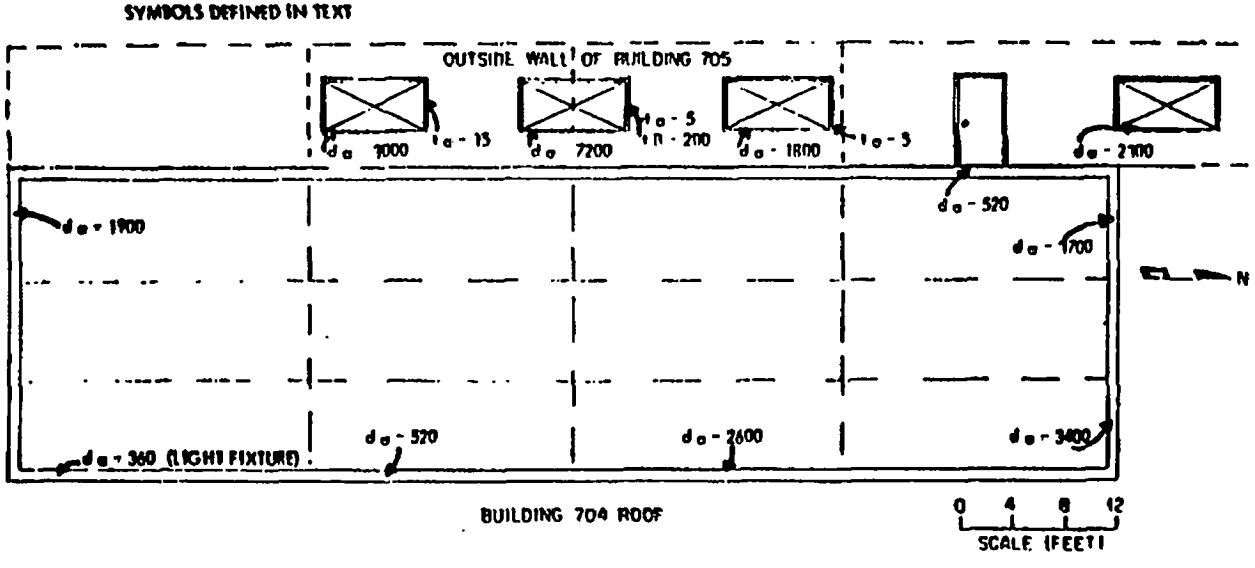


Fig. 26. Radiological measurements on roof of Building 704. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

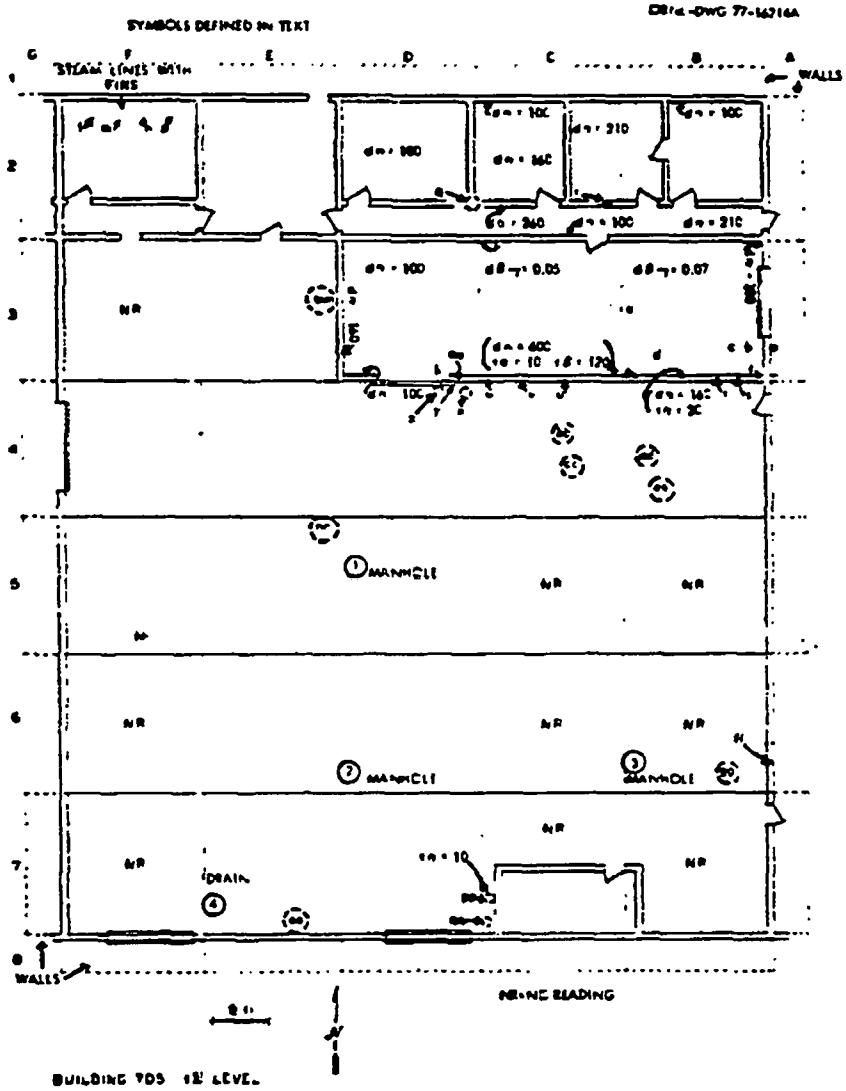


Fig. 27. Radiological measurements in survey blocks in Building 705, first level (measurements in areas indicated by lower-case letters are given in Table 17; measurements in drains and manholes are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Table 17. Directly measured alpha and beta-gamma contamination in areas showing highest contamination in Building 705, first level

Block shown in Fig. 27	Letter designating contaminated area	Directly measured alpha contamination level (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/h)
A3	a	1000	1.3
B3	b	<10	1.3
B3	c	<10	1.1
B3	d	50	0.3
B3	e	<10	0.4
B3 (wall)	f	600	1.1
B3 (wall)	g	50	0.7
C3	h	160	0.4
D3	k	520	2.0
F2	l	100	0.4
F2	m	100	0.7
F2	n	50	2.0
F2	p	NR[a]	0.4
D2	q	50	0.3
C2	r	210	0.2
B4 (wall)	s	260	0.2
B4 (wall)	t	310	0.3
C4 (wall)	u	NR	0.3
C4 (wall)	v	NR	0.7
C4 (wall)	w	360	1.3
D4	x	260	0.9
D4 (wall)	y	520	NR
D4	z	NR	2.0
D3 (wall)	aa	100	0.2
C4	bb	<10	0.1
C4	cc	50	0.1
B4	dd	160	0.3
B4	ee	50	0.2
B6 (floor ledge)	ff	210	0.2
B6	gg	50	0.3
F5	hh	<10	0.2
E3	mm	160	NR
E5	nn	100	0.2
E7	oo	260	NR
C7	pp	260	BG
C7	qq	<10	0.2

[a]NR = No reading.

of these drains were no greater than 0.04 mrad/h and 50 dpm/100 cm^2, respectively (Table 7). Analyses of ^{238}U, ^{226}Ra, ^{230}Th, and ^{210}Pb in water samples DW4 and DW5 (Table 8) taken from manholes 1 and 2 (Fig. 27) indicated concentrations of each radionuclide well below the CG_w stated in 10 CFR 20. Dirt samples taken from drain 4 and manhole 3 contained elevated concentrations of ^{238}U, ^{226}Ra, or ^{232}Th (Table 12).

Second level, north end. The floors in the southern two-thirds of the second, third, fourth, and fifth levels of Building 705 have been removed, leaving the building structural support beams and the outside walls as the only accessible areas for surface measurements. All measurements observed on the floor and lower walls of the north end are shown in Fig. 28. Beta-gamma dose rates at 15 locations measured 0.20 mrad/h or greater at 1 cm from surfaces. The maximum measured beta-gamma dose rate was 3 mrad/h from the surface of a window ledge on the east wall in block F3. Alpha contamination levels were in the range of 100 to 1600 dpm/100 cm^2.

Beta-gamma dose rates and alpha contamination levels were measured at eight randomly selected overhead locations on the second level. All beta-gamma dose rates on overhead surfaces were at the background level. At one point over block C3, the alpha contamination level by direct reading was 100 dpm/100 cm^2. Transferable alpha contamination levels did not exceed 10 dpm/100 cm^2.

Third level, north end. Beta-gamma dose rates measured 0.20 mrad/h at 1 cm from surfaces or greater at 11 locations; the highest beta-gamma dose rate was measured at 6.1 mrad/h at 1 cm from the surface on an outside window ledge in the (wall) survey block D1 (Fig. 29). Beta-gamma dose-rate measurements taken on an outside window ledge in the adjacent block (E1) indicated 1.1 mrad/h at 1 cm. Alpha contamination levels by direct reading were in the range of 100 to 6,400 dpm/100 cm^2. The highest alpha contamination levels were found on the window ledges, both inside and outside the building. Alpha contamination levels and beta-gamma dose rates were measured directly at five randomly selected overhead locations. All beta-gamma dose rates and transferable beta contamination levels were at the background level. Alpha contamination levels were as high as 1,700 dpm/100 cm^2. The average of all direct

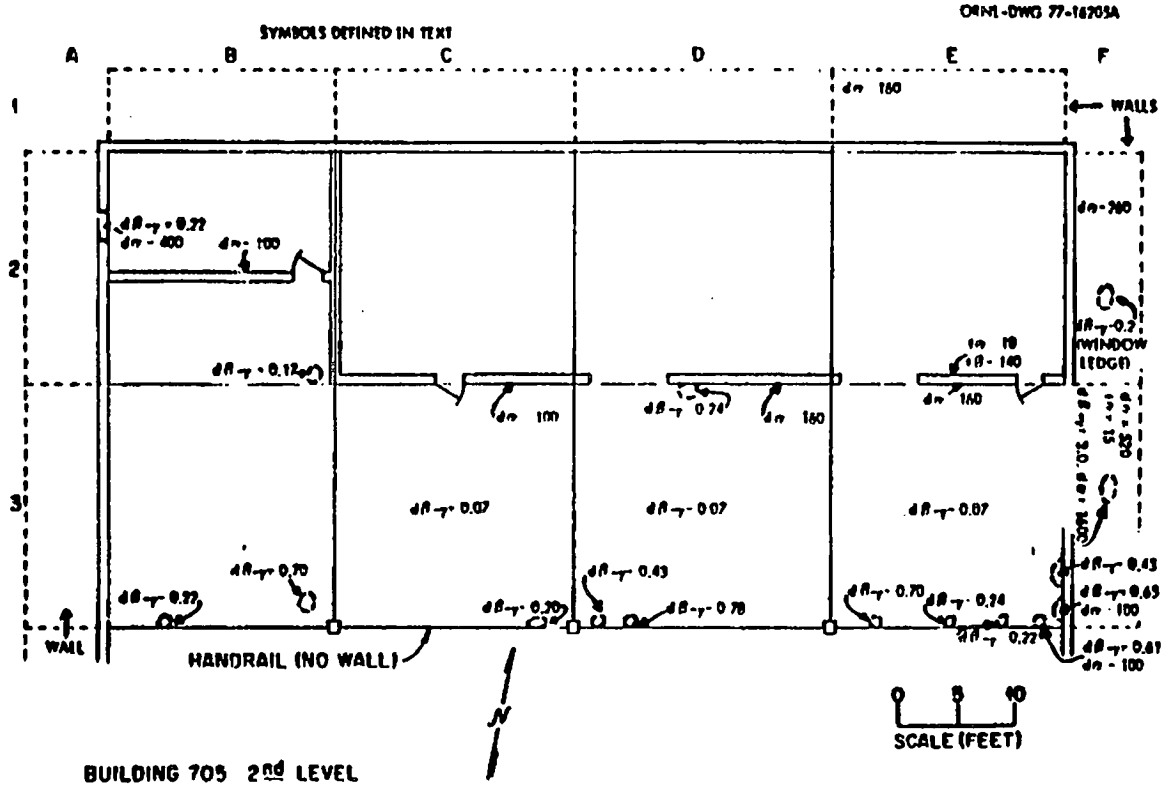


Fig. 28. Radiological measurements in survey blocks in the north end of the second level of Building 705. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

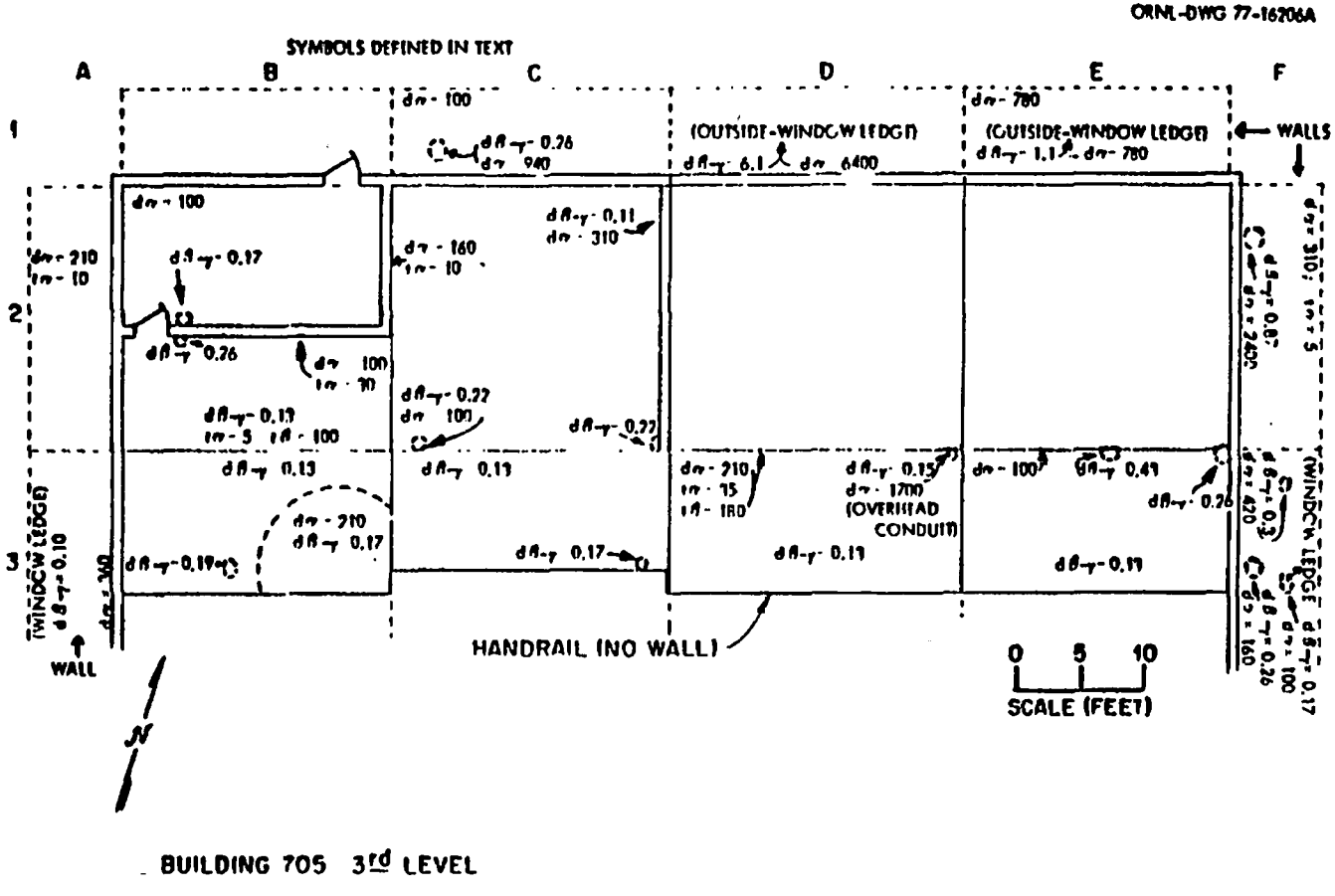


Fig. 29. Radiological measurements in survey blocks in the north end of the third level of Building 705. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

alpha measurements was 100 dpm/100 cm^2. Transferable alpha contamination levels were no higher than 10 dpm/100 cm^2 .

Fourth level. A beta-gamma dose rate of 0.70 mrad/h in block D3 was the only measurement to exceed the NRC guidelines (Fig. 30). Several alpha readings were in the range of 100 to 400 dpm/100 cm^2. The average of all direct alpha measurements was 200 dpm/100 cm^2.

Alpha contamination levels and beta-gamma dose rates were measured directly at eight randomly selected overhead locations. All beta-gamma dose rates were at the background level. Two direct alpha readings of 100 dpm/100 cm^2 each were recorded for vertical surfaces over blocks B2 and B3.

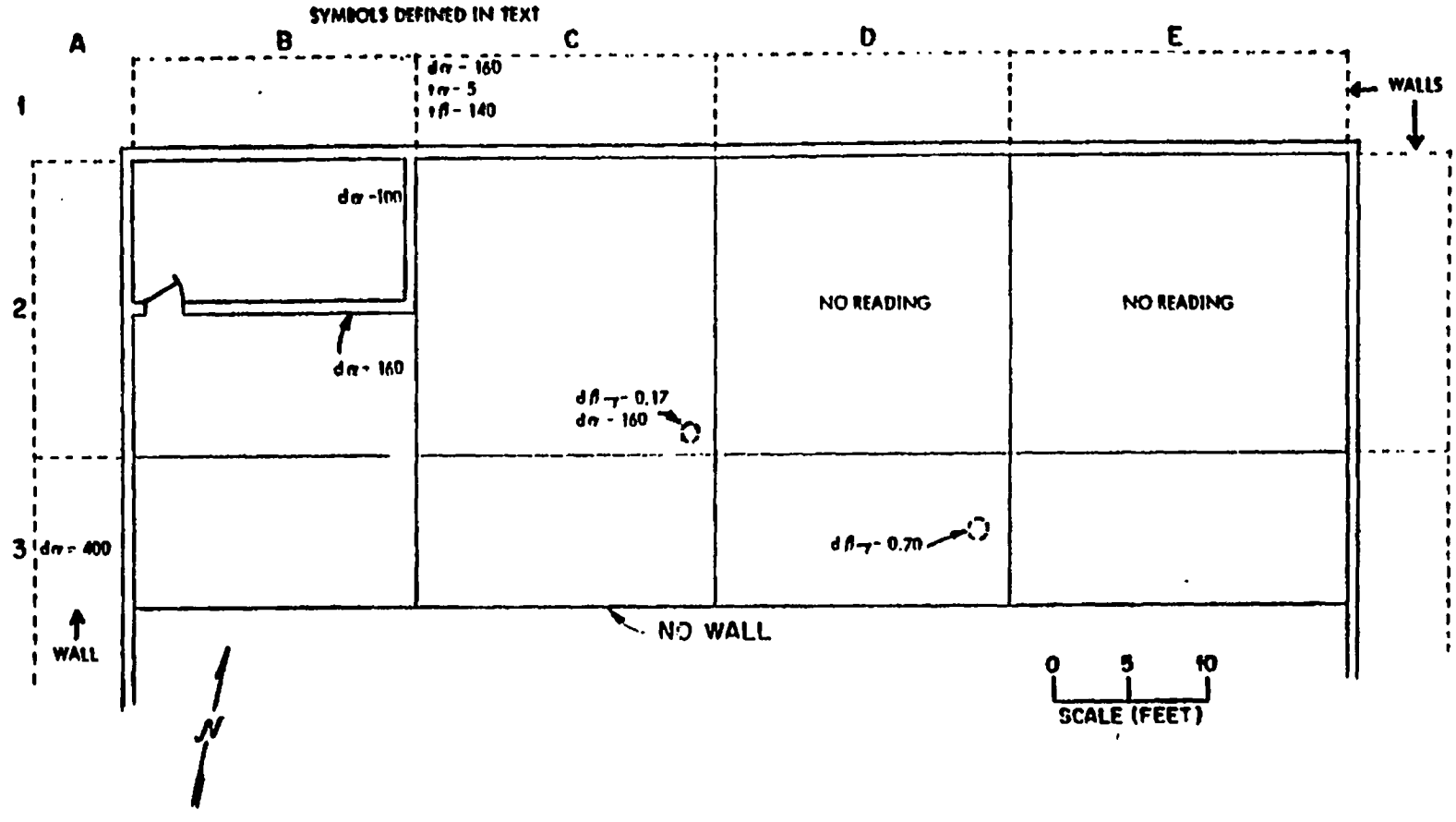
Overhead surfaces of open area in south end of Building 705. Considerable alpha and beta-gamma contamination was found on beams and walls in the large open area of Building 705 where previously existing floors have been removed. Results of the survey of this section are summarized in Table 18.

Roof. Direct alpha measurements on the roof surface indicate an average alpha contamination level of 600 dpm/100 cm^2 by direct reading. The maximum recorded alpha contamination level on the surface was 1,800 dpm/100 cm^2 (by direct reading); this was measured on the northeast end of the roof. Measurements made on the roof cap tiles on the east and south sides of the roof indicated fixed alpha contamination levels of 1,000 and 2,000 dpm/100 cm^2. Similar measurements made on the cap tiles on the west and north sides of the roof indicated fixed alpha contamination levels of 500 to 1,000 dpm/100 cm^2. All beta-gamma dose rates on the roof were at the background level.

Building 706

This building served as a warehouse for uranium materials during uranium operations. Hence, it appears that the NRC guidelines for natural uranium are applicable.

The only measurement in Building 706 which exceeded the NRC guidelines was the beta-gamma dose rate of 0.43 mrad/h measured along the base of the wall in block C6 (Fig. 31). Direct alpha contamination

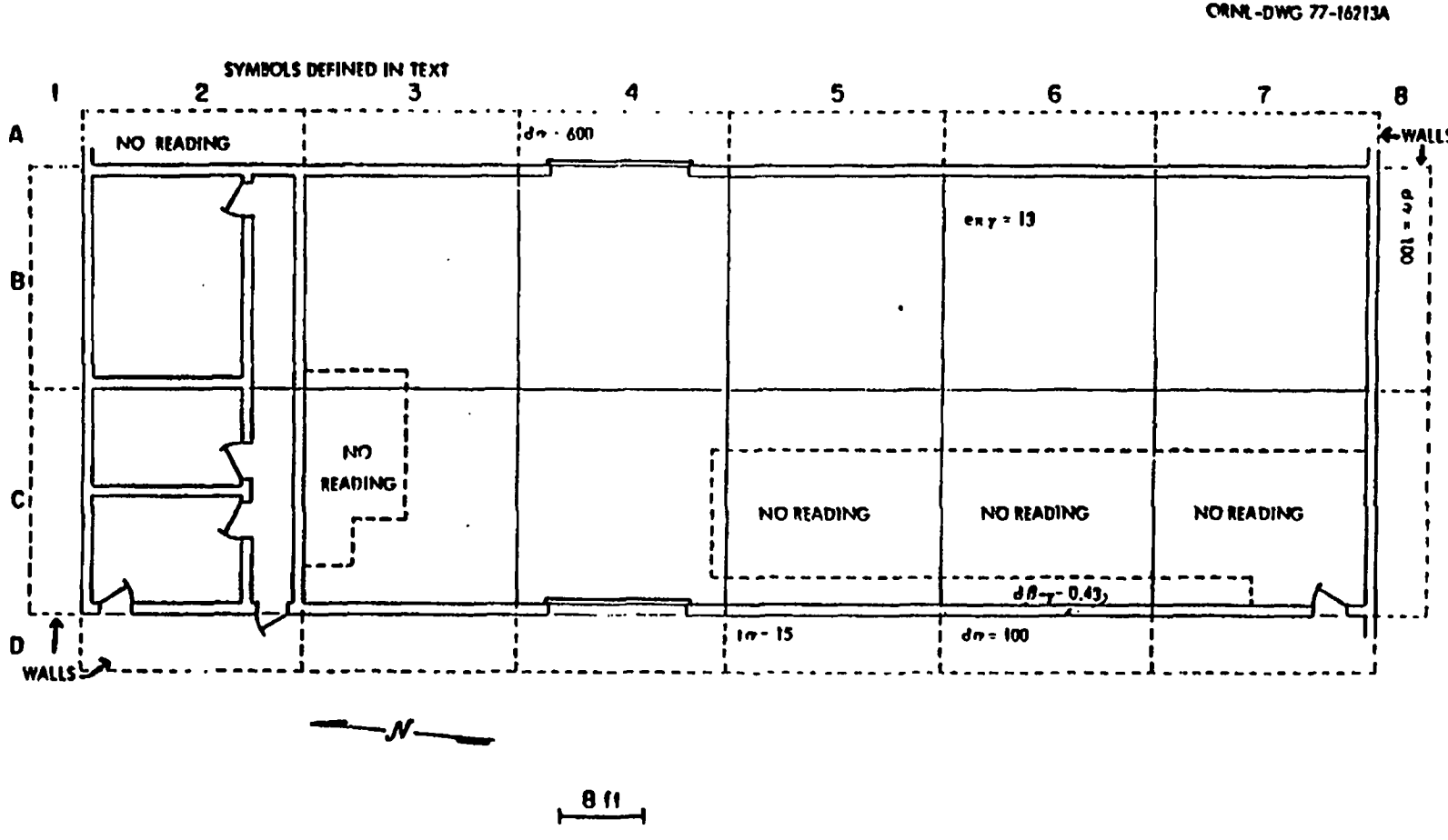


BUILDING 705 4th LEVEL

Fig. 30. Radiological measurements in survey blocks in the north end of the fourth level of Building 705. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Table 18. Alpha and beta-gamma contamination levels on overhead surfaces in open area at south end of Building 705

Level	Type of surface	Directly measured alpha contamination level (dpm/100 cm^2)		Beta-gamma dose rate at 1 cm (mrad/h)	
		Average	Maximum	Average	Maximum
Second	Walls and beams	1,200	12,000	0.16	1.7
Third	Walls and beams	310	3,400	0.08	0.9
Fourth	Walls and beams	1,200	20,000	0.18	1.5
Fifth	Walls and beams	340	4,400	0.07	0.6
Fifth	Ceiling	140	1,300	0.08	0.9



BUILDING 706

Fig. 31. Radiological measurements in survey blocks in Building 706. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

levels and beta-gamma dose rates were measured at 10 randomly selected overhead locations. The direct alpha readings at these points averaged 150 dpm/100 cm^2. All beta-gamma dose rates measured overhead were at the background level. Transferable alpha contamination levels varied from 5 to 20 dpm/100 cm^2.

Alpha contamination levels and beta-gamma dose rates were measured directly at 15 randomly selected points on the roof of Building 706 (Fig. 32). Smear samples were taken at each location. The maximum beta-gamma dose rate observed was 1.7 mrad/h and was found on a window ledge at the southeast corner of the roof. The highest alpha contamination level measured was 4,700 dpm/100 cm^2 and was located at the same point as the maximum beta-gamma dose rate. A smear sample was taken on the window ledge where the maximum alpha and beta-gamma readings were observed. Analysis of this sample indicated a transferable alpha contamination level of 35 dpm/100 cm^2. Other direct alpha readings ranged from 100 to 1,900 dpm/100 cm^2.

Building 707

This building was used as a process building for manufacturing H_2 and N_2 from NH_3 during uranium operations. The NRC guidelines for natural uranium appear to be applicable.

The only measurement made in Building 707 that exceeded NRC guidelines was a beta-gamma dose rate of 0.35 mrad/h measured on the floor in block B2 (Fig. 33). Beta-gamma dose rates and alpha contamination levels were measured directly at two overhead locations, over survey blocks B3 and B4. The only above-background measurement observed overhead was a beta-gamma dose rate of 0.07 mrad/h on a beam over block B3. Direct measurements were made on the roof of Building 707 for the determination of alpha contamination levels and beta-gamma dose rates (Fig. 33). Directly measured alpha contamination levels ranged from 100 to 1,700 dpm/100 cm^2. Beta-gamma dose rates were uniform at 0.10 mrad/h.

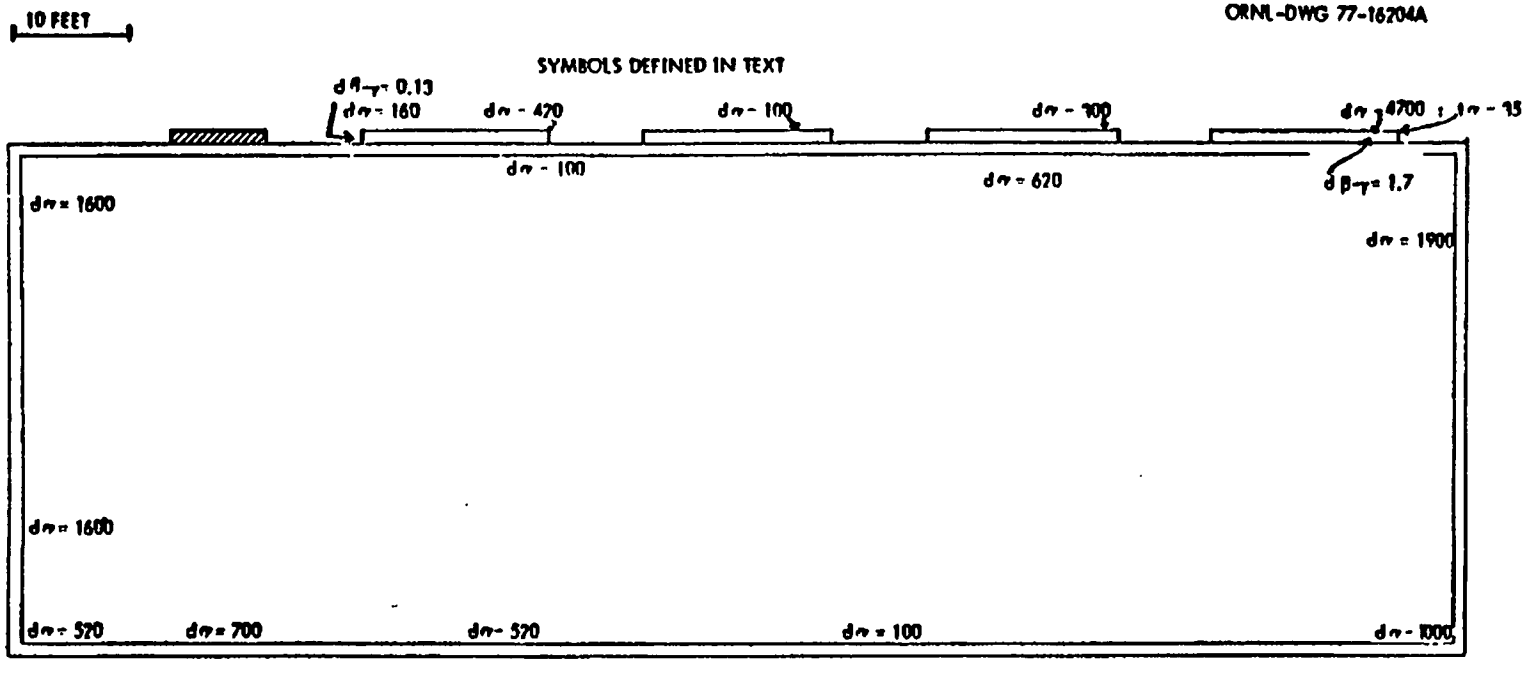
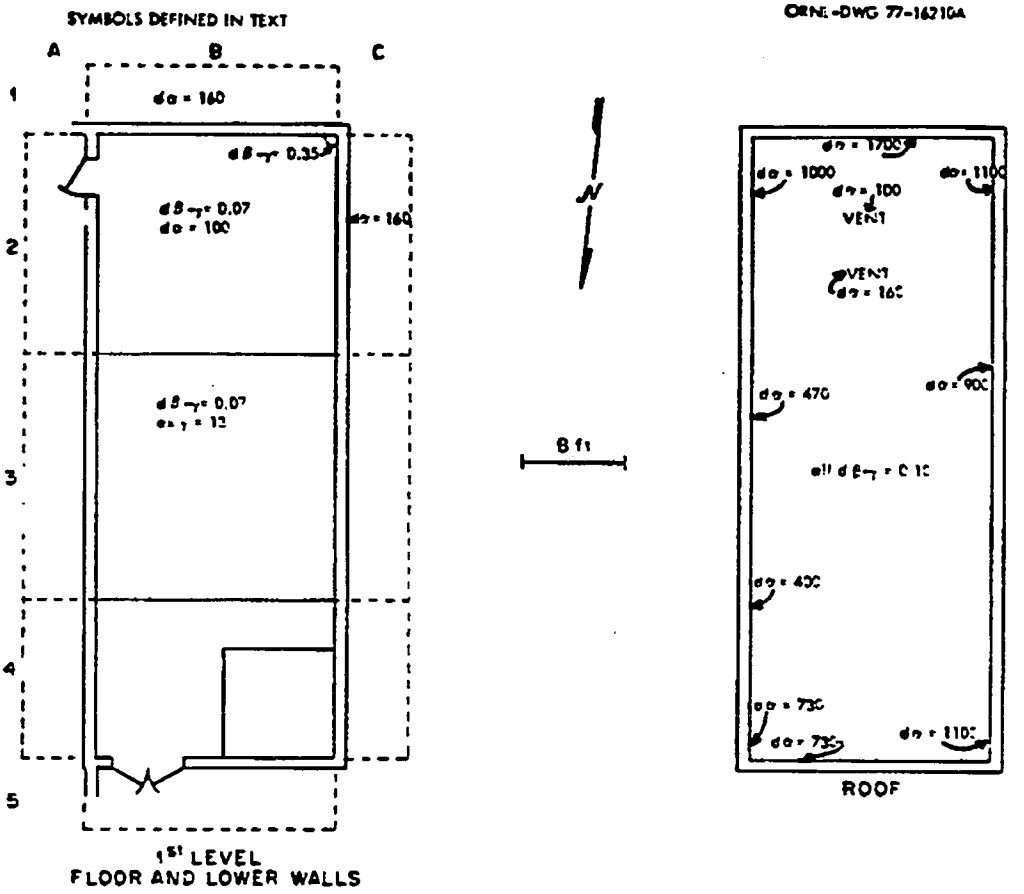


Fig. 32. Radiological measurements made at 15 randomly selected points on roof of Building 706. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)



BUILDING 707

Fig. 33. Radiological measurements in survey blocks on the floor and lower walls, and at randomly selected locations on the roof of Building 707. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Building 708

This building served as a storage and packaging facility for magnesium during uranium operations. There is no indication that radium-bearing materials were brought into the building; hence, it appears that the NRC guidelines for natural uranium are applicable.

None of the measurements made in Building 708 exceeded the NRC guidelines for natural uranium (Fig. 34). Direct alpha contamination levels and beta-gamma dose rates were measured at 10 randomly selected overhead locations over 10 blocks in Building 708. The only measurement which exceeded the background level was an alpha contamination of 100 dpm/100 cm^2 measured on a horizontal beam over block B2. Analysis of a sample of rust and dirt taken from this beam indicated 180 pCi/g of ^{238}U (RC1, Table 6). Beta-gamma dose rates on the roof of this building averaged 0.09 mrad/h on the gravel surface and were at the background level on the tile caps. Direct measurements of alpha contamination levels ranged from 500 to 1,500 dpm/100 cm^2 on the tile caps and from 100 to 160 dpm/100 cm^2 inside the vents on the roof.

Closed-in walkway between Buildings 116 and 705

Alpha contamination levels on the walls and floors of this walkway were in the range of 100 to 1,800 dpm/100 cm^2 by direct reading and averaged 350 dpm/100 cm^2 (Fig. 35). The only beta-gamma dose rate which exceeded the background level was measured in block B12 near the base of the wall; this reading was 0.13 mrad/h.

Radon and Radon Daughter Measurements in the Buildings

Radon measurements were taken in each building that had been surveyed, except for Buildings 38, 40, 100, 116B, and the shed attached to 116B. In Building 81, radon measurements were the only measurements made. Radon daughter measurements were made in each building except 38, 40, 51A, 100, and 116B.

Radon and radon daughter measurements made over a brief period of time often do not reflect average annual conditions. Furthermore,

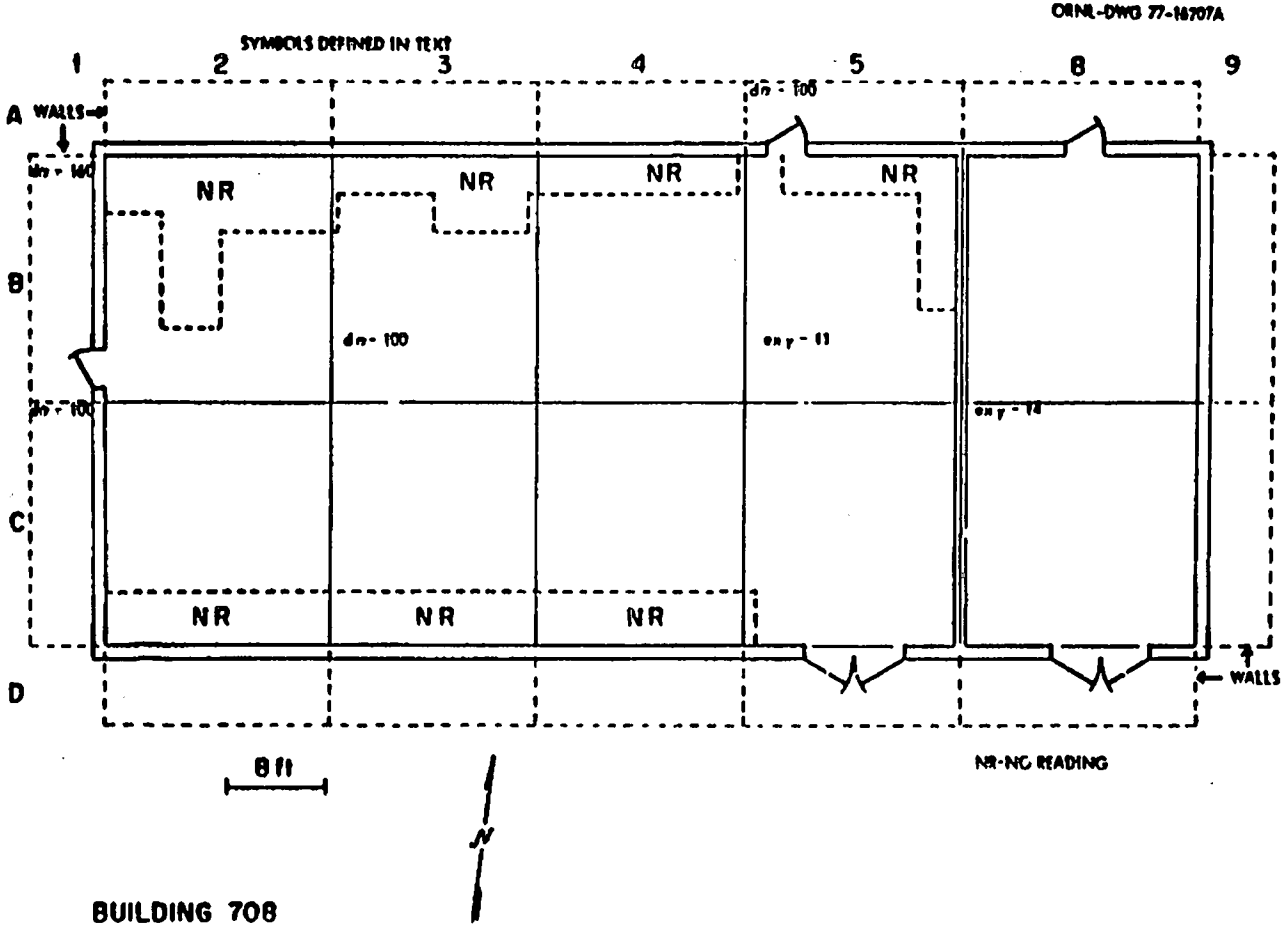


Fig. 34. Radiological measurements in survey blocks in Building 708. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

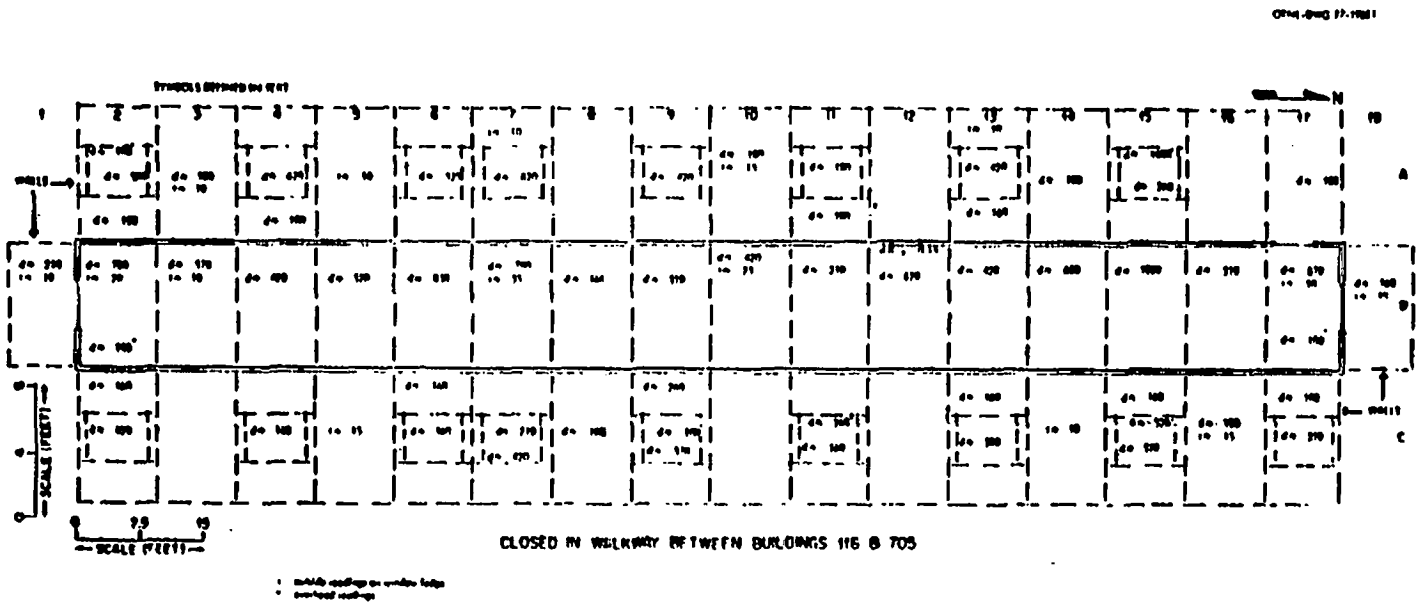


Fig. 35. Radiological measurements in survey blocks in the closed-in elevated walkway between Buildings 116 and 705. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

radon and radon daughter concentrations in a building are affected drastically by changes in its ventilation rate, and by the wide variety of mechanical and human activities within the building.

The maximum and average ^{222}Rn concentrations in each of the buildings where measurements were made are listed in Table 19. Average measured concentrations of ^{222}Rn in Buildings K1E, 101, and 52A exceeded the nonoccupational concentration guide (CG_a) of 3 pCi/l stated in 10 CFR 20. Radon measurements in K1E averaged 6.4 pCi/l and were as high as 22 pCi/l. These elevated radon levels were not surprising in that pitchblende ore had been brought into the building at one time. The elevated radon concentrations in Building 52A (up to 37 pCi/l) are more surprising, since records did not indicate that ^{226}Ra-bearing materials had been handled in this building. Soil samples taken from a core hole (discussed in a later section) drilled through the floor of Building 52A showed a ^{226}Ra concentration of 28 pCi/g from the surface to a depth of 1 ft. Radon measurements in Building 101 averaged 6.6 pCi/l and were as high as 69 pCi/l. This relatively new building is built on the site of several demolished buildings where pitchblende ore was processed. Two core holes were drilled through the floor of Building 101 at randomly chosen locations; the maximum ^{226}Ra concentration in samples taken from these core holes was 7.0 pCi/g.

The maximum measured radon daughter concentration was 0.07 WL; this concentration was measured in Building 52A at 2:05 PM. Radon daughter concentrations measured in the buildings are listed in Table 20.

Beta-Gamma, External Gamma, and Alpha Measurements Outdoors

Area around Buildings 81 and 82

The area around Buildings 81 and 82 was marked off into 30-ft^2 survey blocks. Beta-gamma dose rates at 1 cm from the surface and external gamma-ray measurements at 1 m above the surface are shown in Fig. 36. Measurements made in two areas of 1 m^2 or greater behind Building 82 indicated beta-gamma dose rates of 0.52 and 0.87 mrad/h, respectively. These were the only measurements which exceeded the NRC guidelines in this area.

Table 19 ^{222}Rn concentrations in air in buildings

Building	Location	Figure	Counting interval (h)	No. of measurements	Average ^{222}Rn concentration (pCi/l)	Maximum ^{222}Rn concentration (pCi/l)	Time at which maximum ^{222}Rn concentration was measured
RIE	Block B7	3	16	29	8.8	10.8	1:03 AM
	Block C7		16	29	4.6	5.4	9:45 PM
	Block C6		24	44	3.2	6.0	9:17 AM
	Block C7		24	44	3.6	7.6	9:17 AM
	Block B7		45.6	81	15.2	22	7:00 PM
	Block C7		45.6	81	2.1	4.2	4:21 AM
25, level 1	Block B9	4	22	41	0.5	0.9	10:19 AM
	Block B1		22	41	0.6	1.0	3:43 AM
25, level 2	Secretary's office	5	22	40	0.6	1.3	6:39 AM
	Block C5		22	40	0.6	1.0	7:12 AM
50	Block B9	8	21.5	16	0.6	1.5	4:45 AM
	Block B5		21.5	16	0.5	0.7	8:00 AM
51	Block B7	9	20	42	0.4	0.7	4:30 PM
	Block B4		20	40	0.4	0.6	2:15 PM
51A	Block B5	11	20	17	0.4	0.5	6:37 PM
	Block C2		20	17	0.6	2.0	6:04 PM
52	Block B3	12	21	19	0.7	1.1	2:40 PM
	Block B4		21	19	0.5	0.7	12:27 PM
52A	Southwest corner	11	18	13	9.6	23	11:15 PM
	Northeast corner		18	13	15	37	11:15 PM
81	Southwest corner	36	21	41	0.6	1.1	4:38 PM
	South and center of bldg. just inside door		21	43	0.6	0.9	4:05 PM
101	Block C3	14	26	45	17	69	1:30 AM
	Block C5		26	45	1.3	3.6	2:44 AM
	Block I4		64	101	7.6	53	8:30 PM
	Block I6		64	101	5.6	28	8:00 PM
116, level 1	Block C7	15	11	21	0.5	0.7	12:42 PM
	Block C3		11	21	0.5	0.8	12:42 PM
117, level 1	Block D3	21	14.5	24	0.9	1.6	1:15 PM
	Block H7		14.5	24	0.7	1.1	12:42 PM
700	Block C9	23	19	18	0.6	0.9	10:35 PM; 6:00 AM, and 7:00 AM
	Block D2		19	36	0.6	0.9	8:00 AM
704	Block A4	25	37.5	68	0.5	0.9	2:43 AM
705	Block C2	27	17.5	28	0.5	0.9	2:10 AM
	Block D5		22.5	18	0.4	0.5	2:18 AM
	Block H5		22.5	42	0.5	0.7	6:36 AM
706	Block H6	31	21.5	40	0.5	0.7	11:30 PM
707	Block H6	11	21.5	40	0.5	0.7	8:12 PM
708	Block C2	14	20.5	41	1.0	1.2	8:30 PM
	Block H8		20.5	40	0.6	1.0	1:30 AM

Table 20. ^{222}Rn daughter concentrations in air in buildings

Building	Location	Figure	Radon daughter concentration (WL)	Time
K1E	Block C4	3	0.02	10:00 AM
	Block C7		0.003	10:45 AM
	Block B7		0.009	11:30 AM
25, level 1	Block D9	4	0.001	2:00 PM
25, level 2	Block C4	5	0.0009	2:30 PM
50	Block D7	8	0.0003	2:00 PM
51	Block D9	9	0.0005	1:00 PM
52	Block B4	12	0.0007	10:15 AM
	Block D2		0.001	11:10 AM
52A	Block D2	11	0.07	2:05 PM
81	Southeast end, just inside door	36	0.001	12:00 PM
	Northeast end, just inside door		0.001	2:15 PM
100	Block C4	13	0.0008	1:15 PM
101	Block F6	14	0.02	12:45 PM
	Block F6		0.01	8:30 AM
	Block F2		0.001	1:45 PM
	Block A1		0.0008	2:20 PM
	Block A6		0.002	2:55 PM
	Block C3		0.0007	3:30 PM
	Block C3		0.0008	2:30 PM
	Block C3		0.003	8:00 AM
116	Block C3	15	0.0008	3:50 PM
	Block F4		0.0003	1:40 PM
116, level 2	Block D14	17	0.0005	2:20 PM
116B	Block B3	19	0.001	10:30 AM
117, level 1	Block H3	21	0.0004	3:00 PM
	Block B3		0.0007	4:00 PM
700	Block C3	23	0.004	8:30 AM
	Block C9		0.003	9:00 AM
700	Block D10	23	0.002	11:00 AM
704	Block B3	25	0.002	9:35 AM
705	Block C3	27	0.0008	1:15 PM
	Block E5		0.0008	2:00 PM
706	Block B4	31	0.0009	2:45 PM
707	Block B4	33	0.0005	3:20 PM
708	Block B8	34	0.0007	2:30 PM
	Block B3		0.0009	3:15 PM

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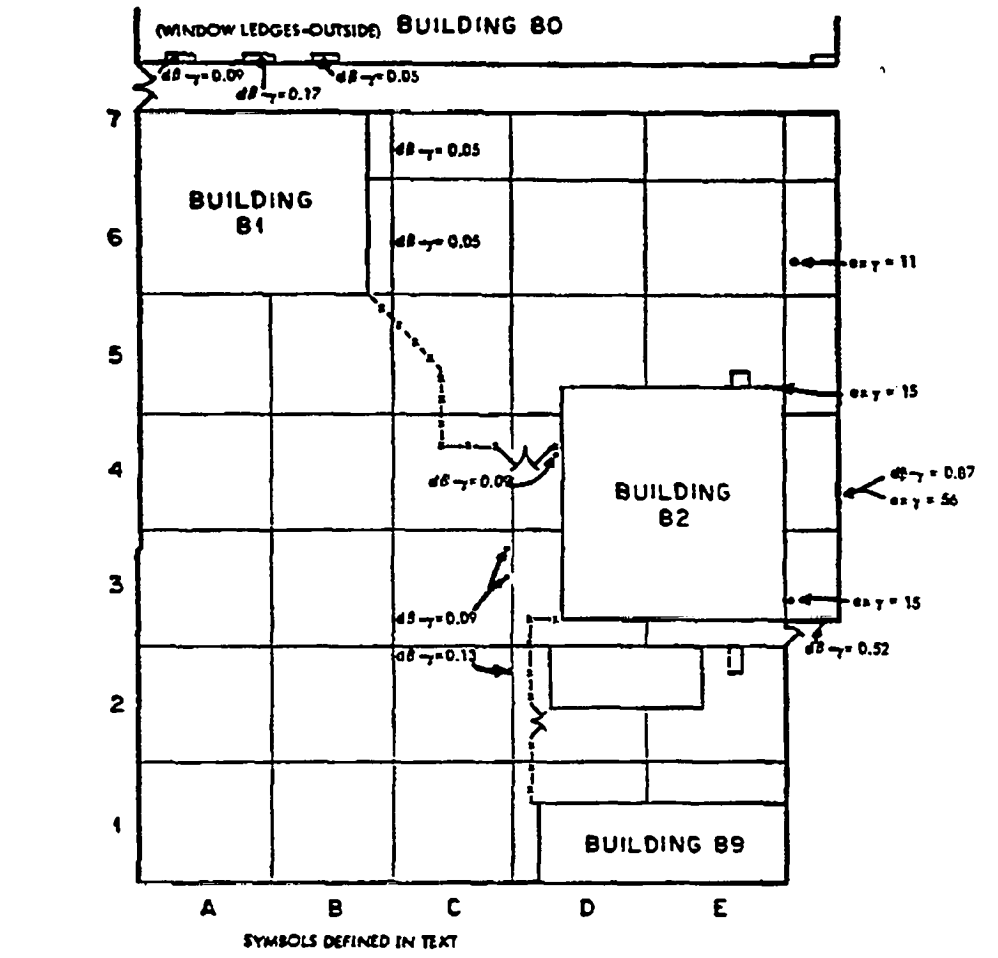

PLANT NO.10 PARKING LOT AND AREA SURVEY

Fig. 36. Radiological measurements in survey blocks around Buildings 81 and 82. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

Area around Buildings 50, 51, 51A, 52, and 52A

This area was divided into survey blocks by the 50-ft grid shown in Fig. 37. The only measurements which exceeded background were those on the outside walls of buildings as indicated. It appears from soil sample analysis that the NRC guidelines for alpha contamination applicable to this area are those for uranium. The maximum directly measured alpha contamination level was 1,600 dpm/100 cm^2, well below the NRC guideline for uranium. However, beta-gamma dose rates exceeded the NRC guidelines over much of the exterior wall surfaces of Buildings 51, 51A, 52, and 52A. The maximum beta-gamma dose rate measured at a distance of 1 cm from the surface was 3.5 mrad/h; measurements of this magnitude were observed in five separate areas along these walls.

Area around Buildings 100, 101, 116, 116B, and 117

The 50-ft grid system used to divide this area into survey blocks is shown in Fig. 38. In several of the survey blocks in this area, beta-gamma dose rates exceeding the NRC guidelines were measured. The maximum observed beta-gamma dose rate (4.4 mrad/h at 1 cm from the surface) was observed in survey block L3, where an external gamma-ray exposure rate of 290 μR/h at 1 m was recorded.

Area around Buildings 700, 704, 705, 706, 707, and 708

The 50-ft grid system used to divide this area into survey blocks is shown in Fig. 39. Maximum observed beta-gamma dose rates in the survey blocks are recorded in this figure, and all measurements of external gamma radiation levels at 1 m are recorded in Fig. 40. The maximum measured beta-gamma dose rate (1.5 mrad/h at 1 cm from the surface) was measured in block G5. Several other beta-gamma dose rates measured in this area exceeded the NRC guidelines.

Measurements of the beta-gamma dose rate and the external gamma radiation levels were made at randomly selected locations generally to the south of the buildings. The results of these measurements are shown in Figs. 41 and 42, respectively. Elevated external gamma radiation levels and surface beta-gamma dose rates were measured at several locations in this area.

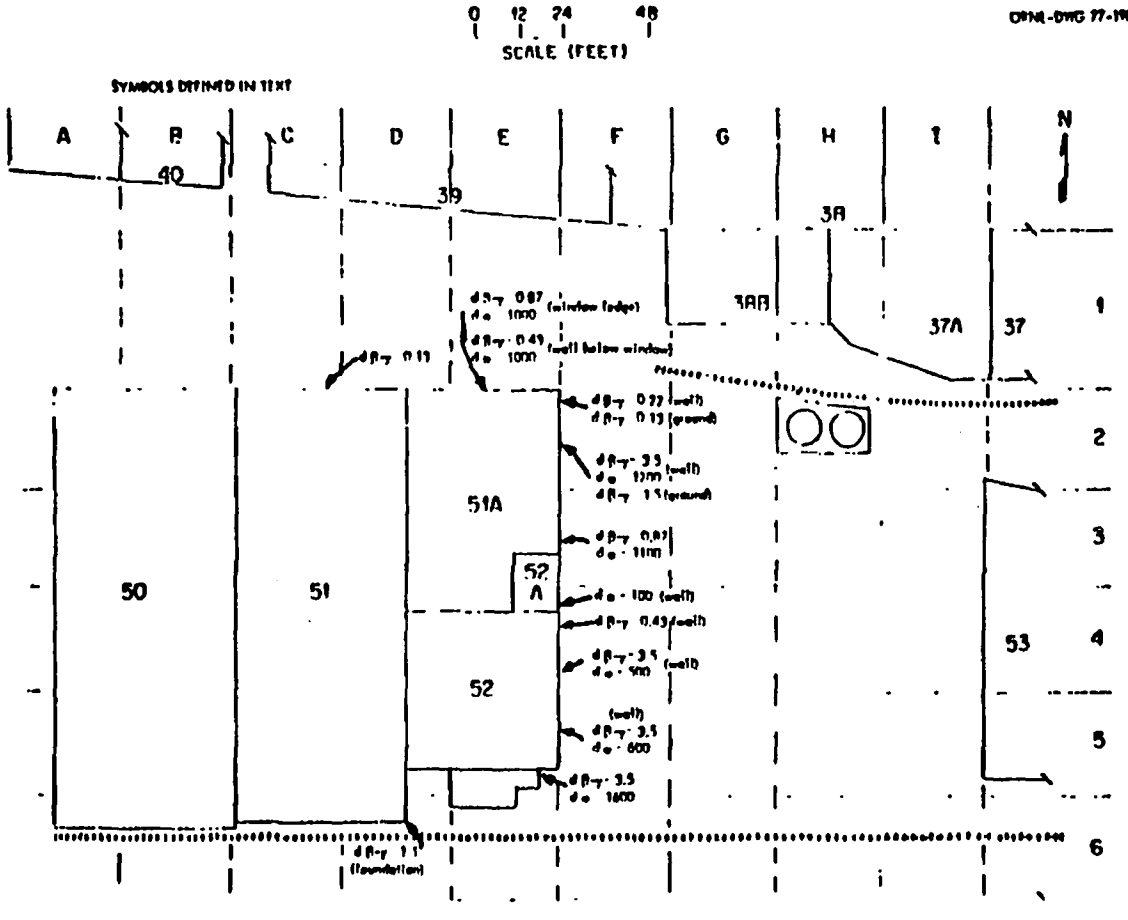

Fig. 37. Radiological measurements in survey blocks near Buildings 50, 51, 51A, 52, and 52A. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

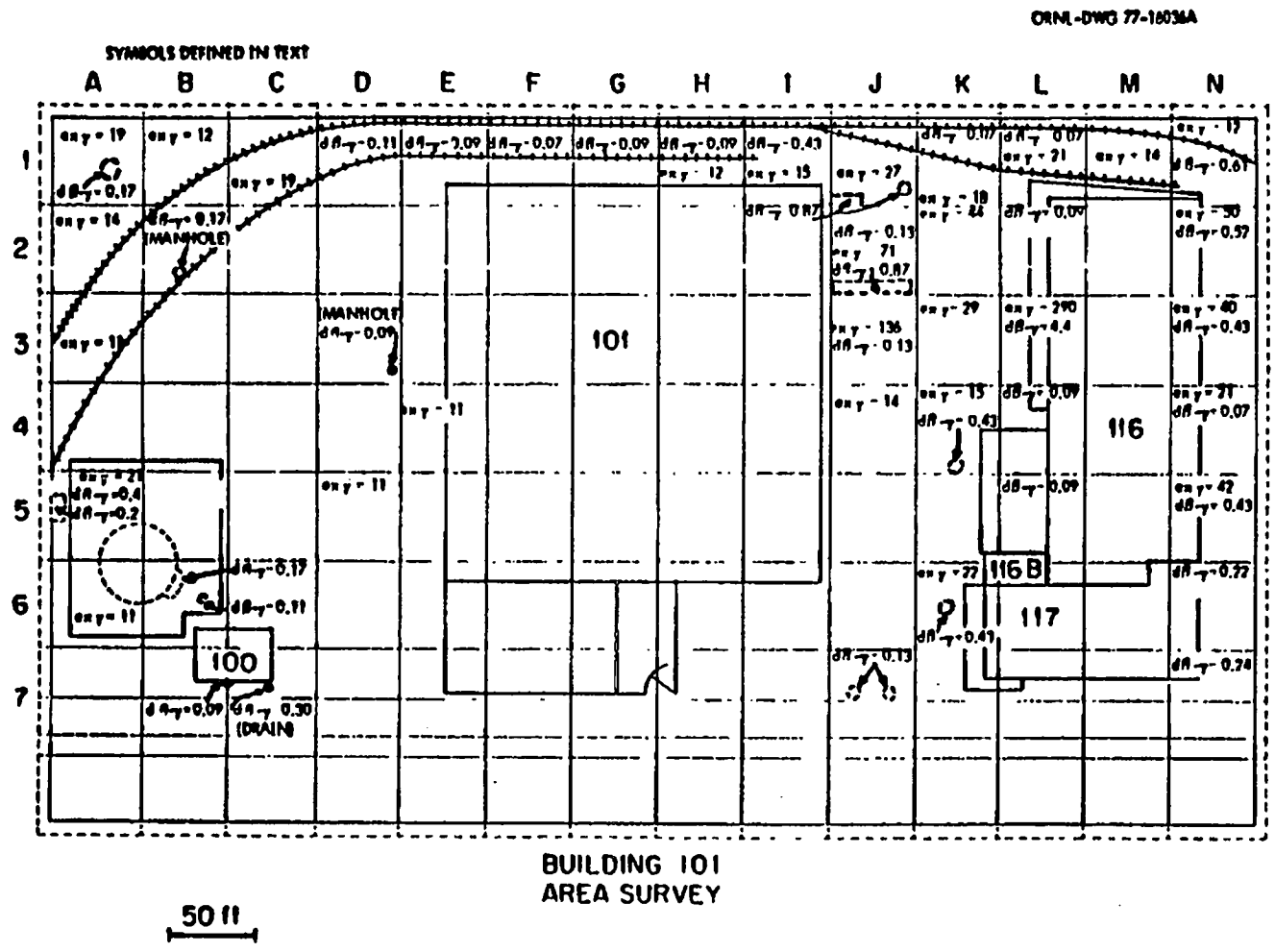

Fig. 38. Radiological measurements in survey blocks in area around Building 101. (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

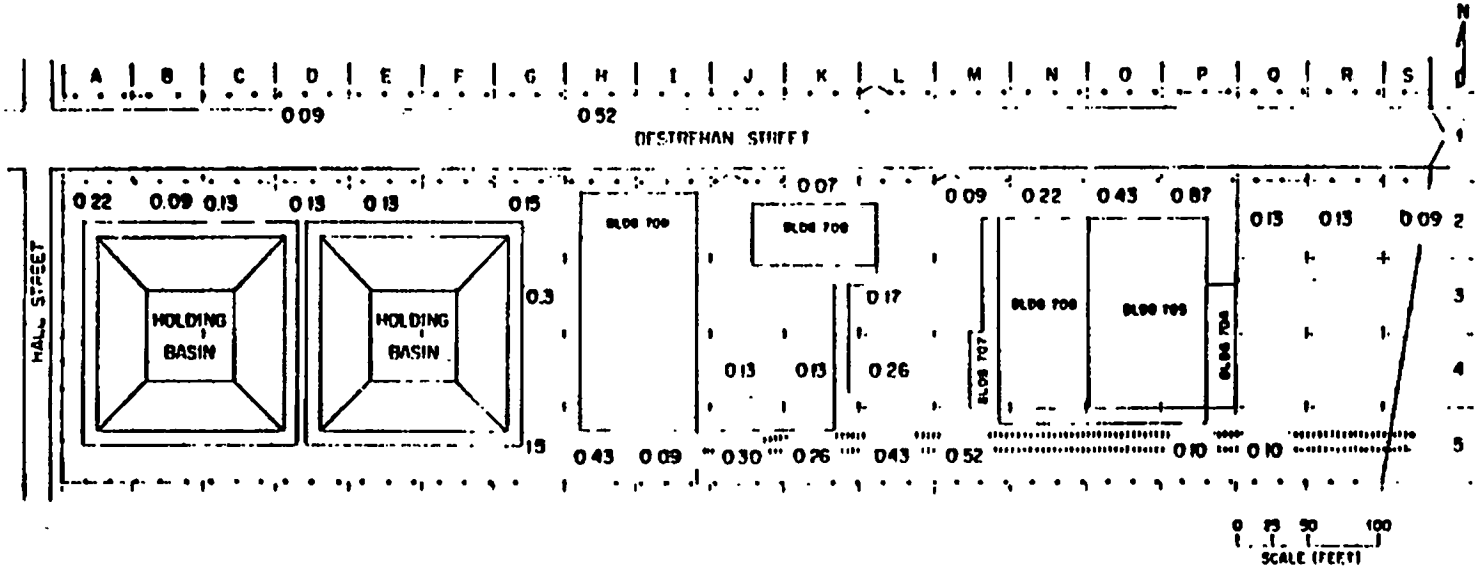

Fig. 39. Maximum observed beta-gamma dose rates (mrad/h) in survey blocks in area around Buildings 700, 704, 705, 706, 707, and 708. (The absence of numbers in survey blocks indicates that background levels were observed within that block.)

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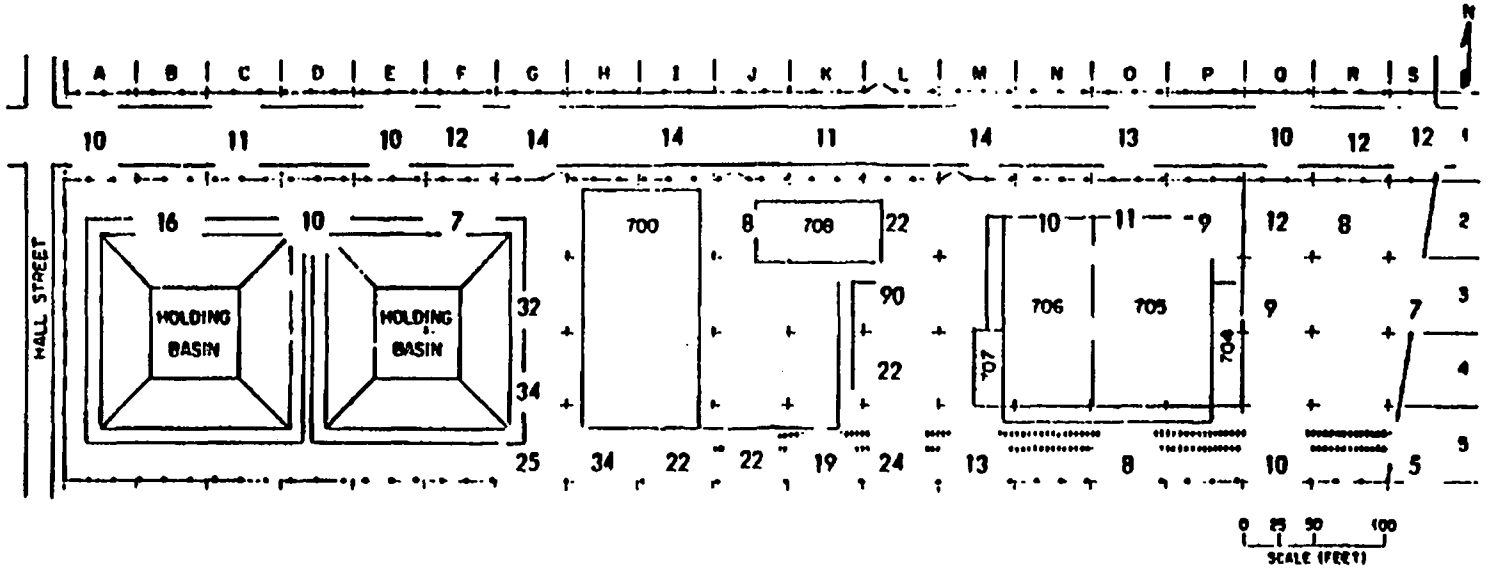

Fig. 40. External gamma radiation levels (μR/h) at 1 m above surface in survey blocks around Buildings 700, 704, 705, 706, 707, and 708.

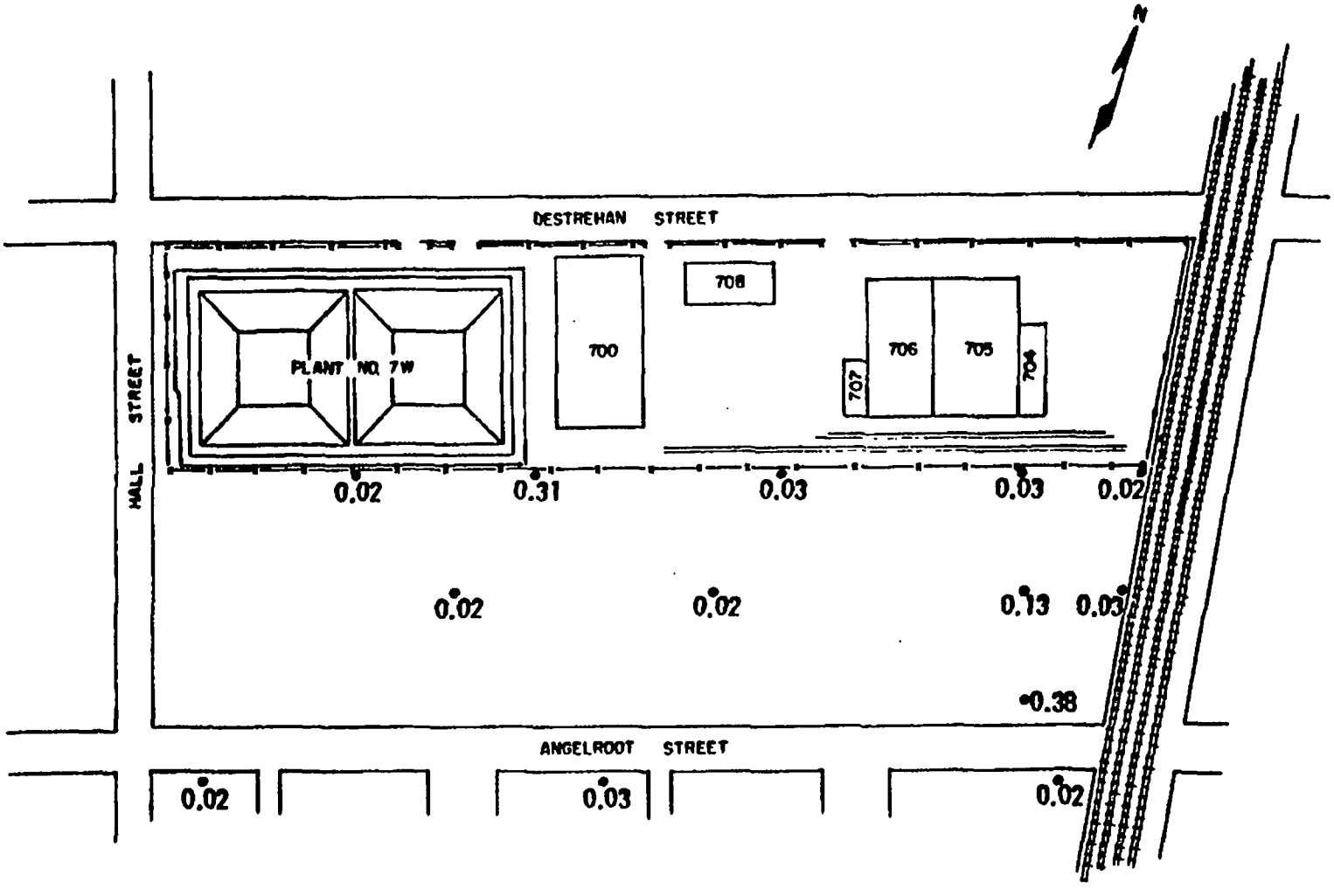

Fig. 41. Beta-gamma dose rates (mrad/h) at 1 cm from the surface in randomly selected locations south of Buildings 700, 704, 705, 706, 707, and 708.

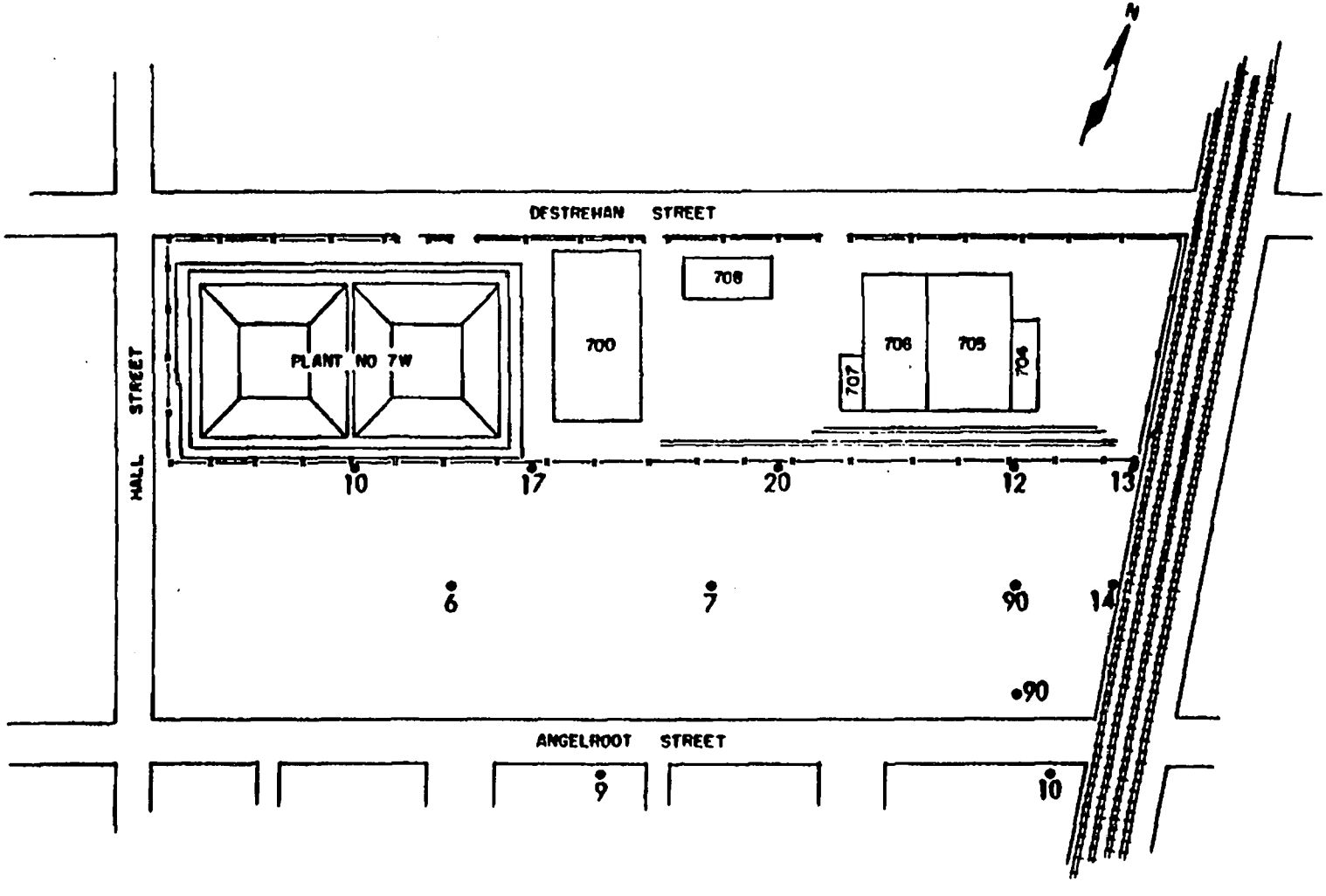

Fig. 42. External gamma radiation levels (μR/h) at 1 m above the surface in randomly selected locations south of Buildings 700, 704, 705, 706, 707, and 708.

Concrete surfaces around buildings

Concrete surfaces around Buildings 117, 705, 706, and 708 were divided into survey blocks and measured directly for external gamma radiation levels, alpha contamination levels, and beta-gamma dose rates. The results of these measurements are shown in Table 21. The maximum beta-gamma dose rate at 1 cm from the surface was 1.3 mrad/h and was measured on a concrete slab at the east end of Building 705. The maximum alpha contamination level was 1,100 dpm/100 cm^2 and was measured on the south dock of Building 708. The maximum external gamma radiation level was 22 μR/h at 1 m from the surface and was also measured on the south dock of Building 708.

Alleyway between Buildings 25 and K1E

As indicated by Fig. 43, the highest beta-gamma dose rates (up to 5 mrad/h at 1 cm from the surface) were measured on the pavement at the base of the outside wall of Building 25. The guidelines for radium should probably be applied here since pitchblende ore was handled in this area. The representative direct alpha measurements indicate that alpha contamination levels over a large fraction of the surface in this area exceeded the NRC guidelines for radium of 100 dpm/100 cm^2 (average).

Ionium pad south of Building 708

A concrete pad lying south of Building 708 was used for storage of ^{230}Th during a brief period when ^{230}Th was being extracted from pitchblende raffinates. Consequently, NRC guidelines for ^{230}Th surface contamination (the same as radium guidelines) should be applied. This pad, commonly referred to as the ionium pad, was divided into survey blocks as shown in Fig. 44. Radiological measurements are recorded in this figure. Beta-gamma dose rates of approximately 0.25 mrad/h were measured at 1 cm above the surface of three drains in blocks C4, D4, and D8. External gamma radiation levels at 1 m above the surface ranging from 22 to 33 μR/h were measured in blocks D17, C17, D18, and C18. Direct reading alpha contamination levels were generally in the range

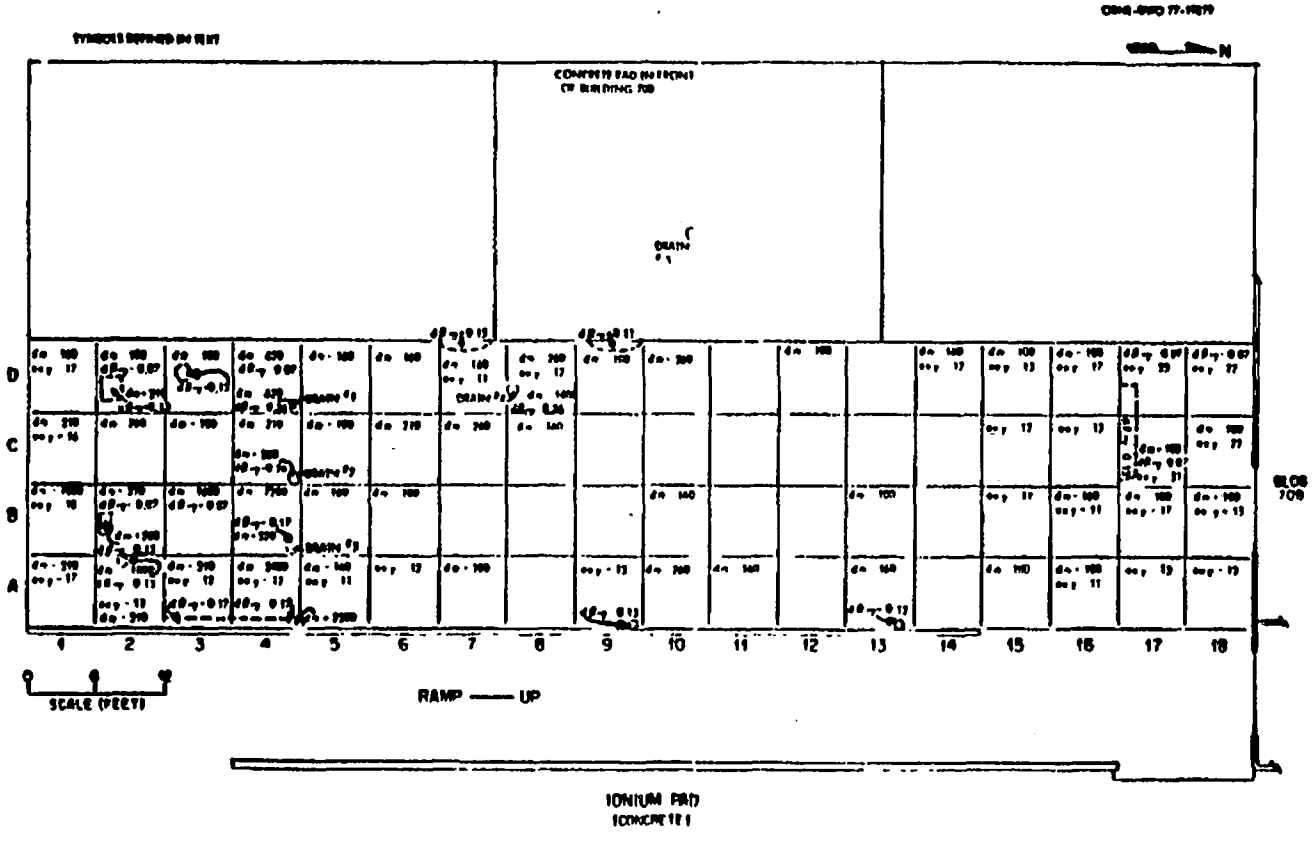

Fig. 44. Radiological measurements in survey blocks on ionium pad south of Building 708 (measurements made in drains are given in Table 7). (See "Interpretation of Data" section on page 19 of text for explanation of symbols. The absence of numbers in survey blocks indicates that background levels were observed within that block.)

of 100 to 7,200 dpm/100 cm^2. Alpha contamination levels measured at 1 cm above drains in blocks B4, C4, D4, and D8 ranged from 360 to 1,400 dpm/100 cm^2. Many of the drains on the ionium pad were plugged, making them inaccessible for sampling.

Dirt samples (SP4, SP5) taken from the pad in survey blocks A4 and D8 (Fig. 44) showed ^{238}U concentrations of 85 and 170 pCi/g, respectively; these samples contained ^{226}Ra concentrations of 67 and 160 pCi/g, respectively (Table 6).

Analysis of Surface Soil Samples

Surface soil samples were taken at the locations S1 through S44 shown in Figs. 45 through 48. Concentrations of ^{238}U, ^{226}Ra, ^{227}Ac, and ^{232}Th in these samples are listed in Table 22. Although some of these surface samples were taken at randomly chosen locations, most were taken in areas where the highest beta-gamma dose rates were found. The maximum ^{226}Ra concentration observed in these samples was 1,900 pCi/g, in sample S4, collected near Building B2 between the old railroad tracks and the loading dock (Fig. 45); this sample also contained a ^{238}U concentration of 36 pCi/g. Analyses of two other samples (S24, S28) indicated ^{226}Ra concentrations exceeding 100 pCi/g (Fig. 48 and Table 22). The maximum ^{238}U concentration measured in surface samples was 150 pCi/g and was measured in samples S10 and S26; both samples were collected near the railroad tracks south of Building 705 (Figs. 46 and 48).

The ionium pad had previously been used for storage of a compound containing ^{230}Th. An attempt has been made to characterize the extent to which this contamination may have been spread to surrounding areas. Surface soil samples S12, S13, and S14 from near the ionium pad were analyzed for ^{230}Th and indicated elevated levels of 10, 370, and 160 pCi/g, respectively. Analysis of two samples of dirt taken directly from the pad surface (SP4, SP5) indicated ^{230}Th concentrations of 210 and 570 pCi/g, respectively. These results indicate that former usage of the pad has caused localized soil contamination by ^{230}Th.

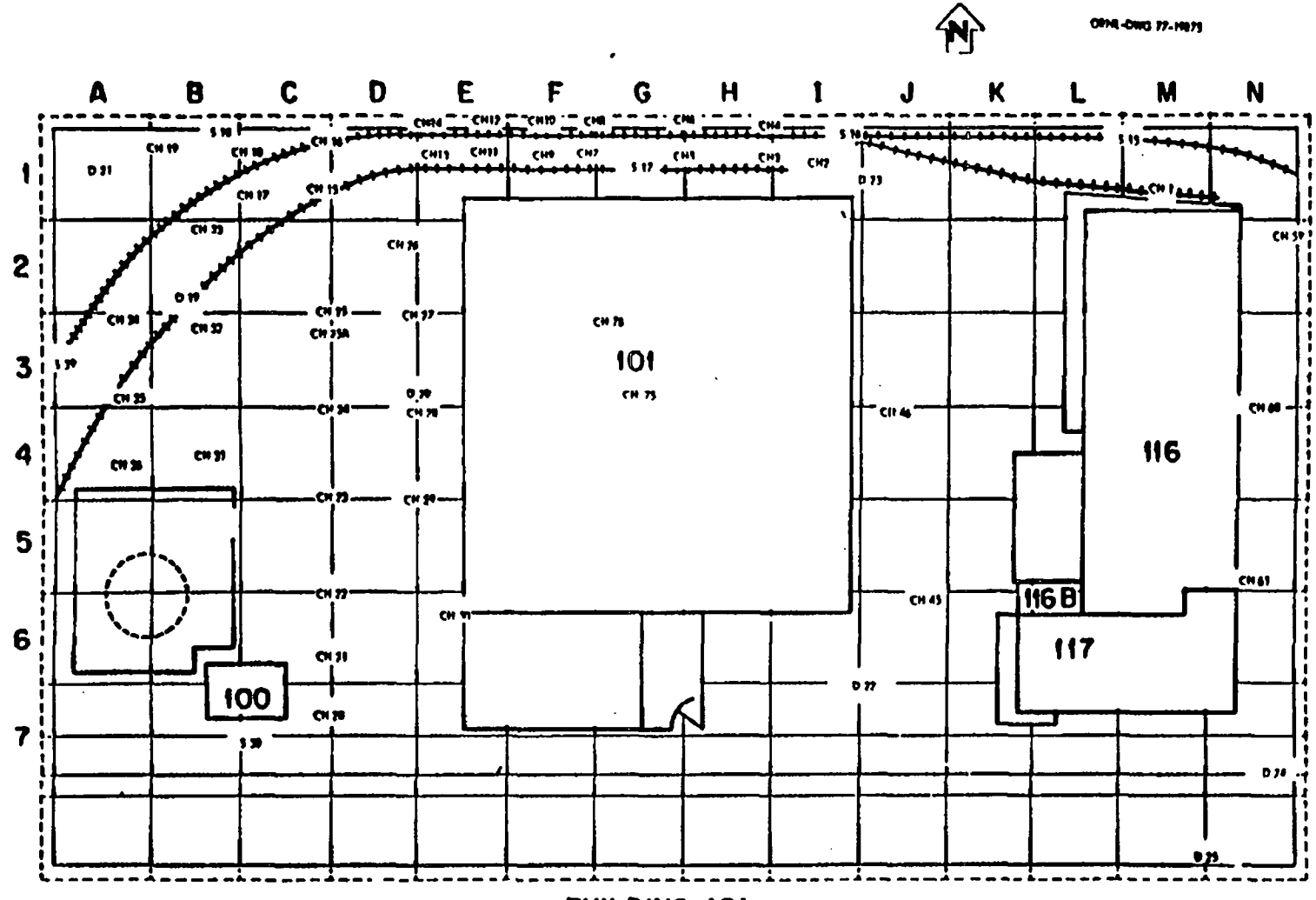

Fig. 47. Auger hole (CH), surface soil (S), and drain (D) locations in the area around Buildings 101, 116, and 117.

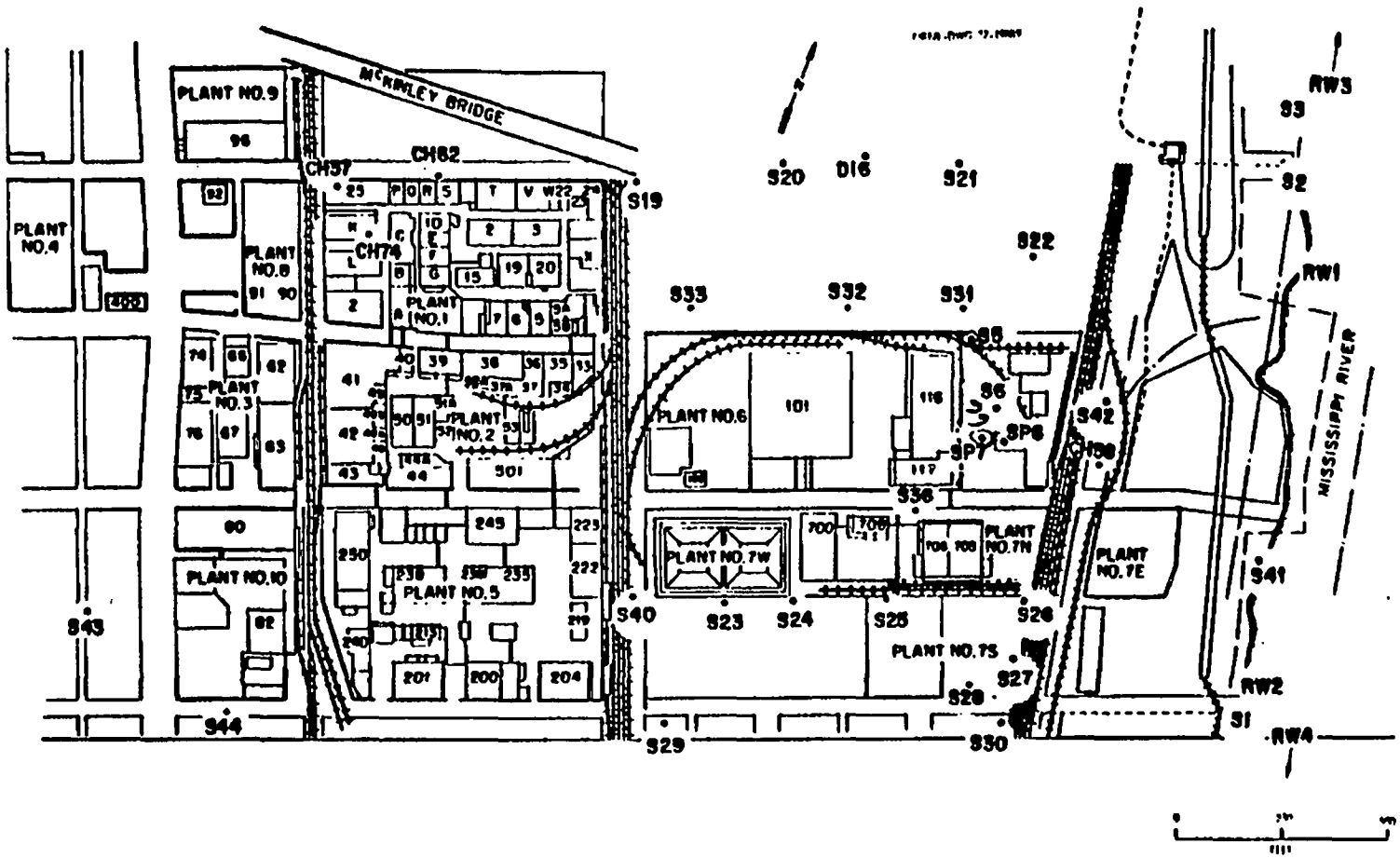

Fig. 48. Auger hole (CH), surface soil (S), and drain (D) locations outside Plants 2, 6, 7N, and 10.

Table 22. Radionuclide concentrations in surface soil

Sample	^{238}U (pCi/g)	^{226}Ra (pCi/g)	^{227}Ac (pCi/g)	^{232}Th (pCi/g)
S1	1.4	1.8	0.6	1.0
S2	0.6	1.1	ND[a]	ND
S3	1.4	1.3	ND	1.4
S4	36	1,900	ND	ND
S5	6.9	1.8	ND	1.1
S6	3.7	2.1	1.0	4.6
S7	18	2.2	ND	1.2
S8	57	3.0	ND	ND
S9	33	4.7	ND	1.7
S10	150	5.1	ND	1.3
S11	23	6.2	ND	3.2
S12	68	15	ND	6.4
S13	110	83	ND	110
S14	75	0.6	ND	180
S15	52	12	0.6	1.3
S16	75	27	2.2	1.4
S17	12	10	0.9	1.7
S18	ND	6.1	ND	1.5
S19	8.4	2.3	ND	0.5
S20	12	5.7	ND	0.8
S21	48	6.2	ND	0.9
S22	4.3	1.2	ND	0.6
S23	7.5	5.1	ND	1.8
S24	120	110	ND	ND
S25	9	7.6	0.6	2.0
S26	150	6.2	0.9	3.0
S27	51	7.7	ND	1.3
S28	16	370	ND	8.5
S29	3.0	2.3	ND	0.8
S30	2.5	2.1	0.2	0.8
S31	37	2.9	ND	1.0
S32	69	20	0.8	1.0
S33	26	10	ND	0.8
S34	37	1.6	ND	ND
S35	22	13	10	42
S36	30	12	12	27
S37	18	26	4.7	25
S38	35	50	5.6	24
S39	24	36	3.6	1.0
S40	7.7	2.4	0.5	ND
S41	4.8	4.3	0.6	1.7
S42	23	5.8	ND	1.0
S43	4	1.2	ND	0.5
S44	6.1	1.5	ND	0.7

[a]ND = Not determined.

Analysis of Subsurface Contamination Levels

Holes were augered at the 80 "CH" locations (CH1 through CH64 and CH70 through CH85) shown in Figs. 45 through 49, and gamma radiation as a function of depth was determined in these auger holes using NaI scintillation probes. Furthermore, soil samples were taken from many of the auger holes at the point of maximum contamination as indicated by the scintillation probe logging, and soil samples were taken throughout some holes at intervals of approximately 1 ft. Measurements and estimates concerning the extent of the contaminated soil, the depth of maximum contamination, and the ^{226}Ra and ^{238}U concentrations at the point of maximum contamination are provided in Table 23, where the maximum scintillation probe reading observed in each hole is also listed for purposes of comparison. Concentrations of ^{238}U, ^{226}Ra, ^{227}Ac, and ^{232}Th in all samples taken from the holes are given in Table 24. The term "contaminated soil" as used in Table 23 indicates that this portion of soil has gamma radiation levels or concentrations of ^{226}Ra or ^{235}U (or other radionuclides) which are too high to be attributable to normal terrestrial radioactivity. It was decided that soil containing 4 pCi/g or more of ^{226}Ra or ^{235}U, or producing more than 1,000 cpm on the shielded scintillator would be referred to as contaminated. Background concentrations of ^{226}Ra or ^{238}U are normally less than 2 pCi/g, and it appears from comparison of the hole logging and sample analyses that any reading higher than 1,000 cpm on the shielded scintillator indicates the presence of elevated concentrations of ^{226}Ra and/or ^{238}U.

In the area east of Buildings 51A and 52 (Fig. 49) and beneath Buildings 51, 51A, and 52A, licensable concentrations of natural uranium (0.05% or more by weight, corresponding to approximately 170 pCi/g of ^{238}U) were found at depths ranging from the surface to 14 ft (Table 24). In fact, subsurface soil containing 5% or more natural uranium by weight (corresponding to ~17,000 pCi/g of ^{238}U) was found beneath the floors of Buildings 51 and 52A. Highest contamination in the area appears to be at 8 to 10 ft beneath the surface, and contamination appears to taper off gradually from Buildings 51A, 52, and 52A toward Building 53 (Fig. 49 and Table 24). The highest ^{226}Ra concentration in this area was measured in samples taken beneath Building 51.

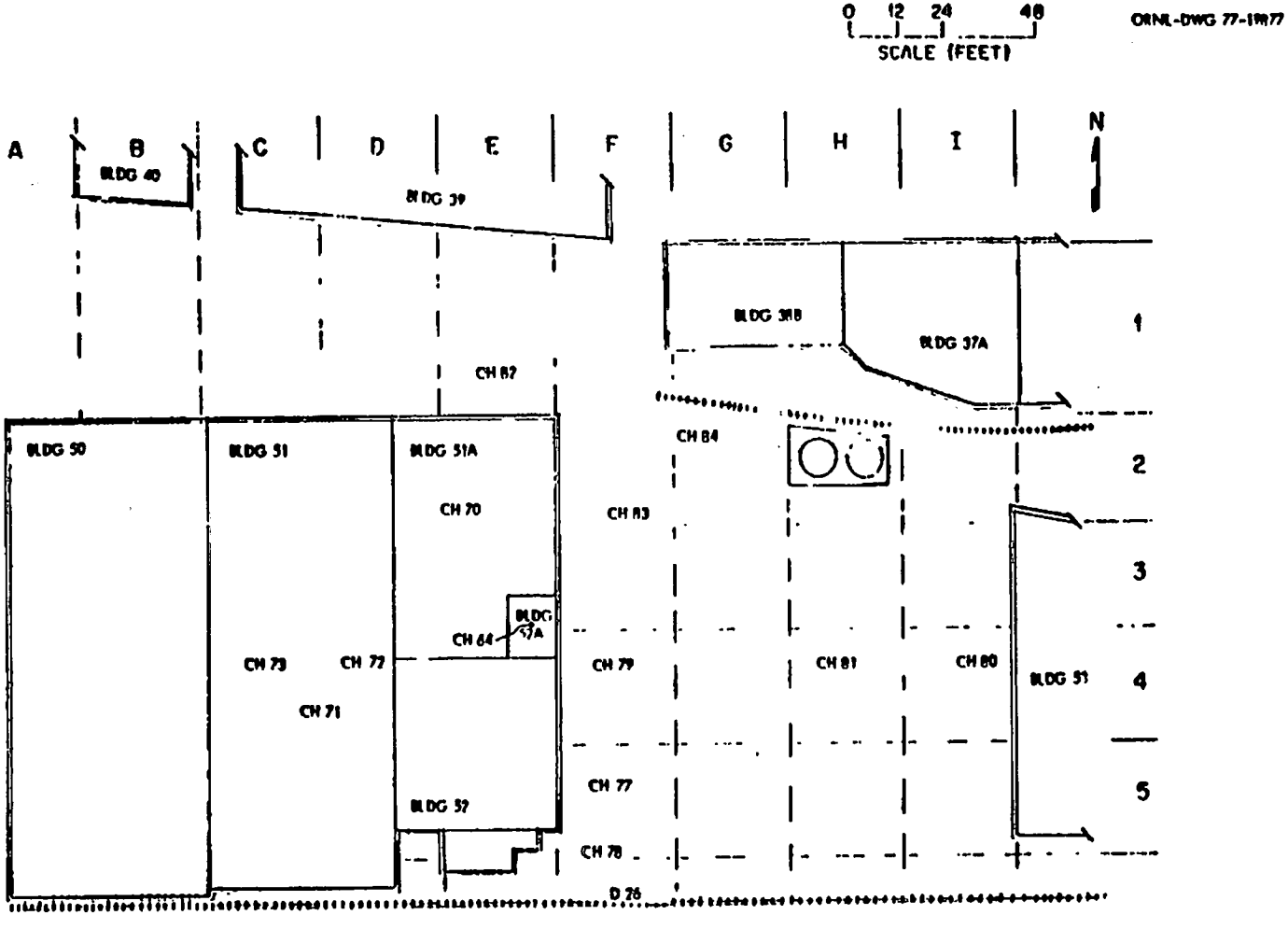

Fig. 49. Auger hole locations in the area around Buildings 50, 51, 51A, 52, and 52A.

Table 23 Extent of subsurface contamination as indicated by scintillation probe loggings and sample analyses

Location	Figure	Estimated extent of contaminated soil (ft)	Depth of maximum contamination (ft)	Maximum reading with shielded scintillator (count cpm)	^{226}Ra concentration at point of maximum contamination (pCi/g)	^{238}U concentration at point of maximum contamination (pCi/g)
1	47	0 - 3.0	1.5 - 3.0		6.0	20
2	47	0 - 10	1.5 - 3.0		27	140
3	47	No logging			Not sampled	
4	47	0 - 2.0	0 - 1.0	2.4	50	72
5	47	No logging			Not sampled	
6	47	0 - 2.0	0 - 1.5	5.5	75	59
7	47	1.5 - 3.0	1.5 - 3.5	1.3	Not sampled	
8	47	1 - 3.5	0 - 3.5	6.2	65	100
9	47	1.5 - 6.0	1.5 - 2.5	3.2	17	11
10	47	0 - 4.0	0 - 2.5	5.5	52	54
11	47	0 - 6.0	0 - 2.5	17	53	28
12	47	0 - 3.5	0 - 3.5	3.2	42	33
13	47	0 - 3.5	1.0 - 3.5	2.1	26	34
14	47	0 - 2.0	0 - 1.0	2.7	25	23
15	47	0 - 2.5	0 - 2.5	1.7	Not sampled	
16	47	0 - 3.5	0 - 2.0	1.6	Not sampled	
17	47	0 - 3.0	0 - 1.5	1.6	Not sampled	
18	47	No contamination detected to 5 ft				
19	47	0 - 2.5	0 - 1.5	6.3	Not sampled	
20	47	1.0 - 11.5	6.5 - 9.5	2.7	Not sampled	
21	47	No logging			55.	620
22	47	0 - 11.5	1.5 - 7.5	7.0	36	ND
23	47	0 - 11.5	2.5 - 9.5	36	Not sampled	
24	47	1.5 - 11.5	2.5 - 9.5	13	Not sampled	
25	47	0 - 11.5	2.5 - 9.5	63	2,700.	100
26	47	0 - 3.5	1.5 - 3.5	2.1	610	ND
27	47	3.5 - 6.5	3.5 - 5.5	2.3	Not sampled	
28	47	1.0 - 16.0	3.0 - 5.0	9.6	2.	50
29	47	0 - 12.5	5.5 - 7.5	15	Not sampled	
30	47	0 - 12.5	2.5 - 5.5	5.3	Not sampled	
31	47	1.0 - 11.0	2.5 - 6.5	2.1	2.9	24
32	47	1.5 - 5.0	3.5 - 5.5	5.3	22	ND
33	47	0 - 6.5	2.5 - 3.0	3.3	35	ND
34	47	2.5 - 7.5	2.5 - 4.0	1.5	Not sampled	
35	47	1.5 - 10.5	1.0 - 3.5	3.5	Not sampled	
36	47	1.5 - 3.5	2.5 - 5.5	2.7	Not sampled	
37	48	4.0 - 6.5	4.5 - 6.0	1.1	Not sampled	
38	45	4.0 - 6.5	4.0 - 6.0	1.2	Not sampled	
39	45	1.5 - 7.0	1.5 - 2.0	1.4	Not sampled	
40	45	3.0 - 6.0	3.0 - 6.0	1.0	Not sampled	
41	45	0 - 5.0	2.0 - 5.0	2.0	Not sampled	
42	45	0 - 6.5	2.0 - 7.0	2.4	Not sampled	
43	45	0 - 13.0	0 - 3.0	3.4	Not sampled	
44	45	0 - 10.0	1.0 - 6.0	2.5	Not sampled	
45	47	5.0 - 8.0	6.0 - 8.0	1.4	Not sampled	
46	47	1.0 - 12.0	6.0 - 12.0	1.6	Not sampled	
47	46	0 - 6.0	0 - 1.0	5.9	1.6	ND
48	46	5.0 - 6.0	5.0 - 6.0	1.1	Not sampled	
49	46	2.5 - 3.5	2.5 - 3.5	1.0	Not sampled	
50	46	2.0 - 3.0	2.0 - 3.0	1.0	Not sampled	

Table 23 (continued)

Location[a]	Figure	Estimated extent of contaminated soil (ft)	Depth of maximum contamination (ft)	Maximum reading with shielded scintillator (100% cpm)[b]	^{226}Ra concentration at point of maximum contamination (pCi/g)	^{238}Pu concentration at point of maximum contamination (pCi/g)
51	46	No contamination detected to 12 ft				
52	46	8.0 - 9.0	8.0 - 9.0	1.1	Not sampled	
53	46	No contamination detected to 12 ft				
54	46	0 - 5.0	0 - 1.0	4.2	2.6	ND
55	46	0 - 3.0	0 - 1.0	6.1	5.4	ND
56	46	1.0 - 12.0	1.0 - 3.0	1.6	Not sampled	
57	46	1.0 - 11.0	1.0 - 4.0	1.5	Not sampled	
58	46	0 - 2.0	1.0 - 2.0	1.1	2.8	5.8
59	47	0 - 2.0	0 - 1.0	1.7	Not sampled	
60	47	0 - 6.0	0 - 2.0	2.2	Not sampled	
61	47	0 - 10.5	0 - 1.0	5.2	6.0	ND
62	46	0 - 12.5	3.0 - 9.0	1.6	Not sampled	
63	46	0 - 1.0	0 - 1.0	3.2	Not sampled	
64[c]	49	0 - 10.0	0 - 3.0	16	28	7,000
64[c]	49	0 - 10.0	8.0 - 9.0	15	ND	17,000
70	45	1.0 - 12.0	5.0 - 9.0	6.2	4.6	3,100
71	45	No logging[d]			260	6,600
72	45	No logging			55	2,900
73[e]	45	0 - 12.0	7.0 - 10.0	--	24	26,000
73[f]	45	0 - 12.0	1.0 - 4.0	121	890	5,700
74	45	0 - 12.0	1.0 - 9.0	25	320	640
75	45	0 - 12.0	1.0 - 5.0	9.6	7.0	55
76	47	2.0 - 12.0	6.0 - 9.0	1.4	5.3	15
77	45	0 - 1.5	0.5 - 1.5		4.9	250
78	45	0 - 9.0	8.0 - 9.0	7.8	1.1	850
79	45	0 - 11.0	7.0 - 11.0	20	2.7	1,300
80	45	0 - 10.0	0.5 - 2.0	3.0	1.5	12
81	45	0 - 11.0	8.0 - 10.0	5.5	1.5	220
82	45	0 - 10.0	6.0 - 10.0	4.5	1.7	140
83	45	Not logged[d]			1.2	9
84	45	0 - 11.0	4.0 - 8.5	5.8	1.6	32
85	45	0 - 14.0	0.5 - 2.0	1.0	14	21

[a] These numbers are accompanied by "CM" (core hole) in figures

[b] The count rate obtained using the shielded scintillator is roughly proportional to the total concentration of gamma-emitting radionuclides in soil. A count rate of 100% cpm indicates a radionuclide concentration of 5 pCi/g or more

[c] Composite sample taken from old burial pit

[d] NC = Not determined

[e] Two separate layers of highly contaminated soil

[f] Sampled at 1.0 - 2.0 ft

[g] Sampled at 0.5 - 1.0 ft

[h] Sampled at 3.0 - 4.0 ft

Table 24. Radionuclide concentrations in subsurface soil

Location[a]	Depth (ft)	^{238}U (pCi/g)	^{226}Ra (pCi/g)	^{227}Ac (pCi/g)	^{232}Th (pCi/g)
1	0 - 1.5	10	1.3	ND[b]	0.6
	1.5 - 3.0	20	6.0	ND	1.1
	3.0 - 4.5	9.6	2.4	ND	1.0
	4.5 - 6.0	1.7	1.2	ND	1.0
	6.0 - 7.5	1.6	1.5	ND	1.0
	7.5 - 9.0	1.3	1.2	ND	1.2
	9.0 - 10.5	1.1	1.2	ND	1.2
2	0 - 1.5	28	27	2.6	2.4
	1.5 - 3.0	140	8.8	3.0	1.4
	3.0 - 4.5	110	7.9	2.1	1.5
	4.5 - 6.0	70	19	0.8	1.4
	6.0 - 7.0	18	3.2	ND	1.1
	7.0 - 8.0	9.0	2.3	ND	1.0
	8.0 - 9.0	5.0	1.9	ND	1.0
	9.0 - 10.0	5.3	7.0	1.1	0.6
4	0 - 1.0	72	50	2.2	ND
6	0 - 2.0	59	75	4.6	1.3
8	0 - 1.0	100	68	3.3	1.4
9	1.0 - 2.0	11	17	ND	1.1
10	@ 1	54	52	2.4	1.6
11	0 - 1.0	28	93	7.3	2.2
12	0 - 1.0	31	42	ND	1.9
13	@ 2	34	25	2.4	1.1
14	0 - 1.0	23	25	ND	1.2
21	composite	620	590	530	1,100
22	1.0 - 2.0	ND	35	ND	45
25	0 - 1.0	ND	38	7.7	14
	1.0 - 2.0	21	2.3	0.3	1.4
	2.0 - 4.0	4.8	2.3	0.6	0.9
	4.0 - 5.0	29	4.4	0.7	1.7
	5.0 - 6.0	22	2.6	ND	1.2
	6.0 - 7.0	7.4	8.5	1.5	1.3
	7.0 - 8.0	100	2,700	350	ND
	10.0 - 11.0	19	74	8.6	ND
	11.0 - 12.0	13	3.1	0.5	0.9
26	@ 3.5	ND	804	ND	ND
28	1.0 - 2.0	51	20	2.1	12
31	1.0 - 2.0	24	2.9	0.4	1.1
32	1.0 - 2.0	ND	22	ND	6.0
33	0 - 1.0	ND	38	7.3	11
47	0 - 1.0	ND	1.6	ND	2.0
54	0 - 1.0	ND	2.6	ND	1.3
55	0 - 1.0	ND	5.4	ND	2.7
58	0 - 1.0	4.9	2.8	ND	1.2
	1.0 - 2.0	5.8	2.4	1.4	1.2
	2.0 - 3.0	2.0	1.8	ND	1.0
	3.0 - 4.0	2.7	2.9	0.8	1.0

1769/39 = 45

Table 24. (continued)

Location[a]	Depth (ft)	^{238}U (pCi/g)	^{226}Ra (pCi/g)	^{227}Ac (pCi/g)	^{232}Th (pCi/g)
58	4.0 - 5.0	2.8	2.0	ND	1.2
	5.0 - 6.0	2.1	1.3	ND	1.0
	6.0 - 7.0	1.8	1.6	ND	1.2
	7.0 - 8.0	1.7	1.4	ND	1.0
	8.0 - 9.0	2.3	1.5	ND	1.0
	9.0 - 10.0	2.3	1.2	ND	0.8
	10.0 - 12.0	1.5	1.4	ND	0.8
	12.0 - 13.0	5.2	3.0	ND	1.0
	13.0 - 14.0	1.9	1.0	ND	1.0
61	0 - 1.0	ND	6.0	3.7	6.0
64	0 - 1.0	7,000	28	23	ND
	1.0 - 2.0	5,000	13	19	ND
	2.0 - 3.0	1,700	7.2	ND	ND
	3.0 - 4.0	2,100	1.1	ND	0.7
	4.0 - 5.0	3,800	2.2	ND	ND
	5.0 - 6.0	2,800	ND	ND	ND
	6.0 - 7.0	500	ND	0.7	ND
	7.0 - 8.0	1,400	3.5	ND	ND
	8.0 - 9.0	17,000	ND	ND	ND
	13.0 - 14.0	680	1.3	ND	ND
	14.0 - 15.0	35	2.3	ND	1.4
70	0.5 - 1.0	ND	2.3	ND	0.6
	1.0 - 2.0	250	3.5	ND	0.9
	2.0 - 3.0	260	3.3	ND	0.9
	3.0 - 4.0	390	1.3	ND	0.9
	4.0 - 5.0	700	1.1	ND	ND
	5.0 - 6.0	2,800	ND	ND	ND
	6.0 - 7.0	620	1.8	ND	ND
	7.0 - 8.0	1,400	2.8	ND	ND
	8.0 - 9.0	3,100	4.6	ND	ND
	9.0 - 10.0	360	1.6	ND	ND
	10.0 - 11.0	150	1.6	ND	1.2
	11.0 - 12.0	110	1.5	ND	1.1
71	0.5 - 1.0	2,000	37	87	ND
	1.0 - 2.0	8,600	260	520	ND
	2.0 - 2.5	2,000	151	260	ND
72	0.5 - 1.0	2,900	55	89	ND
	1.0 - 2.0	940 ←	4.1	ND	ND
73	2.0 - 3.0	3,900	800	1,300	ND
	3.0 - 4.0	9,700	530	1,000	ND
	5.0 - 6.0	6,400	26	71	ND
	6.0 - 7.0	8,200	18	64	ND
	7.0 - 8.0	18,000	20	59	ND
	8.0 - 9.0	20,000	24	59	ND
	10.0 - 11.0	900	2.1	ND	ND
	11.0 - 12.0	280	1.8	ND	1.3
74	1.0 - 1.5	697	320	32	ND
	1.5 - 2.5	600	19	ND	1.0

136,353.6 / 46 = 2964

Table 24. (continued)

Location[a]	Depth (ft)	^{238}U (pCi/g)	^{226}Ra (pCi/g)	^{227}Ac (pCi/g)	^{232}Th (pCi/g)
74	2.5 - 3.5	250	64	7.4	ND
	3.5 - 4.5	820	160	ND	ND
	4.5 - 5.5	600	10	ND	ND
	5.5 - 6.5	840	31	14	ND
	6.5 - 7.5	370	1.9		
	7.5 - 9.0	680	1.7	0.7	1.4
	9.0 - 10.0	34	1.4	ND	1.5
75	0 - 2.0	40	6.4	4.2	4.1
	2.0 - 3.0	33	7.0	5.0	1.6
	3.0 - 4.0	23	3.0	1.3	1.0
	4.0 - 5.0	55	2.2	1.1	1.4
	5.0 - 6.0	48	3.7	ND	1.2
	6.0 - 7.0	45	4.3	ND	1.4
	7.0 - 8.0	28	1.7	ND	1.0
	8.0 - 9.0	32	2.3	ND	1.2
	9.0 - 10.0	18	1.2	ND	1.0
	10.0 - 11.0	41	1.3	ND	1.0
	11.0 - 12.0	79	1.3	ND	0.8
76	0 - 1.0	2.6	2.0	ND	1.4
	1.0 - 2.0	2.3	1.0	ND	0.7
	2.0 - 3.0	1.8	1.5	ND	1.3
	3.0 - 4.0	3.3	1.9	ND	1.2
	4.5 - 5.0	3.0	2.6	ND	1.0
	5.0 - 6.0	3.6	2.5	ND	1.1
	6.0 - 7.0	15	2.7	ND	1.1
	7.0 - 8.0	1.7	1.8	ND	2.2
	8.0 - 9.0	13	5.3	ND	1.3
	9.0 - 10.0	1.5	1.9	ND	1.3
	10.0 - 11.0	1.2	1.4	ND	0.9
	11.0 - 12.0	2.2	1.1	ND	1.0
77	composite	250	4.9	0.8	0.9
78	0 - 0.5	130	1.5	ND	1.0
	1.0 - 2.0	83	1.4	ND	0.9
	2.0 - 3.0	97	0.9	ND	0.8
	3.0 - 4.0	37	0.7	ND	0.7
	4.0 - 5.0	25	1.3	ND	0.8
	6.5 - 7.5	92	1.0	ND	0.8
	7.5 - 8.0	890	ND	ND	ND
	8.0 - 9.5	660	ND	ND	1.1
	9.5 - 11.0	93	1.1	ND	1.2
79	0.5 - 1.0	32	1.5	ND	0.7
	1.0 - 2.0	16	1.6	ND	1.0
	2.0 - 3.0	47	0.9	ND	0.7
	3.0 - 4.0	73	0.8	ND	0.8
	4.0 - 5.0	95	1.6	ND	1.0
79	5.0 - 6.0	37	0.8	ND	0.8
	6.0 - 7.0	20	1.0	ND	0.4

6144/47 = 130

Table 24. (continued)

Location[a]	Depth (ft)	^{238}U (pCi/g)	^{226}Ra (pCi/g)	^{227}Ac (pCi/g)	^{232}Th (pCi/g)
79	7.0 - 8.0	340	1.0	ND	0.9
	8.0 - 9.0	1,300	2.7	ND	ND
	9.0 - 10.0	420	1.4	ND	1.1
	10.0 - 11.0	98	1.1	ND	1.1
80	0.5 - 2.0	12	1.5	ND	ND
	2.0 - 3.0	9.1	0.8	ND	0.7
	3.5 - 5.0	8.8	1.0	ND	ND
	5.0 - 6.5	3.4	0.9	ND	0.8
	6.5 - 8.0	8.7	1.1	ND	0.8
	8.0 - 9.5	10	1.3	0.5	1.0
	9.5 - 11.0	1.5	1.2	ND	ND
81	0.5 - 2.0	2.2	2.0	ND	1.0
	2.0 - 3.5	2.4	1.7	ND	1.0
	3.5 - 5.0	ND	2.9	ND	ND
	5.0 - 6.5	16	2.0	ND	1.0
	6.5 - 8.0	110	1.4	ND	0.9
	8.0 - 9.0	220	1.5	ND	0.9
	9.0 - 10.0	200	1.3	ND	0.9
	10.0 - 11.5	3.2	1.3	ND	1.3
82	0 - 2.0	3.0	0.6	ND	0.4
	2.0 - 3.5	2.3	0.3	ND	0.3
	3.5 - 5.0	2.5	0.3	ND	0.4
	5.0 - 6.5	6.7	0.6	ND	0.5
	6.5 - 8.0	140	1.3	ND	0.7
	8.0 - 9.5	88	1.7	ND	1.0
	9.5 - 11.0	4.3	1.5	ND	1.7
83	1.0 - 2.0	7.7	1.2	ND	0.8
	2.0 - 3.0	7.3	0.9	ND	0.8
	3.0 - 4.0	8.7	1.2	ND	0.9
84	1.0 - 2.0	1.4	1.0	ND	0.6
	2.0 - 3.0	1.8	0.9	ND	0.8
	3.0 - 4.0	10	1.6	ND	1.0
	4.0 - 5.5	14	1.7	ND	1.0
	5.5 - 7.0	14	1.9	ND	1.2
	7.0 - 8.5	32	1.9	ND	ND
	8.5 - 10.5	2.5	ND	ND	ND
	10.5 - 11.5	2.1	1.2	ND	1.3
85	0.5 - 2.0	21	14	ND	3.1
	2.0 - 3.5	4.7	7.6	ND	1.4
	3.5 - 5.0	14	3.9	ND	1.2
	5.5 - 6.0	1.6	1.3	0.51	1.0
	6.5 - 8.0	4.1	3.9	0.27	1.3
	8.0 - 9.5	ND	2.0	ND	1.1
	13.0 - 15.0	4.5	3.4	ND	2.2

[a]Refers to "CH" locations shown in Figs. 45 through 49.

[b]ND = Not determined.

3163.5 - 75.3

Analyses of these samples indicated up to 800 pCi/g of ^{226}Ra (CH73, Table 24). The ^{227}Ac concentration at location CH73 (beneath Building 51) was as high as 1,300 pCi/g. This radionuclide is of importance, because one of its daughters, ^{223}Ra, decays to ^{219}Rn which like ^{222}Rn also has short-lived alpha emitting daughters. For surface deposits of ^{227}Ac, significant airborne concentrations of ^{219}Rn daughters could exist.

A core hole (CH74, Table 24 and Fig. 48) was drilled through the floor in the southeast end of Building K1E. The ^{226}Ra concentration at 1 to 1.5 ft was 320 pCi/g, decreased sharply at 1.5 to 3.5 ft, and increased to 160 pCi/g at 3.5 to 4.5 ft. The ^{238}U concentration in the subsurface soil at this location ranged from 250 to 840 pCi/g at 1 to 9 ft.

Samples of subsurface soil were taken around Buildings 700 and 704-708 at locations CH47, CH54, CH55, and CH85 (Fig. 46). The ^{236}U concentration in these samples did not exceed 21 pCi/g, and the ^{226}Ra concentration did not exceed 14 pCi/g (Table 24).

Subsurface samples were taken at 22 locations in the area around Buildings 101 and 116 (Fig. 47 and Table 24). Concentrations of natural uranium in excess of 0.05 wt.% were found in this area at only location 21 (620 pCi/g of ^{238}U), which is a waste pit for unreacted columbium-tantalum ore from a more recent commercial operation. Most samples taken along the railroad spurs near Building 101 contained elevated concentrations of ^{226}Ra and ^{238}U, with highest contamination levels generally being found (by gamma-ray logging and sampling) within 2 or 3 ft of the surface. At location CH25, which is approximately 75 ft west of Building 101 and approximately 50 ft southeast of the nearest railroad spur, the ^{226}Ra concentration at 7 to 8 ft was 2,700 pCi/g. The ^{226}Ra concentration at most locations was no higher than 100 pCi/g.

Seven holes were augered in the parking lot and in other areas near Building 81 (Fig. 45). No samples were taken since hole loggings indicated background levels of gamma radiation.

Soil samples taken from holes 47, 54, 55, and 85 indicated slightly elevated levels of ^{230}Th, primarily in the top 3 ft of soil. Samples from hole 85 contained an average concentration of ^{230}Th in the

top 3 ft of soil of 28 pCi/g, with a maximum of 47 pCi/g at a depth of 1 ft. The average ^{230}Th concentration in the top foot of soil in the area surrounding the ionium pad was 6 pCi/g.

Analysis of Samples Taken from Outdoor Drains

Samples of dirt or mud were taken from drains labeled D19, D23, and D24 in Fig. 47, from drain D16 shown in Fig. 48, from a drain located in the alleyway between Buildings K1E and 25, and from drain 26 shown in Fig. 47. Analyses of ^{226}Ra, ^{238}U, ^{227}Ac, and ^{232}Th for these samples are given in Table 25. Maximum ^{226}Ra and ^{238}U concentrations (65 and 140 pCi/g, respectively) were measured in a sample taken from drain D24 (near Building 117).

Analysis of Water Samples

Samples of water were taken from 31 of the auger holes; the concentrations of ^{230}Th, ^{226}Ra, and ^{238}U in these samples are listed in Table 26. Water taken from the waste pit (sample CW-21 from location CH21, Fig. 47) showed a ^{238}U concentration of 59 pCi/ml; the concentration guide for water (CG_w) for ^{238}U stated in 10 CFR 20 is 40 pCi/ml. Concentrations of all three radionuclides in the other 30 samples were below the CG_w's stated in 10 CFR 20.

Four water samples were taken from the Mississippi River at points where water runoff from the site drains enter the river (RW samples, Fig. 48). Radionuclide concentrations in the dissolved and suspended state in these samples are listed in Table 27. In all cases in which results are conclusive, radionuclide concentrations were below the corresponding CG_w's. (Results for sample RW-2 were inconclusive when compared with the CG_w for ^{210}Pb.)

SUMMARY

A radiological survey was conducted at the Mallinckrodt Chemical Works Company in St. Louis, Missouri. During the period 1942-1957, this site was used for various projects involving the production of purified uranium products from pitchblende raffinate. The survey was

Table 25. Concentrations of ^{226}Ra, ^{238}U, ^{227}Ac, and ^{232}Th (pCi/g) in dirt samples taken from outdoor drains

Sample code	Drain location	^{226}Ra	^{238}U	^{227}Ac	^{232}Th
D1	Alleyway between Bldgs. K1E and 25	3.3	4.1	17	3.7
D16	Manhole on Salisbury St.	1.0	1.3	ND[a]	0.4
D19	Sewer line junction behind Bldg. 101	33	47	ND	ND
D23	Bottom on manhole ~15 ft from NE corner of Bldg. 101	61	80	5.3	24
D24	Manhole ~50 ft from southeast corner of Bldg. 117	65	140	ND	ND
D26	Manhole ~200 ft from southeast corner of Bldg. 52.	2.3	3.7	ND	3.2

[a] ND - Not determined.

Table 26. Analyses of water samples taken from auger holes

Sample designation	Radionuclide concentration (pCi/ml)		
	^{230}Th	^{226}Ra	^{238}U
CW-2[a]	0.0009 ± 100%	0.0014 ± 67%	0.14
CW-4	<0.000045	0.0009 ± 100%	0.03
CW-6	0.0014 ± 67%	0.0009 ± 100%	0.02
CW-7	0.0014 ± 67%	0.00045 ± 100%	0.10
CW-8	0.00045 ± 200%	<0.00045	0.02
CW-10	0.0002 ± 225%	0.0009 ± 100%	0.01
CW-11	<0.002	0.002 ± 60%	0.43
CW-13	0.0007 ± 20%	0.002 ± 50%	0.25
CW-14	0.0003 ± 43%	0.0005 ± 100%	0.04
CW-15	0.0004 ± 38%	0.0009 ± 100%	0.03
CW-16	0.00045 ± 100%	0.002 ± 50%	0.14
CW-18	0.00009 ± 300%	0.0005 ± 200%	0.07
CW-21	0.0009 ± 50%	0.0014 ± 67%	59
CW-27	0.00045 ± 100%	0.0009 ± 100%	0.07
CW-28	<0.0344	0.0009 ± 100%	0.41
CW-32	0.00045 ± 200%	<0.0005	0.06
CW-33	0.0009 ± 100%	<0.0005	0.56
CW-34	0.0014 ± 100%	<0.0005	0.21
CW-35	0.0014 ± 100%	<0.0005	0.23
CW-36	0.00045 ± 100%	<0.0005	0.05
CW-44	0.00045 ± 100%	0.0009 ± 100%	0.13
CW-47	0.0009 ± 100%	0.0009 ± 100%	0.02
CW-48	<0.000045	0.0009 ± 100%	0.02
CW-49	0.00045 ± 100%	<0.0005	0.04
CW-50	<0.000045	<0.0005	0.02
CW-51	0.00014 ± 300%	0.0009 ± 100%	0.03
CW-52	0.00045 ± 200%	<0.0005	0.03
CW-53	0.00014 ± 300%	<0.0005	0.04
CW-54	<0.000045	<0.0005	0.01
CW-70	<0.0045	0.0009 ± 100%	8
CW-73	0.032 ± 4%	<0.0005	10
CG_w[b]	2	0.03	40

[a] Code numbers agree with auger hole numbers (e.g., CW-2 was taken from hole CH2).

[b] Concentration guide for water listed in 10 CFR 20, Appendix B, and ERDAM 0524, Annex A.

Table 27. Analyses of water samples taken from the Mississippi River near the site

Sample designation	Dissolved radionuclides in water (pCi/ml)				Radionuclides in suspended matter in water (pCi/g)		
	^{210}Pb	^{230}Th	^{226}Ra	^{238}U	^{210}Pb	^{230}Th	^{226}Ra
RW1	<0.0009	0.00009 ± 100%	<0.0005	0.02	7.6 ± 80%	0.45 ± 100%	1.8 ± 50%
RW2	<0.8	0.0005 ± 100%	0.0005 ± 100%	0.01	99 ± 25%	0.90 ± 50%	1.4 ± 67%
RW3	<0.002	<0.0005	<0.0005	0.02	0.90 ± 250%	0.45 ± 100%	0.90 ± 50%
RW4	ND	ND	ND	≤0.005	ND	ND	ND
CG_w^a	0.1	2	0.03	40			

[a]Concentration guide for water listed in 10 CFR 20, Appendix B, and ERDAM 0524, Annex A.

conducted in all areas where radioactive materials had been handled in connection with the uranium project, with special attention being given to the interiors of remaining buildings used in that project.

A large fraction of the area in almost all of the buildings surveyed indicated only background or near-background radiation levels. In the following, a brief summary is given for each building interior concerning radiation and contamination levels considered to be above pertinent radiation guidelines.

Building K1E

Beta-gamma dose rates at 1 cm from the surface exceed NRC guidelines in several small areas on the floor and lower walls, and alpha contamination levels appear to be above NRC guidelines for ^{226}Ra over much of the floor. Radon-222 concentrations in air exceeded the non-occupational concentration guide of 3 pCi/l stated in 10 CFR 20. These elevated ^{222}Rn concentrations apparently result (at least in part) from ^{226}Ra contamination in soil beneath the floor. Licensable concentrations of natural uranium were found in subsurface soil beneath the floor. Elevated gamma radiation levels were observed.

Building 25

Several small spots, mostly on lab benches, sinks, hoods, and cabinets, were found to have directly measured alpha and beta-gamma contamination levels exceeding NRC guidelines.

Building 38

No contamination was found in this buidling.

Building 40

Several isolated spots (principally on the floor and lower walls) show directly measured alpha and beta-gamma contamination levels exceeding NRC guidelines. Transferable alpha contamination levels are above NRC guidelines for ^{226}Ra in at least one small area.

Building 50

Beta-gamma dose rates are above NRC guidelines in several small areas, principally in the north end of the building. A material scraped from the floor and lower wall in the northeast corner of the building contained licensable concentrations of uranium.

Building 51

Beta-gamma dose rates exceed NRC guidelines in several areas. Licensable concentrations of uranium exist in subsurface soil beneath the floor. Radon concentrations were below the CG_a stated in 10 CFR 20; however, the elevated ^{226}Ra concentration measured in subsurface soil beneath Building 51 could conceivably cause elevated radon concentration in the building at times when the building is closed tightly.

Building 51A

Some areas both on lower surfaces and on overhead surfaces were found to have directly measured and/or transferable alpha and beta-gamma contamination levels exceeding NRC guidelines. Licensable concentrations of uranium were measured in soil taken from the floor as well as in soil taken beneath the floor.

Building 52A

Beta-gamma dose rates exceed NRC guidelines in several areas on the lower walls. Radon concentrations in air exceeded the nonoccupational concentration guide stated in 10 CFR 20. Licensable concentrations of uranium exist in soil beneath the floor.

Building 52

Beta-gamma dose rates exceed NRC guidelines in several spots, principally on lower walls.

Building 81

Only radon and radon daughter measurements were taken; measured concentrations were near the background level.

Building 100

It appears that the alpha contamination level (by direct measurement) exceeds NRC guidelines for ^{226}Ra over a large fraction of the floor and lower wall surfaces.

Building 101

This is a relatively new building built on the site of demolished buildings where pitchblende ore was processed. Radon concentrations exceeded the nonoccupational concentration guide stated in 10 CFR 20, and some elevated gamma radiation levels were observed.

Building 116

In the large (main) section and on the second level of the north end, NRC guidelines for beta-gamma dose rates are exceeded at some points. Analysis of a gravel and dirt sample from the roof indicated licensable concentrations of uranium.

Building 117

Beta-gamma dose rates at several points on both the first and second levels exceed NRC guidelines. Also, alpha contamination levels (by direct reading) exceed the NRC guideline for ^{226}Ra over much of the floor and lower wall surfaces of both the first and second levels. Analyses of dirt samples taken from drains and from the floor indicated licensable concentrations of uranium (more than 0.05% by weight). The ratio of activities of ^{238}U and ^{226}Ra may vary significantly from point to point in this building, and if the NRC guidelines for uranium were applied, the alpha contamination levels would be well below the guidelines.

Building 700

Beta-gamma dose rates exceed NRC guidelines at some spots on the floor and lower walls. Analysis of a dirt sample taken from a drain indicated licensable concentrations of uranium.

Building 704

Beta-gamma dose rates exceed NRC guidelines in two small areas on the floor.

Building 705

Directly measured alpha and/or beta-gamma contamination levels exceed NRC guidelines for uranium at numerous points on the floors, walls, rafters, and ceilings.

Building 706

Beta-gamma dose rates exceed NRC guidelines in one area along the base of the west wall.

Building 707

Beta-gamma dose rates exceed NRC guidelines in one area on the floor in the southwest corner of the building.

Building 708

Licensable concentrations of uranium were indicated in the analysis of a rust and dirt sample taken from an overhead surface, otherwise measurements did not exceed pertinent guidelines.

Other Areas

On the grounds of the entire site, beta-gamma dose rates at 1 cm from the surface exceed NRC guidelines at points in the following areas: along the outside walls of Buildings 51, 51A, 52, and 52A; in the area around Buildings 81 and 82; in the area around Buildings 101, 116, and 117; in the area around Buildings 700, 704, 705, 706, 707, and

708; on the concrete slab at the east end of Building 705; on the ionium pad south of Building 708; on the roofs of Buildings 51A, 52A, 116, 116B, and 706; and in the alleyway between Buildings 25 and K1E. Alpha contamination levels on outdoor surfaces are above NRC guidelines at points in the following areas (the applicable guideline for the area is given in parentheses): on the ionium pad south of Building 708 (radium); on the roof of Building 100 (radium, although it is possible that the elevated alpha readings resulted from a glaze on the cap tiles containing thorium); and in the alleyway between Buildings 25 and K1E (radium).

Some surface soil samples taken outdoors on the Mallinckrodt property in areas of suspected contamination (in particular, near railroad spurs) contained elevated concentrations of ^{226}Ra (up to 1,900 pCi/g) and ^{238}U (up to 150 pCi/g). Licensable concentrations of ^{235}U exist in subsurface soil in some outdoor areas on the site, particularly in the area east of Buildings 51, 51A, 52, and 52A (Plant 2). One water sample taken from a hole augered into an old waste pit showed a ^{238}U concentration exceeding the nonoccupational concentration guide for water as stated in 10 CFR 20.

Columbium-tantalum ore, from some of Mallinckrodt's commercial operations, and which contain small amounts of uranium and thorium is stored in some areas of Plants 6, 7N, and 7W. A waste pit for the unreacted ore is located between Buildings 100 and 101, and a sample taken from the pit contained licensable concentrations of uranium. The presence of the columbium-tantalum ore may add to the radioactivity background in these plant areas and may have increased some radiation measurements.

An evaluation has been made of current radiation exposures at the Mallinckrodt Chemical Works and is presented as Appendix V of this report. The purpose of this evaluation is to present information which will permit the reader to compare current radiation exposures from the site to normal background exposures for that part of Missouri, as well as to scientifically based guideline values established for the protection of radiation workers and members of the general public.

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APPENDIX I

DESCRIPTION OF RADIATION SURVEY METERS AND SMEAR COUNTERS

RADIATION SURVEY METERS

Alpha Survey Meters

The type of alpha survey meter used at this site to measure alpha radioactivity on surfaces uses a ZnS scintillator to detect the alpha radiation.

The alpha scintillation survey meter consists of a large area (100 cm^2) ZnS detector with a photomultiplier tube in the probe which is coupled to a portable scaler/ratemeter (Fig. I-A). The ZnS detector is covered with a 0.28-mil aluminized mylar sheet in order to make the instrument light-tight. A metal grid is used to avoid puncturing the mylar when surveying over rough surfaces. This instrument is capable of measuring alpha surface contamination levels of a few disintegrations per minute per 100 cm^2 but must be used in the scaler mode for this purpose. It is highly selective for densely ionizing radiation such as alpha particles; the instrument is relatively insensitive to beta and gamma radiation. This instrument is calibrated at ORNL using ^{239}Pu alpha sources. Calibration factors are typically 5 to 7 dpm/cpm.

Beta-Gamma Survey Meter

A portable Geiger-Mueller (G-M) survey meter (Fig. I-B) is the primary instrument for measuring beta-gamma radioactivity. The G-M tube is a halogen-quenched stainless steel tube having a 30 mg/cm^2 wall thickness and presenting a cross-sectional area of approximately 10 cm^2. Since the G-M tube is sensitive to both beta and gamma radiation, measurements are taken in both an open- and a closed-window configuration. Beta radiation cannot penetrate the closed window, and, thus, the beta reading can be determined by taking the difference between the open- and closed-window readings.

The G-M survey meters were calibrated by comparison with a pre-calibrated Victoreen Model 440 ionization chamber (Fig. I-C). The open-window calibration factor was found to be 2,000 cpm/(mR/h) for surfaces contaminated with ^{226}Ra in equilibrium with ^{238}U and 2,300 cpm/(mR/h)

ORNL-Photo 6705-76

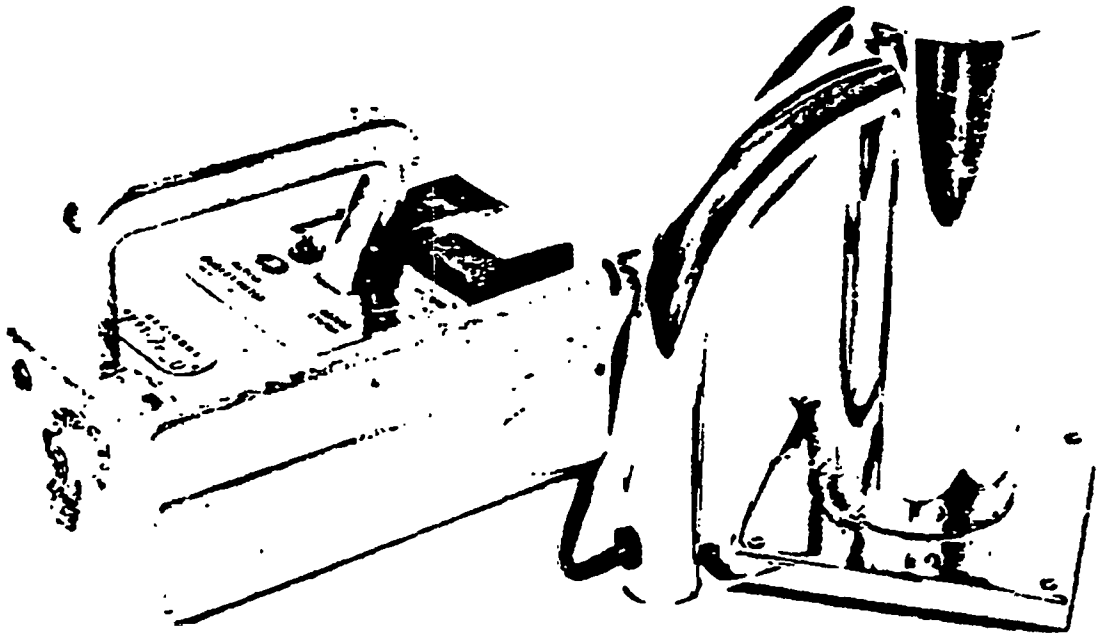

Fig. I-A. Alpha scintillation survey meter.

ORNL-Photo 6704-76

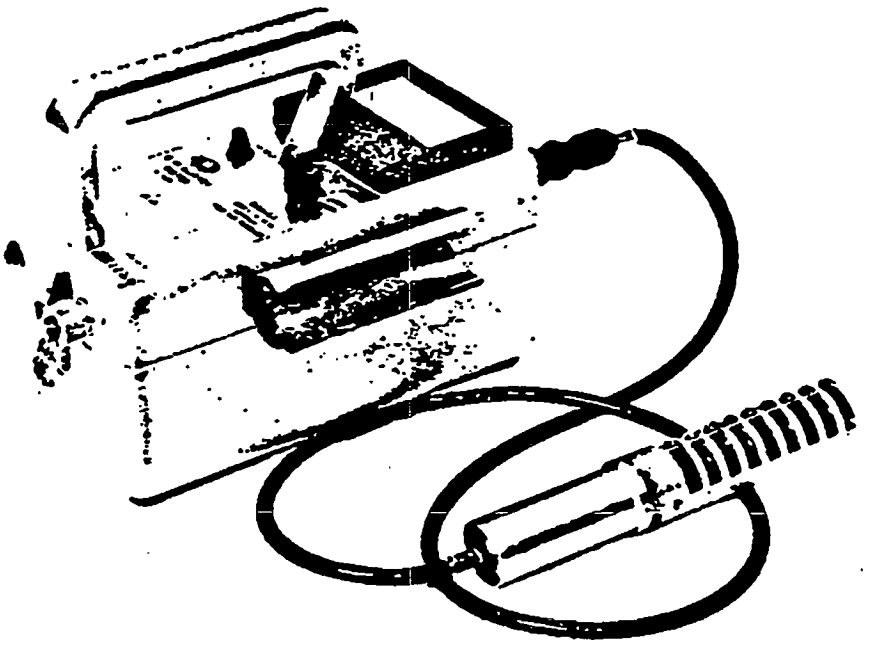

Fig. I-B. Geiger-Mueller survey meter.

ORNL-Photo 6710-76

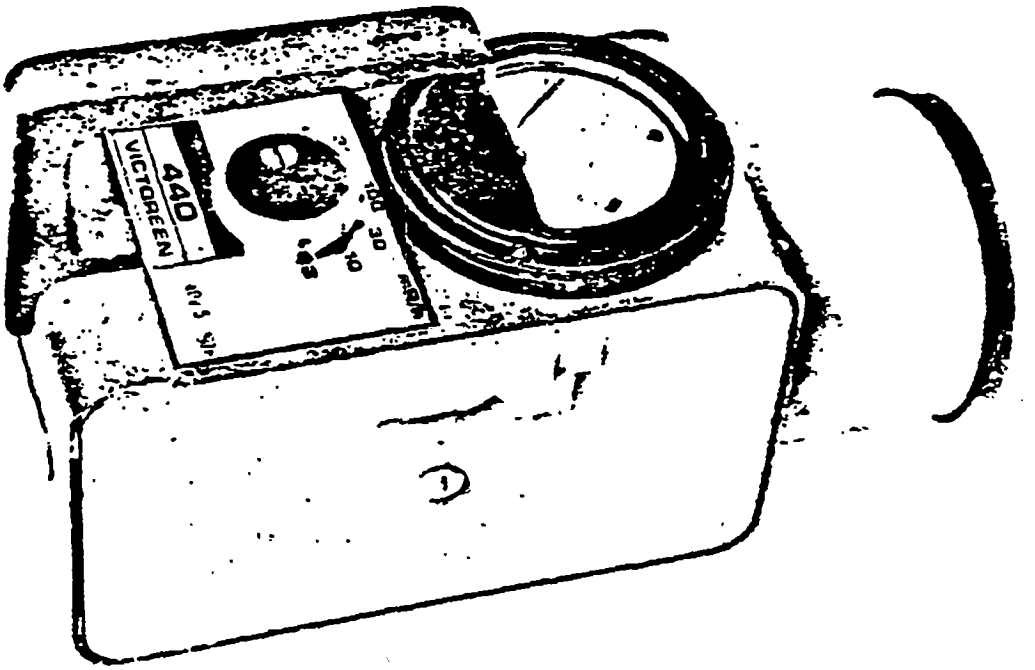

Fig. I-C. Victoreen Model 440 ionization chamber.

for surfaces contaminated with initially pure uranium. The closed-window (gamma) calibration factor, determined by use of a National Bureau of Standards (NBS) standard ^{226}Ra source, was 3,200 cpm/(mR/h).

Gamma Scintillation Survey Meter

A portable survey meter using a NaI scintillation probe is used to measure low-level gamma radiation exposure. The scintillation probe is a 3.2 x 3.8-cm NaI crystal coupled to a photomultiplier tube. This probe is connected to a Victoreen Model Thyac III ratemeter (Fig. I-D). This unit is capable of measuring radiation levels from a few microroentgens per hour to several hundred microroentgens per hour. This instrument is calibrated at ORNL with an NBS standard ^{226}Ra source. Typical calibration factors are of the order of 300 cpm/(μR/h).

SMEAR COUNTERS

Alpha Smear Counter

This detector assembly, used for the assay of alpha emitters on smear paper samples, consists of a light-tight sample holder, a zinc sulfide phosphor, and a photomultiplier tube. This detector assembly was used with electronic components housed in a portable NIM bin (Fig. I-E). The electronics package consisted of a preamplifier, an ORTEC 456 high voltage power supply, a Tennelec TC 211 linear amplifier, and a Tennelec TC 545 counter-timer.

The alpha smear counter was used in the field and was calibrated daily using an alpha source with a known disintegration rate.

Beta Smear Counter

The beta smear counter consisted of a thin mica window (~2 mg/cm^2) G-M tube mounted on a sample holder and housed in a 23-cm-diam x 35-cm-high lead shield. Located under the counter window is a slotted sample holder, accessible through a hinged door on the shield. An absorber can be interposed in the slot between the sample and the counter window to determine relative beta and gamma contributions to the observed sample counting rate. The electronics for this counter were housed in

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ORNL-Photo 6707-76

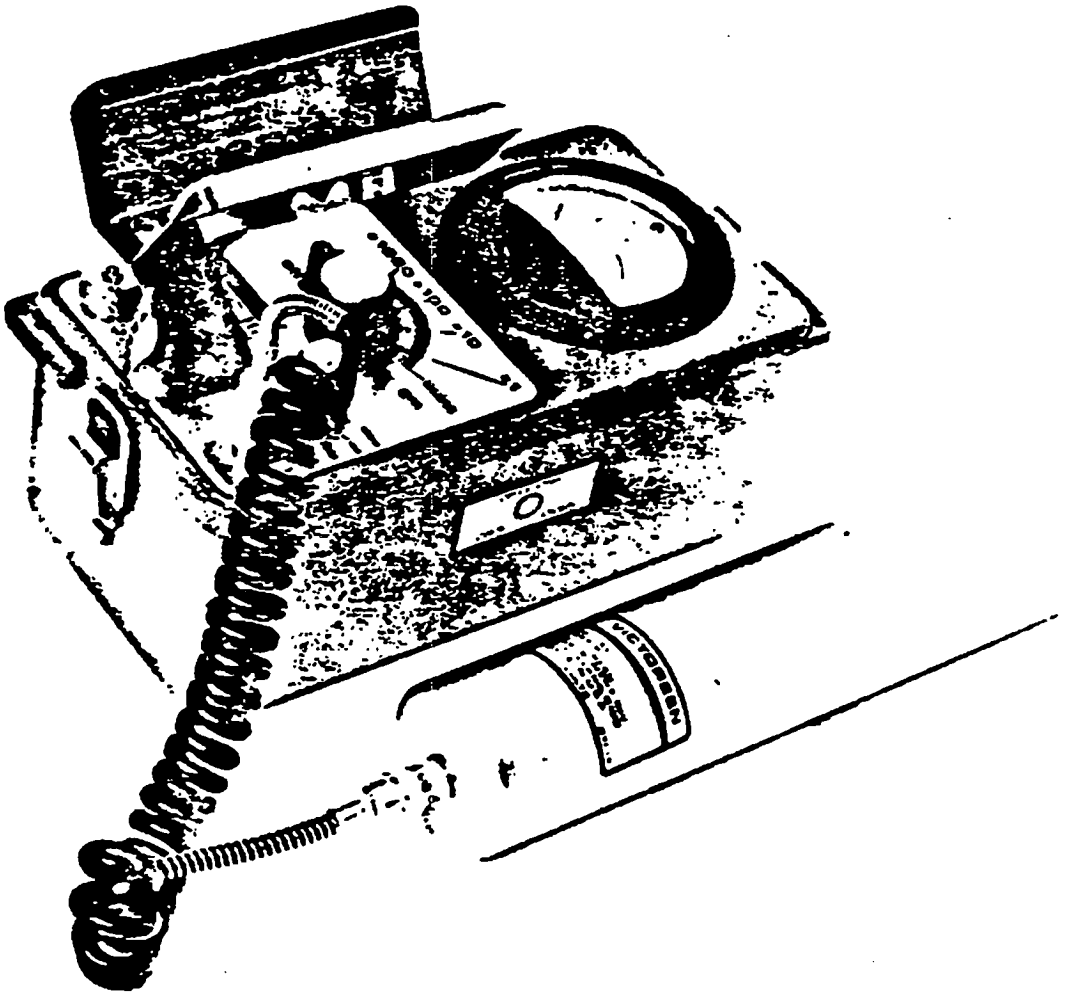

Fig. I-D. Gamma scintillation survey meter.

ORNL-Photo 1070-78

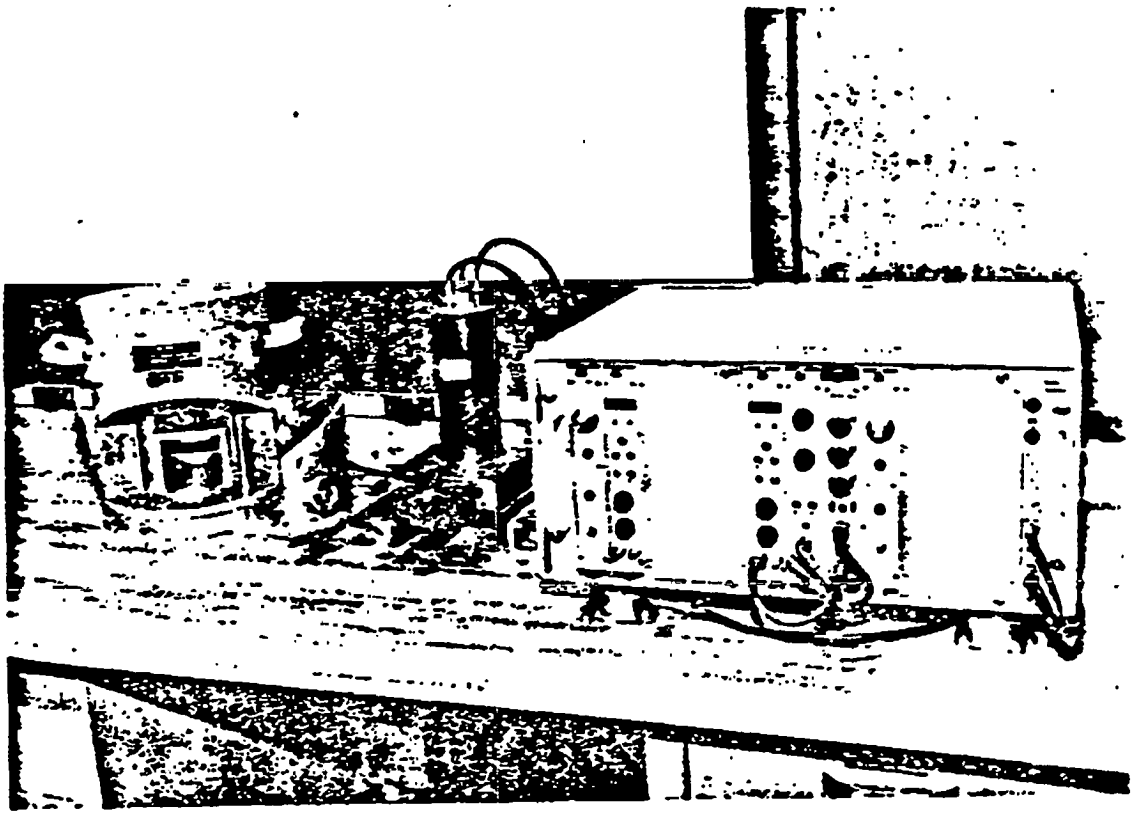

Fig. I-E. Smear counter and associated electronics. The beta counter is on the left and the alpha counter is on the right.

a portable NIM bin and consisted of a Tennelec TC 148 preamplifier, an ORTEC 456 high voltage power supply, and a Tennelec TC 545 counter-timer.

This unit was used in the field to measure beta activity on smear papers and was calibrated daily using a beta standard of known activity (Fig. I-E).

MOBILE LABORATORIES

The mobile laboratories (Fig. I-F) are used during each formal survey to serve as a control center, and to house instruments and other equipment needed during the survey. Each lab is equipped with its own electric generator, mobile radio-telephone, and contains a wide range of well maintained and calibrated instruments. One of the mobile labs has its own microcomputer for data reduction in remote locations.

ORNL-Photo 1068-78

Fig. I-F. Mobile labs used for logistic support during surveys.

APPENDIX II

PERTINENT RADIOLOGICAL REGULATIONS, STANDARDS AND GUIDELINES

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

U. S. Nuclear Regulatory Commission
Division of Fuel Cycle and
Material Safety
Washington, D. C. 20555

November 1976

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The instructions in this guide in conjunction with Table II-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 I 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 I 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 ductwork 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 ductwork. Surfaces of premises, equipment, or scrap, which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.

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

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

   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 I. 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 premies.

   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.

Table II-1. Acceptable surface contamination levels

Nuclides[a]	Average[b,c,f]	Maximum[b,d,f]	Removable[b,e,f]
U-nat, U-235, U-238, and associated decay products	5,000 dpm α/100 cm²	15,000 dpm α/100 cm²	1,000 dpm α/100 cm²
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm²	300 dpm/100 cm²	20 dpm/100 cm²
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm²	3,000 dpm/100 cm²	200 dpm/100 cm²
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except SR-90 and other noted above	5,000 dpm βγ/100 cm²	15,000 dpm βγ/100 cm²	1,000 dpm βγ/100 cm²

[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, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[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 cm².

[e] The amount of removable radioactive material per 100 cm² 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/hr at 1 cm and 1.0 mrad/hr at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

Excerpts from
Proposed
ANSI N328-197

Proposed American National Standard

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

Secretariat
Health Physics Society

Property shall not be released for uncontrolled use unless documented measurements show the total and removable contamination levels to be no greater than the values in Table II-2 or Table II-3. (Table II-3 is easier to apply when the contaminants cannot be individually identified.)

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 made the subject of case-by-case evaluation. Credit shall not be taken for coatings over contamination.

TABLE II-2

SURFACE CONTAMINATION LIMITS

The levels may be averaged[a] over the 1 m^2 provided the maximum activity in any area of 100 cm^2 is less than 3 times the limit value.

Nuclide	Limit (Activity) dpm/100 cm^2	
	Total	Removable
Group 1: Nuclides for which the non-occupational MPC_a^b is 2×10^{-13} Ci/m^3 or less or for which the nonoccupational MPC_w^c is 2×10^{-7} Ci/m^3 or less; includes Ac-227; Am-241; -242m, -243; Cf-249; -250, -251, -252; Cm-243, -244, -245, -246, -247, -248; I-125, -129; Np-237; Pa-231; Pb-210; Pu-238, -239, -240, -242, -244; Ra-226, -228; Th-228, -230.	100	20
Group 2: Those nuclides not in Group 1 for which the nonoccupational MPC_a is 1×10^{-12} Ci/m^3 or less or for which the nonoccupational MPC_w^c is 1×10^{-6} Ci/m^3 or less; includes Es-254; Fm-256; I-126, -131, -133; Po-210; Ra-223; Sr-90; Th-232, U-232.[d]	1000	200
Group 3: Those nuclides not in Group 1 or Group 2.	5000	1000

[a] See note following table on application of limits.

[b] MPC_a: 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 NCRP, ICRP or NRC (10 CFR 20, Appendix B, Table 2, Column 1).

[c] MPC_w: Maximum Permissible Concentration in Water applicable to members of the public.

[d] Values presented here are obtained from 10 CFR Part 20. The most limiting of all given MPC values (e.g., soluble vs insoluble) are to be used. In the event of the occurrence of a mixture of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fractions must be less than one.

TABLE II-3

ALTERNATE SURFACE CONTAMINTION LIMITS

(All alpha emitters, except U-nat and Th-nat are considered as a group.) The levels may be averaged over 1 m^2* provided the maximum activity in any area of 100 cm^2 is less than 3 times the limit value.

Nuclide	Limit (Activity) dpm/100 cm^2	
	Total	Removable
If the contaminant cannot be identified; or if alpha emitters other than U-nat and Th-nat are present; or if the beta emitters comprise Ac-227, Ra-226, Ra-228, I-125, and I-129	100	20
If it is known that all alpha emitters are generated from U-nat and Th-nat; and beta emitters are present which, while not identified, do not include Ac-227, I-125, I-129, Ra-226, and Ra-228	1,000	200
If it is known that alpha emitters are generated only from U-nat and Th-nat; and the beta emitters, while not identified, do not include Ac-227, I-125, I-129, Sr-90, Ra-223, Ra-228, I-126, I-131, and I-133	5,000	1,000

*NOTE ON APPLICATION OF TABLES 1 AND 2 TO ISOLATED SPOTS OR ACTIVITY:

For purposes of averaging, any m^2 of surface shall be considered to be contaminated above the limit, L, applicable to 100 cm^2 if:

a. 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 dpm/100 cm^2 determined from measurement of section i; or

b. On surfaces less than 1 m^2, it is determined that $1/n \sum_n S_i \geq AL$, where A is the area of the surface in units of m^2; or

c. It is determined that the activity of all isolated spots or particles in any area less than 100 cm^2 exceeds 3L.

SURGEON GENERAL'S GUIDELINES
10 CFR 712
Grand Junction Remedial Action Criteria

Federal Register, Vol. 41, No. 253, pp. 56777-8,
Thursday, December 30, 1976

PART 712 - GRAND JUNCTION REMEDIAL ACTION CRITERIA

712.1 Purpose

(a) The regulations in this part establish the criteria for determination by ERDA of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colo., 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 Publ. 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, Colo., 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 the Energy Research and Development Administration or his duly authorized representative.

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

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

(d) "ERDA" means the Energy Research and Development Administration or 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.

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) averaging the results of 6 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-218), 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, Colo.

(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 mill operation involved in the federal uranium procurement program.

(n) "Working Level" (WL) means any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 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 ERDA other than a written interpretation by the General Counsel will be recognized to be binding upon ERDA.

712.5 Communications

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director, Division of Safety, Standards, and Compliance, U.S. Energy Research and Development Administration, 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 recommend 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/hr	Greater than 0.05 WL	Remedial action indicated
From 0.05 to 0.1 mR/hr	From 0.01 to 0.05 WL	Remedial action may be suggested
Less than 0.05 mR/hr	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 ERDA 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 ERDA approved data on indoor radon daughter concentration levels are not available:

(1) For dwellings and schoolrooms:

(i) An external gamma radiation level of 0.05 mR/hr 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 exceeds 0.02 mR/hr 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/hr above background, the indoor radon daughter concentration level is less than 0.01 WL above background and no possible need for remedial action exists.

(C) If the external gamma radiation level is equal to or greater than 0.001 mR/hr above background but is less than 0.02 mR/hr 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/hr 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 or 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.

(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 which the application is received.

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

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

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

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

712.10 Selection of appropriate remedial action

(a) Tailings will be removed from those structures where the appropriately averaged external gamma radiation level is equal to or greater than 0.05 mR/hr above background in the case of dwellings and schools and 0.15 mR/hr 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. ERDA shall select the remedial action technique or combination of techniques, which it determined to be the most appropriate under the circumstances.

ENVIRONMENTAL PROTECTION AGENCY

Title 40-Part 141

Interim Primary Drinking Water Regulations
Promulgation of Regulations on Radionuclides
Federal Register, Vol 41, No. 133, pp. 28402-9
Friday, July 9, 1976

Part 141.15 *Federal Register*
Vol. 41, No. 133, p. 28404, Friday, July 9, 1976

Maximum contaminant levels for ^{226}Ra, ^{228}Ra, and gross alpha particle radioactivity.

(a) Combined ^{226}Ra and ^{228}Ra - 5 pCi/liter.

(b) Gross alpha particle activity (including ^{226}Ra but excluding radon and uranium) - 15 pCi/liter.

APPENDIX III

TECHNIQUES FOR THE MEASUREMENT OF RADON AND RADON DAUGHTER CONCENTRATIONS IN AIR

TECHNIQUE FOR THE MEASUREMENT OF ^{222}Rn PROGENY CONCENTRATIONS IN AIR

An alpha spectrometry technique has been developed for the measurement of ^{222}Rn progeny concentrations in air. From one integral count of the ^{218}Po alpha activity and two integral counts of the ^{214}Po alpha activity, the concentration in air of ^{218}Po, ^{214}Bi, and ^{214}Pb may be calculated.

Particulate ^{222}Rn daughters attached to airborne dust are collected on a membrane filter with a pore size of 0.4 microns. A sampling time of 5 min and a flow rate of 12 LPM are used. This filter sample is then placed under a silicon surface barrier detector and counted. The detector and counting system used for radon daughter measurements are shown in Fig. III-A. Usually, counting of this kind is performed with a vacuum between the sample and the detector which requires a complicated sample holder and time-consuming sample changing methods. Experiments at this laboratory have shown that ease in sample handling is obtained with little loss in resolution when helium is used as a chamber fill gas. In this counter, helium is flowed between the diode and the filter sample, which are separated by a distance of 0.5 cm. One integral count of the ^{218}Po alpha activity is obtained from 2 to 12 min, and two integral counts of the ^{214}Po activity are obtained from 2 to 12 min and 15 to 30 min, respectively. All counting intervals are referenced to $t = 0$ at the end of sampling.

The equations describing the ^{222}Rn progeny atoms collection rates on the filter are of the form

$$\frac{dn_i(t)}{dt} = C_i v + \lambda_{i-1}(t) - \lambda_i n_i(t), \qquad (1)$$

where

n_i = number of the i^{th} species of atom on the filter as a function of time,

λ_i = radioactive decay constant of the i^{th} species (min^{-1}),

C_i = concentration of the i^{th} species (atoms l^{-1}), and

v = air sampling flow rate (liters min^{-1}).

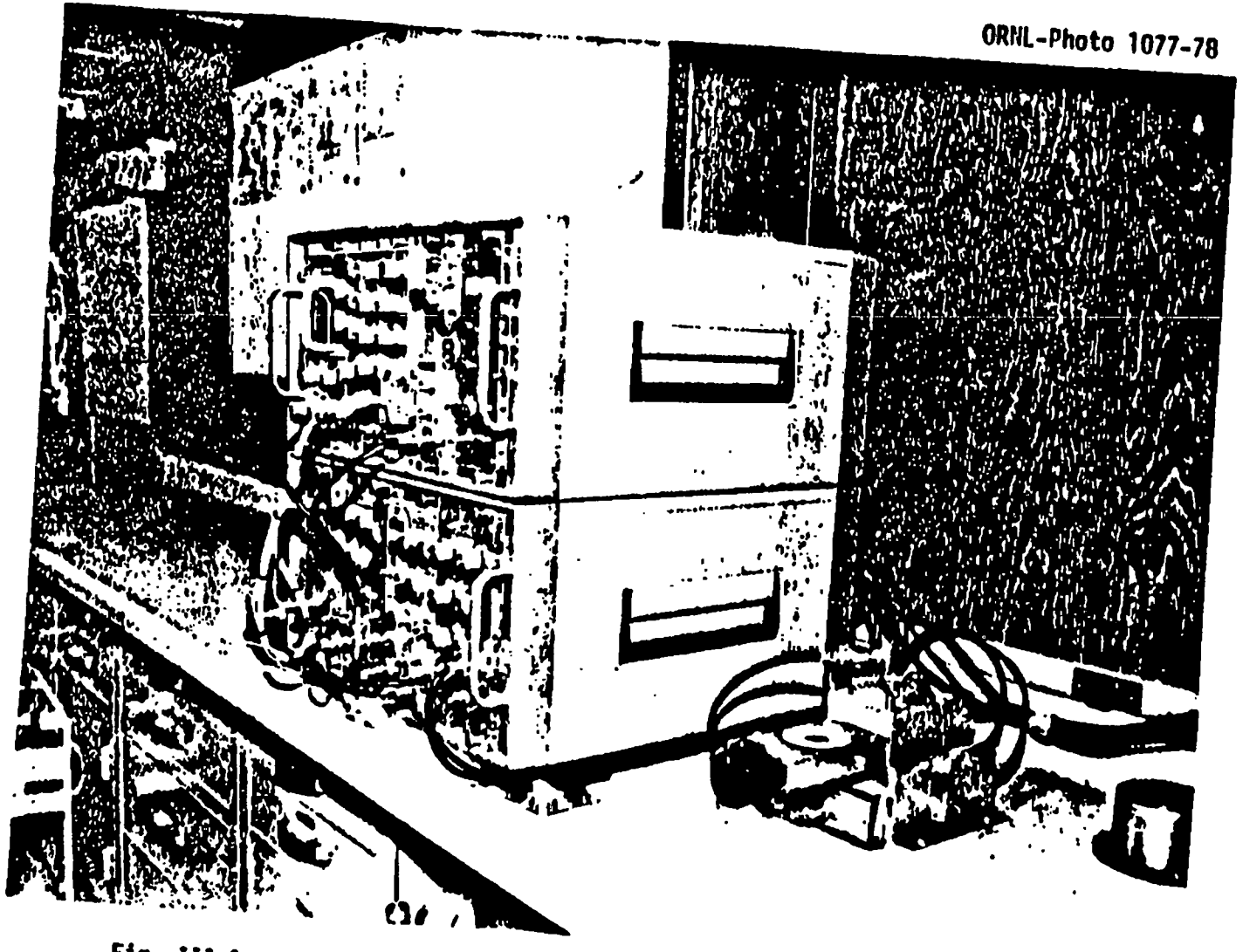

Fig. III-A. System used for measurement of radon daughter concentrations.

The solution of Eq. (1) is of the form

$$n_i(t) = e^{-\lambda_i t}\left\{n_i^o + \int\left[C_i V + \lambda_{i-1} n_{i-1}(t)\right] e^{\lambda_i t} dt\right.$$

From the general form of the solution, specific equations can be obtained describing the number of each ^{222}Rn decay product collected on the filter as a function of time. Also by letting v = 0 in Eq. (1), a set of equations describing the decay on the filter of each ^{222}Rn progeny can be obtained. The equations describing the decay of ^{222}Rn progeny on the filter can be integrated and related to the integral counts obtained experimentally. Values for the total activities of ^{218}Po, ^{214}Pb, and ^{214}Bi on the filter at the end of sampling are obtained by applying matrix techniques. The airborne concentrations are obtained by solving the equations describing the atom collection rates on the filter. A computer program has been written to perform these matrix operations, to calculate the air concentrations of the radon progeny, and to estimate the accuracy of the calculated concentrations.

TECHNIQUE FOR THE MEASUREMENT OF RADON CONCENTRATIONS IN THE AIR

Wrenn Chambers were used for the measurement of ^{222}Rn concentrations in air. The Wrenn Chamber (shown in Figs. III-B and III-C) operates on the principle that most of the RaA ions are postively charged. Radon is allowed to diffuse through a foam-rubber-covered, hemispherically shaped metal screen, which filters radon daughters. As radon decays, after diffusing into the cavity, RaA ions are attracted to a thin aluminized mylar film which is stretched over a zinc sulfide scintillation detector. The potential between this aluminized mylar film and the hemispherically shaped wire screen creates a strong electric field which serves to attract the charged ions. The ions thus attracted remain on the surface of the mylar film and continue their radioactive decay to other radon daughters. The principal radiation detected by a radon monitor of this type is the alpha particles from RaA and RaC'. Alpha pulses are counted and integrated for a fixed period of time,

ORNL-Photo 0686-78

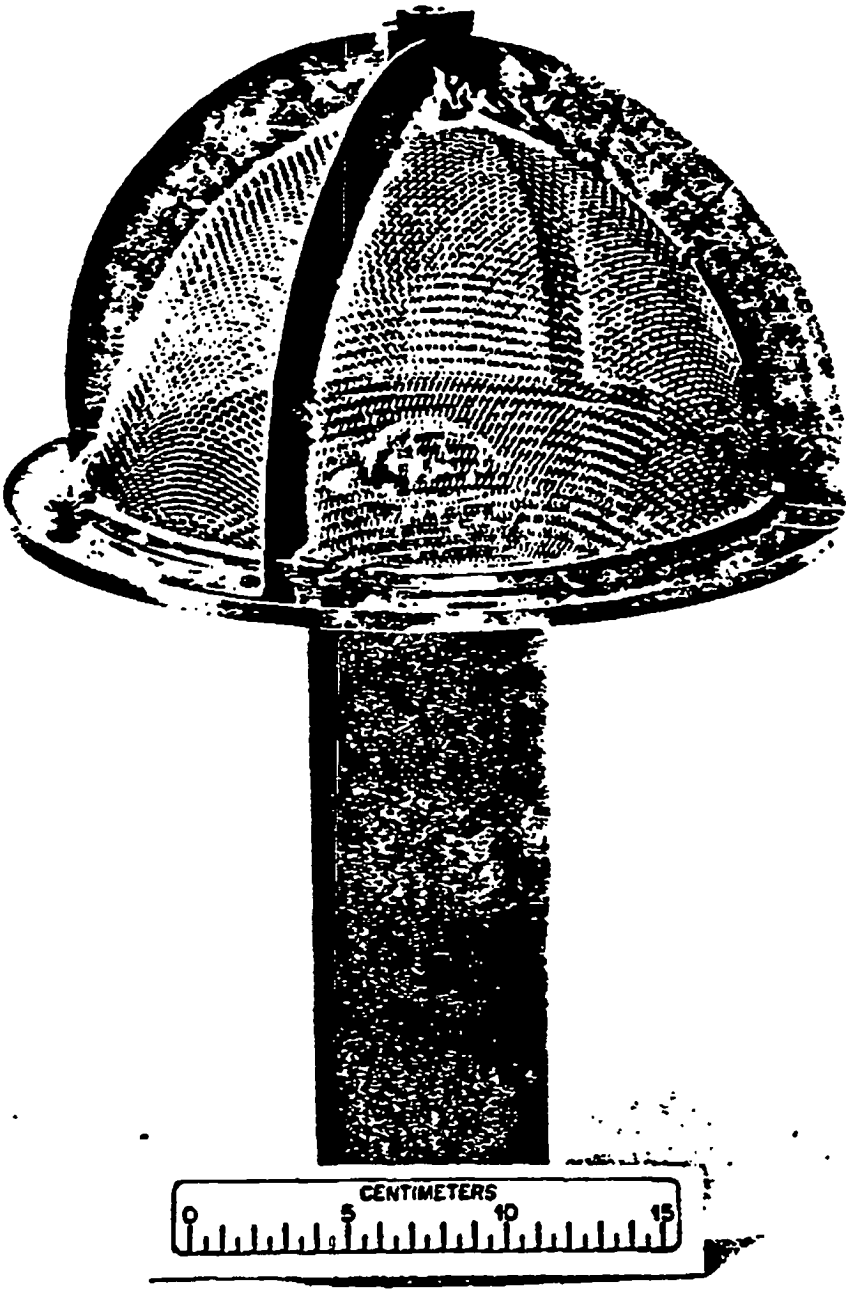

Fig. III-B. View of ionization chamber utilized in ORNL radon monitor. Shown is the photomultiplier housing, screen mesh hemisphere housing, and aluminized mylar covered ZnS scintillator.

ORNL-Photo 0685-78

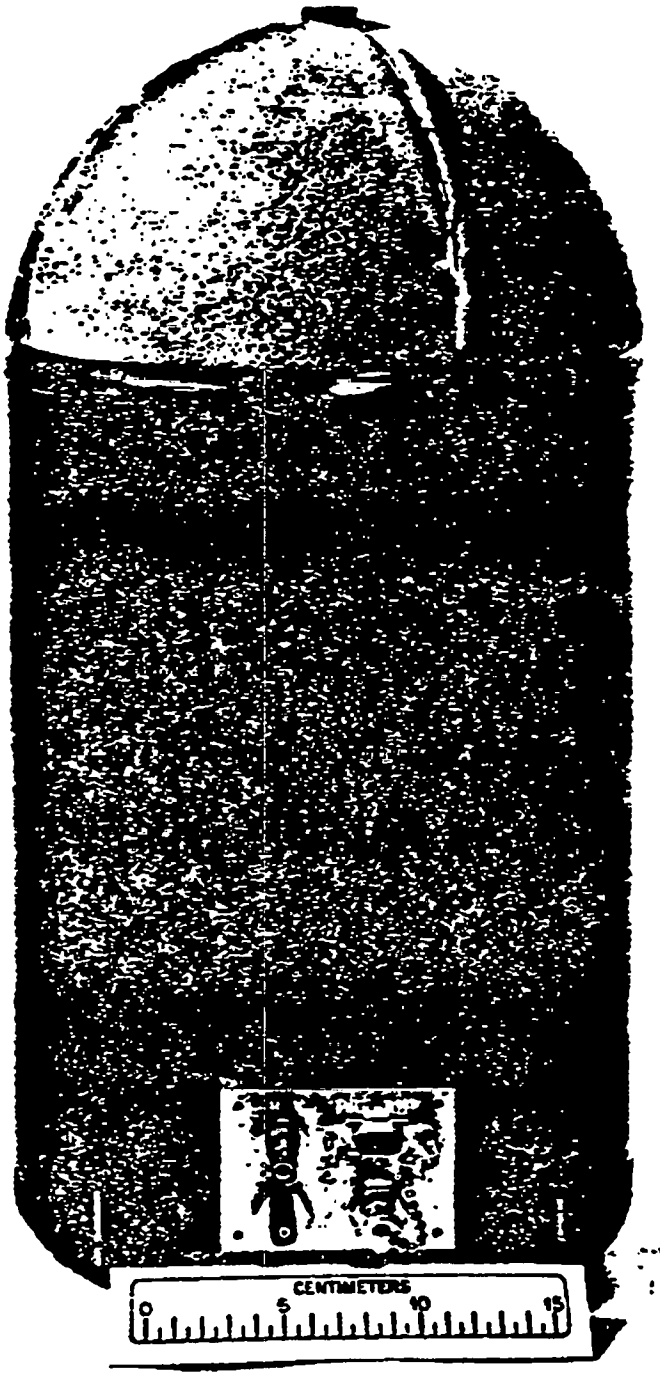

Fig. III-C. Overall view of ORNL continuous radon monitor.

usually 30 min. At the end of each timed counting period, the total count is printed automatically and the system is reset and counting for the next period is initiated. The Wrenn Chambers are calibrated by using a known radon source.

The radon monitor in use by ORNL is similar to that developed by Wrenn, Spitz, and Cohen.[1] However, the scintillation detector is larger (2 in. diam), and a provision has been made to use an alpha check source in order to standardize the chamber before putting it into service (Fig. III-B). The alpha standard is inserted through a hole in the top of the chamber and rests in a fixed and repeatable position. During use of the monitor, the source access hole is plugged with a rubber stopper.

REFERENCE FOR APPENDIX III

1. M. E. Wrenn, H. Spitz, and W. Cohen, *IEEE Trans. Nucl. Sci.* 22, 645 (1975).

APPENDIX IV

DESCRIPTION OF Ge(Li) DETECTOR AND SOIL COUNTING PROCEDURES

DESCRIPTION OF Ge(Li) DETECTOR SYSTEM

A holder for twelve 30-cm^3 polyethylene bottles (standard containers for liquid scintillation samples) and a background shield have been designed for use with a 50-cm^3 Ge(Li) detector system in laboratory counts of radioactivity in environmental samples (Fig. IV-A). During counting of the samples, the holder is used to position ten of the sample bottles around the cylindrical surface of the detector, parallel to and symmetric about its axis, and two additional bottles across the end surface of the detector, perpendicular to and symmetric with its axis. With a 300-cm^3 sample and a graded shield developed for use with the system, it is possible to measure 1 pCi/g of ^{232}Th or ^{226}Ra with an error of ±10% or less and ^{227}Ac within an error of ±30%.

Pulses are sorted by a multichannel analyzer (Fig. IV-B), stored on magnetic tape, and subsequently entered into a computer program which uses an iterative least squares method to identify radionuclides corresponding to those gamma-ray lines found in the sample. The program, which is accessible through a remote terminal, relies on a library of radioisotopes which contains approximately 700 isotopes and 2500 gamma-rays and which runs continuously on the IBM-360 system at ORNL. In identifying and quantifying ^{226}Ra, six principal gamma-ray lines are analyzed. Most of these are from ^{214}Bi and correspond to 295, 352, 609, 1120, 1765, and 2204 KeV. An estimate of the concentration of ^{238}U is obtained from an analysis of the 93 KeV line from its daughter ^{234}Th.

ORNL-Photo 2172-75

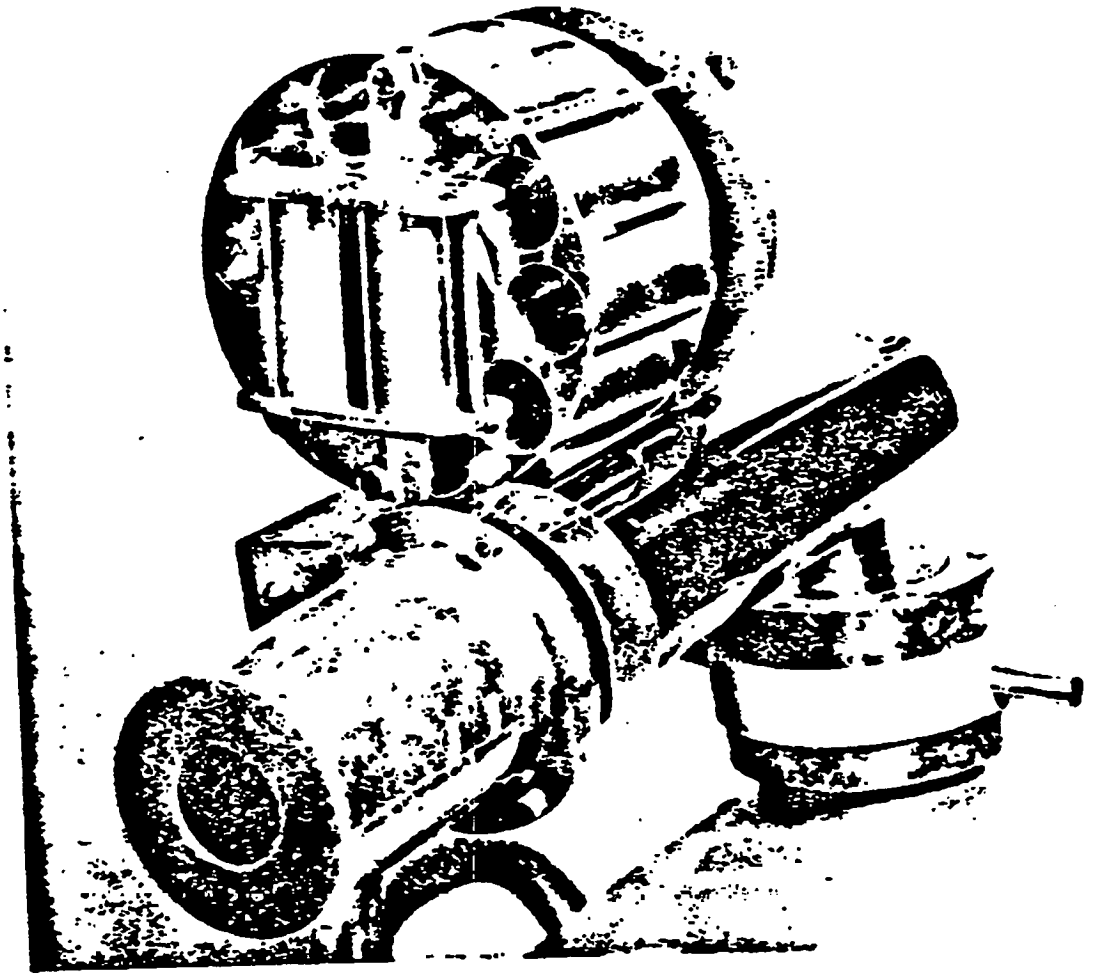

Fig. IV-A. Holder for Ge(Li) detector system.

ORNL-Photo 6719-76

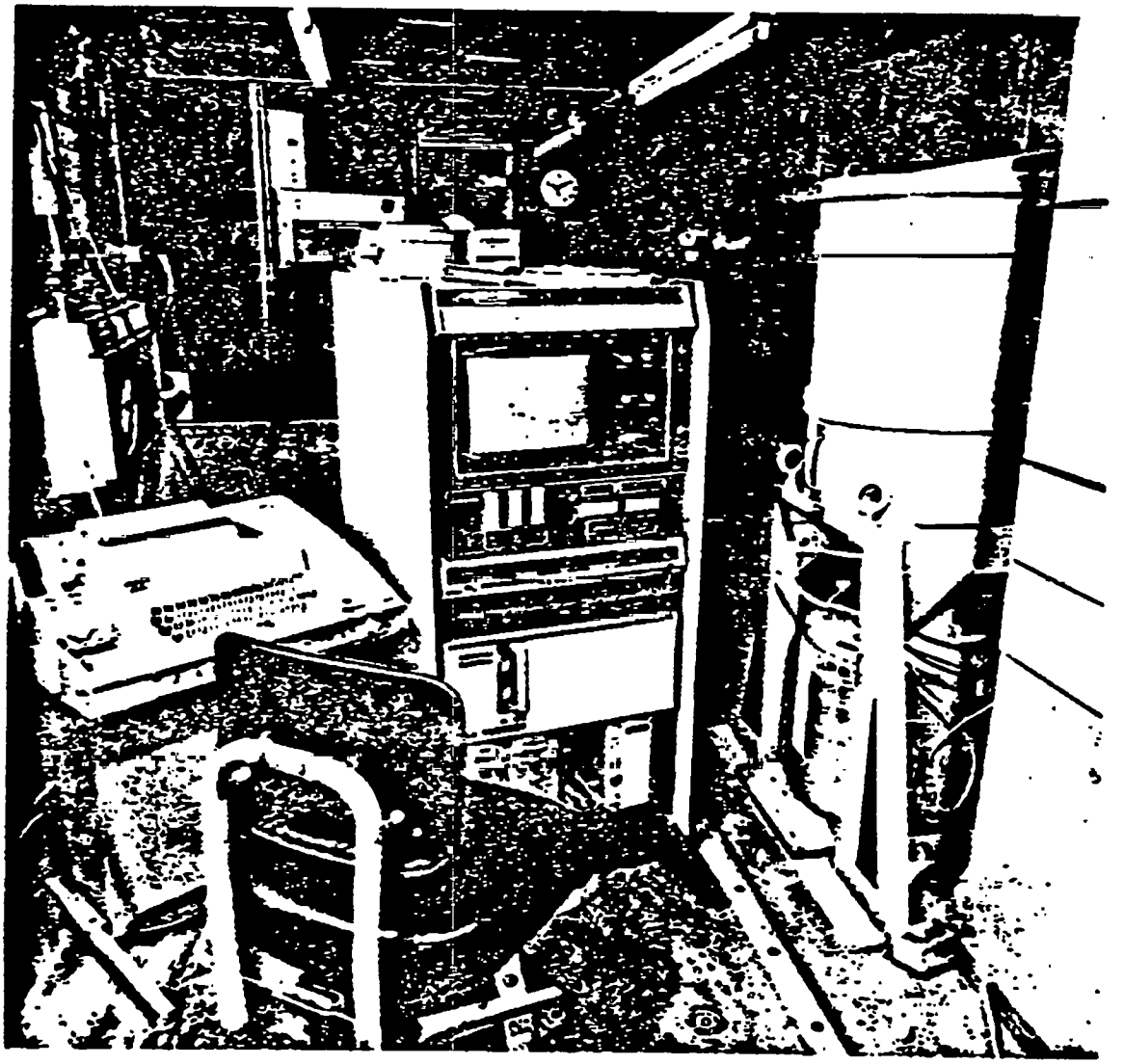

Fig. IV-6. Computer based multichannel analyzer.

APPENDIX V

EVALUATION OF RADIATION EXPOSURES AT THE MALLINCKRODT CHEMICAL WORKS, ST. LOUIS, MISSOURI

EVALUATION OF RADIATION EXPOSURES AT THE MALLINCKRODT CHEMICAL WORKS, ST. LOUIS, MISSOURI

The U. S. Department of Energy has determined that the Mallinckrodt Chemical Works (former Destrehan and Broadway Street plants) in St. Louis, Missouri, is presently contaminated with radioactive residues resulting from previous uses of this property. The Mallinckrodt Chemical Works performed uranium processing for the Manhattan Engineer District (MED) between 1942 and 1947. The contract was shifted to the newly formed U. S. Atomic Energy Commission (AEC) in 1947 and remained under the New York Operations Office until 1954. At this time, the contract was transferred to the AEC operations in Oak Ridge, where it remained until terminated in 1966.

Five separate plants performed a variety of uranium operations. These plants are designated as the Main Plant, Plant 4, Plant 6, Plant 6E, and Plant 7. The Main Plant was used as a refinery for U_3O_8 feed material and pitchblende. These operations ceased in 1945. Plant 6 began operations in 1946 and was used to process pitchblende ore and to produce uranium dioxide (UO_2). Plants 6E and 7 were in operation during the period 1950-51. Plant 6E produced uranium metal and Plant 7 produced green salt (UF_4). Plant 4 operations between 1942 and 1945 consisted of refining pitchblende ore. In 1946, this plant was modified to be used as a metallurgical pilot plant for development work with uranium metal. This operation continued until 1956.

Decontamination surveys were carried out at the Main Plant from 1948 to 1950. A radiological survey was conducted at the Plant 4 site in 1958. This plant and the Destrehan properties were released in 1961-62 for unrestricted use after decontamination work by an AEC subcontractor and Mallinckrodt personnel. All contaminated buildings were removed from Plant 4, followed by the removal of contaminated soil and subsequent backfill with noncontaminated soil. Since 1962, Mallinckrodt has used the property for various purposes related to its commercial chemical operations. It should be kept in mind that parts of the property near Destrehan Street have been used for the storage of naturally radioactive columbian-tantalum ore, which may contribute to

the "background" radioactivity in Plant 6 and parts of Plant 7. In addition, these plants are used for the storage of potassium compounds, which contain potassium-40, a naturally radioactive material.

Contamination at the Mallinckrodt site is due primarily to deposits of natural uranium and radium-226. Employees at this site receive elevated radiation exposures from this contamination. These exposures result primarily from beta-emitting radionuclides located on building surfaces and in surface soils. Additional exposures result from the inhalation of radon and its short-lived daughters produced by radium contamination in the soil. Somewhat lower exposures result from gamma radiation emitted by contamination on surfaces and in soil. Exposures are highest inside structures. Exposures received by ingestion (e.g., eating or drinking in one of the buildings) are relatively small compared with the other means of exposure. A summary of radiation exposures at the Mallinckrodt site is provided in Table V-1 along with appropriate guidelines and background values.

The naturally occurring radionuclides present at the Mallinckrodt site are also present in minute quantities throughout our environment. Concentrations of these radionuclides in normal soils, air, water, food, etc., are referred to as background concentrations. Radiation exposures resulting from this environmental radioactivity are referred to as background exposures. These background exposures are not caused by any human activity and, to a large extent, can be controlled only through man's moving to areas with lower background exposures. Each and every human receives some background exposure daily.

The use of radioactive materials for scientific, industrial, or medical purposes may cause radiation exposures above the background level to be received by workers in the industry and, to a lesser extent, by members of the general public. Scientifically based guidelines have been developed to place an upper limit on these additional exposures. Limits established for exposures to the general public are much lower than the limits established for workers in the nuclear industry.

Table V-1

Summary of Exposure Data at the Mallinckrodt Chemical Works
St. Louis, Missouri

Exposure Source	Background levels	Guideline value for general public	Guideline value for radiation workers	Average levels at St. Louis site
Radon in air	Less than one picocurie[a] per liter of air	Continuous exposure to 3 picocuries per liter of air	Exposure for 40 hours per week and 50 weeks per year to 30 picocuries per liter of air	Average daytime indoor concentration ranged from 0.4 to 37 picocuries per liter of air. Maximum daytime concentration was 69 picocuries per liter of air
Radon daughters in air	Less than 0.01 "working-level"[b]	0.01 working level for residences and school rooms, and 0.03 working level for other structures	0.13 working level for uranium miners exposed for 40 hours per week and 50 weeks per year	Average daytime concentration ranged from 0.(MN)9 working level to 0.07 working level
Gamma radiation from daughters of radium and uranium contamination	8 micro-Roentgens[c] per hour in the St. Louis area	250 microRoentgens per hour above natural background for 40 hours per week and 50 weeks per year for an individual in the general public. This is equivalent to 0.5 Roentgens per year	2500 microRoentgens per hour for 40 hours per week and 50 weeks per year. This is equivalent to 5 Roentgens per year	Gamma radiation levels one meter above the floor or ground ranged from 8 to 290 microRoentgens per hour

[a] The picocurie is a unit which was defined for expressing the amount of radioactivity present in a substance.

[b] The working level is a unit which was defined for radiation protection purposes for uranium miners. It represents a specific level of energy emitted by the short-lived daughters of radon.

[c] The Roentgen is a unit which was defined for radiation protection purposes for people exposed to penetrating gamma radiation. A microRoentgen is one millionth of a Roentgen.

Uranium-238 is believed to have been created when the earth was formed. It is still present today because it takes a very long time to decay. The half-life is a measure of the time required for radioactive decay; for uranium-238, it is 4.5 billion years. Thus, if 4.5 billion years ago you had one curie* of uranium-238, today you would have one-half curie; 4.5 billion years hence, this would only be one-fourth curie. As the uranium-238 decays, it changes into another substance, thorium-234. Thorium-234 is called the "daughter" of uranium-238. In turn, thorium-234 is the "parent" of protactinium-234. Radioactive decay started by uranium-238 continues as shown in Table V-2 until stable lead is formed. The "decay product" listed in Table V-2 is the radiation produced as the parent decays.

Direct Beta-Gamma Dose Rates From Contaminated Surfaces

Nuclear Regulatory Commission (NRC) guidelines state that the combined dose from weakly penetrating beta particles and from gamma rays, measured at a distance of one centimeter from any surface, should not exceed 0.2 millirad† per hour when averaged over an area of one square meter. The combined dose rate should not exceed 1.0 millirad per hour in small areas of 100 square centimeters. Twenty-one buildings were surveyed at the Mallinckrodt site. These buildings are designated as Buildings K1E, 25, 38, 40, 50, 51, 51A, 52, 52A, 81, 100, 101, 116, 116B, 117, 700, 704, 705, 706, 707, and 708. Only buildings 38, 100, 101, and 708 showed no significant surface contamination by beta-gamma emitters. All other buildings had isolated spots of contamination for which these guidlines are exceeded. Dose rates up to 20 millirads per hour were found in these isolated spots. The only building in which guidelines are exceeded over a large fraction of exposed surfaces is Building 705, in which most surfaces display contamination which is

*The curie is a unit used to measure the amount of radioactivity in a substance; one curie represents 37 billion radioactive disintegrations per second.

†The millirad is a unit for measuring radiation dose to tissue and is one-thousandth of a rad.

Table V-2
Uranium-238 Decay Series

Parent	Half-life	Decay products	Daughter
Uranium-238	4.5 billion years	Alpha	Thorium-234
Thorium-234	24 days	Beta, gamma	Protactinium-234
Protactinium-234	1.2 minutes	Beta, gamma	Uranium-234
Uranium-234	250 thousand years	Alpha	Thorium-230
Thorium-230	80 thousand years	Alpha	Radium-226
Radium-226	1600 years	Alpha	Radon-222
Radon-222	3.8 days	Alpha	Polonium-218
Polonium-218[a]	3 minutes	Alpha	Lead-214
Lead-214[a]	27 minutes	Beta, gamma	Bismuth-214
Bismuth-214[a]	20 minutes	Beta, gamma	Polonium-214
Polonium-214[a]	$\frac{2}{10,000}$ second	Alpha	Lead-210
Lead-210	22 years	Beta	Bismuth-210
Bismuth-210	5 days	Beta	Polonium-210
Polonium-210	140 days	Alpha	Lead-206
Lead-206	Stable	None	None

[a]Short-lived radon daughters.

above guidelines. Furthermore, these guidelines are exceeded at many points outdoors, primarily around buildings. Highest readings were obtained around Buildings 50, 51, 51A, 52, 100, 101, 116, 116B, and 117, with beta-gamma dose rates ranging up to 5 millirads per hour on the ground and on exterior walls.

The primary concern of the NRC guidelines is exposure of skin surfaces. The thickness of ordinary shoe soles is adequate to protect the skin of the feet from beta radiation. Other areas of body skin are adequately protected from these exposures if they remain away from these surfaces. In most cases, exposures are negligible at a distance of 1 foot away from these surfaces.

Direct contact with the most contaminated indoor area (20 millirads per hour) for one hour would produce a beta-gamma dose of 20 millirads to the skin. For comparison, the skin dose which would be expected from a normal year's watching of color television by an adult is 1.6 millirads; for a child less than 15 years of age, the comparable dose is 3.6 millirads per year (according to the United Nations Scientific Committee on the Effects of Atomic Radiation). For another comparison, the NRC limit for beta-gamma dose rate for skin of the whole body of radiation workers would be equivalent to 15 millirads per hour for 500 hours in any calendar quarter; the dose rate limit for hands, forearms, feet, and ankles would be equivalent to 37.5 millirads per hour for radiation workers.

External Gamma-Ray Exposure

As may be seen in Table V-2, several of the daughters of uranium-238 and of radium-226 emit gamma radiation (gamma rays are penetrating radiation like X-rays). Hence, the contaminated areas are sources of external gamma radiation exposure. External gamma-ray exposure rates measured at one meter above the ground both in buildings and in the outside area are generally on the order of 10 microRoentgens* per hour. Background external gamma-ray exposure rates in the St. Louis area

*The Roentgen is a unit which was defined for radiation protection purposes for people exposed to penetrating gamma radiation. A micro-Roentgen is one-millionth of a Roentgen.

range from 7 to 9 microRoentgens per hour. Most measurements made at the Mallinckrodt site were within the range of normal background for the St. Louis area, with only isolated readings exceeding this range. The highest single indoor exposure rate of 100 microRoentgens per hour was obtained in Building K1E. The highest measurement obtained at the site was 290 microRoentgens per hour at a point located between Buildings 101 and 116.

The highest indoor gamma radiation level averaged over an entire building was 30 microRoentgens per hour averaged over the floor of building K1E. Exposure to this level for 2000 hours per year, a typical work year, would lead to an exposure of 60,000 microRoentgens. For comparison, a typical chest X-ray (according to Department of Health, Education, and Welfare data might yield an exposure of 27,000 microRoentgens.

The National Council on Radiation Protection and Measurement (NCRP) has recommended as a maximum annual whole-body exposure rate of 500,000 microRoentgens per year to an individual in the general public. This value corresponds to 250 microRoentgens per hour for 2000 exposure hours (40 hours per week and 50 weeks per year). This guideline would be exceeded only at the one outdoor point where the maximum exposure rate was observed. It appears that employees at the Mallinckrodt site are receiving gamma radiation exposures which are little different from background.

Inhalation of Radionuclides

Radon-222, the daughter of radium-226, is an inert gas which may leave the soil and enter the atmosphere. This gas can also seep through concrete floors and accumulate in structures. Exposures to radon-222 produced by contamination at the Mallinckrodt site exceed, in several cases, the concentration guideline for the general public of 3 picocuries* per liter given in 10 CFR 20.† Highest concentrations were

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*One picocurie is one million-millionth of a curie, previously defined.

†Title 10, Code of Federal Regulations, Part 20, is a regulatory document published by the Nuclear Regulatory Commission and may be found in the *Federal Register*.

obtained in Buildings K1E, 52A, and 101, where the radon concentration ranged up to 22, 37, and 69 picocuries per liter of air, respectively, and averaged 6.4, 37, and 6.6 picocuries per liter, respectively. Concentrations in all other buildings were below the guidelines in 10 CFR 20, but estimates indicate that concentrations in several of these structures could exceed guidelines under certain conditions of poor ventilation, as in winter months.

As may be seen in Table V-2, the decay of radon-222 produces a series of short-lived daughters. The unit which has been developed to measure the concentration of daughters is the working level.* Measurements at the Mallinckrodt site were generally below the guideline value of 0.03 working level suggested in 10 CFR 20. This guideline was exceeded only in Building 52A where a daughter concentration of 0.07 working level was observed. Concentrations in Buildings K1E and 101 approached, but did not exceed this guideline. However, even slight decreases in the amount of ventilation air flowing through these buildings could raise the daughter concentrations above the 0.03 working level guideline.

Studies of uranium and other hard rock miners have established that inhalation of large quantities of daughters of radon-222 over long periods of time increases an individual's risk of contracting lung cancer. The present federal guide value for uranium mine workers (given by the Environmental Protection Agency), when translated to the units discussed here, would limit mine workers to an exposure of 0.33 working levels, assuming exposure for 2000 hours per year, a typical work year. This level is significantly lower than the exposures received by most of the miners included in the studies.

Other Considerations of Exposure

The concentrations of radionuclides in water samples taken at the site were generally below the concentration guide for water (CG_w) set forth in 10 CFR 20. The only sample in which the concentration exceeded

*The working level is a unit which was defined for radiation protection purposes for uranium miners. It represents a specific level of energy emitted by the short-lived daughters of radon.

this guide value was a ground water sample taken from a hole drilled into a waste pit near Buildings 101 and 116. This sample contained uranium-238 in a concentration of 59 picocuries per milliliter. The concentration guide value for uranium-238 is 40 picocuries per milliliter. Water samples taken at the point where site drainage enters the Mississippi River indicate that no signficant contamination is being eroded into this river.

While no crops are currently grown on this site, use of the contaminated soil for such purposes could produce additional human exposure through consumption of crops which have incorporated radium-226. In addition, actions which involve considerable scraping of dry soil or contaminated surfaces, particularly in the areas showing high concentrations of radium in surface soil and in areas near and on the ionium pad, could lead to additional human exposures through inhalation of airborne radioactive dust.

Risk and Radiation Exposures

Risks resulting from radiation exposures should be considered within the context of other risks incurred in normal living. For simplicity, risks to health may be classified in four categories:

1. Unacceptable--problems with risk so high as to require immediate action, such as severe diseases where medical treatment is required to save a life.
2. Concerned--problems where people are willing to spend time and money to reduce potential hazards. Examples of this include the maintenance of public highways and signs, signals, fire departments, and rescue squads.
3. Recognized--problems where people may accept some inconvenience to avoid certain activities such as flying in airplanes, swimming alone, etc.
4. No great concern--problems with a low frequency of occurrence. There is an awareness of potential hazard, but an accompanying feeling that these problems occur only to other people.

An individual may be exposed to risks over which he can exercise some control (voluntary), and risks over which he feels he has no personal control or choice (involuntary).

Daily, an individual is confronted with decisions about risks which have an associated benefit--for example, driving a car. This can serve as an illustration that a voluntary, concerned risk may be deemed appropriate due to the desirable perceived benefit. As another example, an individual who smokes cigarettes has subjected himself to a risk of lung cancer which is about ten times higher than that for a nonsmoker.

For purposes of radiation protection, all radiation exposures are assumed to be capable of increasing an individual's risk of contracting cancer. A precise numerical value cannot be assigned with any certainty to a given individual's increase in risk attributable to radiation exposure. The reasons for this are numerous; they include the individual's age at onset of exposure, variability in latency period (time between exposure and physical evidence of disease), the individual's personal habits and state of health, previous or concurrent exposure to other cancer-causing agents, and the individual's family medical history. Because of these variables, large uncertainties would exist in any estimates of the number of increased cancers in the relatively small working population at the Mallinckrodt site.

The normal annual death rate* from lung cancer for all population groups in St. Louis County (as of 1970) was 23.4 deaths per 100,000 population. At the same time, the annual death rate from lung cancer for all population groups in the United States and the State of Missouri were 21.1 and 20.6 deaths per 100,000 population, respectively. A one-year exposure to the guideline value for uranium miners (0.33 working level for 2000 hours) might increase the risk of death due to lung cancer by approximately four percent.

The annual death rate from all types of cancer among all population groups in St. Louis County (as of 1970) was 154 deaths per 100,000

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*Mortality statistics were obtained from data in *U. S. Cancer Mortality by County: 1950-1969*, prepared by the National Cancer Institute, 1973, available from the U. S. Government Printing Office.

population. At the same time, the death rate from all types of cancer for population groups in the United States and in the State of Missouri were 151 and 150 per 100,000 population, respectively. A one-year exposure to penetrating gamma radiation of 500,000 microRoentgen might increase the risk of death due to all types of cancer by about one-tenth of a percent. Exposures in excess of these guideline values would be expected to result in proportionately higher increases in risk. Consequently, any action taken to reduce either the rate or the duration of radiation exposures would also reduce the risk attendant to that exposure.

There are no data at present which give evidence of a relationship between low-level exposure of the skin and the development of skin cancers. This does not mean that skin cancer cannot be produced by low-level exposures. This does mean that the risk associated with guideline level exposures of the skin is so small that it cannot be quantified.

Remedial Measures

Radiation exposures associated with beta and gamma contamination of surfaces might be reduced by a thorough cleaning, washing, and vacuuming of all building surfaces in Buildings K1E, 40, 50, 51, 51A, 52, 116, 117, 700, and 705. Contaminated outdoor surfaces throughout the site and isolated areas in Buildings 25 (benches, etc.), 704, 706, 707 also might be thoroughly cleaned. Exposures to radon and radon daughters could be reduced by removal of contaminated soil which appears to spread over the site. This contamination is typically distributed in the soil to a depth of three to five feet, but extends to a depth of ten feet or more in some areas, particularly in soil located near and under Buildings 50, 51, 51A, 52A, and 52. Short-term remedial measures, such as sealing porous building surfaces to reduce radon entry might be applicable to Buildings K1E, 52A, and 101. Drains in buildings and outdoor areas which were involved in the processing operations should be cleaned and sealed. The Department of Energy is now actively evaluating these and other alternatives under a priority program designed to assure public protection.

SUMMARY

The Mallinckrodt Chemical Works is contaminated with residues containing naturally occurring uranium-238 and radium-226. This contamination results from previous uses of this site for uranium processing under MED and AEC contracts. Contamination on many building surfaces exceeds guidelines set by the Nuclear Regulatory Commission for the release of property for unrestricted use. In addition, this contamination is producing exposures to radon and its short-lived daughters which exceed guidelines in several buildings on the site. Consequently, remedial measures are in order. The Department of Energy has developed a coordinated plan which addressed the specific problems at the Mallinckrodt site and other formerly utilized MED/AEC sites. Currently, work is under way to implement the elements of this plan.

APPENDIX VI

SI METRIC CONVERSION TABLE

SI METRIC CONVERSION TABLE

The following table has been developed for use with this report in the conversion of units of measurement from those utilized in the text to the newly adopted International System of Units (SI). Units used in the text which do not appear in this table are considered as standard under the new system.

Standards units of measurement

To convert from	Into SI units	Multiply by
Gallons (gal)	liters (l)	3.785
Inches (in)	centimeters (cm)	2.540
Square inches (in^2)	square centimeters (cm^2)	6.452
Feet (ft)	meters (m)	0.3048
Square feet (ft^2)	square meters (m^2)	0.0929
Acres (a)	hectare (ha)	0.4047
Miles (mi)	kilometer (km)	1.609
Millirad (mrad)	microgray (μGy)	10.0
Microroentgen (μR)	coulomb per kilogram (C/kg)	2.85×10^{-10}
Disintegrations per minute (dpm)	becquerel (Bq)	0.02
Picrocurie (pCi)	becquerel (Bq)	0.037
Microcurie (μCi)	becquerel (Bq)	3.7×10^4

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