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Radiological Survey of the Former Uranium Recovery Pilot and Process Sites, Gardinier, Incorporated, Tampa, Florida

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HEALTH AND SAFETY RESEARCH DIVISION
OAK RIDGE NATIONAL LABORATORY

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FINAL REPORT

RADIOLOGICAL SURVEY OF THE FORMER URANIUM RECOVERY PILOT AND PROCESS SITES, GARDINIER, INCORPORATED, TAMPA, FLORIDA

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Work performed
as part of the
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RADIOLOGICAL SURVEY OF THE FORMER URANIUM RECOVERY PILOT AND PROCESS SITES, GARDINIER, INCORPORATED, TAMPA, FLORIDA

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ABSTRACT

A radiological survey was conducted at a former uranium recovery plant near Tampa, Florida, operated as a part of a phosphoric acid plant. The uranium recovery operations were conducted from 1951 through 1960, the primary goal being the extraction of uranium from phosphoric acid. Pilot operations were first carried out at a small plant, and full-scale extraction was later carried out at a larger adjacent process plant. The survey included measurement of the following: beta-gamma dose rates at 1 cm from surfaces and external gamma radiation levels at the surfaces and 1 m above the floor inside the pilot operations building and process building and outdoors in areas around these buildings; fixed and transferable alpha and beta-gamma contamination levels on the floor, walls, ceilings, and roof of the process building and on the floor, walls, and ceiling of the pilot plant offices; concentrations of ^{226}Ra and ^{238}U in soil samples taken at grid points around the buildings and in residue samples taken inside the process building; concentrations of ^{226}Ra and ^{238}U in water and sediment samples taken outdoors on the site and the concentration of these same nuclides in background samples collected off the site. It was found that beta-gamma and/or alpha contamination levels on surfaces exceed current guidelines for the release of property for unrestricted use at some points inside the process building and in the outdoor area near the process building and pilot operations building. Some samples of soil and residue taken from the floor and equipment on the second level of the process building contained natural uranium in excess of 0.05% by weight and contained natural radium in excess of 900 pCi/g.

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*Consultant.

INTRODUCTION

At the request of the Department of Energy (DOE), a radiological survey was conducted during the period December 14-19, 1977, at a former uranium recovery plant area near Tampa, Florida, presently operated by Gardinier, Inc., and now used for the production of phosphoric acid and other phosphate products. The plant is located on the west side of U.S. Highway 41, approximately seven miles south of the intersection of this highway with Interstate 4. A plan view of the former uranium recovery plant is shown in Fig. 1, and a plan view of the entire Gardinier plant (with the surveyed area outlined) is shown in Fig. 2.

The primary purpose in Gardinier's uranium work was the extraction of uranium from phosphoric acid. This extraction process employed by Gardinier consisted of five main steps: (1) pretreatment of wet process phosphoric acid, (2) solvent extraction of uranium, (3) precipitation of the uranium product, (4) drying and crushing, and (5) handling, packaging, and shipping. Pilot operations were carried out from 1951 through 1954, and the process plant was operated from 1956 through 1960, reaching a peak output of 60 tons of uranium concentrate per year. The process plant (see Fig. 1) consisted of a three-story building, an adjacent chemical processing plant area, and a small area where drying and crushing equipment was located. The building currently houses a workshop, a lunchroom, and offices on the first floor, and an office and machinery on the third floor. The second floor serves as a storage area for abandoned equipment used for the uranium recovery operations. The former pilot operations building (Fig. 1) now serves as office space. There are approximately 20 full-time employees in the former pilot operations building. These buildings, along with the surrounding area which includes the old drying and crushing, and chemical processing sites, were surveyed.

Some pilot uranium recovery operations are presently underway in an area immediately west of the processing plant (Figs. 1 and 2). Since this work is being done under a license issued by the state of Florida, no measurements were made in this area.

The present survey was undertaken to determine the extent of residual radioactivity on the site resulting from the former uranium recovery operations. It was conducted by five members and one consultant of the Health and Safety Research Division, Oak Ridge National Laboratory (ORNL), during the period December 14-19, 1977. The survey included (1) measurement of beta-gamma dose rates at 1 cm and external gamma radiation levels at the surface and at 1 m above the floor inside the pilot building and process building and outdoors in the areas around these buildings; (2) measurement of fixed and transferable alpha and beta-gamma contamination levels on the floors, walls, ceiling, and roof of the process building, and on the floor, walls, and ceiling of the pilot plant offices; (3) measurement of ^{226}Ra and ^{238}U in soil samples taken at grid points around the buildings and in residue samples taken inside the process building; (4) measurement of ^{226}Ra and ^{238}U in water and sediment samples taken outdoors on the site; and (5) measurement of ^{226}Ra and ^{238}U in background soil samples collected off the site.

SURVEY METHODS

Instrumentation

Direct Beta-Gamma Measurements

Beta-gamma dose rates were measured with a Geiger-Mueller (G-M) survey meter described in Appendix I. The instrument was calibrated at ORNL through the use of sealed isotopic sources and by comparison with a Victoreen Model 440 ionization chamber (see Appendix I). It was determined that, for surfaces contaminated with ^{226}Ra in equilibrium with ^{238}U and other radionuclides of the ^{238}U chain, an open-window reading of 2,000 cpm on the G-M survey meter is equivalent to approximately 1 mrad/hr. For surfaces contaminated with initially ^{226}Ra-free uranium, the proper conversion factor is 2,300 cpm = 1 mrad/hr. Since the

relative activities of the radionuclides on the surface are uncertain at most points, the more conservative conversion factor of 2,000 cpm = 1 mrad/hr was used for all surfaces. It appears that, in extreme cases, the error involved in using this conversion factor may be as high as 60% for individual measurements; however, the error involved in determining the 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 is 3,200 cpm = 1 mrad/hr with an error of ±30%. This factor was determined at ORNL using a ^{226}Ra source.

External Gamma Radiation Measurements

External gamma radiation levels at 1 m were measured with NaI scintillation survey meters described in Appendix I. These instruments are extremely sensitive and are capable of detecting increments of 1 to 2 μR/hr at low levels of gamma radiation. Since the response of these instruments is highly energy dependent, a cross calibration was performed on and near the site with a scaler-equipped G-M counter[1] which is filtered with a combination of tin and lead in thin layers to provide an estimate of the exposure rate that is nearly independent of photon energy. A conversion factor of 500 cpm = 1 μR/hr was determined for the scintillation counter.

Direct Alpha Measurements

Direct alpha measurements were made with alpha scintillation survey meters described in Appendix I. These instruments are equipped with scalers which allow integration of counts over 15, 30, or 60 sec, permitting direct alpha measurements on surfaces with low-level alpha contamination. If counts are integrated over a period of 15 sec, the count-rate error associated with a direct measurement of 5,000 dpm/100 cm^2 [a Nuclear Regulatory Commission (NRC) guideline value for surfaces contaminated with natural uranium] is ±15%. A direct measurement of 300 dpm/100 cm^2, determined over a period of only 15 sec, would

have a count-rate error of ±60%, and a direct measurement of 100 dpm/100 cm^2, determined over a period of only 15 sec, would have a count-rate error of ±100%. Hence, for those points where measurements were integrated for only 15 sec, results are given only to the nearest hundred dpm/100 cm^2.

Measurement of Transferable Alpha and Beta Contamination

Transferable alpha and beta contamination levels were measured using the standard smear techniques described in NRC guidelines (Appendix III). The smears were counted using the alpha and beta smear counters shown in Appendix I. The count-rate error associated with a 1-min count of a smear showing a transferable alpha contamination level of 1,000 dpm/100 cm^2 (an NRC guideline value for natural uranium) is approximately ±6%; the count-rate error for a transferable beta contamination level of 1,000 dpm/100 cm^2 is approximately ±15%. Indeterminable errors are introduced in taking smear samples because of variations in pressure applied, in surface area actually contacted, and in the condition of the surface.

Methods Used to Analyze Samples

Soil samples collected outdoors were packed in plastic bags and returned to ORNL, where they were dried for 24 hr at 110°C and then pulverized to a particle size of no greater than 500 μm in diameter (-35 mesh). Next, aliquots from each sample were transferred to plastic bottles, weighed, labeled, 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 II. Concentrations of ^{238}U, ^{226}Ra, and ^{232}Th were estimated in this way. In addition, a second measurement of the ^{238}U concentration in each sample was obtained by neutron activation techniques described in Ref. 2, and it is the latter value for ^{238}U which is used in this report.

Water samples collected on the site were analyzed by the Analytical Chemistry Division of ORNL for ^{210}Pb, ^{226}Ra, and ^{230}Th, using techniques described in Appendices to the ORNL Master Manual. Neutron activation techniques were also used for the analysis of ^{238}U in water.

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. The division of large areas into small survey blocks is convenient for reporting purposes. In addition, the measurement of radiation levels in numerous small, equally "weighted" areas allows statistically meaningful estimates of average contamination levels on the site. Finally, the reporting of both randomly chosen and maximum contamination levels for individual survey squares serves to define the degree of nonuniformity of contamination. For these reasons, wherever practical, areas were divided into survey blocks by rectangular grid systems.

Indoor Survey Plan

All floors and lower walls were divided into survey blocks, usually by grid systems consisting of lines parallel to the bases of the walls and separated by distances of approximately 2 m. Hence, a typical survey block covers an area of approximately 4 m^2. The particular survey blocks used for each floor are shown in Figs. 3 through 7. Small offices in the pilot plant and on the first floor of the process plant were considered as separate survey blocks and results are reported for the entire room. Those survey blocks which were inaccessible due to machines, storage cabinets, or other equipment are labeled NA (not accessible) in the tables.

At the center of each survey block (or as close as possible to the center, if the center was inaccessible) five open-window and five closed-window G-M survey meter readings at 1 cm were taken within a predetermined area of 1 m^2, and the averages of these readings were recorded. Also, five direct measurements were made of alpha contamination on the surface at the same points at the beta-gamma measurements and the average of these readings was recorded. Then the external gamma radiation level was measured at 1 m above the midpoint of floor blocks. Next, the entire survey block was scanned with the open-window G-M survey meter and the maximum reading was recorded. A closed-window G-M reading at 1 cm and a direct alpha reading at the surface were then taken at this

"maximum beta-gamma point." Finally, a smear was taken at random points in the block for the determination of transferable alpha and beta contamination levels.

On overhead surfaces (i.e., ceilings, structural members, and wall surfaces more than 6 ft above the floor) direct alpha and beta-gamma contamination levels and transferable alpha and beta contamination levels were measured within blocks defined by the survey blocks on the floor. A distinction was made between horizontal and vertical overhead surfaces because horizontal overhead surfaces often show higher contamination levels than vertical overhead surfaces.

The roof of the process building was surveyed for alpha and beta-gamma contamination. Measurements were made at randomly selected points within the survey blocks indicated in Fig. 8.

The floor surface of the process plant's second level was covered over most of its area with a residue extending from a few millimeters to several centimeters in thickness. This residue originated from airborne material which precipitated over the years. It became necessary to clean an area in each survey block before surface radioactivity readings could be taken. In place of smear samples, residue samples were taken in each survey block and analyzed for ^{238}U using neutron activation techniques. Since the floor was still wet after removal of the residue, the direct alpha measurements may be lower than if the floor had been dry.

The ceilings in both the former pilot plant and the office area of the process plant had been lowered using the suspended ceiling techniques. As a result, it was necessary to remove selected ceiling tiles and take readings on the old support structure located above. These readings are reported in the tables as ceiling readings for these two sections.

Outdoor Survey Plan

The areas surrounding the process plant and the pilot plant were divided by the rectangular grid systems indicated in Figs. 9 and 10. Open- and closed-window G-M readings at 1 cm were taken, along with gamma scintillation survey meter readings at 1 m at those points indicated by circles (open and closed) in Figs. 9 and 10.

Surface samples were taken at several points in both parcels of land; sampling locations are shown as closed circles in Figs. 9 and 10. All surface samples were analyzed for ^{226}Ra and ^{238}U. In addition, water samples were taken from several surface deposits in both parcels. All water samples were returned to ORNL for determination of their ^{226}Ra and ^{238}U content. Water sediment samples were also taken at the same points as water samples and were returned to ORNL for analysis.

The site of the dryer for uranium concentrates was located and divided with the grid system shown in Fig. 11. Again, open- and closed-window G-M readings at 1 cm and gamma scintillation survey meter readings at 1 m were taken at the grid points, and several soil samples were collected.

In addition to the systematic survey of the areas defined by the grid lines, several points were chosen for a more extensive survey because of possible contamination suggested by the history of the site. One such site was a storage vault, located at one time on the east side of the pilot plant (see Fig. 1). This area was scanned with a G-M survey meter at 1 cm, with maximum and average readings being recorded. Direct alpha readings were taken in this area, as were scintillation survey meter measurements at 1 m.

There exists on the west end of the process plant a series of pipes and reaction vessels which had been used in the uranium extraction process. Preliminary G-M survey meter measurements indicated elevated dose rates inside certain pipes and at the surfaces and flanges of the reaction vessels. A more systematic survey was conducted on all three levels and the findings are discussed in the section on survey results.

Background Measurements

Background external gamma radiation levels at 1 m above the ground were measured at points several miles from the site at five widely separated points (see locations FL3 through FL7 in Fig. 12). The average of these background measurements was 5 μR/hr.* Soil samples taken at

*This is in good agreement with Ref. 3, where an average background of 5 to 7 μR/hr is claimed for Central Florida.

these same points showed ^{226}Ra concentrations ranging from 0.3 to 2.3 pCi/g, ^{238}U concentrations ranging from 0.1 to 1.1 pCi/g, and ^{232}Th concentrations ranging from 0.3 to 0.4 pCi/g.

Background beta-gamma dose rates, as measured with the G-M survey meters used on the site, are typically in the range 0.01 to 0.05 mrad/hr. Geiger-Mueller survey meter readings in this range (below 100 cpm) are frequently not reproducible; however, these typical background readings are reported for purposes of comparison with on-site readings. Background alpha readings for the type of alpha survey meter used on this site are negligible.

All direct survey 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. 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.

Guidelines Used to Evaluate Survey Results

Radiation guidelines used to evaluate survey data are given in detail in Appendix III. The applicability of certain guidelines to this site is discussed in this section.

The strictest NRC guidelines for alpha emitters apply to ^{226}Ra (among other radionuclides), and the contamination levels at the Gardinier site have been referenced to NRC guidelines for radium as given in Appendix III. While elevated concentrations of ^{226}Ra may be present at some points on this site, it must be borne in mind that the gypsum dust which is emitted from nearby operations contains above-background levels of ^{226}Ra and that this dust has coated many surfaces in the survey area. Also, ^{226}Ra is probably precipitated with calcium sulfate at some point in the uranium extraction process,[4] as well as in the production of phosphoric acid, and, as a result, appears to have become plated out on the insides of certain pipes and reaction vessels. According to the NRC guidelines, average and maximum alpha contamination levels on surfaces

contaminated with radium should not exceed 100 dpm/100 cm^2 and 300 dpm/100 cm^2, respectively, by direct reading.* The NRC guidelines specify that average and maximum beta-gamma dose rates at 1 cm from the surface may not exceed 0.20 mrad/hr and 1.0 mrad/hr, respectively, regardless of the surface contaminant. Alpha and beta-gamma measurements were made on this site in such a manner that contamination levels in survey blocks could be compared with both maximum and average guideline values. Transferable alpha contamination levels may not exceed 20 dpm/100 cm^2 (according to NRC guidelines) provided the surface contaminant is radium, and this limit seems appropriate for surface contamination on this site.

SURVEY RESULTS

Measurements in Building Interiors

Pilot Plant Building

The pilot plant building is a single-story structure with dimensions of 20 ft x 40 ft, giving a total floor area of 800 ft^2. It currently houses eight small offices and a restroom as shown in Fig. 3. Exterior walls are concrete blocks, and the floor is a single concrete slab. The original ceiling is corrugated metal; however, a new interior ceiling has been added which consists of suspended acoustical tile.

In each survey area shown in Fig. 3., single direct alpha measurements, beta-gamma measurements at 1 cm, and external gamma measurements at the surface and 1 m above the surface were taken in the center of each floor and wall surface. Results are given in Table 1 of this report and indicate little or no contamination on the floors and lower walls. (The notation A3S, for example, in Table 1 refers to the south wall adjacent to floor area A3.) The average alpha contamination was found to be less than 15 dpm/100 cm^2 with most blocks showing no contamination, and all blocks are below the standard of 300 dpm/100 cm^2.

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*Readings may not be averaged over an area of more than 1 m^2, and the maximum guideline value applies to an area of not more than 100 cm^2.

Direct beta-gamma readings show an average of 0.03 mrad/hr with a maximum reading of 0.05 mrad/hr. External gamma radiation levels at the surface ranged from 13 μR/hr to 38 μR/hr with an average exposure rate of 24 μR/hr. External gamma radiation measurements at 1 m above the floors of the building ranged from 14 μR/hr to 24 μR/hr with an average of 19 μR/hr.

Since the acoustic tile ceiling is a relatively new addition, ceiling tiles were removed in each office and measurements were taken on the upper surfaces. These values are shown in Table 2 and indicate little contamination. Average direct alpha measurements on horizontal surfaces was 25 dpm/100 cm^2. No contamination was found on vertical surfaces. Beta-gamma dose rates for horizontal and vertical surfaces show an average of 0.09 mrad/hr and 0.07 mrad/hr, respectively.

Fifteen smear samples were taken on the floors and ceilings in the pilot plant. The transferable alpha contamination level was 30 dpm/100 cm^2 on the floor in area A4 (Fig. 3). The contamination on all other smear samples was too low to be distinguishable from background on the smear counters.

Process Building

The process building is a three-story building with concrete floors, steel framing, corrugated walls, and precast concrete slab roof. The floors of the first and second levels measure approximately 50 ft x 75 ft and the third level measures 30 ft x 75 ft. Floor plans are shown in Figs. 4 through 7. Also shown in these figures are all direct beta-gamma and direct alpha measurements which exceed NRC guidelines.

First floor of process building. The first floor (shown in Fig. 4) consists of a workroom, a lunchroom, and a series of offices with a central hall. Contamination measurements which exceed NRC guidelines are shown in the appropriate area in Fig. 4.

The values for directly measured alpha and beta-gamma contamination, as well as for external gamma radiation at 1 m, for the offices and hall on the first level are given in Table 3. Survey areas are shown in Fig. 5. Direct alpha measurements on the floor range from 0 dpm/100 cm^2 to 1,600 dpm/100 cm^2 with an average of 300 dpm/100 cm^2. These same

measurements for the walls range from 0 dpm/100 cm^2 to 200 dpm/100 cm^2 with an average of 60 dpm/100 cm^2. Beta-gamma dose rates at 1 cm from the floors and walls showed an average of 0.05 mrad/hr and 0.02 mrad/hr, respectively. External gamma levels at 1 m ranged from 2 to 10 μR/hr with an average of 5 μR/hr.

As in the case of the pilot plant, the ceiling of the first floor offices had been covered with acoustical tile which had to be removed in order to get readings on the old ceiling. The results of these readings are given in Table 4 and show average direct alpha measurements on vertical and horizontal surfaces of 60 dpm/100 cm^2 and 90 dpm/100 cm^2, respectively. Direct beta-gamma dose rates for vertical and horizontal surfaces yield averages of 0.01 mrad/hr and 0.02 mrad/hr, respectively.

The floors and lower walls of the lunchroom and workroom areas of the first level were divided into survey blocks by the grid system shown in Fig. 4. Wall survey blocks are identified by adjacent floor blocks and by compass directions; for example, A1N is the survey block on the north wall adjacent to floor block A1. Measurements made in all survey blocks are reported in Table 5. Average direct alpha and beta-gamma measurements for the floor are 160 dpm/100 cm^2 and 0.11 mrad/hr, respectively. Many average direct alpha readings exceed NRC guidelines, and several survey blocks show levels exceeding the 0.20 mrad/hr guidelines for average beta-gamma dose rates. These blocks are shown in Fig. 4. In addition, the guidelines for maximum beta-gamma and/or alpha measurements were exceeded in several blocks, and these values are shown in the same figure. External gamma radiation levels at 1 m are listed in Table 5 and show an average of 14 μR/hr with a maximum measurement of 70 μR/hr. Average and maximum alpha and beta-gamma contamination levels in these survey blocks are listed in this same table. The lower 6-ft section of walls was divided by the same grid system as was used for the floors. Survey block D7S (the wall block on the south wall adjacent to floor block D7) showed a direct alpha reading of 17,000 dpm/100 cm^2 and was the only wall for which NRC guidelines for direct alpha measurements were exceeded. Beta-gamma readings in several wall blocks exceeded the guidelines. These are shown in Fig. 4. Direct alpha and beta-gamma readings for the walls are shown in Table 5 and yield averages of 150 dpm/100 cm^2 and 0.07 mrad/hr, respectively.

The ceiling of the lunchroom and workroom was divided using the same grid lines as were used on the floor. Direct alpha and beta-gamma measurements were taken on vertical and horizontal surfaces in each survey block. A summary of these results is given in Table 6 and indicates average direct alpha measurements on vertical and horizontal surfaces of 50 dpm/100 cm^2 and 110 dpm/100 cm^2, respectively. Averages of direct beta-gamma readings for horizontal and vertical surfaces were 0.05 mrad/hr and 0.05 mrad/hr, respectively.

A total of 187 smear samples were taken on floor, wall, ceiling, and equipment surfaces on the first level of the process building. Highest transferable contamination levels were found near the ceiling on a duct extending through the floor of the second level and leading from an old dryer located on the second level. A flange on this duct showed transferable alpha and beta contamination levels of 250 and 2,000 dpm/100 cm^2, respectively. The transferable beta contamination level on this flange exceeds the NRC guideline of 20 dpm/100 cm^2 for radium. Transferable alpha and beta contamination levels in the range 50 to 70 dpm/100 cm^2 were found on the floor (block D8, Fig. 4) and the south wall of the tool room. Transferable alpha contamination levels in the range 20 to 30 dpm/100 cm^2 were found on the floor in blocks A7, A11, B1, and C12, and in office areas 6 and 10 (see Figs. 4 and 5), on the walls in blocks A13S, D3E, and E11N (Fig. 4), and on the ceiling over floor blocks A10, A12, B8, and in office areas 2, 3, 5, and 9 (Fig. 4). On all other smear samples, alpha and beta contamination levels were too low to be distinguishable from background on the smear counters.

Second level of process building. The second level of the process building is abandoned. It is used for storage of equipment presumed to have been used during full uranium recovery operations. The floor and lower walls were divided into survey blocks by the grid system shown in Fig. 6. There are no walls on the south and west sides of the second level and the floor is nearly covered with a residue, probably precipitation from airborne material carried by the wind from operations in other parts of the Gardinier plant. As mentioned earlier, a sample of this residue in intimate contact with the floor was taken from each floor survey block (whenever residue was present) for analysis of ^{238}U.

Results are reported in Table 7. A sample taken from the floor in the survey block (E1) containing an old dryer used in the uranium operations showed a ^{238}U concentration of 4,000 pCi/g, and a sample taken in an adjacent block showed a ^{238}U concentration of 750 pCi/g. It is thought that the uranium in these two samples originated from material spilled on the floor when loading or unloading the dryer. The ^{238}U concentration in the remaining 34 floor residue samples ranged from 26 pCi/g to 180 pCi/g. Samples of solid residue were removed from equipment stored on the second floor which showed elevated beta-gamma dose rates. Results of sample analyses are given in Table 8. A sample taken from inside the dryer showed 13,000 pCi/g of ^{238}U. This concentration exceeds the licensable level of 172 pCi ^{238}U/g (corresponding to 0.05% natural uranium by weight as stated in 10 CFR 40). Samples of residues on the second floor were analyzed for their concentration of ^{226}Ra. Results are given in Fig. 7 and indicate that the concentration of ^{226}Ra in residues on the floor surface average in excess of 50 pCi/g.

Average and maximum direct alpha and beta-gamma measurements made on the floor and lower walls of the second level are reported in Table 9. If residues were present in the area of measurement, these residues were removed before the measurement was made. Since the floor was wet in most places, the direct alpha measurements reported in Table 9 may be lower than if the floor had been dry. Direct alpha measurements on the floor and lower walls averaged approximately 300 dpm/100 cm^2 and were as high as 2,600 dpm/100 cm^2. Beta-gamma dose rates at the same points averaged 0.11 mrad/hr and exceeded NRC guidelines (0.20 mrad/hr averaged over 1 m^2) in floor blocks A3 and E1 (see Fig. 6). External gamma radiation levels at 1 m above the floor ranged from 4 μR/hr to 80 μR/hr and averaged 32 μR/hr (see Table 9).

Results of direct measurements taken on overhead surfaces on the second level are reported in Table 10. Direct alpha and beta-gamma measurements averaged approximately 250 dpm/100 cm^2 and 0.07 mrad/hr, respectively, on horizontal overhead surfaces and approximately 180 dpm/100 cm^2 and 0.05 mrad/hr, respectively, on vertical overhead surfaces.

A total of 36 smear samples were taken on the ceiling and lower walls of the second level. Transferable contamination levels were at or near background at all points of measurements.

A separate survey was made of equipment on the second level. Results of direct measurements of alpha and beta-gamma contamination levels and of measurement of transferable alpha and beta contamination levels on this equipment are reported in Table 11 (see also Fig. 6). Beta-gamma dose rates on the equipment generally exceeded the NRC (average) guideline of 0.20 mrad/hr and were as high as 50 mrad/hr inside a rotary drum dryer. This equipment has since been removed and transported to Barnwell, South Carolina.

Third level of process building. On the third level of the process building, which is open on three sides, there is a small office at the west end (blocks A1, A2, B1, and B2 in Fig. 8) and machinery on the east end. The floor was divided into survey blocks as indicated in Fig. 8. Measurements in each survey block are reported in Table 12. Direct alpha measurements ranged from 0 to 400 dpm/100 cm^2 and averaged approximately 250 dpm/100 cm^2. Beta-gamma dose rates ranged from background to 0.14 mrad/hr and averaged approximately 0.05 mrad/hr. External gamma measurements at 1 m were as high as 70 μR/hr and averaged 40 μR/hr. Smear samples taken in blocks A1 and C5 each showed transferable alpha contamination levels of 30 dpm/100 cm^2. Twelve other smear samples were taken; contamination levels on these smears were too low to be distinguishable from background on the smear counters.

Results of Measurements on the Roof of the Process Building

The roof of the process building was divided into survey blocks as shown in Fig. 9. Measurements taken in these blocks are reported in Table 13. Contamination on the roof appeared uniform, with alpha contamination levels (by direct measurement) averaging approximately 200 dpm/100 cm^2 and beta-gamma dose rates averaging approximately 0.09 mrad/hr. Smear samples taken at 16 locations indicate that transferable alpha contamination levels are generally less than 20 dpm/100 cm^2, and transferable beta contamination levels are too low to be distinguishable

from background on the beta smear counter. External gamma radiation levels at 1 m above the roof averaged approximately 40 μR/hr.

Results of the Outdoor Survey

In the Vicinity of the Former Pilot Plant

Beta-gamma dose rates at 1 cm from the ground and external gamma radiation levels at 1 m above the ground and at the surface were measured at the grid points indicated by open and closed circles in Fig. 10. Results are presented in Table 14. Surface soil samples were collected at those points indicated in Fig. 10 by closed (darkened) circles, and concentrations of ^{238}U and ^{226}Ra in those samples are reported in Table 15. The survey points shown in Fig. 10 were selected according to a scheme designed to allow representative sampling in the area around the pilot operations building, with emphasis being given to the area within a few meters of the building, where (it was thought) the contamination levels were likely to be most nonuniform.

It appears that, for comparison of beta-gamma dose rates listed in Table 14 with NRC guidelines, the "average" guideline (0.20 mrad/hr) should be used, since these measurements were made at randomly selected points and hence are more likely to represent average levels than maximum levels. The beta-gamma dose rate at 1 cm exceeded 0.20 mrad/hr at one grid point in this area, namely, at point K1 approximately 20 m from the pilot operations building. External gamma radiation levels at 1 m at grid points in the former pilot operations area ranged from 20 to 100 μR/hr with the highest levels being observed on the south and east side of the pilot operations building (see Fig. 14). A soil sample taken from an isolated spot near grid point I2 showed 26 pCi ^{226}Ra/g and 70 pCi ^{238}U/g.

The surface soil samples collected at randomly selected points in this area showed an average ^{238}U concentration of approximately 19 pCi/g. Uranium-238 was in approximate equilibrium with ^{226}Ra in all samples except the sample taken at grid point K1, which showed a ^{226}Ra concentration of 98 pCi/g and a ^{238}U concentration of 22 pCi/g.

An open-window G-M survey meter was used to scan an old "uranium vault" area at the southeast corner of the pilot operations building, located in a region bounded by grid lines G and H and grid lines 3 and 4 (see Figs. 1 and 10). Beta-gamma dose rates in this area were as high as 0.20 mrad/hr.

In the Vicinity of the Process Building

Beta-gamma dose rates at 1 cm from the ground and external gamma radiation levels at 1 m above the ground and at the surface were measured at the grid points indicated by open and closed circles in Fig. 11. Results are presented in Table 16. Surface soil samples were collected at those points in Fig. 11 indicated by closed (darkened) circles, and concentrations of ^{226}Ra and ^{238}U in these samples are reported in Table 17. The survey points shown in Fig. 11 were selected according to a scheme similar to that for the former pilot operations area.

As before, it appears that, for comparison of beta-gamma dose rates listed in Table 16 with NRC guidelines, the "average" guideline (0.20 mrad/hr) should be used. Beta-gamma dose rates at 1 cm exceeded NRC guidelines at 15 of the measurement points and were as high as 0.70 mrad/hr. Highest dose rates were measured in the areas adjacent to the process building on the west and north sides and in a larger area north of the process building. External gamma radiation levels at 1 m in the grid area ranged from 20 to 300 μR/hr with highest readings being observed in the area north of the process building (see Fig. 15).

The ^{238}U concentrations in the randomly selected surface soil samples were well below the licensable level of 172 pCi/g (corresponding to 0.05% natural uranium by weight as stated in 10 CFR 40); in fact, the ^{238}U concentrations in these samples averaged 20 pCi/g and did not exceed 39 pCi/g. The ^{226}Ra concentrations in the same samples averaged approximately 47 pCi/g; this average was heavily weighted by the ^{226}Ra concentration of 190 pCi/g measured in the sample taken at grid point L17.

A survey was made of piping beneath two tanks on the west side of the process building (the centers of these tanks are located approximately 0.8 m and 1.7 m, respectively, from the process building wall.

Beta-gamma dose rates inside the pipes were between 8 and 15 mrad/hr at some points. Samples of rust and residue taken from these pipes showed up to 2,400 pCi/g of ^{226}Ra and less than 30 pCi/g of ^{238}U. As mentioned earlier, it appears that ^{226}Ra has plated out in these pipes.

In the Old Dryer Area

The grid system shown in Fig. 12 was used to determine survey points in the area thought to have contained a dryer used in the former uranium operations. Beta-gamma dose rates measured at 1 cm from the surface and external gamma radiation levels measured at the surface and at 1 m above the surface at the grid points are listed in Table 18. Beta-gamma dose rates ranged from 0.03 to 0.17 mrad/hr (all below NRC guidelines) and averaged 0.06 mrad/hr. External gamma radiation levels at 1 m at the grid points (see Fig. 16) ranged from 14 to 70 μR/hr and averaged 28 μR/hr. Soil samples were taken at grid points B6 and C6. Uranium-238 concentrations in these samples were 28 and 6.8 pCi/g, respectively, and ^{226}Ra concentrations were 29 and 7.6 pCi/g, respectively (see Table 8).

Analyses of Water and Water Sediment Samples Collected Outdoors on the Site

Water and water sediment samples were collected at seven outdoor locations. Analyses of radionuclide concentrations are shown in Table 19. Concentrations of ^{238}U and ^{226}Ra in the sediment samples were comparable to the concentrations of these radionuclides in surface soil samples taken on the site. The concentrations of radionuclides in the water samples were highest in the sample collected near grid point C1 in the former pilot plant area. This sample, as well as one taken near grid point K1, had a ^{226}Ra concentration greater than the concentration guide for water (CG_W) stated in 10 CFR 20, Appendix B, and ERDAM 0524, Annex A.

SUMMARY

A radiological survey was conducted at a former uranium recovery plant near Tampa, Florida. The pilot and full-scale recovery operations were conducted from 1951 through 1960, the primary goal being the

extraction of uranium from phosphoric acid. The survey was performed at the former uranium recovery plant which consisted of a pilot operations building, a process building, and a total area of approximately 1 acre around these buildings. This plant is presently owned and operated by Gardinier, Inc., and is part of a large plant used for the production of phosphoric acid and other phosphate products. Gypsum dust emitted from nearby operations at the Gardinier plant contains above-background levels of radionuclides in the uranium chain, and this dust has settled out in most survey areas. Also, ^{226}Ra has probably precipitated out at some point in the uranium separation process[3] and in the production of phosphoric acid, and, as a result, appears to have become plated out on the insides of certain pipes and reaction vessels. In comparing measured alpha contamination levels on building surfaces with NRC guidelines for the release of property for unrestricted use, it will be assumed that radium is the primary contaminant. (Nuclear Regulatory Commission guidelines for beta-gamma dose rates do not require identification of the contaminant.)

In the former pilot operations building, all alpha and beta-gamma measurements were well below NRC guidelines for natural uranium, and external gamma radiation levels at 1 m did not exceed 38 μR/hr. On the first level of the process building, beta-gamma dose rates and/or alpha contamination levels in several areas of the floors and walls exceeded NRC guidelines for the release of property for unrestricted use. The maximum observed external gamma radiation level at 1 m on the first level was 70 μR/hr. Highest levels of uranium and radium contamination on this site appear to be on the second level of the process building, where equipment used during the uranium recovery operations is stored. Some samples of material taken from the floor and from equipment on the second level contained licensable concentrations of natural uranium (more than 172 pCi/g of ^{238}U or, as stated in 10 CFR 40, more than 0.05% natural uranium by weight) and contained ^{226}Ra in concentrations of up to 900 pCi/g. In particular, samples of residue taken from the floor on the second level near an old dryer showed a ^{238}U concentration of 4,000 pCi/g, and a sample of material taken from inside the dryer showed 13,000 pCi/g of ^{238}U. Most points on the floor and on equipment on the

second level showed beta-gamma dose rates and/or alpha contamination levels exceeding NRC guidelines. In fact, the beta-gamma dose rates on the equipment were as high as 50 mrad/hr. The maximum measured external gamma radiation levels at 1 m on the second level was 80 μR/hr. On the third level of the process building, several areas showed alpha contamination levels which were above NRC guidelines. The maximum external gamma radiation level at 1 m was 70 μR/hr. Measurements on the roof of the process building were generally above background but were below NRC guidelines.

In the outdoor grid areas around the former pilot and process buildings, beta-gamma dose rates at 1 cm in some areas were above NRC guidelines for the release of property for unrestricted use, and external gamma radiation levels were as high as 300 μR/hr. It is likely that the highest gamma radiation levels on the site result from small pockets of ^{226}Ra which have plated out inside some pipes and vessels.

Uranium-238 concentrations in surface soil and water sediment collected outdoors on the site averaged approximately 20 pCi/g, and ^{226}Ra concentrations were generally of the same magnitude. No licensable quantities of natural uranium were found outdoors on the site. Samples of water taken from surface water outdoors on the site showed concentrations of ^{226}Ra above the concentration guide for water (CG_w) stated in 10 CFR 20, Appendix B, and ERDAM 0524, Annex A.

An evaluation has been made of current radiation exposures at this site and is presented as Appendix IV (page 95) 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 Florida, as well as to scientifically based guideline values established for the protection of radiation workers and members of the general public.

Appendix V provides a table of factors for use in the conversion of the units of measurement utilized in this report to the newly adopted International System of Units (SI). This table can be consulted when comparison of survey data and results in SI units is required.

REFERENCES

1. E. B. Wagner and G. S. Hurst, "A Geiger-Mueller Gamma-Ray Dosimeter with Low Neutron Sensitivity," *Health Phys.* 5, 20 (1961).
2. F. F. Dyer, J. F. Emery, and G. W. Leddicotte, *Comprehensive Study of the Neutron Activation Analysis of Uranium by Delayed Neutron Counting*, Oak Ridge National Laboratory Report ORNL-3342 (October, 1962).
3. "Florida Phosphate Lands, Interim Recommendations for Radiation Levels," U.S.E.P.A. in *Federal Register* 41, 26066-8, June 24, 1976.
4. W. Davis, Jr., F. F. Haywood, J. L. Danek, R. E. Moore, E. B. Wagner, E. M. Rupp, and P. J. Walsh, *Potential Radiological Impacts of Recovery of Uranium from Wet Process Acid*, Oak Ridge National Laboratory Report ORNL/EPA-2 (January, 1979).

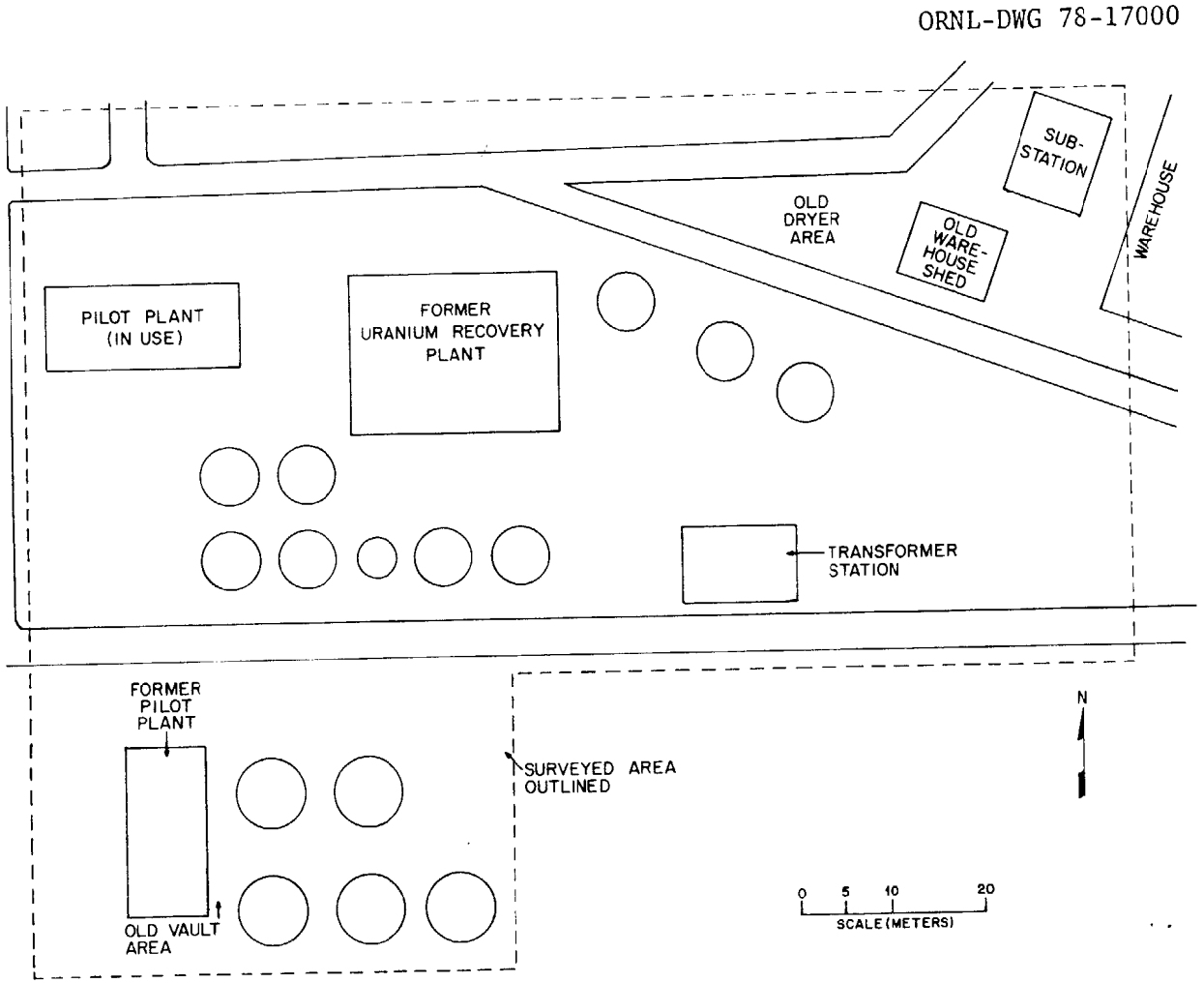

Fig. 1. Plan view of the surveyed area.

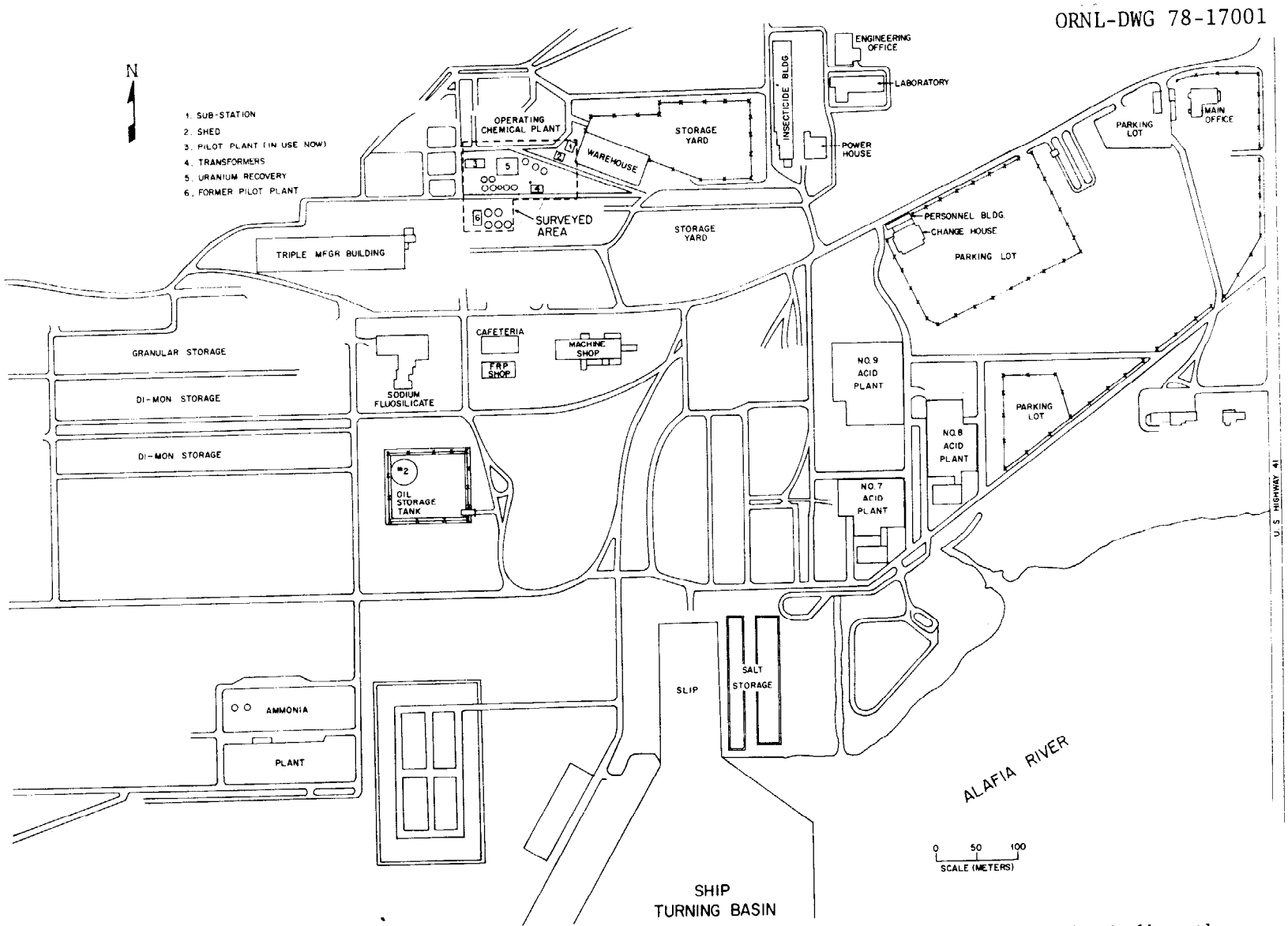

Fig. 2. Plan view of the Gardinier, Inc., phosphoric acid production plant, including the surveyed area.

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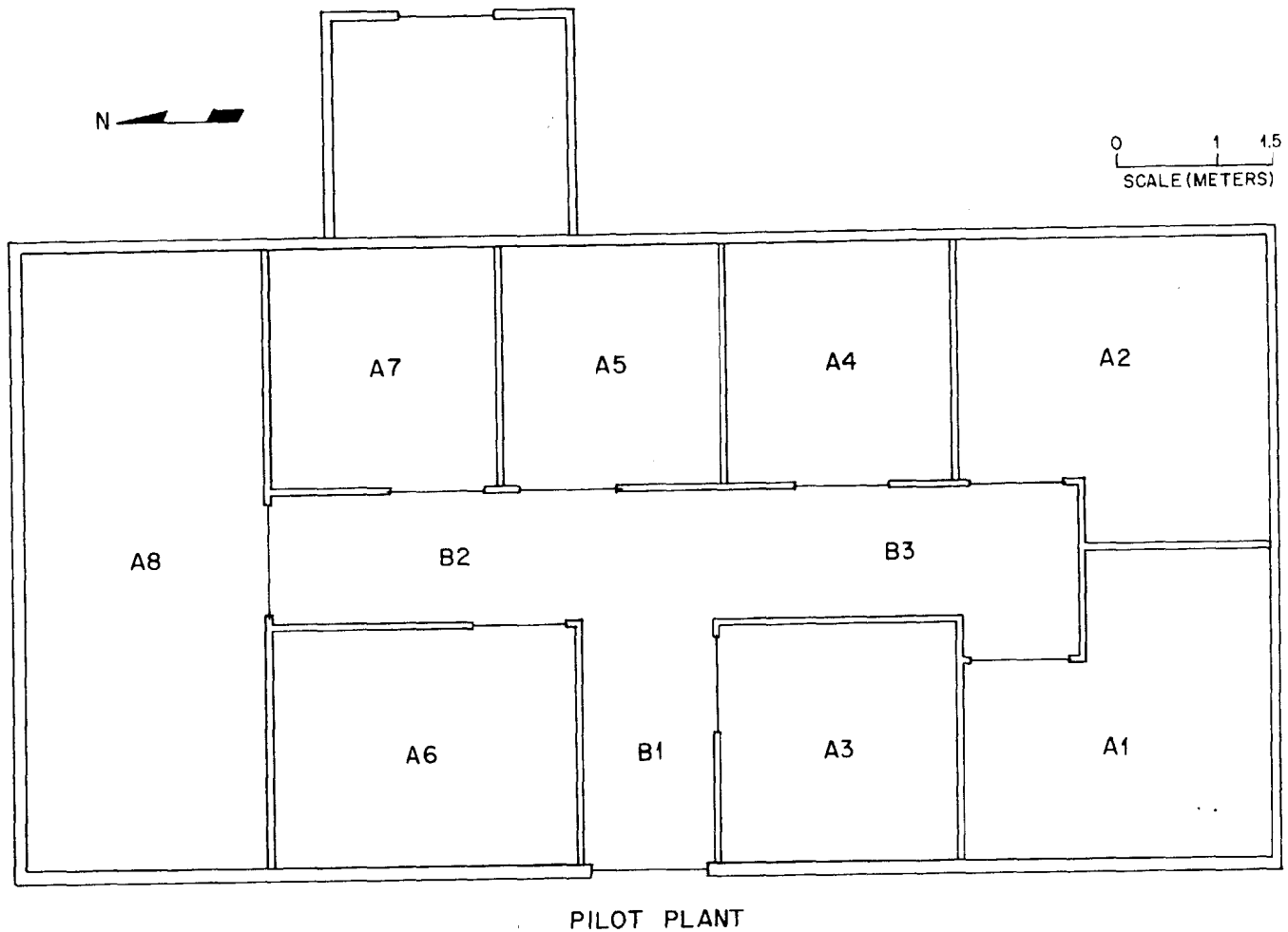

Fig. 3. Survey areas in the pilot operations building (see Tables 1 and 2 for data).

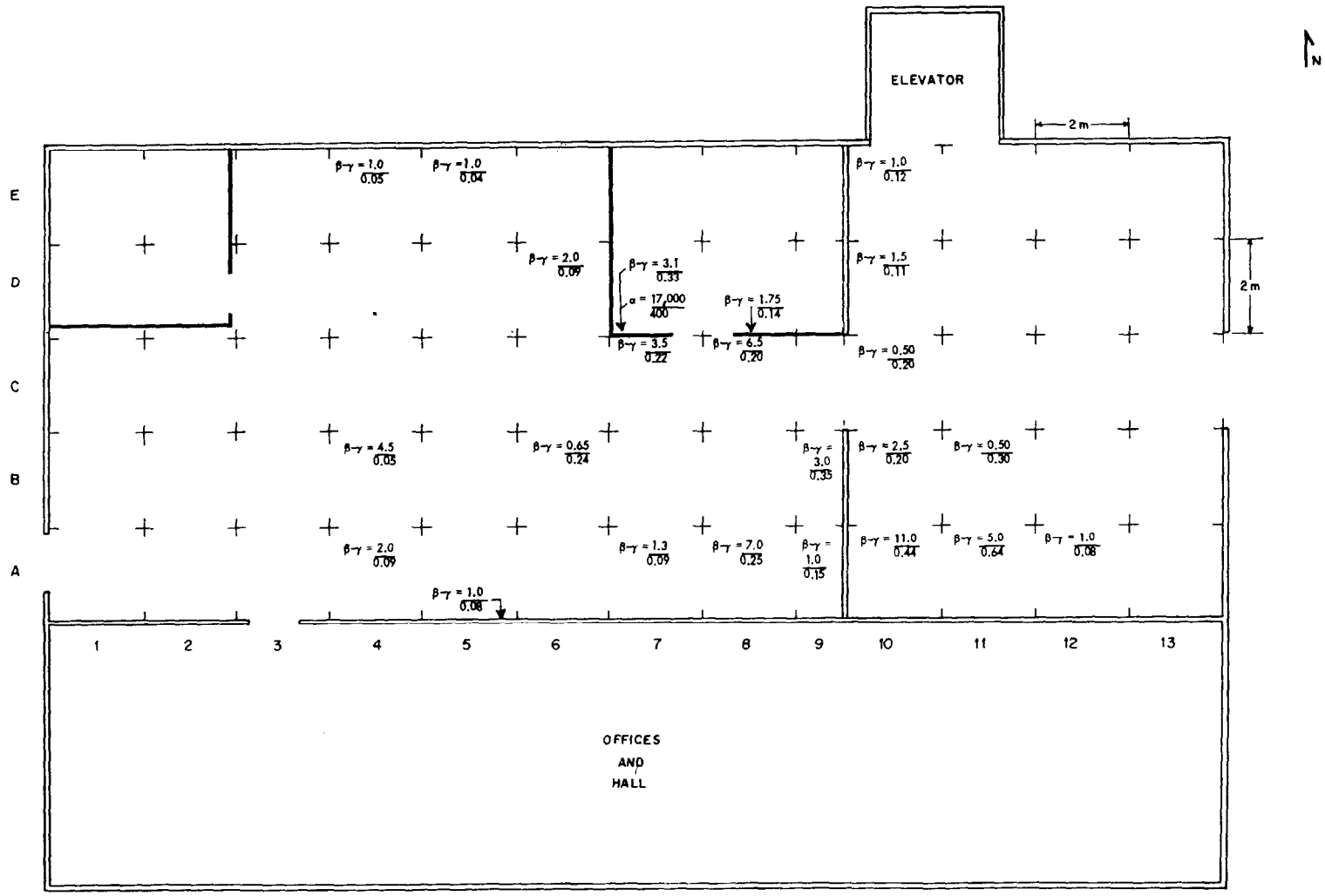

Fig. 4. Direct alpha and beta-gamma measurements (in dpm/100 cm^2 and mrad/hr, respectively) exceeding guidelines in survey blocks on first level of process building (maximum/average is given if either exceeded guidelines). (See Tables 5 and 6.)

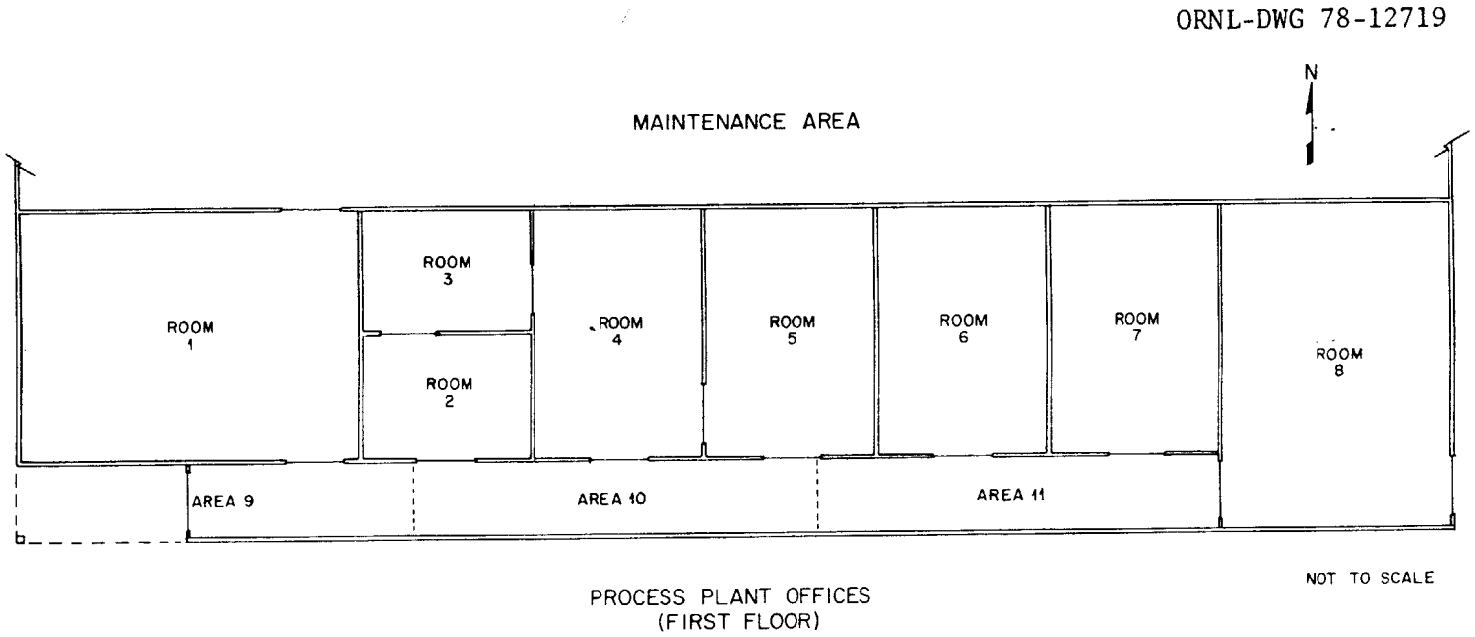

Fig. 5. Survey areas in the group of offices and adjacent hallway on the first level of the process building.

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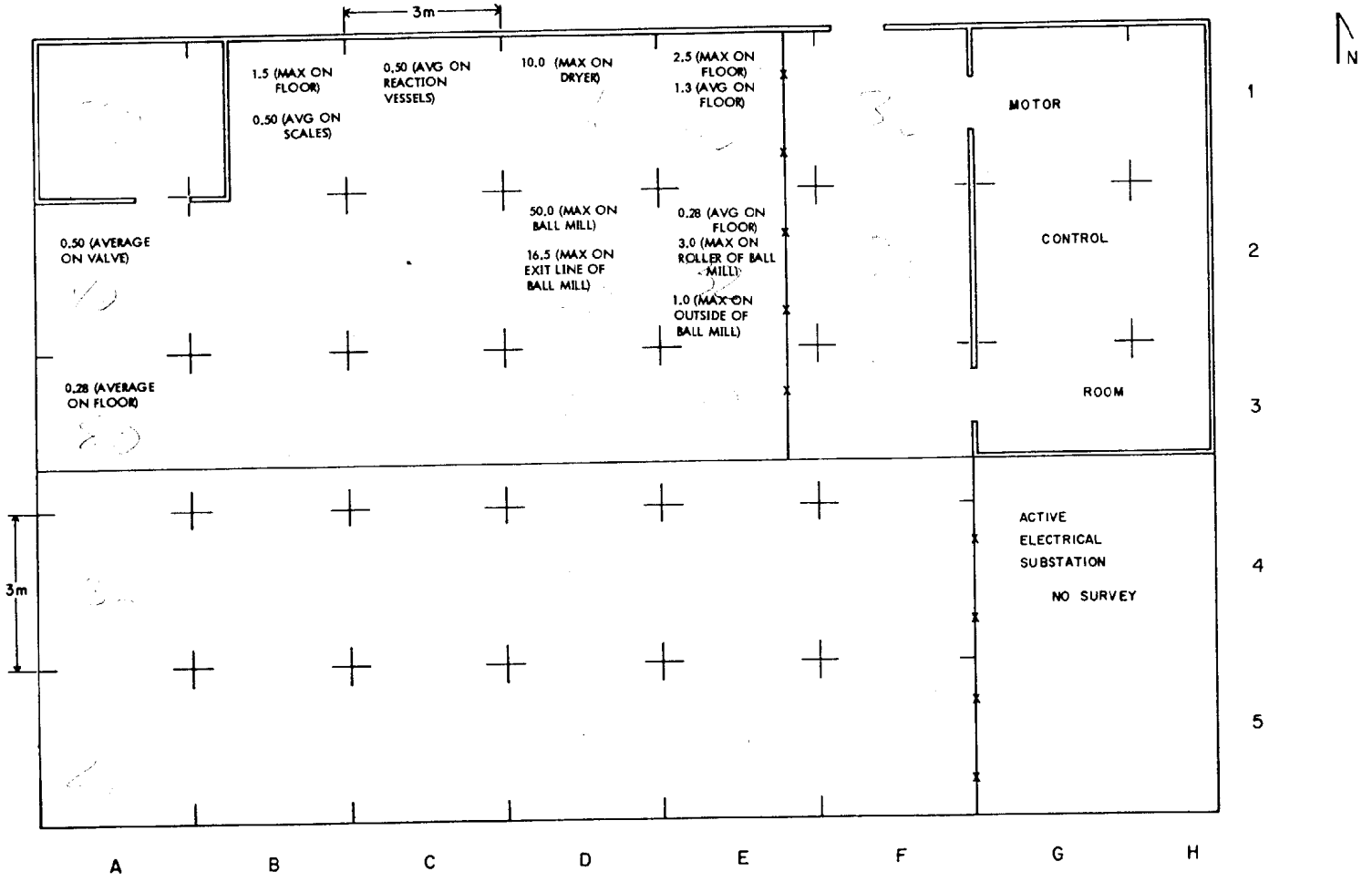

Fig. 6. Beta-gamma dose rates (in mrad/hr) exceeding guidelines in survey blocks and on equipment on second level of process building (additional data presented in Tables 9 and 10).

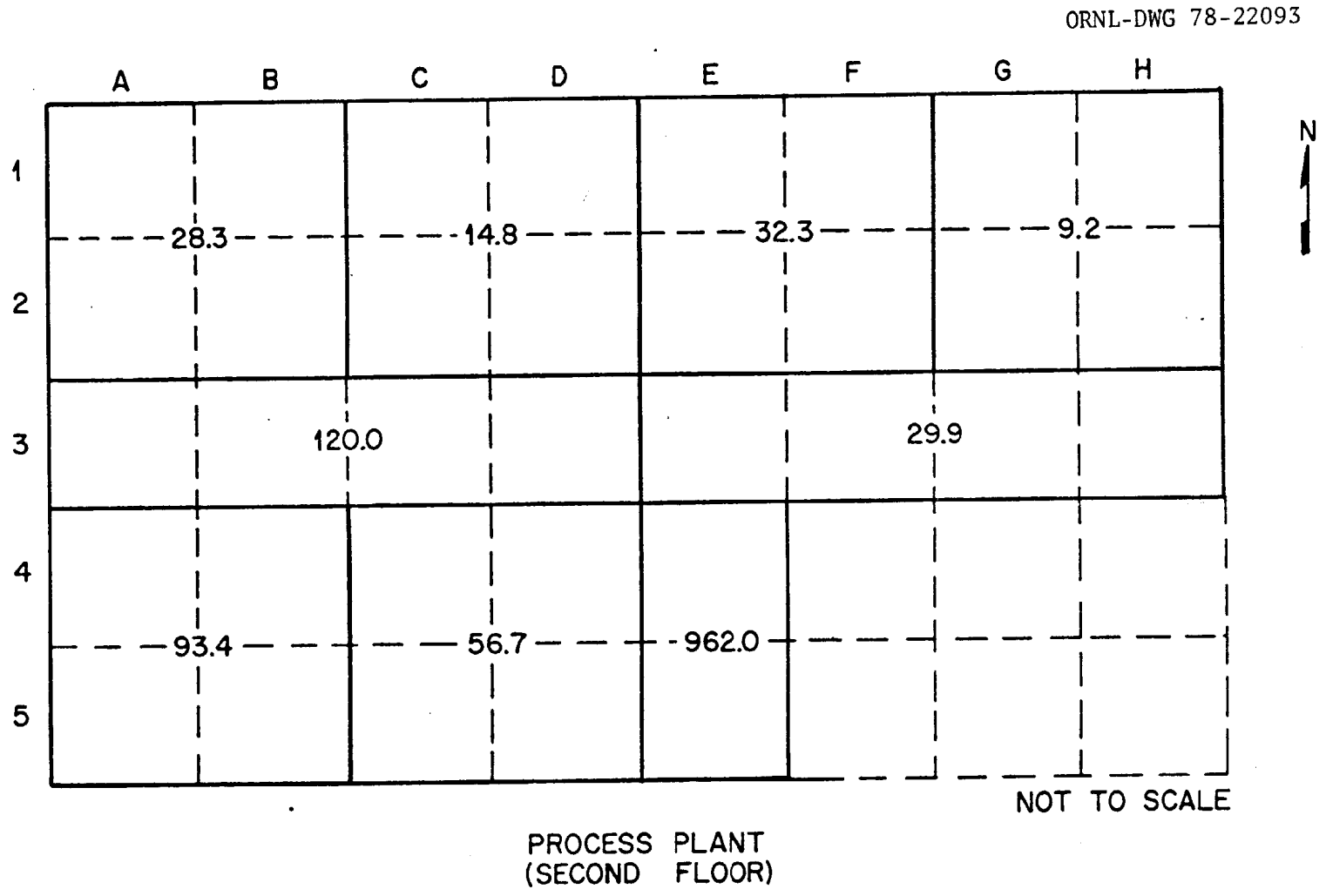

Fig. 7. Radium-226 concentration (pCi/g) in floor surface samples on the second floor of the process building. (Values are average concentrations within indicated areas enclosed by solid lines.)

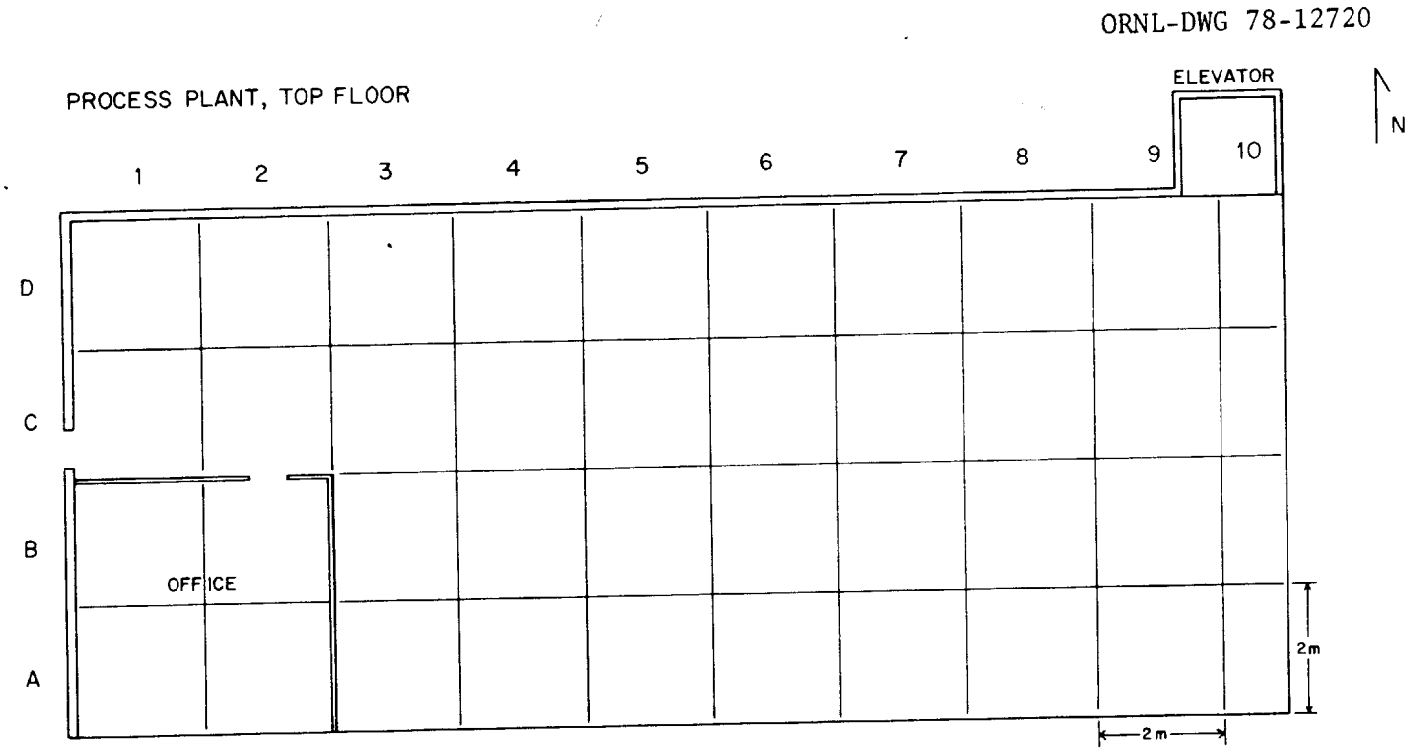

Fig. 8. Survey blocks on the third level of the process building.

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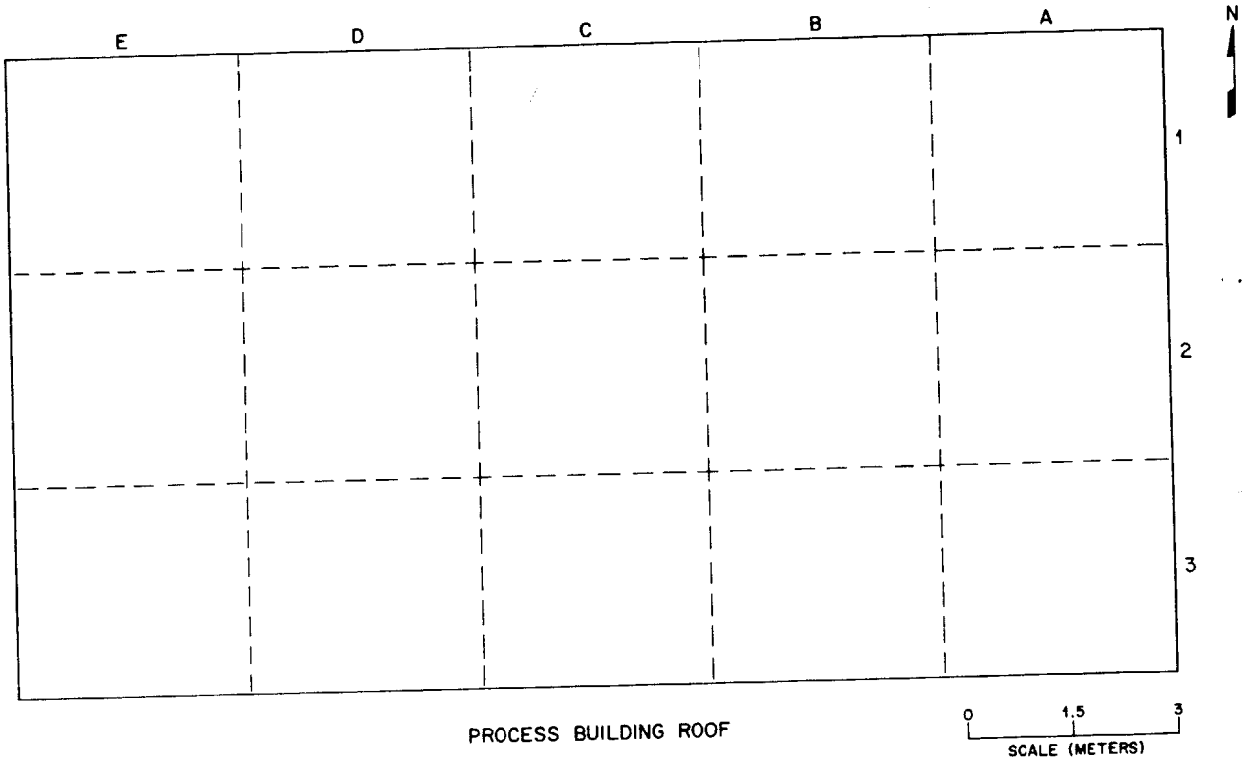

Fig. 9. Survey blocks on roof of former process building (see Table 13 for data).

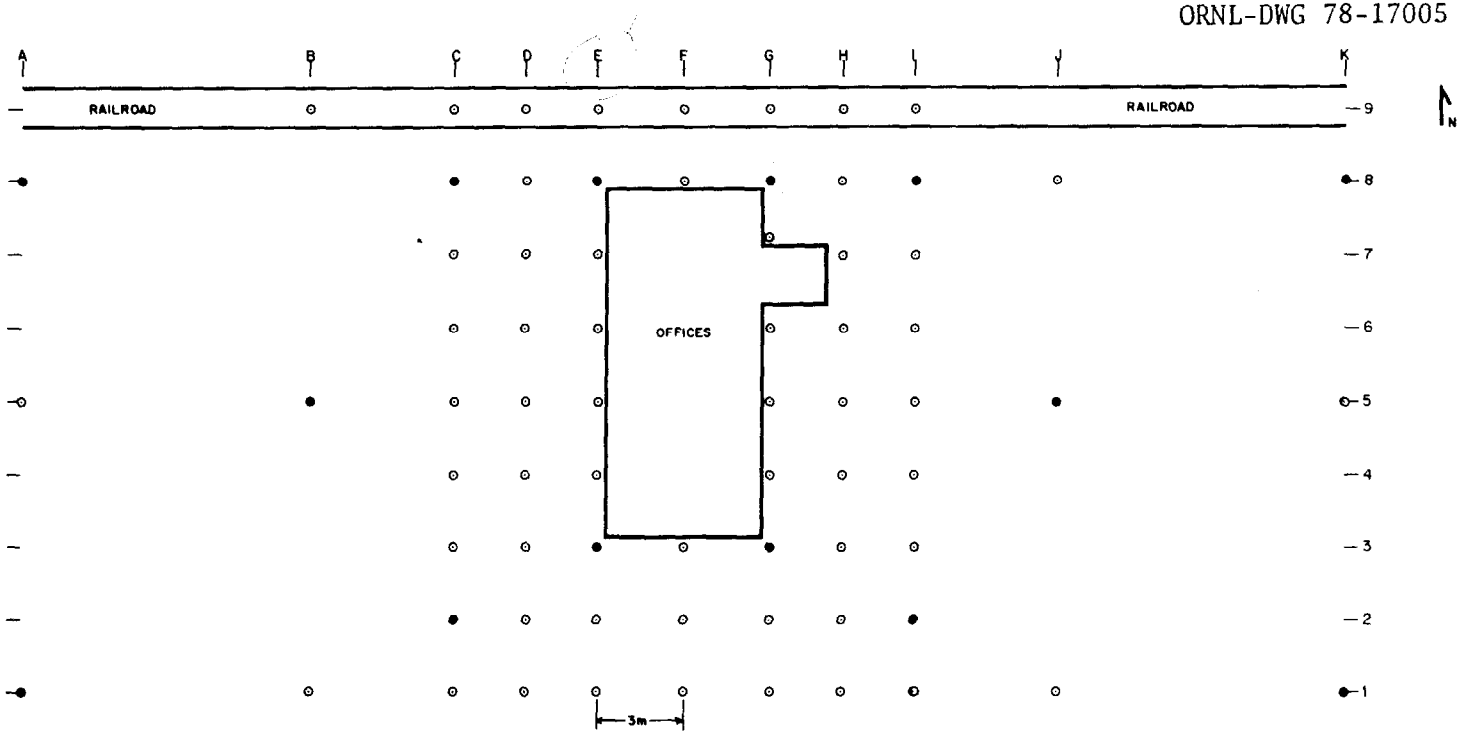

Fig. 10. Outdoor survey points and sampling points in the vicinity of the former pilot plant operations building (darkened circles are both soil sampling points and meter measurement points; other circles are meter measurement points). (See Tables 14, 15, 16, and 17 for data.)

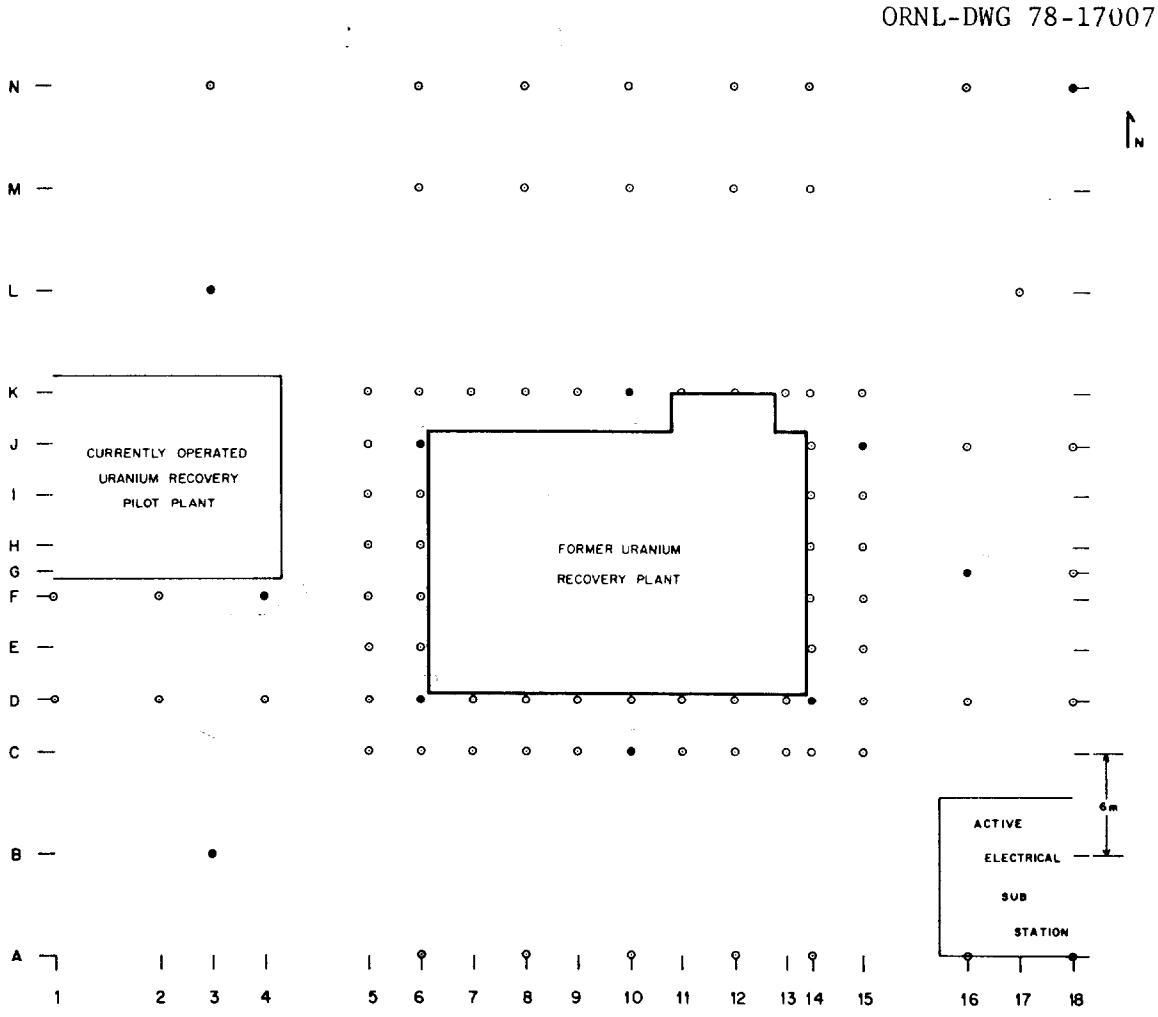

Fig. 11. Outdoor survey points and sampling points in the vicinity of the former process building (darkened circles are both soil sampling points and meter measurement points; other circles are meter measurement points).

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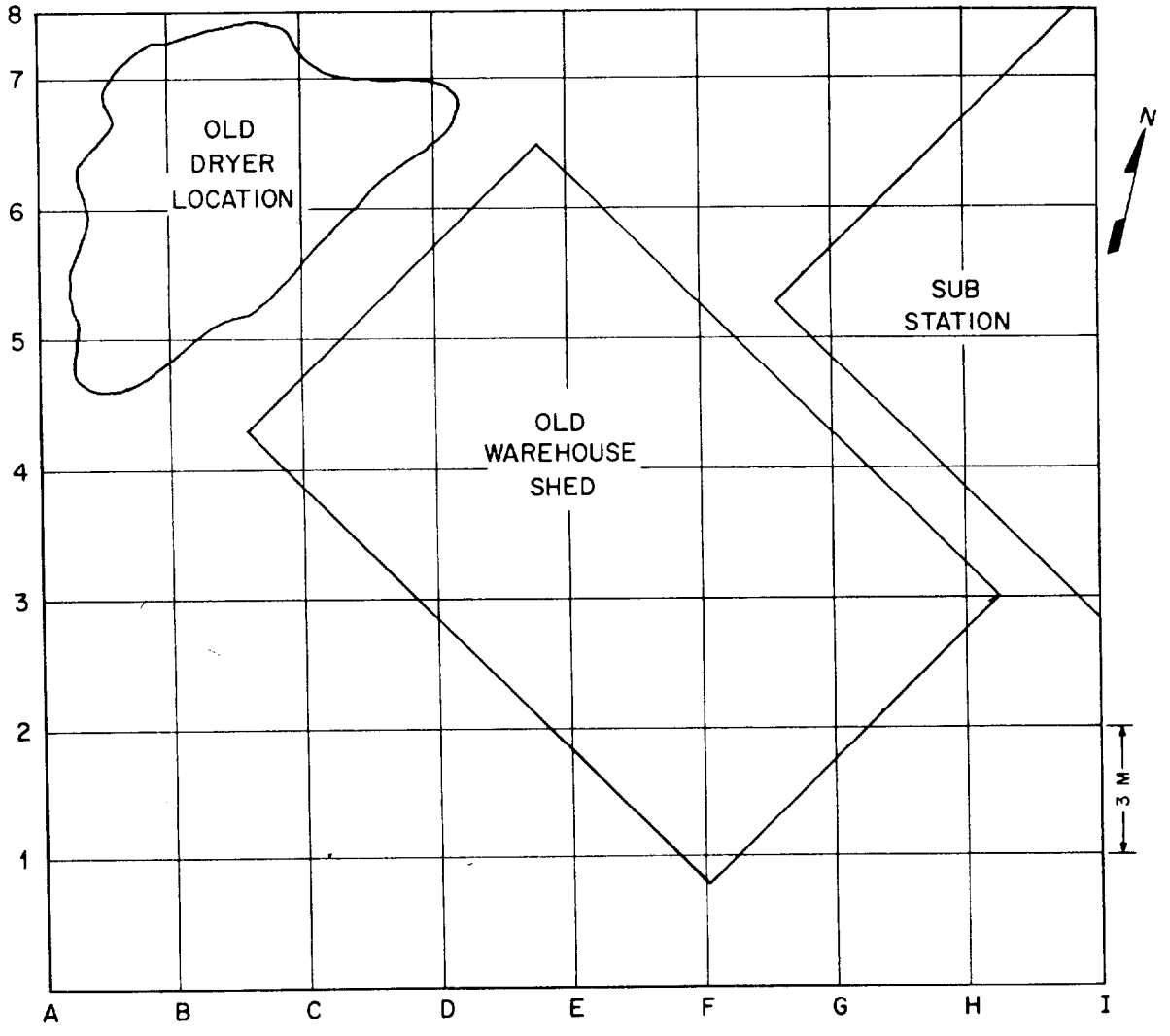

Fig. 12. Grid system used in the former dryer area.

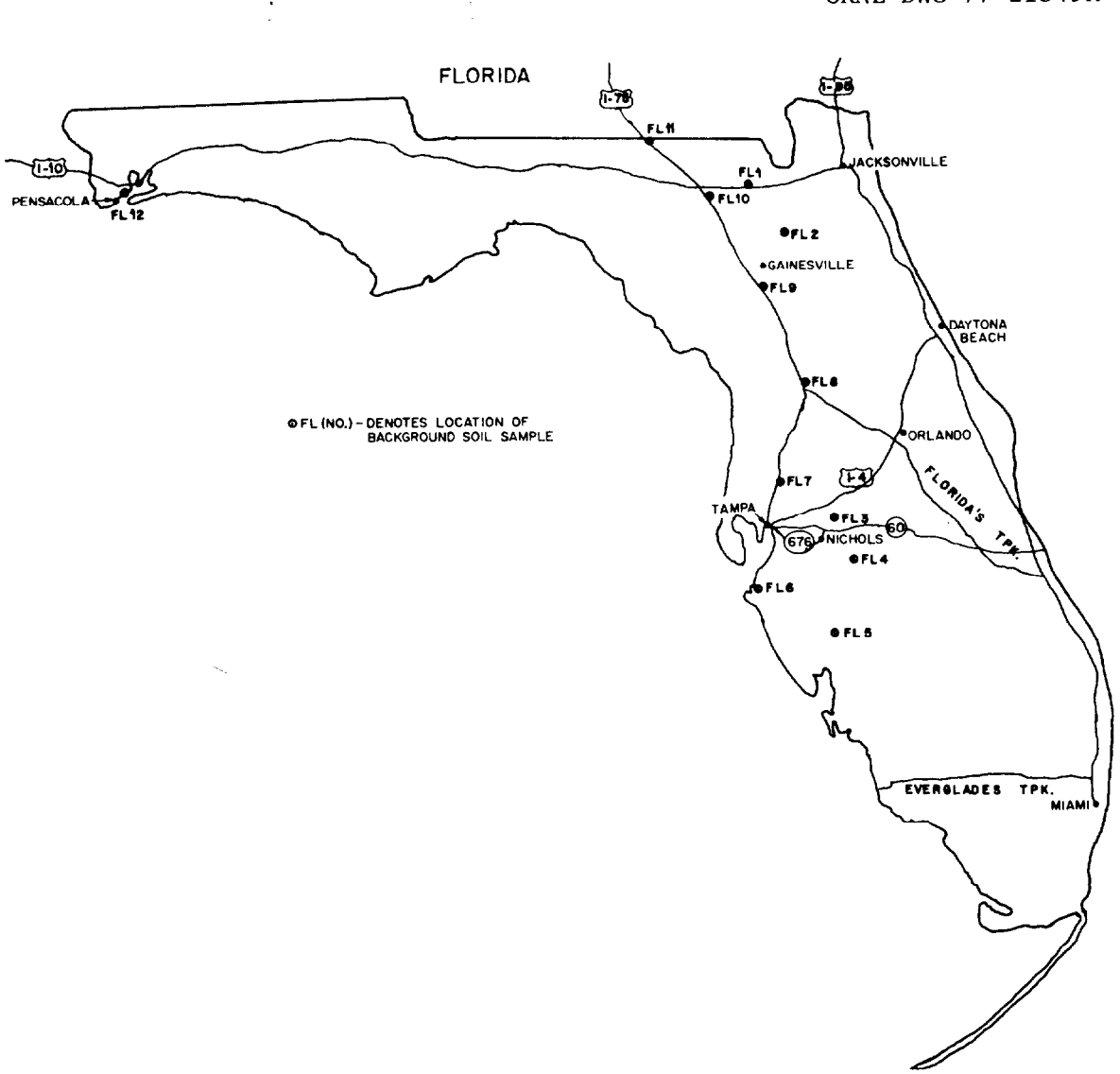

Fig. 13. Off-site background sampling points.

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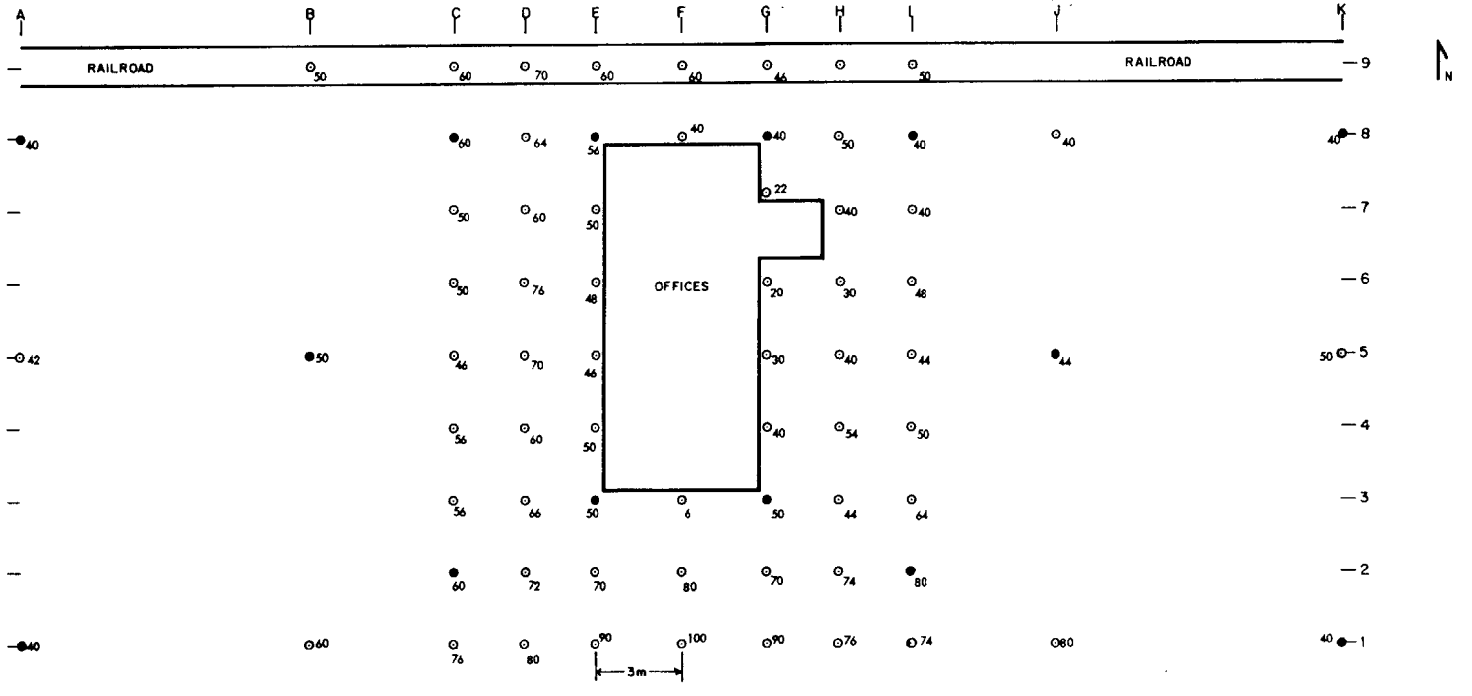

Fig. 14. External gamma radiation levels at 1 m (μR/hr) outside in the pilot operations area.

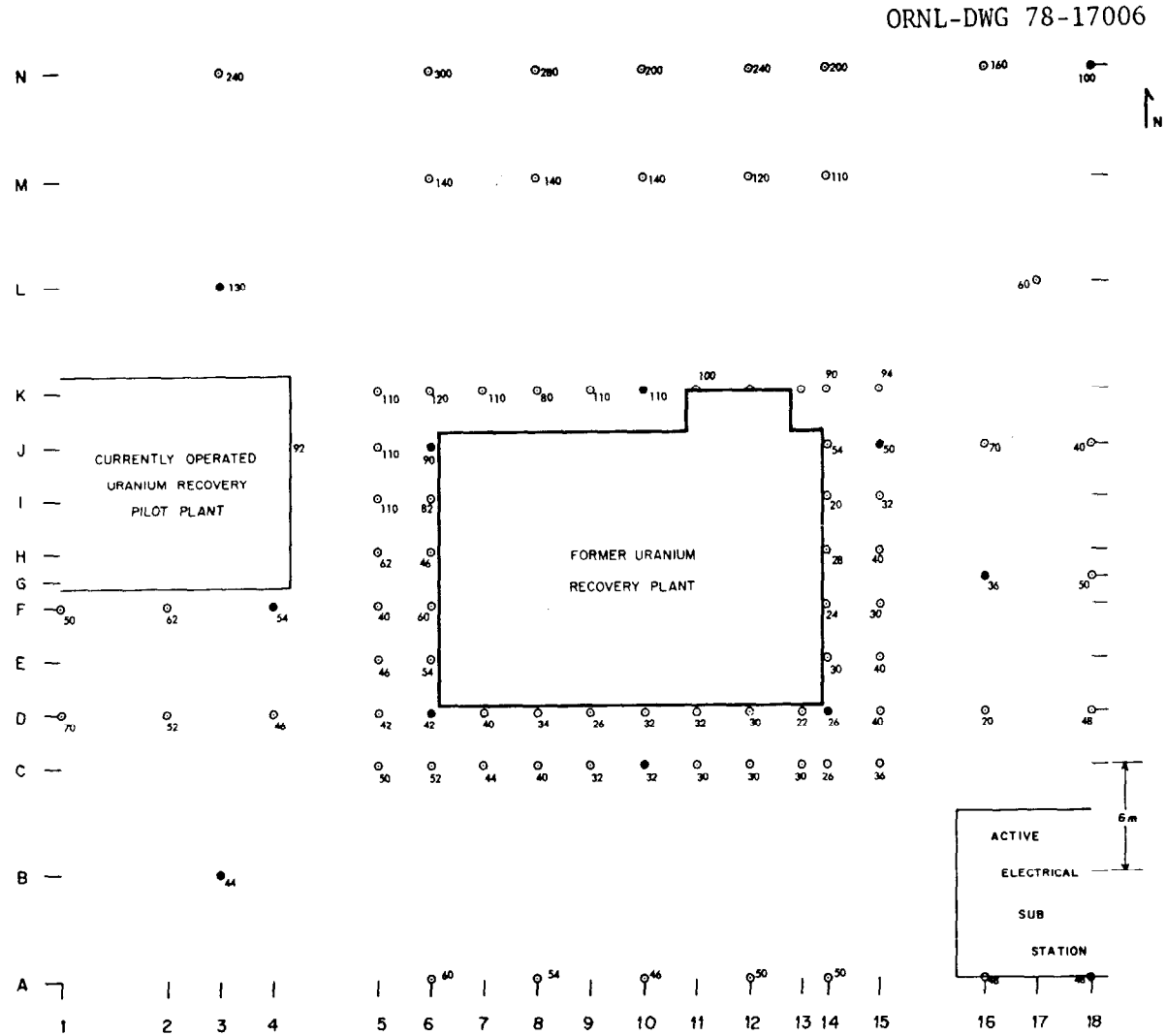

Fig. 15. External gamma radiation levels at 1 m (μR/hr) outside in the area around the process building.

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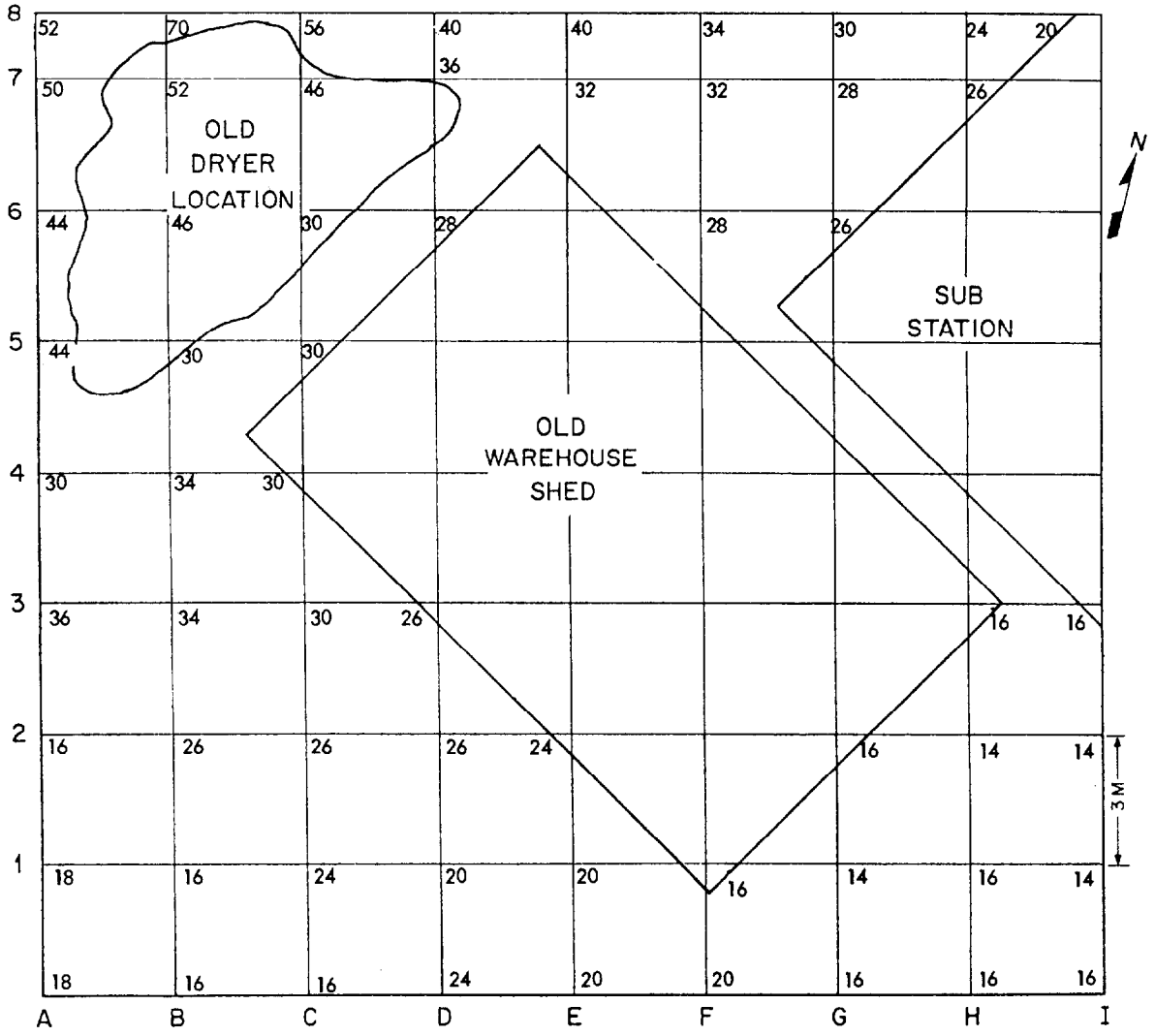

Fig. 16. External gamma radiation levels at 1 m (μR/hr) outside at grid points in the dryer area.

Table 1. Directly measured alpha and beta-gamma contamination levels and external gamma radiation levels in the pilot plant

Survey area shown in Fig. 3	Direct alpha measurement in center of survey area (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm in center of survey area (mrad/hr)	External gamma radiation level	
			at surface (μR/hr)	at 1 m (μR/hr)
A1	0	0.04	22	20
A1N	0	0.03	31	NR[a]
A1E	0	0.03	25	NR
A1W	0	0.03	22	NR
A1S	0	0.03	28	NR
A2	0	0.03	19	18
A2N	0	0.04	25	NR
A2S	0	0.02	22	NR
A2E	0	0.03	25	NR
A2W	0	0.04	31	NR
A3	0	0.02	19	20
A3N	0	0.03	31	NR
A3S	0	0.04	25	NR
A3E	0	0.02	19	NR
A3W	0	0.03	19	NR
A5	100	0.02	13	NR
A5N	100	0.04	25	NR
A5S	0	0.03	38	NR
A5E	0	0.04	25	NR
A5W	0	0.03	28	NR
A7	0	0.04	16	14
A7S	0	0.03	22	NR
A7E	0	0.03	19	NR
A7N	0	0.03	31	NR
A7W	0	0.03	31	NR
A6	0	0.02	16	18
A6N	100	0.04	16	NR
A6S	0	0.02	22	NR
A6E	0	0.03	25	NR
A6W	0	0.02	19	NR
A4	0	0.04	31	18
A4N	0	0.03	28	NR
A4S	0	0.05	31	NR
A4E	0	0.04	38	NR
A4W	0	0.04	28	NR
A8	0	0.03	25	20
A8N	100	0.03	31	NR
A8S	0	0.03	19	NR
A8E	0	0.02	13	NR
A8W	200	0.02	19	NR
B1	0	0.04	16	18
B2	0	0.03	25	24
B3	0	0.02	19	20

[a] NR = no reading.

Table 2. Directly measured alpha and beta-gamma contamination levels on overhead surfaces of pilot plant building

Survey area shown in Fig. 3.	Surface	Alignment	Directly measured contamination	
			Alpha (dpm/100 cm^2)	Beta-gamma (mrad/hr)
Intersect of B1, B2 and B3	Ceiling	Horizontal	100	0.08
Intersect of B1, B2, and B3	Beam	Vertical	0	0.04
A8	Ceiling	Horizontal	0	0.08
A8	Beam	Vertical	0	0.06
A6	Ceiling	Horizontal	0	0.10
A6	Beam	Vertical	0	0.08
A2	Ceiling	Horizontal	0	0.10
A2	Beam	Vertical	0	0.10

Table 3. Directly measured alpha and beta-gamma contamination levels and external gamma radiation levels in the first-level offices of the process building

Survey area shown in Fig. 5	Beta-gamma dose rate at 1 cm (mrad/hr)		Direct alpha contamination level (dpm/100 cm^2)		External gamma radiation level at 1 m (μR/hr)
	On floor	On lower walls	On floor	On lower walls	
1	0.06	0.03 (N,S)[a] 0.01 (E) 0.02 (W)	100	0 (N,E) 100 (S,W)	10
2	0.03	0.02 (N) 0.01 (S,E,W)	0	0 (N,S,E) 200 (W)	4
3	0.15	0.01 (N,S) 0.02 (E) 0.04 (W)	1600	100 (N,E) 0 (S,W)	6
4	0.01	0.01 (N,S) 0.02 (E,W)	200	0 (N,S) 100 (E,W)	4
5	0.01	0.01 (walls)	100	100 (N,E,W) 0 (S)	2
6	0.02	0.02 (N) 0.01 (S,E,W)	200	0 (N,E) 100 (S,W)	2
7	NA[b]	NA	NA	NA	NA
8	0.02	0.03 (N) 0.01 (S,E) 0.02 (W)	100	100 (N,E) 0 (S,W)	6
9	0.06	0.07 (N) 0.04 (S)	100	100 (N) 0 (S)	8

Table 3 (cont.). Directly measured alpha and beta-gamma contamination levels and external gamma radiation levels in the first-level offices of the process building

Survey area shown in Fig. 5	Beta-gamma dose rate at 1 cm (mrad/hr)		Direct alpha contamination level (dpm/100 cm^2)		External gamma radiation level at 1 m (μR/hr)
	On floor	On lower walls	On floor	On lower walls	
10	0.07	0.02 (N,S)	500	100 (N,S)	4
11	0.04	0.02 (N,S)	100	0 (N) 100 (S)	4

[a] N = north wall; S = south wall; E = east wall; and W = west wall.

[b] NA = not accessible.

Table 4. Directly measured alpha and beta-gamma contamination levels on the overhead surfaces of the first-level offices in the process building

Survey area shown in Fig. 5	Surface	Surface alignment	Directly measured contamination	
			Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)
1	Ceiling	Horizontal	0	0.03
1	Beam	Vertical	0	0.03
2	Ceiling	Horizontal	300	0.01
2	Beam	Vertical	0	0.01
3[a]	Ceiling	Horizontal	100	0.05
3	Beam	Vertical	0	0.02
4	Ceiling	Horizontal	0	0.01
4	Beam	Vertical	0	0.01
5	Ceiling	Horizontal	100	0.02
5	Beam	Vertical	300	0.01
6	Ceiling	Horizontal	300	0.01
6	Beam	Vertical	100	0.01
7	Ceiling	Horizontal	NA[b]	NA
7	Beam	Vertical	NA	NA
8	Ceiling	Horizontal	0	0.01
8	Beam	VErtical	0	0.01
9	Ceiling	Horizontal	0	0.01
9	Beam	Vertical	100	0.02
10	Ceiling	Horizontal	0	0.02
10	Beam	Vertical	0	0.01
11	Ceiling	Horizontal	100	0.01
11	Beam	Vertical	100	0.01

[a]Room 3 had original concrete. Five points were randomly chosen for a scan for alpha and beta-gamma contamination. The average beta-gamma measurement was 0.20 mrad/hr, and the average alpha measurement was 840 dpm/100 cm^2. Maximum observed beta-gamma dose rate was 0.70 mrad/hr; maximum observed direct alpha measurement was 2000 dpm/100 cm^2.

[b]NA = not accessible.

Table 5. Directly measured alpha and beta-gamma contamination levels and external gamma radiation levels in survey blocks on the first level of the process building

Survey block shown in Fig. 4	Direct alpha measurements averaged (dpm/100 cm^2)	Maximum observed direct alpha measurements (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm averaged over 1 m^2 (mrad/hr)	Maximum observed beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at 1 m (μR/hr)
Floor					
A1	200	300	0.05	0.06	14
A2	200	200	0.04	0.15	12
A3	100	200	0.05	0.80	10
A4	200	500	0.09	2.0	11
A5	200	300	0.05	0.06	12
A6	100	900	0.09	0.15	13
A7	100	200	0.09	1.3	12
A8	100	200	0.25	7.0	28
A9	100	700	0.15	1.0	12
B1	100	200	0.04	0.07	9
B2	200	300	0.04	0.05	9
B3	200	300	0.07	0.13	10
B4	100	200	0.05	4.5	12
B5	100	200	0.05	0.08	14
B6	100	200	0.24	0.65	13
B7	200	200	0.15	0.20	20
B8	0	200	0.17	0.60	70
B9	200	200	0.35	3.0	13
C1	100	300	0.10	0.28	12
C2	100	100	0.03	0.10	8
C3	200	300	0.04	0.10	11
C4	100	200	0.06	0.15	11
C5	0	200	0.10	0.23	13
C6	100	200	0.14	0.75	11
C7	100	300	0.22	3.5	12
C8	100	300	0.20	6.5	11
C9	100	200	0.13	0.25	10
D1	200	200	NR[a]	NR	15
D2	200	500	NR	NR	11
D3	200	300	0.04	0.05	16
D4	100	200	0.04	0.08	14
D5	100	200	0.08	0.20	10
D6	100	200	0.09	2.0	15
D7	300	400	0.16	0.23	12
D8	500	1,100	0.16	0.28	13
D9	200	400	0.10	0.23	9
E1	100	200	0.05	0.15	18
E2	100	100	0.05	0.13	15
E3	100	100	0.02	0.04	20
E4	100	300	0.05	1.0	18
E5	100	300	0.04	1.0	20
E6	100	200	0.03	0.50	18
E7	500	1,100	NR	NR	NR
E8	600	900	NR	NR	NR
E9	NA[b]	NA	NA	NA	NA
A10	200	300	0.44	11.0	10
A11	100	200	0.64	5.0	10
A12	100	200	0.08	1.0	8
A13	100	200	0.08	0.50	8
B10	100	100	0.20	2.5	10
B11	200	400	0.30	0.50	10
B12	100	100	0.08	0.15	10
B13	100	200	0.06	0.20	10
C10	100	400	0.20	0.50	14
C11	100	300	0.05	0.25	14
C12	100	200	0.06	0.12	12
C13	100	100	0.06	0.08	14
D10	200	300	0.11	1.5	26
D11	100	300	0.05	0.11	18
D12	100	300	0.07	0.15	12
D13	100	300	0.04	0.08	10
E10	200	300	0.12	1.0	10
E11	100	300	0.07	0.10	10
E12	100	300	0.08	0.18	24
E13	100	200	0.05	0.10	30

Table 5 (cont.). Directly measured alpha and beta-gamma contamination levels and external gamma radiation levels in survey blocks on the first level of the process building

Survey block shown in Fig. 4	Direct alpha measurements averaged (dpm/100 cm^2)	Maximum observed direct alpha measurements (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm averaged over 1 m^2 (mrad/hr)	Maximum observed beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at 1 m (μR/hr)
Walls					
A1S	0	100	0.02	0.05	NR
A2S	100	200	0.02	0.05	NR
A3S	0	100	0.02	0.15	NR
A4S	0	100	0.04	0.15	NR
A5S	0	100	0.08	1.0	NR
A6S	NA	NA	NA	NA	NR
A7S	0	100	0.04	0.08	NR
A8S	NA	NA	NA	NA	NR
A9S	NA	NA	NA	NA	NR
A1W	100	200	0.04	0.40	NR
B1W	0	100	0.03	0.85	NR
C1W	100	100	0.04	0.06	NR
D1W	0	100	0.03	0.07	NR
E1W	NA	NA	NA	NA	NR
E1N	NA	NA	NA	NA	NR
E2N	NA	NA	NA	NA	NR
E3N	100	200	0.08	0.13	NR
E4N	100	200	0.07	0.08	NR
E5N	0	200	0.05	0.08	NR
E6N	0	100	0.04	0.05	NR
A9E	0	100	0.03	0.13	NR
B9E	100	100	0.07	0.13	NR
C9E	0	100	0.03	0.18	NR
D9E	0	100	0.03	0.05	NR
C1N	100	200	0.03	0.05	NR
C2N	0	200	0.02	0.03	NR
D3W	0	100	0.07	0.08	NR
E3W	0	100	0.07	0.08	NR
D1S	0	100	0.05	0.08	NR
D2S	0	100	0.05	0.08	NR
D3E	200	200	0.07	0.50	NR
D7W	300	6,000	0.09	0.70	NR
E7W	200	600	0.06	0.25	NR
D7S	400	17,000	0.33	3.1	NR
E7N	200	400	0.16	0.75	NR
D8S	700	12,000	0.14	1.75	NR
E8N	NA	NA	NA	NA	NR
D9S	NA[c]	5,000	0.08	0.18	NR
D9E	NA	NA	NA	NA	NR
E8E	100	1,300	0.15	0.75	NR
A10S	1,000	2,100	0.11	0.23	NR
A11S	600	1,500	0.09	0.18	NR
A12S	200	300	0.05	0.08	NR
A13S	200	300	0.07	0.08	NR
A13E	100	200	0.03	0.05	NR
B13E	100	200	0.04	0.08	NR
C13E	NR	NR	NR	NR	NR
D13E	100	300	0.03	0.06	NR
E13E	100	500	0.03	0.06	NR
E13N	NA	NA	NA	NA	NR
E12N	NA	NA	NA	NA	NR
E11N	200	400	0.05	0.06	NR
E10N	NR	NR	NR	NR	NR
E10W	100	800	0.19	0.50	NR
D10W	0	200	0.06	0.08	NR
A10W	600	900	0.11	0.23	NR
B10W	100	200	0.15	0.18	NR
C10W	200	200	0.05	0.08	NR

[a] NR - no reading.

[b] NA - not accessible.

[c] Area was not accessible for more than one reading.

Table 6. Directly measured alpha and beta-gamma contamination levels on the overhead surfaces of the first level of the process building

Block no. shown in Fig. 4	Surface	Surface alignment	Directly measured contamination	
			Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)
E6C[a]	Ceiling	Horizontal	0	0.03
E6C	Beam	Vertical	100	0.04
D6C	Ceiling	Horizontal	0	0.02
D6C	Beam	Vertical	0	0.02
D5C	Ceiling	Horizontal	100	0.02
D5C	Beam	Vertical	100	0.02
D4C	Ceiling	Horizontal	200	0.02
D4C	Beam	Vertical	0	0.02
E5C	Ceiling	Horizontal	0	0.03
E5C	Beam	Vertical	100	0.02
E4C	Ceiling	Horizontal	100	0.02
E4C	Beam	Vertical	0	0.02
D3C	Ceiling	Horizontal	0	0.03
D3C	Beam	Vertical	0	0.03
E3C	Ceiling	Horizontal	0	0.01
E3C	Beam	Vertical	100	0.01
C1C	Ceiling	Horizontal	100	0.02
C1C	Beam	Vertical	0	0.02
B1C	Ceiling	Horizontal	100	0.02
B1C	Beam	Vertical	0	0.01
C2C	Ceiling	Horizontal	100	0.02
C2C	Beam	Vertical	0	0.02
A1C	Ceiling	Horizontal	0	0.03
A1C	Beam	Vertical	100	0.04
A2C	Ceiling	Horizontal	0	0.04
A2C	Beam	Vertical	0	0.03
A3C	Ceiling	Horizontal	100	0.03
A3C	Beam	Vertical	100	0.02
A4C	Ceiling	Horizontal	0	0.01
A4C	Beam	Vertical	100	0.01
B4C	Ceiling	Horizontal	200	0.02
B4C	Beam	Vertical	0	0.01
A5C	Ceiling	Horizontal	0	0.01
A5C	Beam	Vertical	0	0.01
A6C	Ceiling	Horizontal	0	0.02
A6C	Beam	Vertical	0	0.01
B5C	Ceiling	Horizontal	0	0.08
B5C	Beam	Vertical	100	0.23
B6C	Ceiling	Horizontal	0	0.08
B6C	Beam	Vertical	0	0.05
C4C	Ceiling	Horizontal	200	0.02
C4C	Beam	Vertical	0	0.02
C5C	Ceiling	Horizontal	100	0.02
C5C	Beam	Vertical	0	0.0
A7C	Ceiling	Horizontal	0	0.03
A7C	Beam	Vertical	100	0.01
A8C	Ceiling	Horizontal	100	0.03
A8C	Beam	Vertical	100	0.01
A9C	Ceiling	Horizontal	0	0.01
A9C	Beam	Vertical	0	0.01
B9C	Ceiling	Horizontal	0	0.01
B9C	Beam	Vertical	100	0.01

Table 6 (cont.). Directly measured alpha and beta-gamma contamination levels on the overhead surfaces of the first level of the process building

Block no. shown in Fig. 4	Surface	Surface alignment	Directly measured contamination	
			Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)
B8C	Ceiling	Horizontal	100	0.01
B8C	Beam	Vertical	0	0.01
C6C	Ceiling	Horizontal	0	0.01
C6C	Beam	Vertical	100	0.02
C8C	Ceiling	Horizontal	0	0.01
C8C	Beam	Vertical	100	0.02
C7C	Ceiling	Horizontal	200	0.03
C7C	Beam	Vertical	0	0.05
D10C	Ceiling	Horizontal	200	0.04
D10C	Beam	Vertical	0	0.02
D11C	Ceiling	Horizontal	100	0.04
D11C	Beam	Vertical	100	0.02
D12C	Ceiling	Horizontal	400	0.05
D12C	Beam	Vertical	100	0.03
D13C	Ceiling	Horizontal	0	0.03
D13C	Beam	Vertical	0	0.03
E10C	Ceiling	Horizontal	300	0.03
E10C	Beam	Vertical	0	0.01
E11C	Ceiling	Horizontal	100	0.04
E11C	Beam	Vertical	0	0.01
E12C	Ceiling	Horizontal	200	0.04
E12C	Beam	Vertical	0	0.04
E13C	Ceiling	Horizontal	300	0.04
E13C	Beam	Vertical	0	0.03
B10C	Ceiling	Horizontal	100	0.05
B10C	Beam	Vertical	100	0.03
B11C	Ceiling	Horizontal	100	0.18
B11C	Beam	Vertical	100	0.03
C11C	Ceiling	Horizontal	100	0.14
C11C	Beam	Vertical	0	0.03
C10C	Ceiling	Horizontal	100	0.03
C10C	Beam	Vertical	0	0.03
C12C	Ceiling	Horizontal	100	0.05
C12C	Beam	Vertical	100	0.03
B12C	Ceiling	Horizontal	100	0.05
B12C	Beam	Vertical	100	0.04
C13C	Ceiling	Horizontal	400	0.08
C13C	Beam	Vertical	100	0.03
B13C	Ceiling	Horizontal	300	0.08
B13C	Beam	Vertical	100	0.03
A13C	Ceiling	Horizontal	200	0.20
A13C	Beam	Vertical	200	0.03
A12C	Ceiling	Horizontal	100	0.16
A12C	Beam	Vertical	0	0.03
A11C	Ceiling	Horizontal	200	0.15
A11C	Beam	Vertical	100	0.03
A10C	Ceiling	Horizontal	100	0.09
A10C	Beam	Vertical	200	0.13

[a] C = ceiling.

Table 7. Uranium-238 concentrations in samples of residue collected in survey blocks on the second floor of the former uranium recovery process plant

Block no. shown in Fig. 6	^{238}U concentration (pCi/g)
A1	150
A2	50
A3	26
A4	40
A5	37
B1	130
B2	56
B3	87
B4	36
B5	43
C1	95
C2	75
C3	180
C4	45
C5	39
D1	130
D2	110
D3	58
D4	27
D5	38
E1	4000
E2	750
E3	38
E4a	27
E4b	26
E5a	29
E5b	35
F1	67
F2	38
F3	28
G1	68
G2	43
G3	38
H1	41
H2	36
H3	41

Table 8. Radionuclide concentrations in miscellaneous residue and soil samples

Sample code	Sample location	Radionuclide concentrations (pCi/g)		
		^{238}U	^{226}Ra	^{232}Th
GEQ1	Second level, process building; intersection of blocks D2 and E2; part of ball mill	3,000	50	12
GEQ2	Second level, process building; block C1; taken from two reaction vessels	300	18	<0.4
GEQ3	Second level, process building; inside dryer	13,000	[a]	[a]
GARSA	Outside process building; northernmost pipe joints--at west end	27	380	<0.8
GARSB	Outside process building; southernmost pipe joints--at west end	17	2,400	<0.6
GARC	Grid block K12 in elevator pit on north side of process building	85	17	0.9
GARSB6	Surface, old dryer location at grid point B6	28	29	0.9
GARSC6	Old dryer location outside process plant at grid point C6	6.8	7.6	0.4
GAROS1	Surface soil from east side of bridge on U.S. 41 over Alafia River	0.2	0.5	0.2

[a]This radionuclide not determined in this sample due to spectral interferences.

Table 9. Directly measured alpha and beta-gamma contamination levels and external gamma radiation levels on the floor and lower walls of the second level of the process building

Survey block shown in Fig. 6	Direct alpha measurements averaged (dpm/100 cm^2)	Maximum observed direct alpha measurements (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm averaged over 1 m^2 (mrad/hr)	Maximum observed beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at 1 m (μR/hr)
Floor					
A1	100	300	0.08	0.15	32
A2	200	300	0.07	0.10	40
A3	1,500	1,800	0.28	0.40	80
A4	500	600	0.11	0.13	36
A5	600	1,100	0.09	0.10	24
B1	300	500	0.12	1.5	30
B2	500	1,100	0.12	0.15	40
B3	100	300	0.09	0.10	44
B4	400	600	0.11	0.13	36
B5	200	300	0.06	0.10	44
C1	300	600	0.07	0.10	30
C2	200	500	0.09	0.13	40
C3	400	900	0.12	0.18	40
C4	200	600	0.09	0.10	24
C5	300	600	0.16	0.18	56
D1	200	400	0.14	0.20	30
D2	200	300	0.15	0.20	32
D3	100	200	0.13	0.15	52
D4	200	200	0.10	0.15	32
D5	200	400	0.06	0.10	52
E1[a]	1,400	2,600	1.3	2.5	30
E2[a]	200	300	0.28	0.75	32
E3[a]	200	300	0.13	0.15	30
E4	NA[b]	NA	NA	NA	40
E5	NA	NA	0.09	0.10	70
F1[a]	100	300	0.11	0.13	30
F2	NA	NA	0.09	0.15	30
F3	NA	NA	0.08	0.10	30
F4	NA	NA	NA	NA	24
F5	NA	NA	0.07	0.10	34
G1	100	200	0.04	0.08	22
G2	0	200	0.03	0.05	13
G3	100	200	0.03	0.08	5
G4	NA	NA	NA	NA	4
G5	NA	NA	NA	NA	12
H1	100	300	0.04	0.08	26
H2	200	300	0.02	0.08	26
H3	200	300	0.04	0.09	6
H4	NA	NA	NA	NA	9
H5	NA	NA	NA	NA	12

Table 9 (cont.). Directly measured alpha and beta-gamma contamination levels and external gamma radiation levels on the floor and lower walls of the second level of the process building

Survey block shown in Fig. 6	Direct alpha measurements averaged (dpm/100 cm^2)	Maximum observed direct alpha measurements (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm averaged over 1 m^2 (mrad/hr)	Maximum observed beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at 1 m (μR/hr)
Walls					
A1N	0	100	0.08	0.13	NR[c]
B1E	100	200	0.05	0.13	NR
B1W	200	200	0.08	0.13	NR
A1S	100	400	0.05	0.60	NR
A1W	100	200	0.06	0.08	NR
A2N	200	700	0.08	0.70	NR
B1N	200	300	0.16	0.25	NR
C1N	100	300	0.18	0.23	NR
D1N	100	200	0.17	0.20	NR
E1N	100	100	0.15	0.18	NR
F1N	100	200	0.07	0.13	NR
F1E	100	200	0.07	0.10	NR
F2E	100	200	0.04	0.08	NR
F3E	100	100	0.06	0.08	NR
G3W	100	200	0.02	0.08	NR
G2W	100	100	0.02	0.05	NR
G1W	0	100	0.02	0.05	NR
G1N	100	200	0.05	0.08	NR
H1N	0	100	0.04	0.06	NR
H1E	100	200	0.03	0.05	NR
H2E	100	400	0.06	0.15	NR
H3E	100	200	0.01	0.05	NR
H3S	100	200	0.01	0.05	NR
G3S	100	100	0.01	0.05	NR

[a] Surface area covered with moisture.

[b] BA - not accessible.

[c] NR - no reading.

Table 10. Directly measured alpha and beta-gamma contamination levels on overhead surfaces in the second level of the process building

Block no. shown in Fig. 6	Surface	Surface alignment	Directly measured contamination	
			Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)
A1C[a]	Ceiling	Horizontal	200	0.08
A1C	Beam	Vertical	400	0.06
A4C	Ceiling	Horizontal	200	0.05
A4C	Beam	Vertical	0	0.06
A3C	Ceiling	Horizontal	500	0.10
A3C	Beam	Vertical	0	0.06
B1C	Ceiling	Horizontal	300	0.11
B1C	Beam	Vertical	100	0.10
B4C	Ceiling	Horizontal	200	0.08
B4C	Beam	Vertical	100	0.04
B3C	Ceiling	Horizontal	0	0.07
B3C	Beam	Vertical	0	0.05
C1C	Ceiling	Horizontal	200	0.11
C1C	Beam	Vertical	100	0.10
C4C	Ceiling	Horizontal	0	0.06
C4C	Beam	Vertical	100	0.05
C3C	Ceiling	Horizontal	200	0.06
C3C	Beam	Vertical	200	0.06
D1C	Ceiling	Horizontal	600	0.13
D1C	Beam	Vertical	200	0.08
D4C	Ceiling	Horizontal	100	0.08
D4C	Beam	Vertical	200	0.05
D3C	Ceiling	Horizontal	200	0.06
D3C	Beam	Vertical	100	0.05
E1C	Ceiling	Horizontal	200	0.13
E1C	Beam	Vertical	200	0.08
E4C	Ceiling	Horizontal	200	0.04
E4C	Beam	Vertical	100	0.01
E3C	Ceiling	Horizontal	200	0.03
E3C	Beam	Vertical	300	0.03
F1C	Ceiling	Horizontal	100.	0.08
F1C	Beam	Vertical	500	0.06
F4C	Ceiling	Horizontal	0	0.06
F4C	Beam	Vertical	0	0.06
F3C	Ceiling	Horizontal	200	0.04
F3C	Beam	Vertical	100	0.01
G1C	Ceiling	Horizontal	700	0.06
G1C	Beam	Vertical	300	0.07
G2C	Ceiling	Horizontal	400	0.03
G2C	Beam	Vertical	400	0.01
G3C	Ceiling	Horizontal	500	0.03
G3C	Beam	Vertical	100	0.01
H1C	Ceiling	Horizontal	200	0.04
H1C	Beam	Vertical	100	0.03
H2C	Ceiling	Horizontal	300	0.05
H2C	Beam	Vertical	400	0.02
H3C	Ceiling	Horizontal	400	0.06
H3C	Beam	Vertical	300	0.03

[a] C - ceiling.

Table 11. Directly measured and transferable alpha and beta-gamma contamination levels on process equipment surveyed on the second level of the process building

Block no. shown in Fig. 6	Description of equipment	Directly measured contamination		Transferable contamination	
		Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta (dpm/100 cm^2)
A2	Valve on floor	NR[a]	0.50	15	<50
B1	Top of scales	500	0.50	30	<50
C1	Reaction vessels (two)	NR	0.50	NS[b]	NS
D1	Inside a dryer	3,000	15	NS	NS
D2	Inside a rubber-lined ball mill	4,000	50	140	130
D2	Inside exit line of ball mill	1,300	16.5	10	0
E2	Inside the roller of the ball mill	7,000	3.0	320	260
E2	Outside ball mill on the roller	0	1.0	NS	NS

[a] NR - no reading.

[b] NS - no sample taken.

Table 12. Directly measured alpha and beta-gamma contamination levels and external gamma radiation levels on the floor of the third level of the process building

Survey block shown in Fig. 7	Directly measured contamination		External gamma radiation levels in μR/hr	
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	At surface	At 1 m
A1	100	0.08	35	32
B2	0	0.05	31	38
C1	100	0.04	44	40
C2	200	0.03	31	38
C3	400	0.05	31	42
C4	200	0.03	31	42
C5	300	0.04	31	50
C6	100	0.04	31	48
C7	300	0.03	31	40
C8	200	0.04	19	20
C9	300	0.05	31	40
C10	100	0.05	47	28
E10[a]	200	0.05	47	40
D5	200	0.14	140	70

[a]On floor of elevator pit.

Table 13. Directly measured alpha and beta-gamma contamination levels and external gamma radiation levels on the roof of the process building

Block no. shown in Fig. 12	Direct alpha measurements averaged over 1 m^2	Maximum observed direct alpha measurement	Beta-gamma dose rate at 1 cm averaged over 1 m^2	Maximum observed beta-gamma dose rate at 1 cm	External gamma radiation level at 1 m (μR/hr)	
	(dpm/100 cm^2)		(mrad/hr)		Average	Maximum
A1	350	400	0.09	0.10	58	68
A2	150	200	0.10	0.10	38	44
A3	200	200	0.05	0.05	33	36
B1	200	300	0.10	0.13	59	70
B2	200	300	0.08	0.08	34	38
B3	250	300	0.06	0.08	30	30
C1	250	300	0.11	0.13	65	80
C2	250	300	0.08	0.08	30	34
C3	100	100	0.08	0.08	29	30
D1	50	100	0.08	0.08	50	70
D2	200	300	0.13	0.15	29	34
D3	100	200	0.07	0.08	25	26
E1	100	100	0.09	0.10	41	42
E2	200	200	0.09	0.10	38	44
E3	200	200	0.07	0.08	24	26

Table 14. Directly measured beta-gamma contamination levels and external gamma radiation levels outdoors in the former pilot operations area

Grid point shown in Fig. 8	Beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at the surface (μR/hr)	External gamma radiation level at 1 m (μR/hr)
A1	0.11	78	40
A5	0.05	47	42
A8	0.08	31	40
B1	0.07	47	60
B5	0.08	63	50
B9	0.06	63	50
C1	0.12	94	76
C2	0.08	78	60
C3	0.08	63	56
C4	0.05	16[a]	56
C5	0.07	47	46
C6	0.07	47	50
C7	0.13	78	50
C8	0.10	78	60
C9	0.15	110	60
D1	0.11	63	80
D2	0.08	78	72
D3	0.06	63	66
D4	0.06	78	60
D5	0.05	47	70
D6	0.08	63	76
D7	0.10	63	60
D8	0.11	69	64
D9	0.18	63	70
E1	0.08	94	90
E2	0.13	94	70
E3	0.05	47	50
E4	0.06	47	50
E5	0.05	44	46
E6	0.08	31	48
E7	0.03	31	50
E8	0.07	47	56
E9	0.11	110	60
F1	0.09	94	100
F2	0.17	140	80
F3	0.08	31	60
F8	0.02	16	40
F9	0.03	23	60
G1	0.13	130	90
G2	0.13	94	70
G3	0.06	63	50
G4	0.05	47	40

Table 14 (cont.). Directly measured beta-gamma contamination levels and external gamma radiation levels outdoors in the former pilot operations area

Grid point shown in Fig. 8	Beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at the surface (μR/hr)	External gamma radiation level at 1 m (μR/hr)
G5	0.02	16	30
G6	0.02	16	20
G7	0.02	16	22
G8	0.02	16	40
G9	0.03	23	46
H1	0.08	56	76
H2	0.10	78	74
H3	0.14	63	44
H4	0.06	38	54
H5	0.08	78	40
H6	0.09	25	30
H7	0.09	47	40
H8	0.10	78	50
I1	0.10	78	74
I2	0.13	110	80
I3	0.06	63	64
I4	0.07	56	50
I5	0.08	38	44
I6	0.09	56	48
I7	0.06	63	40
I8	0.05	31	40
I9	NA[b]	NA	50
J1	0.12	94	80
J5	0.08	78	44
J8	0.06	63	40
K1	0.23	190	90
K5	0.07	63	50
K8	0.06	47	40

[a] Concrete surface.

[b] NA - not accessible.

Table 15. Radionuclide concentrations (pCi/g) in surface soil samples taken in the pilot plant area at grid points

Sample location shown in Fig. 8	^{238}U	^{226}Ra	^{232}Th
A1	20	33	0.7
A8	18	25	0.6
B5	5.6	7.7	0.4
C2	3.4	4.3	0.3
C8	32	40	1.6
E3	5.1	8.6	0.3
E8	22	26	0.9
G3	24	27	1.9
G8	36	36	1.9
I2	19	30	1.2
I8	38	32	1.8
J5	13	15	0.6
K1	22	98	1.5
K8	12	9.8	0.6

Table 16. Directly measured beta-gamma contamination levels and external gamma radiation levels outdoors in the process plant area

Grid point shown in Fig. 8	Beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at the surface (μR/hr)	External gamma radiation level at 1 m (μR/hr)
A6	0.09	56	60
A8	0.14	63	54
A10	0.08	63	46
A12	0.08	63	50
A14	0.11	31	50
B3	0.04	31	44
C5	0.06	47	50
C6	0.09	25	52
C7	0.05	31	44
C8	0.05	47	40
C9	0.05	31	32
C10	0.05	38	32
C11	0.04	31	30
C12	0.07	47	30
C13	0.03	25	30
C14	0.03	25	26
C15	0.08	50	36
D1	0.09	63	70
D2	0.09	50	52
D4	0.06	56	46
D5	0.13	31	42
D6	0.16	69	42
D7	0.07	47	40
D8	0.04	38	34
D9	0.07	47	26
D10	0.12	31	32
D11	0.07	47	32
D12	0.13	31	30
D13	0.06	16	22
D14	0.03	31	26
D15	0.10	63	40
D16	0.06	47	20
D18	0.07	47	48
E5	0.11	78	46
E6	0.29	190	54
E14	0.03	22	30
E15	0.10	44	40
F5	0.11	63	40
F6	0.07	31	60
F14	0.03	22	24
F15	0.08	44	30
G16	0.05	31	36

Table 16 (cont.). Directly measured beta-gamma contamination levels and external gamma radiation levels outdoors in the process plant area

Grid point shown in Fig. 8	Beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at the surface (μR/hr)	External gamma radiation level at 1 m (μR/hr)
G18	0.09	63	50
H5	0.05	56	62
H6	0.08	47	46
H14	0.03	28	28
H15	0.10	25	40
I5	0.16	160	110
I6	0.16	140	82
I14	0.01	13	20
I15	0.03	47	32
J4	NA[a]	NA	92
J5	0.19	190	110
J6	0.24	160	90
J10	NA	NA	66
J11	NA	NA	60
J14	0.02	13	54
J15	0.09	63	50
J16	0.12	94	70
J18	0.13	38	40
K5	0.14	94	110
K6	0.20	94	120
K7	0.19	130	110
K8	0.08	78	80
K9	0.13	110	110
K10	0.18	160	110
K11	0.30	130	100
K14	0.11	94	90
K15	0.11	94	94
L3	NA	NA	130
L17	NA	NA	60
M6	0.32	280	140
M8	0.26	220	140
M10	0.29	250	140
M12	0.13	130	120
M14	0.17	130	110
N6	0.47	470	300
N10	0.70	470	200
N14	0.50	340	200
A16	0.08	50	48
A18	0.08	56	48
F1	0.09	56	50
F2	0.11	110	62
F4	0.10	88	54

Table 16 (cont.). Directly measured beta-gamma contamination levels and external gamma radiation levels outdoors in the process plant area

Grid point shown in Fig. 8	Beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at the surface (μR/hr)	External gamma radiation level at 1 m (μR/hr)
N3	0.38	380	240
N8	0.50	310	280
N12	0.31	310	240
N16	0.25	250	160
N18	0.28	190	100

[a]NA - not accessible.

Table 17. Radionuclide concentrations (pCi/g) in surface soil samples taken in the process building area at grid points

Sample location shown in Fig. 10	^{238}U	^{226}Ra	^{232}Th
A18	32	31	1.1
B3	39	14	0.8
C10	12	14	0.4
D6	22	76	1.1
D14	29	26	1.8
F4	7.9	20	[a]
G16	33	31	1.3
J6	17	38	0.5
J15	22	25	0.7
K10	9.7	42	0.5
L3	10	49	0.6
L17	11	190	
N18	15	49	1.4

[a]This sample was not analyzed for this radionuclide.

Table 18. Directly measured beta-gamma contamination levels and external gamma radiation levels outdoors in the former dryer location

Grid point shown in Fig. 10	Beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at the surface (μR/hr)	External gamma radiation level at 1 m (μR/hr)
A0	0.17	63	18
B0	0.07	56	16
C0	0.06	38	16
A1	0.04	6	18
A2	0.03	25	16
A3	0.04	44	36
A4	0.06	50	30
A5	0.07	56	44
A6	0.07	63	44
A7	0.09	81	50
A8	0.08	75	52
B1	0.03	19	16
B2	0.05	44	26
B3	0.04	50	34
B4	0.06	56	34
B5	0.09	50	30
B6	0.05	44	46
B7	NA[a]	NA	52
B8	NA	NA	70
C1	0.05	50	24
C2	0.05	50	26
C3	0.06	44	30
C4	0.04	44	30
C5	0.05	44	30
C6	0.07	63	30
C7	0.06	56	46
C8	0.08	81	56
D1	0.05	47	20
D2	0.05	44	26
D3	0.03	28	26
D4	NA	NA	NA
D5	NA	NA	NA
D6	0.09	47	28
D7	0.07	50	36
D8	0.04	44	40
D0	0.05	31	24
E0	0.04	38	20
E1	0.08	25	20
E2	0.08	44	24
F0	0.06	50	20
F1	0.08	38	16
G0	0.06	16	16

Table 18 (cont.). Directly measured beta-gamma contamination levels and external gamma radiation levels outdoors in the former dryer location

Grid point shown in Fig. 10	Beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at the surface (μR/hr)	External gamma radiation level at 1 m (μR/hr)
G1	0.05	41	14
G2	0.04	31	16
H0	0.05	50	16
H1	0.05	38	16
H2	0.08	19	14
H3	0.06	19	16
I0	0.06	38	16
I1	0.05	38	14
I2	0.04	16	14
I3	0.05	38	16
E7	0.05	38	32
E8	0.05	38	40
F6	0.08	38	28
F7	0.07	31	32
F8	0.07	66	34
G6	0.07	50	26
G7	0.07	69	28
G8	0.05	50	30
H7	0.04	44	26
H8	0.07	56	24
I8	0.06	28	20

[a]NA - not accessible.

Table 19. Radionuclide concentrations in water and water sediment samples

Sample designation	Location[a]	Radionuclides in water (pCi/liter)				Radionuclides in water sediment (pCi/g)	
		^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{238}U	^{226}Ra
GAR1	Grid point A1	30	0.9	2	2	22	39
GAR2	Grid point K1	180	0.4	3	6	3	42
GAR3	10 ft west and 3 ft south of point K1	2	0.2	0.5	3	39	37
GAR4	15 ft west and 5 ft south of point C1	900	1,000	60	100	16	65
GAR5	14 ft west and 5 ft south of point K1	700	20	50	10	9	59
GAR6	5 ft south of point M6	300	3	0.9	8	10	77
GAR7	At point where plant water discharges into bay	20	0.5	5	8	29	30
CG_w[b]		40,000	2,000	30	100		

[a] In former pilot plant area, unless otherwise specified.

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

APPENDIX I

DESCRIPTION OF RADIATION SURVEY METERS AND SMEAR COUNTERS

RADIATION SURVEY METERS

Alpha Survey Meters

The type of alpha survey meter used at the Gardinier 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 (see Fig. I-A). The ZnS detector is covered with a 5-mil aluminized mylar sheet in order to make the instrument light-tight. A metal grid is used to avoid puncturing the mylar when surveying rough surfaces. This instrument is capable of measuring alpha surface contamination levels of a few dpm/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.

Beta-Gamma Survey Meter

A portable Geiger-Mueller (G-M) survey meter 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-window 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. This meter is shown in Fig. I-B.

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 per mR/hr for surfaces contaminated with ^{226}Ra in equilibrium with ^{238}U and 2,300 cpm per mR/hr for surfaces contaminated with initially pure uranium. The closed-window (gamma) calibration factor, determined by use of a NBS standard ^{226}Ra source, was 3,200 cpm per mR/hr.

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 (see Fig. I-D). This unit is capable of measuring radiation levels from a few μR/hr to several hundred μR/hr. This instrument is calibrated at Oak Ridge National Laboratory (ORNL) with an NBS standard ^{226}Ra source. Typical calibration factors are of the order of 500 cpm per μR/hr. The sensitivity of this instrument may be influenced by factors such as temperature, humidity, and small changes in photomultiplier tube voltage. Therefore, each instrument used in the field is standardized daily, and its response is compared with readings made with a gamma-ray dosimeter developed at ORNL by Hurst and Wagner[I-1] and called the "Phil" dosimeter. This latter instrument, described below, has response which is proportional to exposure in Roentgens over a wide energy range. Readings made with the portable scintillation survey meter and compared with exposure rates determined at the same time using the "Phil" may be used as a factor to convert the reading in counts per unit time to exposure rate per unit time (μR/hr).

"Phil" Gamma-Ray Dosimeter

The "Phil" dosimeter was developed at ORNL to fill a need for a sensitive low-level gamma-ray dosimeter. A halogen-filled G-M counter is used as the detector. Hurst and Wagner developed the original version[I-1] as a neutron-insensitive dosimeter for use in mixed neutron and gamma-ray fields. The current version of this instrument utilizes an RCL 10-60 G-M tube with a 30 mg/cm^2-thick glass wall. Counters of this type have a "peaked" response to low-energy photons. An energy compensation filter consists of perforated layers of tin and lead. The inner layer is a 1-mm-thick sheet of tin containing 20 holes, each of which is 4-mm diam, and 24 holes of 4.7-mm diam. A 0.1-mm outer layer of lead contains 24 holes, each of which is 5-mm diam. The inherent background count rate for this detector is 40 counts/min. It is used in

the pulse mode in conjunction with a portable scaler. The response was found to be essentially constant (±12%) for photon energies down to 50 keV. Calibration of the instrument is performed using sealed NBS sources. A typical unit of this type yields 3,400 counts/min for an exposure rate of 1 mR/hr.

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 (see 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 ($\sim$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 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, shown in Fig. I-E, was used in the field to measure beta activity on smear papers and was calibrated daily using a beta standard of known activity.

REFERENCES FOR APPENDIX I

I-1. P. T. Perdue, W. H. Shinpaugh, J. H. Thorngate, and J. A. Auxier, "A Convenient Counter for Measuring Alpha Activity of Smear and Air Samples," *Health Phys.* 26, 114 (1974).

ORNL-Photo 6705-76

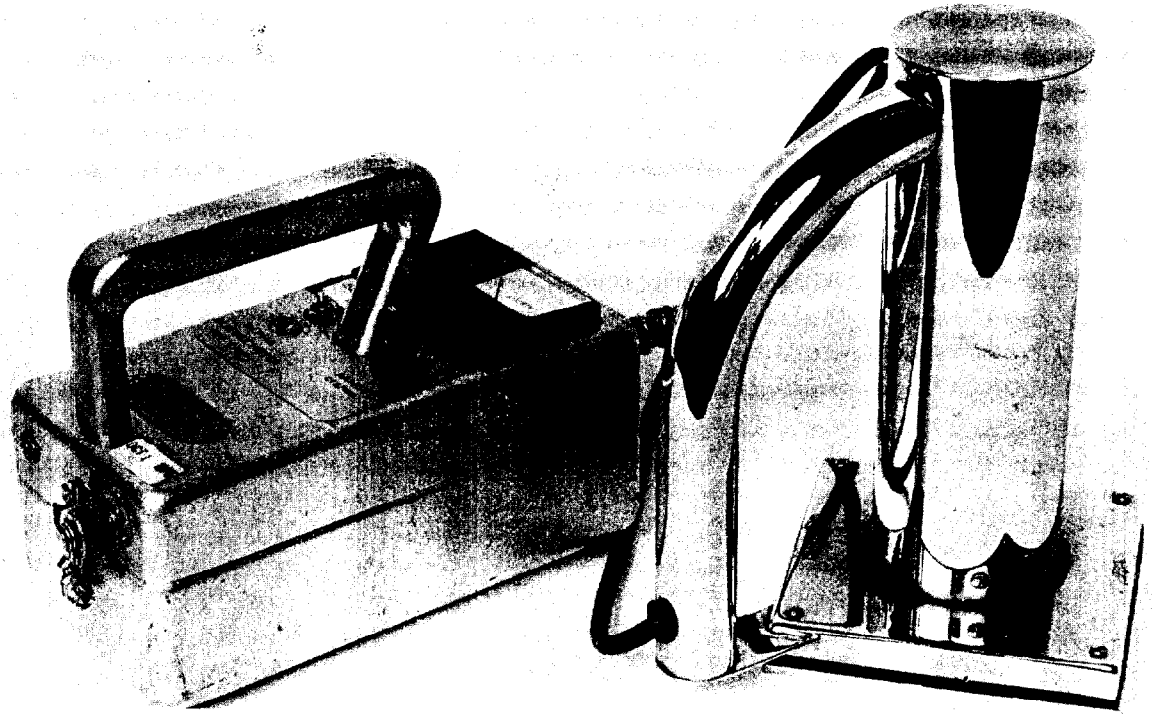

Fig. I-A. Alpha scintillation survey meter.

ORNL-Photo 6704-76

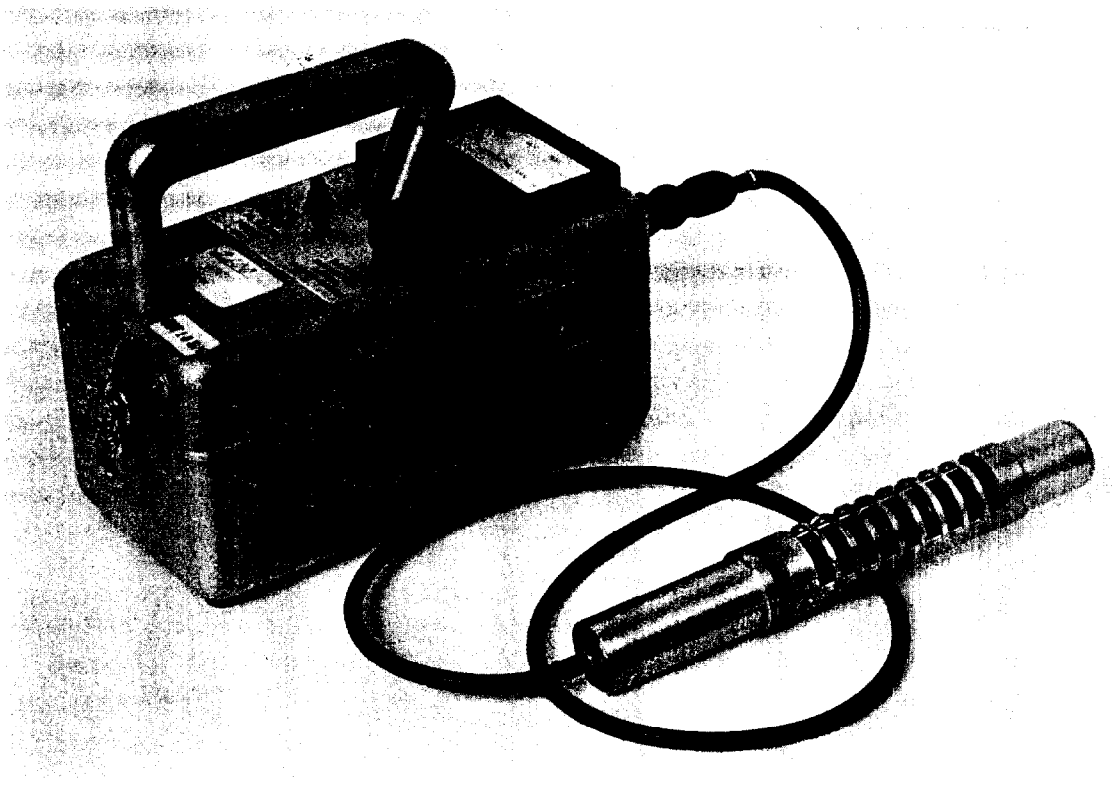

Fig. I-B. Geiger-Mueller survey meter.

ORNL-Photo 6710-76

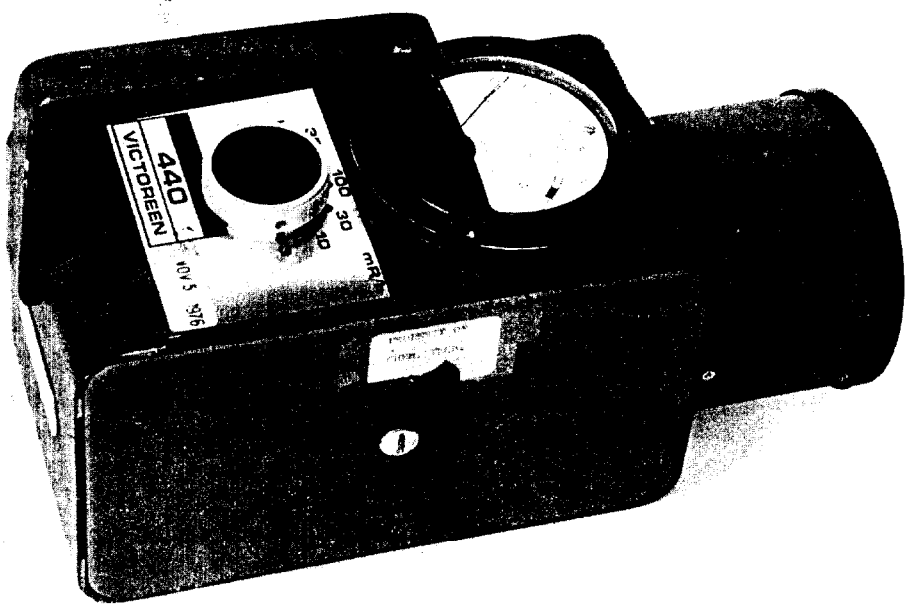

Fig. I-C. Victoreen Model 440 ionization chamber.

ORNL-Photo 6707-76

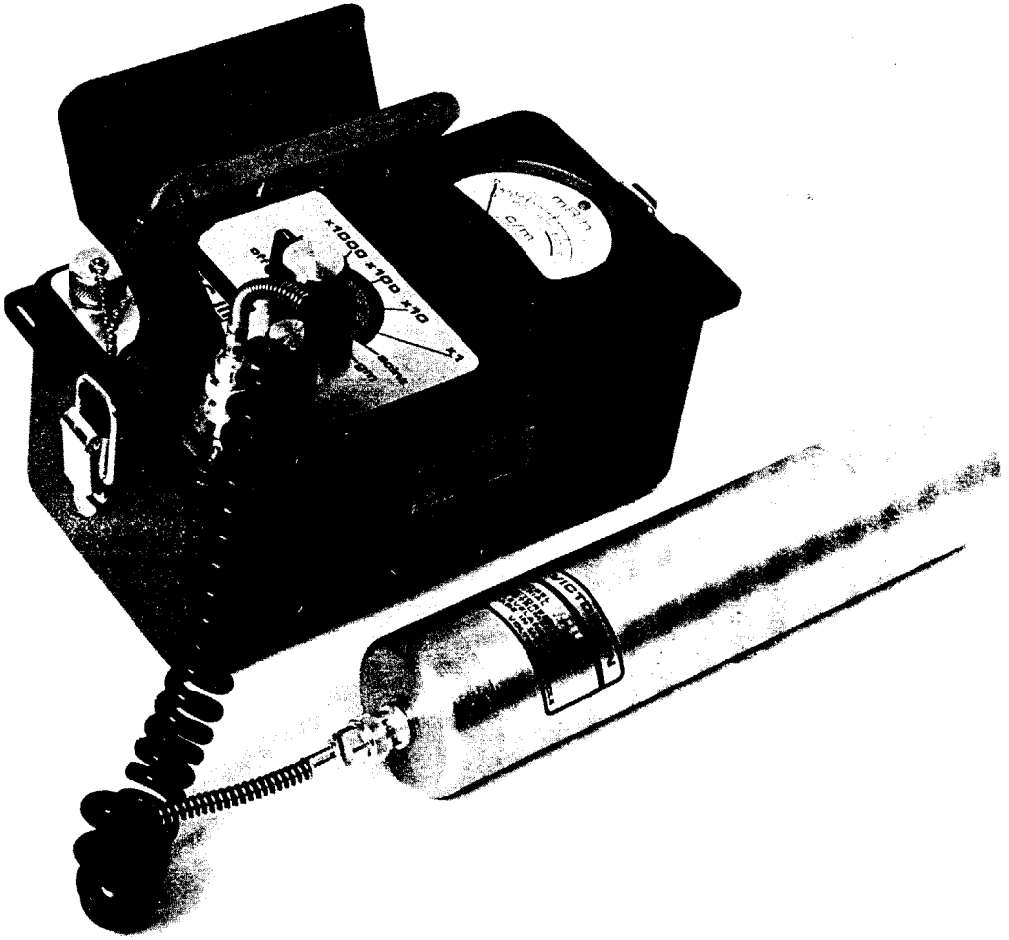

Fig. I-D. Gamma scintillation survey meter.

ORNL-Photo 1070-78

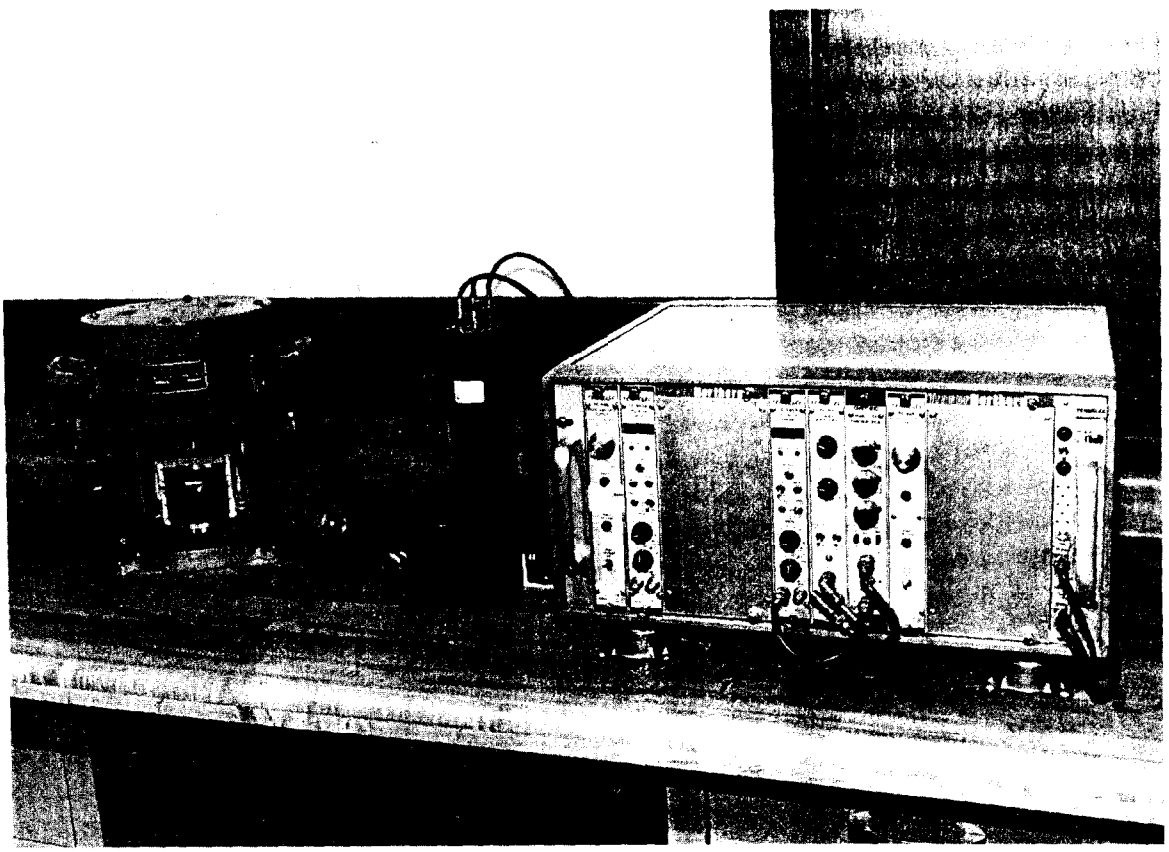

Fig. I-E. Smear counter and associated electronics. The beta counter is on the left and the alpha counter is on the right.

APPENDIX II

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 counting of radioactivity in environmental samples (see Fig. II-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 4096-channel analyzer (see Fig. II-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 2,500 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, 1,120, 1,765, and 2,204 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

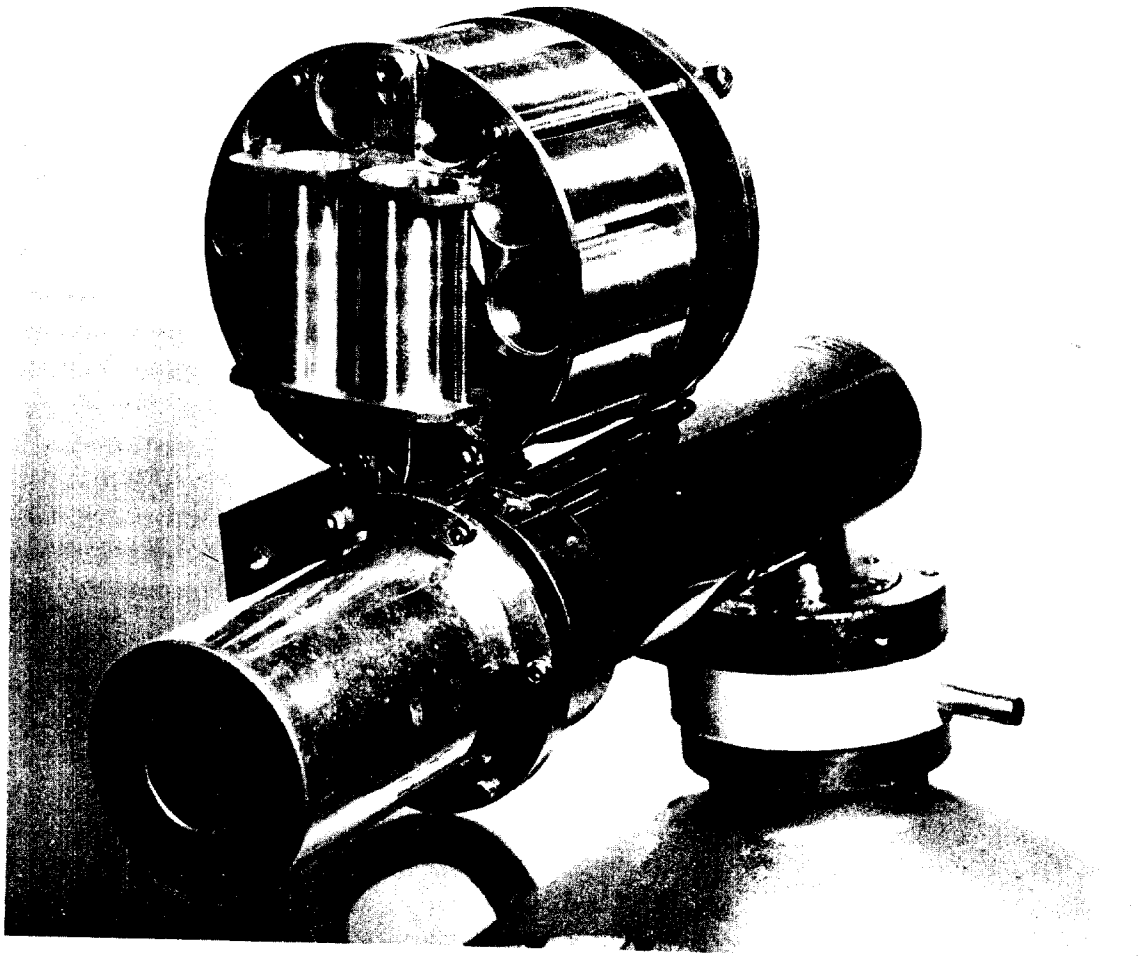

Fig. II-A. Holder for Ge(Li) detector system.

ORNL-Photo 6719-76

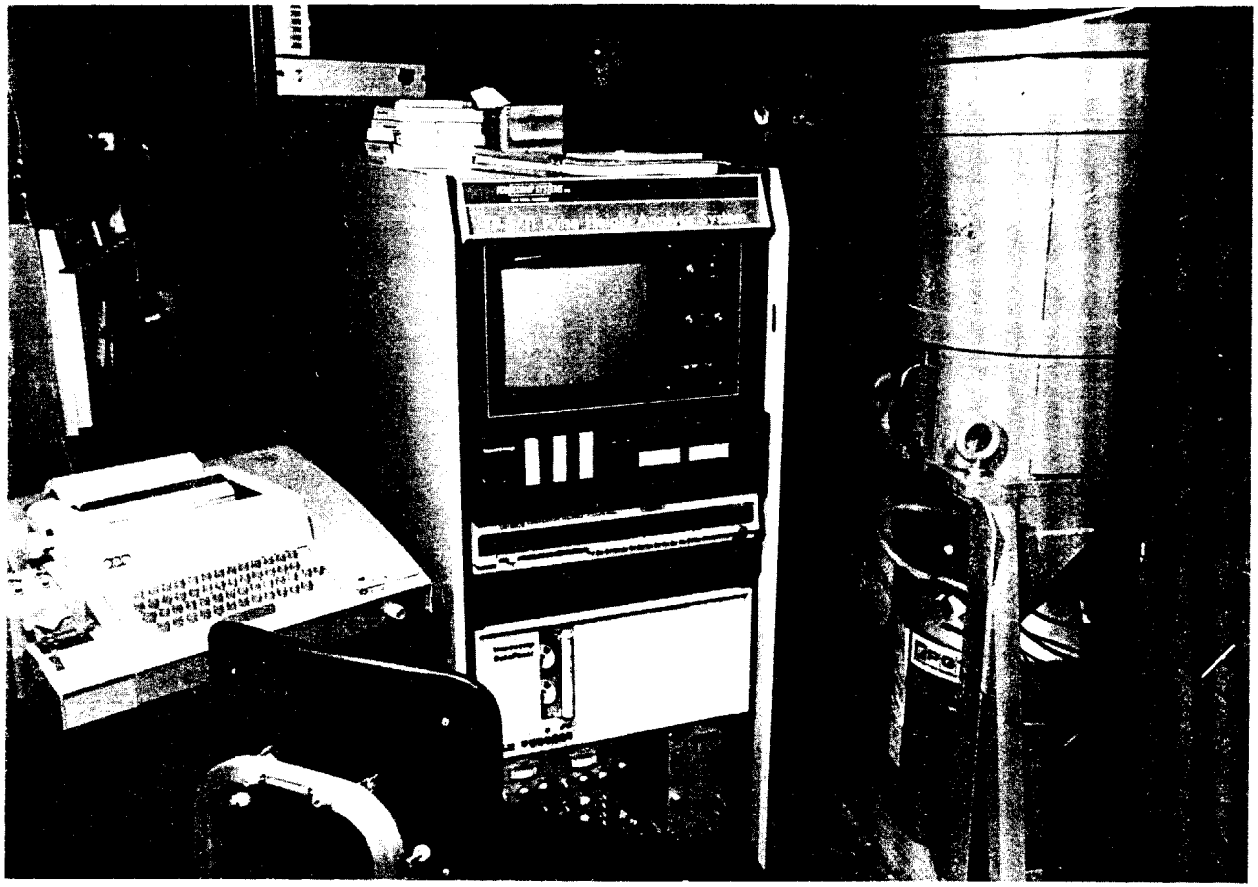

Fig. II-B. Computer-based multichannel analyzer.

APPENDIX III

PERTINENT RADIOLOGICAL REGULATIONS, STANDARDS, AND GUIDELINES

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

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

November 1976

The instructions in this guide in conjunction with Table III-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 III-1 do not apply to premises, equipment, or scrap containing induced radioactivity for which the radiological considerations pertinent to their use may be different. The release of such facilities or items from regulatory control will be considered on a case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate residual contamination.
2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table III-1 prior to applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.
3. The radioactivity on the interior surfaces of pipes, drain lines, or 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 material in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer or 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 material 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 III-1. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also with the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:

   a. Identify the premises.

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

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

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

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

Table III-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 cm^2	15,000 dpm α/100 cm^2	1,000 dpm α/100 cm^2
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-nat, Th-232, Sr-90 Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm^2	3,000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and other noted above.	5,000 dpm $\beta\gamma$/100 cm^2	15,000 dpm $\beta\gamma$/100 cm^2	1,000 dpm $\beta\gamma$/100 cm^2

[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 cm^2.

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

[f] The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/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 III-2 or Table III-3. (Table III-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 III-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 nonoccupational MPC_a[b] is 2 x 10^{-13} Ci/m^3 or less or for which the nonoccupational MPC_w[c] is 2 x 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, -238.[d]	100	20
Group 2: Those nuclides not in Group 1 for which the nonoccupational MPC_a[b] is 1 x 10^{-12} Ci/m^3 or less or for which the nonoccupational MPC_w[c] is 1 x 10^{-6} Ci/m^3 or less; includes Es-254; Fm-256; I-126,[d] -131, -133; Po-210; Ra-223; Sr-90; Th-232; U-232.	1000	200
Group 3: Those nuclides not in Group 1 or Group 2.	5000	1000

[a] See note following table on applications 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 III-3. Alternate surface contamination limits

(All alpha emitters, except U-nat and Th-nat are considered as a group.) The levels may be averaged over 1 m^2[a] 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.	1000	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.	5000	1000

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[a]Note on application of Tables III-2 and III-3 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 $1/n \sum_{1}^{n} Si \geq L$, where Si 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 $1/n \sum_{1}^{n} Si \geq AL$, 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 $3L$.

APPENDIX IV

EVALUATION OF RADIATION EXPOSURES AT GARDINIER, INCORPORATED, TAMPA, FLORIDA

The U.S. Department of Energy has determined that the former Uranium Recovery Pilot and Process Site at Gardinier, Incorporated, in Tampa, Florida, is presently contaminated with radioactive residues resulting from previous uses of this property. This site was involved in the extraction of uranium from phosphoric acid under a contract with the Atomic Energy Commission (AEC) from 1956 to 1960. Pilot operations were performed under an AEC contract from 1951 to 1954. The former processing plant consists of a three-story building, an adjacent chemical processing plant area, and a small area where drying and crushing equipment was located. The former pilot plant building is a single-story structure which now serves as office space. The process building currently houses a workshop, a lunchroom, and office space on the first floor, and an office and machinery on the third floor. The second floor and roof are unoccupied. There are approximately 20 full-time employees in the former process building and 10 full-time employees in the former pilot operations building.

The contamination from previously contracted operations is producing slight radiation exposures to employees working at this site. These exposures result primarily from beta and gamma radiation emitted by contamination in the ground or on building surfaces. The additional exposure received by ingestion (e.g., eating or drinking in one of the buildings) is relatively small as compared with exposures to external radiation. A summary of radiation exposures at the Gardinier site is provided in Table IV-1 along with appropriate guidelines and background values.

The naturally occurring radionuclides present at the Gardinier 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 exposure 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.

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 you begin with one curie* of uranium-238, one-half curie will remain after 4.5 billion years. After 9 billion years, there would only be one-fourth curie of uranium-238. 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 IV-2 until stable lead is formed. The "decay product" listed in Table IV-2 is the radiation produced as the parent decays.

Direct Gamma-Ray Exposures

As shown in Table IV-2, some of the radioactive daughters in the uranium decay series emit gamma rays. (Gamma rays are a highly penetrating radiation like X-rays.) The maximum gamma radiation level indoors was recorded on the second floor of the process building and was equal to 80 microRoentgens per hour.† Average indoor readings were 14, 32, and 40 microRoentgens per hour for the first, second, and third floors of the process building and 19 microRoentgens per hour for the former pilot operations building. Outdoor readings ranged from background

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*A curie is a unit defined for expressing the amount of radioactivity present in a substance; one curie represents 37 billion radioactive disintegrations per second.

†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.

to 300 microRoentgens per hour, with an average value of 56 microRoentgens per hour near the pilot building and 73 microRoentgens per hour near the process plant building. Exposure to the maximum indoor gamma radiation level, 80 microRoentgens per hour, for 2,000 per year (a typical work year) would lead to an exposure of 160,000 microRoentgens. For comparison, a typical chest X-ray (according to Department of Health, Education and Welfare data) might yield an exposure of about 27,000 microRoentgens.

The National Council on Radiation Protection and Measurements (NCRP) has recommended a maximum annual whole-body exposure of 500,000 microRoentgens per year to an individual continually exposed in the general population; this would correspond to exposure to 250 microRoentgens per hour for 2,000 exposure hours. Two locations were found outdoors where this guideline would be exceeded; however, the points are infrequently occupied. All indoor areas had exposure rates much less than 250 microRoentgens per hour. Consequently, workers on the site are receiving average gamma exposures that are below the recommended guideline.

Direct Beta-Gamma Exposures

Nuclear Regulatory Commission (NRC) guidelines state that the combined dose from weakly penetrating beta particles and from gamma rays, measured at a distance of 1 centimeter above any surface, should not exceed 0.2 millirad* per hour when averaged over an area of 1 square meter. The combined dose rate should not exceed 1.0 millirad per hour in small areas of 100 centimeters. These guidelines are exceeded in the lunchroom, workshop, and second floor of the process building and at several points outdoors. In addition, equipment and pipes located on the second floor and west wall, respectively, display beta-gamma dose rates which exceed the guidelines. (Parts of the equipment have recently been removed and transported to a licensed commercial radioactive waste burial facility.) The maximum value obtained was 50 millirad per hour on

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*The rad is the unit for measuring radiation dose to tissue. One millirad is equal to one-thousandth of a rad.

a ball mill on the second floor of the process building. Handling this ball mill for one hour would result in a skin dose of 50 millirad. For comparison, the skin dose which would be expected from a normal year's watching of color television by an adult is 1.6 millirad; for a child less than 15 years of age, the comparable dose is 3.6 millirad per year (according to the United Nations Scientific Committee on the Effects of Atomic Radiation).

The primary concern of the NRC guideline is exposure of skin surfaces. The thickness of ordinary shoe soles is adequate to protect the skin of 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. Although potential exists for exposures far in excess of the guidelines, beta and gamma exposures are believed to be small to employees at this site due principally to a low frequency of occupancy. For example, during a normal month, there is a total of approximately 3,200 man hours spent in first floor areas of the process building.

Other Considerations of Exposure

In almost all areas of this site, the soil contains elevated levels of radium-226 and uranium-238 as a result of normal ongoing operations of the plant. Use of this site for agricultural purposes could lead to significant radiation exposures by intake from eating contaminated crops. Furthermore, use of this site for residential purposes could lead to significant exposures to soil-produced radon-222 which would accumulate in enclosed structures.

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 risk 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 Gardinier site.

The normal annual death rate* from all types of cancer among all population groups in Hillsborough County (as of 1970) was 151 deaths per 100,000 population. At the same time, the death rate from all types of cancer for all population groups in the United States and in the state of Florida was 151 and 150 per 100,000 population, respectively. A one-year exposure to penetrating gamma radiation of 500,000 microRoentgens 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

A number of control measures are possible to reduce actual, and, more serious potential, exposures of people working at the Gardinier site. The most immediate remedy is to thoroughly clean all building and equipment surfaces and restrict the working time of people at the site in areas displaying the highest levels of exposure. Decontamination of the entire site by removal of the radioactive residues or stabilization in place and restricting future activities on the site would, of course, provide maximum protection. Remaining contaminated equipment and pipes should be cleaned or removed to a remote, licensed burial ground. The Department of Energy is now actively evaluating alternatives under a priority program designed to assure adequate protection of the working population.

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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.

SUMMARY

In summary, the former Uranium Recovery Pilot and Process site at Gardinier, Inc., is contaminated with residues containing naturally occurring radionuclides. This contamination is producing slight radiation exposures to employees working at this site. However, the contamination has the potential to produce radiation exposures which could approach, and in some cases exceed, scientifically based guidelines. These more serious potential exposures could be caused by small changes from the present occupancy and use of the site and associated equipment. Consequently, remedial measures are in order. The Department of Energy has developed a coordinated plan which addresses specific problems at facilities such as the Gardinier plant. Currently, work is underway to implement the elements of this plan.

Table IV-1. Summary of exposure data at Gardinier, Incorporated, Tampa, Florida

Exposure source	Background levels	Guideline value for general public	Guideline value for radiation workers	Average levels at Gardinier site
Gamma radiation from daughters of uranium and radium contamination	5 microRoentgens[a] per hour in Hillsborough County area	250 microRoentgens per hour above natural background for 40 hours per week and 50 weeks per year for an individual. This is equivalent to 0.5 Roentgen per year	2500 microRoentgens per hour for 40 hours per week and 50 weeks per year. This is equivalent to 5 Roentgens per year	Average gamma radiation levels 1 meter above the floor or ground ranged from 14 to 73 microRoentgens per hour
Beta-gamma radiation from daughters of uranium and radium contamination	Less than 0.02 millirad[b] per hour	Maximum of 0.2 millirad per hour at 1 centimeter above surface of 1 square meter	15 millirads per hour for 40 hours per week and 50 weeks per year. This is equivalent to 30 rads per year	Range from 0.01 to 50 millirads per hour. Guideline value for general public exceeded at many points indoors and outdoors

[a]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.

[b]The rad is the unit for measuring radiation dose to tissue. One millirad is equal to one-thousandth of a rad.

Table IV-2. Uranium 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	1,600 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
polonium-210	140 days	alpha	lead-206
lead-206	stable	none	none

[a]Short-lived radon daughters.

APPENDIX V

STANDARD UNITS OF MEASUREMENT

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.

Table V-1. Standard 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)	1.61
millirad (mrad)	microgray (μGy)	10.0
microroentgen (μR)	coulomb per kilogram (C/kg)	2.58×10^{-10}
disintegrations per minute (dpm)	becquerel (Bq)	0.02
picocurie (pCi)	becquerel (Bq)	0.037
microcurie (μCi)	becquerel (Bq)	3.7×10^{4}

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