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Formerly Utilized MED/AEC Sites Remedial Action Program

**Radiological Survey of the Former
VITRO Rare Metals Plant
Canonsburg, Pennsylvania
June 1979**

Final Report

Prepared for

U.S. Department of Energy
Assistant Secretary for Environment
Division of Environmental Control Technology

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PREFACE

This series of reports results from a program initiated in 1974 by the Atomic Energy Commission (AEC) for determination of the condition of sites formerly utilized by the Manhattan Engineering District (MED) and the AEC for work involving the handling of radioactive materials. Since the early 1940's, the control of over 100 sites that were no longer required for nuclear programs has been returned to private industry or the public for unrestricted use. A search of MED and AEC records indicated that for some of these sites, documentation was insufficient to determine whether or not the decontamination work done at the time nuclear activities ceased is adequate by current guidelines.

This report contains the results of surveys of the current radiological condition of the former Vitro Rare Metals Plant. This site is contaminated with residues containing naturally occurring radioactivity. This radioactive contamination is resulting in radiation exposures to people working on this site. Furthermore, these radiation exposures approach and, in many cases, exceed scientifically-based Federal radiation protection guidelines. People working in these facilities did not knowingly incur such radiation exposures and are receiving no benefits from their involuntary exposures to radiation; the risk of cancer may be elevated somewhat by these exposures. Consequently, remedial action at this site is necessary to preclude any further unnecessary radiation exposure to the public.

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RADIOLOGICAL SURVEY OF THE FORMER VITRO RARE METALS PLANT,
CANONSBURG, PENNSYLVANIA

ABSTRACT

The results of a radiological survey of the former Vitro Rare Metals Plant in Canonsburg, Pennsylvania, are presented in this report. This 18-acre site was used from 1911 to 1922 to extract radium from carnotite ore, from 1930 to 1942 to extract radium and uranium salts from onsite residues and carnotite ore, and from 1942 to 1957 to recover uranium from various ores and scrap materials. The radiological survey was conducted in two phases. Phase I included measurement of radon and radon daughter concentrations in onsite buildings; concentrations measured in this part of the survey were well above guideline levels. Phase II consisted of measurement of surface contamination levels on the site, external gamma radiation levels at 1 m above surfaces on and near the site, radionuclide concentrations in surface and subsurface soil and water on and near the site, and radon concentrations in air at offsite locations. The results of the second phase of the survey indicate that large quantities of the radioactive wastes generated during radium and uranium recovery operations still remain on the site. Radium-bearing

wastes are present in soil beneath or adjacent to each of the buildings on the site and in the top few feet of soil over almost the entire site, with some areas being contaminated to a depth of 16 ft or more. Alpha contamination levels, beta-gamma dose rates, and external gamma radiation levels in some areas of the buildings and outdoors on the site are above current federal guidelines concerning the release of property for unrestricted use. Concentrations of ^{226}Ra in water in holes drilled on the site are above the maximum permissible concentration (MPC_w). Also, measurements made offsite show that contamination from the site has spread to nearby offsite locations, and that there is significant atmospheric transport of ^{222}Rn from the site.

INTRODUCTION

At the request of the Department of Energy (then the Energy Research and Development Administration, ERDA), Oak Ridge Operations, a radiological survey was conducted during the period March to July, 1977, at the Canonsburg, Pennsylvania site of the former Vitro Manufacturing Company's Rare Metals Plant.¹⁸ The property involved, about 18 acres, is located on Strabane Avenue; it is bounded by Chartiers Creek, the Pennsylvania Railroad, George's Pottery Company, and the Washington-Canonsburg Street Railway right-of-way. This property is presently owned by the Canon Development Company, Inc., and is called the Canon Industrial Park. The various buildings in the Park are leased to tenant companies with a total of approximately 110 employees. An aerial photograph of the site is shown in Fig. 1, and a scaled drawing that identifies the existing buildings is displayed in Fig. 2. Data for the current use

use and approximate number of occupants of each building are given in Table 1. The site is divided into three separate parcels, as shown in Fig. 2.

From 1911 to 1922 the Standard Chemical Company extracted radium as bromide or sulfate from carnotite ore at this site. No further operations were performed until about 1930 when the Vitro Manufacturing Company (now the Vitro Corporation of America) acquired the plant. From 1930 to 1942 Vitro extracted radium and uranium salts from onsite residues and carnotite ore. Operation turned to the recovery of uranium from various ores, concentrates, and scrap materials under U.S. government contracts in 1942.¹ Buildings that existed at the site in 1956, during uranium recovery operations, are identified in Fig. 3, as adapted from a Vitro blueprint dated April, 1956.

Records¹ show that in October, 1948, approximately 30,000 lbs of uranium oxide per month was being extracted from 300,000 lbs of waste received from different AEC installations. The scrap material arrived in assorted containers and information as to the expected amount of recoverable uranium was provided. After the material was carried through an extensive process, the extracted uranium oxide (U_3O_8) was weighed into 400-lb drums and stored in the warehouse until shipment.¹

Liquid wastes were discharged into an open drain which went under Strabane Avenue and emptied into a swamp (Parcel C, Fig. 2). Roughly oval in outline, the swamp was approximately 260 ft in length, with a maximum width of approximately 150 ft. A drainage ditch connected the swamp and Chartiers Creek, which flows into the Ohio River west of Pittsburgh.²

Solid wastes were accumulated after 1911 in several mounds. The approximate location of these waste mounds is shown in Fig. 4, adapted from a sketch by Bruce Wallace.³ The oldest of these mounds (labeled 1 in Fig. 4) was a rough circle which covered approximately 500 yd² and contained material dumped in 1911 and 1934. A second mound of slightly larger area (2, Fig. 4) dated from the 1911 to 1922 Standard Chemical Company period. A "Y" shaped mound, No. 3, covering approximately 40 yd², dated from 1937; mound No. 4 was in use in 1948. All these mounds are located in Parcel A (Fig. 2). A second Standard Chemical Company dump (1911-1922) was located somewhere within Parcel B (Fig. 4, No. 5). Early survey work indicated that adjacent roads and fields showed above background radiation levels, suggesting that waste material had eroded from its original position or had been used for fill.¹

In a report on a reconnaissance visit to the Vitro plant in October, 1948, B. S. Wolf stated that radiation levels throughout approximately 10 acres of liquid and solid wastes ranged from 0.5 to 3.0 mrad/hr.⁴ In November of that same year, R. E. Heyden and A. R. Picot made some preliminary radiation measurements but stated that the readings they obtained were "inconsistent and unreliable."⁵

By May, 1949, Vitro was processing waste materials from Mallinckrodt Chemical Works, Hanford, Harshaw, and Electro Metallurgical Company--all AEC contractors. A slag material designated "C-special" from Mallinckrodt was processed to recover uranium. Another material, "D-4," an impure black oxide, was received from all four contractors mentioned. This was

reprocessed and returned to one of the originators. A slag from Hanford was received containing approximately 40% tin, 20% copper, and 9% uranium; this was processed to recover the tin. In addition, experimental work was conducted at Vitro to improve this particular recovery process. Graphite from Hanford and Niagara Falls was burned for its ash, which contained a considerable amount of uranium. A fourth material, from Hanford, "MC-6," consisted of drippings from uranium metal.⁶

During May, 1949, L. F. Randolph made a preliminary study of the swamp area (Parcel C mentioned above) and surrounding vegetation.² The vegetation study was only a visual inspection of the plants growing in the vicinity. The swamp area was essentially level and covered with a deposit of fine silt and ground rock having the consistency of soft mud. Survey meter readings at eight points around the edge of the mud flats varied from 0.03 to 1.3 mrem/hr. Randolph states in his report that there was no pronounced damage to the plant life due to radioactivity present in the soil, and he suggests that factors other than radiation, such as the chemical composition of the waste, were inhibiting the growth of plants in the vegetation-free central portion of the swamp.

A study was made of the exhaust stack effluent in September of 1950.⁷ It was determined that uranium was emitted in the effluent at a maximum rate of 200 g/hr.

An estimate of uranium concentration in the waste stream discharged to Chartiers Creek was made in February, 1951.⁸ The level was estimated to be 10^{-8} g/ml or about 10 times normal background levels. As this concentration was not considered harmful, no corrective measures were taken.

In September, 1956, S. R. Sapirie of Oak Ridge Operations approved the removal of 12,003,726 lbs of waste residues containing 0.097% U_3O_8 from the Vitro site.^{9,10} The uranium (approximately 6 tons of U_3O_8) was classified as "unrecoverable material-measured." The wet weight of the residues was estimated to be 10,000 tons. These waste residues were generated under AEC contract AT-(30-1)-1683 and were comprised of 130-H pitchblende (9/10/45 to 1/1/46), Q-55 pitchblende (9/18/47 to 12/8/47), 306 residues (prior to 1948), carbonate cake BFC-6 and S-109 (from 1948), and calcium fluoride and magnesium fluoride (1952 to 1953).¹¹ Sapirie approved a land fill on Pennsylvania Railroad property near Blairsville, Pennsylvania, as the disposal site.⁹ It is known that at least part of the carbonate cake was dumped at Blairsville in 1957; it seems probable that all, or nearly all, of the material mentioned above was moved to that location.

The last AEC contract with Vitro was terminated in 1957. A "storage only" license was issued in 1961, and the contaminated site was controlled under an AEC source material license until February 14, 1966. Since 1967 the property has been owned by the Canon Development Company; it is leased to tenant companies for light industrial use.

In this report the results of the radiological survey of the Vitro site are described. Phase I of this survey, the measurement of radon and radon daughters in buildings was conducted during the period March 14 through April 1, 1977 by three members of the Health and Safety Research Division (HASRD), of the Oak Ridge National Laboratory. The remainder of the survey (Phase II) was conducted during the period April through July, 1977, by twelve members of (or consultants to) HASRD.

The radiological survey data obtained at the Vitro site logically fall into four classifications: measurement of radon and radon daughters in air in onsite buildings; measurements of interior building surface contamination; exterior, onsite measurements above, on, and below the ground; and offsite measurements. The data are arranged according to these classifications and are presented in the order indicated above.

SURVEY METHODS

Instrumentation

Direct alpha measurements

Direct alpha measurements were made with alpha scintillation survey meters described in Appendix I. These meters are equipped with scalers which allow integration of counts over 15, 30, or 60 sec, permitting direct alpha measurements on surfaces with low-level alpha contamination. If counts are integrated over a period of 60 sec, the count rate error associated with a direct reading of $300 \text{ dpm}/100 \text{ cm}^2$ is $\pm 30\%$ for this instrument, and the count rate error associated with a direct reading of $100 \text{ dpm}/100 \text{ cm}^2$ is $\pm 50\%$.

Direct beta-gamma measurements

Beta-gamma dose rates were measured with Geiger-Muller (G-M) survey meters described in Appendix I. The meters were calibrated at Oak Ridge National Laboratory (ORNL) 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 from the ^{238}U chain, an open-window reading of 2000 cpm on the G-M meter

is equivalent to approximately 1 mrad/hr. For surfaces contaminated with initially ^{226}Ra -free uranium, the proper conversion factor is 2300 cpm = 1 mrad/hr. Since various materials, including uranium ore, purified uranium, and purified radium, were handled on the site, and since the relative activities of the radionuclides on the surface are uncertain at most points on the site, the more conservative conversion factor of 2000 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 an average beta-gamma dose rate for a large contaminated surface, such as a floor or wall, appears to be no higher than 15%.

Beta radiation cannot penetrate the closed window on the G-M probe; hence, gamma radiation levels can be measured with the window closed. The conversion factor for gamma radiation is 3200 cpm = 1 mrad/hr, with an error of $\pm 30\%$. This factor was determined at ORNL using a ^{226}Ra source. A significant difference in the open-window and closed-window readings on the G-M meter at some point indicates the presence of beta-emitting surface contamination (since most beta particles can penetrate only a few millimeters of dense materials). It should be pointed out that, for any particular measurement point, the quantification of the beta-fraction* of the beta-gamma dose rate may involve a large error because of the potential errors associated with both the beta-gamma and the gamma conversion factors. For this reason, the closed-window G-M

* The beta-fraction of the beta-gamma dose rate is estimated by the formula $\frac{x-y}{x}$ where $x = \frac{(\text{G-M cpm (open-window)})}{2000}$ and $y = \frac{\text{G-M cpm (closed-window)}}{3200}$

This formula applies only when the open-window reading is much higher than the closed-window reading. A beta-fraction is usually reported as a percentage; e.g., a beta-fraction of 0.77 is reported as 77%.

readings and the calculated beta-fraction of the beta-gamma dose rates are not listed in tables but are used to evaluate beta radiation levels (and hence, surface contamination levels) for large areas.

Measurements of transferable alpha and beta contamination

Transferable alpha and beta contamination levels were measured using the standard smear techniques described in NRC guidelines (Appendix IV). The smears were counted using the alpha and beta smear counters shown in Appendix I. Because of the large number of smear samples taken, groups of 4 or 5 smears were counted for alpha radiation using alpha scintillation survey meters except when significant levels of transferable contamination were encountered. Then the samples were counted individually. The same procedure was used to measure transferable beta contamination.

External gamma radiation measurements

External gamma radiation levels were measured with NaI scintillation survey meters described in Appendix I. These meters are extremely sensitive and are capable of detecting increments of 1 or 2 $\mu\text{R/hr}$ at low-levels of gamma radiation. Since the response of these meters is highly energy dependent, a cross-calibration was performed on and near the site with a scaler-equipped G-M counter¹² which is shielded to provide an estimate of the exposure rate that is nearly independent of photon energy. Additional comparisons of the response of the scintillation meters and G-M counter were made at ORNL using soil samples taken from the Vitro site. A conversion factor of 450 cpm = 1 $\mu\text{R/hr}$ was determined for the scintillation counter using all (26) comparative measurements.

With this conversion factor, the gamma scintillation and G-M counter measurements differed by no more than 25% for 19 of the 26 measurements, by 25 to 60% for 4 measurements, and by 60 to 100% for the other 3 measurements.

Radon measurements

Radon (^{222}Rn) concentrations at several indoor and outdoor locations both on and off the site were estimated using a continuous measurement instrument developed by Wrenn et al.,¹⁴ commonly referred to as a Wrenn Chamber (see Appendix I). Although radon concentrations are measured continuously over periods of 24 hr or longer, the concentrations are recorded (automatically) at much shorter intervals, typically 2000 sec. Because some radon and progeny from previous 2000 sec intervals remain in the Wrenn Chamber, each reading actually represents a concentration which has been integrated over a period of 2 to 4 hr. In Fig. I-G, Appendix I, a typical twenty-four hour radon concentration measured with the Wrenn Chamber is shown for Building 9 on this site. The integrating tendency of the Wrenn Chamber acts to "smooth out" sharp "instantaneous" variations in the radon concentration caused by short term changes in the ventilation rate in the room. As illustrated by Fig. I-G, highest radon concentrations on this site were usually observed between midnight and 8 AM, when the buildings had been closed for an extended length of time.

The Wrenn Chamber is normally used for indoor radon measurements and is not water-proof. For this reason, for outdoor measurements the Wrenn Chambers were set on blocks (in some cases, atop a mobile

lab), and large plastic garbage cans with cut out "windows" were placed in an inverted position on the blocks, over the Wrenn Chambers. Since this arrangement probably reduced air movement around the Wrenn Chambers, the resulting measurements may be higher than typical outdoor radon concentrations at the points of measurement. Nevertheless, these measurements give some indication of the magnitude of radon emanations on and near the site.

Several comparative measurements of instantaneous radon concentrations were made using Lucas flasks. The Lucas flask measurements were made at the same locations as the Wrenn Chamber measurements and were usually made at widely spaced intervals while the Wrenn Chambers were operating. Averages of the Lucas flask measurements were compared with the Wrenn Chamber measurements. The Lucas flasks are described in Appendix I.

Radon daughter measurements

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

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 no greater than 500 μm in diameter (-35

mesh). Next, aliquots from each samples were transferred to plastic bottles, weighed, and counted using a Ge(Li) detector and a multi-channel 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 ^{226}Ra , ^{238}U , and ^{227}Ac were estimated in this way. In addition, a second measurement of the ^{238}U concentration in each sample was obtained by neutron absorption techniques.¹⁴

Water samples removed from drains and samples of dirt, scale, and building materials taken from surfaces and drains inside the buildings 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. The activity reported for each of these radionuclides in each soil sample taken inside the buildings represents only that fraction of the activity (normally between 50 and 100%) available by leaching with nitric acid. The concentration of ^{238}U in each surface and drain sample, as well as that in water samples, was determined using neutron absorption techniques.¹⁴ Filters used in high-volume air samples were analyzed by methods similar to those used for small samples of material taken inside buildings.

Survey Schemes for Indoor and Outdoor Measurements

Throughout this report, the term "lower walls" refers to wall surfaces up to a height of 6 ft. A "survey block" is a rectangular subsection of some large area to be surveyed, either indoors or outdoors. The division of large areas into small survey blocks is convenient for

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

Survey plan for measurements of radon and radon daughter concentrations in air in the buildings

In structures where uranium-bearing ores were processed, there are frequently radium-bearing residues remaining in floor cracks, sumps, ore dump pits beneath the floor, floor drains, and process drains, as well as radium-bearing solutions which may have been spilled on floors, or on the ground. Radon emanates from such residues and will build up in structures to a level dependent on its emanation rate and the rate of ventilation of the structures. Therefore, the specific objective of Phase I (radon and daughter measurements) was to identify those structures where potential exposure hazards exist and to provide that information to appropriate regulatory authorities.

Radon concentrations were measured continuously for periods typically between 24 hr and 48 hr in each building. Radon daughter measurements were made at least twice each day, usually in the morning and in the afternoon, at each Wrenn Chamber location. It should be pointed out that radon daughter measurements represent concentrations only for the sampling time, which is typically 10 min or less. However, concentrations of progeny at indoor sampling locations appear to follow the concentration of radon. Factors such as ventilation, aerosol concentration, and physical activity can have a major effect on radon and progeny concentration.

Measurements were made in Buildings 15, 16, and 19 on two separate occasions. Initial 24 hr measurements were started in these buildings on March 14, 1977, according to the original plan and 24 hr measurements were to be repeated in these and the other buildings after an interval of a few days. However, it was found that considerable time was lost in moving the equipment from building to building, and consequently measurements for the other buildings on the site were lengthened to single periods of approximately 48 hr. Locations were chosen so that measurements would be, as nearly as practicable, representative of actual exposure to workers on the site. Information concerning location and duration of radon measurements and location and frequency of radon daughter measurements is provided in Table 2.

Survey plan for measurements of contamination on building interiors

With the exception of the second level of Building 1 (which consists of several small rooms used principally as offices) and the north section of Building 18 (which was built after the termination of uranium processing by Vitro), all floors and lower walls in Buildings 1, 2, 2A, 3, 7, 9, 10, 11, 15, 16, 18, and 19 were divided into survey blocks by grid systems consisting of lines parallel to the bases of the walls and separated by distances of 1.5 to 3.0 m. A typical survey block covers an area of approximately 4 m^2 . The particular grid system used for each building is shown in a figure in the section on building survey results. In each building, the surfaces of some of the survey blocks formed by the grid systems were partially or totally inaccessible because of large machines, stored materials, etc. Those survey blocks which were completely inaccessible are labelled "NR" (no reading) in the figures and tables.

At the midpoint of each survey block (or as close as possible to the midpoint, if the midpoint was inaccessible), open- and closed-window G-M meter readings were taken at 1 cm from the surface for the determination of both the beta-gamma dose rate and the approximate fraction of beta radiation. Also, a direct measurement was made of alpha contamination on the surface at the same point and the external gamma radiation level was measured at 1 m above the midpoint of floor blocks. Since floor and wall measurements are included in the same tables of building survey results, external gamma measurements for wall survey blocks are marked "NA" (not applicable). Next, the entire survey block was scanned with the open-window G-M 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" (this term is used throughout the report). If the beta-gamma readings were uniform throughout the block, no additional direct alpha or closed-window G-M meter readings were taken. Finally, a smear was taken at random points in the block for the determination of transferable alpha and beta contamination levels.

On overhead surfaces (that is: 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 at approximately uniformly spaced, randomly chosen points. A distinction was made between horizontal and vertical overhead surfaces because horizontal overhead surfaces often show higher contamination levels than vertical overhead surfaces.

High-volume air samples were taken in Buildings 2, 3, 10, 11, 16, and 19. A 4-in. diameter glass fiber filter with an efficiency of nearly 100% for 0.3- μ m particles was used at each location to sample air for 6 to 8 hr at an average flow rate of approximately 11.5 cfm.

Holes were drilled with motorized drillings rigs through the concrete floor in Buildings 2A, 10, and 18, and soil samples were taken from depths of 6.5 ft or less beneath the floor using a split-spoon sampler. All samples were analyzed for ^{226}Ra and ^{238}U .

Outdoor survey plan

The entire site, excluding the area covered by buildings, was divided into 50-ft x 50-ft survey blocks by the rectangular grid system shown in Fig. 2. Note that the grid extends 200 ft south of Parcel A to include the railroad tracks in that area. At each grid point (that is, at the intersection of perpendicular lines forming the grid system), open-and closed-window G-M meter readings were taken at the surface and, at 1 m above the grid point, the external gamma radiation level was measured with a scintillation survey meter. Then, each grid block was scanned with an open-window G-M meter held near the surface, and beta-gamma dose rates higher than those at the grid points associated with that block were recorded. Finally, several additional external gamma radiation measurements were taken at 1 m above the ground around each building on the site.

Holes were drilled with a motorized rig equipped with an 8-in. diameter auger, usually to depths of 6 to 15 ft, at 91 outdoor locations on and near the site. A plastic pipe with a 4-in. inner diameter was

placed in each hole and a NaI scintillation probe was lowered inside the pipe. The probe was encased in a lead shield with a narrow opening on the side. This arrangement allowed measurement of gamma radiation intensities resulting from contamination within small fractions of the hole depth. Measurements were usually made at 6-in. or 1-ft intervals, depending on the variation of gamma radiation as a function of depth beneath the surface. This "logging" of the core holes was done as a first step in determining the extent of subsurface contamination at each location. Moreover, the loggings were used to estimate the ^{226}Ra concentration in contaminated regions. The procedure used for these estimates is described in Appendix III. From each of approximately half of the auger holes, a soil sample was taken at the point showing the highest gamma radiation level. These samples were analyzed for ^{226}Ra , ^{227}Ac , and ^{238}U . On Parcel C (Fig. 2), some of the auger holes quickly filled with muck and samples of this muck were taken for determination of ^{238}U and ^{226}Ra content.

The auger hole loggings were used to select outdoor locations where further soil sampling would be useful. At points as close as practical to selected auger holes, a split-spoon sampler was used to collect soil samples at 6-in. or 1-ft intervals throughout the contaminated zone. The concentrations of ^{226}Ra , ^{227}Ac , and ^{238}U were determined for these samples.

Surface soil samples were taken at several locations in all three parcels. While surface samples from Parcels B and C were taken at random points, it appeared from the extreme nonuniformity of meter

readings in Parcel A that a nonrandom system would be required to adequately assess the outdoor surface contamination levels in this parcel. First, thirty grid points were selected at nearly uniformly spaced intervals over the entire parcel. Then an attempt was made to determine (from open- and closed-window G-M meter readings) whether the area within 15 ft of the selected grid point was uniformly contaminated. If it was, a surface soil sample was taken at the grid point; if not, the sample was removed at the point showing the highest surface contamination level. The object of the procedure was to test the hypothesis (suggested by an earlier beta-gamma scan of Parcel A) that at almost any given location on Parcel A, high radionuclide concentrations on the surface could be found within a few feet. To insure that areas with highest surface contamination levels on Parcel A were determined, eight additional surface samples were taken at points which were outside these 30 circular areas and which had been identified in a previous beta-gamma scan of the entire parcel as having high beta radiation levels. All surface samples were analyzed for ^{226}Ra , ^{227}Ac , and ^{238}U .

Water samples were taken from each auger hole in which water was found. The samples were returned to ORNL for determination of their ^{226}Ra and ^{238}U content.

Offsite Measurements

Measurements on nearby property

On each lot adjacent to the site (and at additional selected offsite locations) external gamma radiation levels were measured outdoors at randomly selected points; whenever convenient, additional measurements

were made inside homes. If an unusually high reading was found outdoors at some point, a soil sample was taken there and later analyzed at ORNL for ^{226}Ra , ^{227}Ac , and ^{238}U . Continuous 24-hr radon measurements were made at two indoor and several outdoor locations within a few hundred yards of the site. Finally, water and mud samples were taken from Chartiers Creek both upstream and downstream from the site.

Background measurements

Background external gamma radiation levels at 1 m above the ground were measured at points at least 1 mile from the site in each compass direction. The average of these background measurements was 11 $\mu\text{R/hr}$. Soil samples taken at these 4 points contained, on the average, 1.2 pCi $^{226}\text{Ra/g}$ and 1.3 pCi $^{238}\text{U/g}$. The concentration of ^{227}Ac was below the detectable level in all 4 samples.

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

All direct meter readings reported in this document represent gross readings; background radiation levels have not been subtracted. Similarly, background levels have not been subtracted from radionuclide concentrations measured in environmental samples and building materials. For the measurements 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.

SURVEY RESULTS

The results of various measurements are discussed in the following order: radon and radon daughter concentrations in air in the buildings, contamination on building interiors, outdoor survey on the site, and offsite survey. Radiation guidelines used to evaluate survey data are given in detail in Appendix IV. The applicability of certain guidelines to this site is discussed in the following section.

Guidelines for Radon and Radon Daughter Concentrations in Air, Surface Alpha and Beta-Gamma Contamination, and External Gamma Radiation

The situation at the Vitro site is similar to that encountered in Grand Junction, Colorado, where radium-bearing uranium mill tailings were used for private purposes in construction of residences and commercial structures.

At the request of the state of Colorado, the U. S. Surgeon General developed a set of guidelines for use in considering the need for remedial action in such cases. These guidelines were adopted by ERDA as the basis for the Grand Junction Remedial Action Criteria, which have been codified as 10 CFR 712. These criteria are given in Appendix IV. In considering the need for remedial action in structures where radon daughter concentrations exceed background, it is recommended that indoor radon daughter concentrations be determined by "(1) averaging the results of six air samples each of at least 100 hours duration, and taken at a minimum of

4 week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission".

For structures other than residences and schools, an observed average indoor radon daughter concentration level of 0.03 WL or greater above background will qualify the structure for consideration by DOE and regulatory authorities of the need for remedial action. As discussed later in the section "Survey Methods", measured radon daughter concentrations at the Vitro site were found to exceed 0.03 WL in all structures except one built after termination of AEC contract operations. Thus, if the criteria in 10 CFR 712 are applied to the Vitro site, further sampling to satisfy the requirements for determination of indoor radon daughter concentrations would be necessary. As an alternative, the limited exploratory measurements reported herein would have to be accepted by the appropriate authority.

Strictest Nuclear Regulatory Commission (NRC) guidelines for alpha emitters apply to ^{226}Ra and ^{230}Th , among other radionuclides. According to those guidelines, average and maximum alpha contamination levels on surfaces contaminated with ^{226}Ra or ^{230}Th should not exceed 100 dpm/100 cm^2 and 300 dpm/100 cm^2 , respectively, by direct reading. (Readings may not be averaged over an area of more than 1 m^2 , and the maximum limit applies to an area of not more than 100 cm^2 .) Since ^{226}Ra and ^{230}Th are two of the most abundant alpha emitters on this site, it appears that these limits are applicable. Moreover, since direct alpha readings reported for each survey block reflect alpha contamination levels at selected points (including the maximum beta-gamma point) rather than

average alpha contamination levels, evaluation of the data for direct alpha readings is made in this report by comparing the maximum observed direct alpha reading in each survey block with the maximum limit (300 dpm/100 cm²).

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. Since beta-gamma dose rates reported in this document generally reflect conditions over areas considerably larger than 100 cm², evaluation of beta-gamma data in this report will be made by comparing measured dose rates with the average rather than the maximum NRC limit.

Transferable alpha contamination levels may not exceed 20 dpm/100 cm² (according to the NRC guidelines) provided the surface contaminant is ²²⁶Ra or ²³⁰Th. For surfaces contaminated with radionuclides in the ²³⁸U chain, the NRC guideline limit for transferable beta contamination is 1000 dpm/100 cm², and this limit seems appropriate for surface contamination on this site.

Results of Radon and Radon Daughter Measurements inside Buildings

Thousands of individual radon and radon daughter measurements were made during the course of this survey. Information concerning specific measurement locations, radon sampling time, and the number of radon daughter measurements at each location is provided in Table 2. To evaluate the radon and radon daughter measurements in terms of potential exposure to individuals working at the site, average daytime and 24-hr

concentrations of radon and radon daughters were calculated and are presented in Tables 3 through 6.

The estimated average daytime radon daughter concentrations in each building are given in Table 3. The values in this table were determined from actual measurements. Although the radon monitors operated continuously, the actual readings consisted of a series of measurements integrated over 2000-sec periods for the duration of sampling. The average radon concentration during the daytime period was taken as the average of these individual 2000-sec measurements made throughout the day.

Average radon daughter concentrations were estimated through a comparison of measured radon concentrations and measured values of RaA, RaB, and RaC at specific times during the day. From a series of such comparisons, average disequilibrium ratios (Rn: RaA: RaB: RaC) were estimated to be 1: 0.83: 0.43: 0.27. If the average radon concentration for daytime in a building was determined to be A pCi/liter, then the average daytime concentrations of RaA, RaB, and RaC for that building were estimated to be 0.83A, 0.43A, and 0.27A, respectively, and the average radon daughter concentration in WL^{*} was calculated from these estimated concentrations. The disequilibrium ratios used here represent an average of all observed disequilibrium ratios. Some variation was found between buildings; however, the buildings are of similar construction and are used for similar purposes.

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

The estimated average 24-hr radon daughter concentration in each building was determined using a similar technique (Table 4). The values in Table 4 are somewhat more conservative than the estimated daytime concentrations. Disequilibrium ratios used for this series of estimates were 1 : 0.92 : 0.67 : 0.54; these ratios represent an average of the observed values and those for a sealed room as given by Toth.¹⁵ Average 24-hr values were estimated in this fashion because each building was closed and locked during nonworking hours. Average radon concentrations for the 24-hr period were determined from actual measurements, and the above disequilibrium ratios were applied to these measured radon values in order to estimate average radon daughter concentrations.

To obtain estimates of maximum potential radon daughter concentrations, the maximum radon levels for each building were multiplied by typical disequilibrium factors for a sealed room (results are given in Table 5). Such a procedure probably results in unrealistically high values for some times of the year. However, because these measurements were made during a time of the year when outdoor temperatures were moderate, the buildings were probably not closed as tight as in severe winter months.

The measurements are summarized in Table 6. The lowest radon daughter concentration was found in the CCC Trucking Company terminal on the north end of Building 18. This is a new structure with no known history of uranium or radium handling activities. Two other structures were built after termination of AEC contract operations (Buildings 19 and 2A). These buildings were, however, constructed over existing concrete slabs. Although radon daughter concentrations (average daytime) were not as

elevated in these as for some of the other structures, it is seen in Table 5 that the maximum radon concentrations were 99.0 and 61.3 pCi/liter in Buildings 19 and 2A, respectively. As discussed in later sections, these radon levels probably result from radon emanating from deposits of radium in or under the floor of these buildings. It is unlikely that this radon originates outside of the buildings. The maximum measured daytime progeny concentration (0.5 WL) occurred in Building 3, which is used as the headquarters for a heating and ventilation contractor. The maximum observed radon concentration, 227 pCi/liter was measured in Building 11. It is estimated that the radon daughter concentration in Building 11 could be as high as 2 WL when the building is tightly closed.

It can be seen from Tables 3 through 6 that the measured ^{222}Rn concentration in each building on the site at some time exceeded the limit of 3 pCi/liter stated in 10 CFR 20, Appendix B, and that the measured and estimated average ^{222}Rn daughter concentrations in the buildings generally far exceeded the Surgeon General's guideline of 0.03 WL as stated in 10 CFR 712. If the criteria in 10 CFR 712 are applied to this site, further ^{222}Rn daughter sampling to satisfy the requirements for determination of indoor radon daughter concentrations would be necessary.

The alpha spectrometry techniques used for determining ^{222}Rn daughter concentrations revealed the presence of another radon isotope on this site, namely, ^{219}Rn . The presence of this isotope was actually

discovered after completion of the field work, during a study of radon daughter alpha spectra generated by air sampling on the Vitro site. It appears that airborne concentrations of ^{219}Rn and its daughters on this site are small compared with concentrations of ^{222}Rn and its daughters, and that the presence of ^{219}Rn and its daughters did not significantly decrease the accuracy of the measurements of ^{222}Rn and its daughters. A technique for measuring airborne concentrations of ^{219}Rn daughters (as well as ^{220}Rn daughters) in the presence of ^{222}Rn daughters has now been developed by the Health and Safety Research Division at ORNL and could be applied at the Vitro site, if further information concerning the dose to the worker from ^{219}Rn daughters is desired.

Results of Measurements of Contamination on Building Interiors

In the following discussion it should be understood that transferable alpha contamination is less than 20 dpm/100 cm² and transferable beta contamination is less than 100 dpm/100 cm² unless otherwise noted.

Building 1

This structure, built in 1951, is a two-story building with concrete block walls, steel framing, concrete floors and a precast concrete slab roof (tar and gravel covered).¹⁶ Building dimensions are 92 ft 4 in. x 31 ft 10 in., giving a floor area of 5880 ft². It was used as a laboratory and office area during Vitro operations.

Alpha, beta-gamma, and external gamma data obtained in Building 1, first level, are shown in Table 7. Recall that the term "lower walls" refers to wall surfaces up to a height of 6 ft above floor level. Any wall measurements made above this height are included with other data

obtained on overhead surfaces. Measurements made on interior dividing walls are recorded in Table 8 while those from overhead surfaces are shown in Table 9. Building drain survey results are contained in Table 10.

Contamination measurements made on the floor and lower walls of the first level that exceed guidelines (300 dpm/100 cm² for directly measured surface alpha contamination and 0.20 mrad/hr for surface beta-gamma dose rate) included in Appendix IV, are shown in Fig. 5 for alpha measurements and in Fig. 6 for beta-gamma data. In these figures, as well as in subsequent building grid drawings, interior lower wall surfaces are represented as 6-ft extensions of the floor areas.

It is apparent from Figs. 5 and 6 that both alpha and beta-gamma contamination levels on a large fraction of the interior floor and lower wall surfaces of Building 1, first level, exceed established guidelines. Data in Table 10 show varying levels of contamination in the six building drains surveyed with both directly measured and transferable contamination exceeding guidelines in most cases. Sediment analyses also show significant concentrations of ²²⁶Ra, ²³⁸U, and ²³⁰Th present in four of the drains.

Values for external gamma radiation in Building 1 vary from 22 to 220 μ R/hr. The maximum value (220 μ R/hr) multiplied by 2000 hr gives a maximum annual on-the-job exposure figure of 440 mrem, and the average external gamma radiation level measured at 1 m (72 μ R/hr) multiplied by 2000 hr gives an exposure of approximately 140 mrem. (Here and throughout this report we assume a quality factor of 1.0 for gamma radiation.)

As mentioned in the section on survey methods, readings were taken using G-M survey meters with the window open and with it closed. The

difference between these readings is an indication of the beta surface contamination level. Examination of the G-M survey meter data obtained in Building 1, first level, reveals a range of values for the beta fraction of the beta-gamma dose rate (as defined in the Survey Methods section) from zero to 77%. A zero beta^s reading indicates a subsurface or, possibly, an exterior contamination source of gamma radiation.

Overhead survey data (Table 9) show directly measured alpha levels above the guideline (300 dpm/100 cm²) at a large majority of the locations measured. The beta-gamma contamination values were not excessively high. The maximum observed figure was 0.15 mrad/hr.

The second level of Building 1 is almost entirely office space and the floors are carpeted. Because of the low contamination level shown by preliminary surveys in this area, a detailed survey was deemed unnecessary. The results of beta-gamma measurements at 1 cm above the floor and of external gamma measurements at 1 m above the floor are shown for each room in the floor plan (Fig. 7).

Building 2

This building, also constructed in 1951, is similar to Building 1, but it has only one level. Its dimensions are 92 ft x 38 ft, giving 3496 ft² floor space. It was used during Vitro^o operations as a service area with showers and a lunchroom.¹⁶

Results of floor and lower wall contamination¹⁶ measurements in Building 2 are recorded in Table 11, while Table 12 shows overhead contamination levels and Table 13 gives building drain data. Data from Table 11 that are above alpha contamination guidelines are displayed in Fig. 8.

These data show that directly measured alpha contamination in Building 2 exceeds the guideline value ($300 \text{ dpm}/100 \text{ cm}^2$) over a large fraction of the floor area. The beta-gamma dose rate exceeded the guideline (0.20 mrad/hr) in only one survey block (E15 in Fig. 8) where the measured dose rate 1 cm above the floor was 0.23 mrad/hr , due principally to gamma radiation. Overhead contamination levels (Table 12) are relatively low and drain contamination levels (Table 13) are comparable to those in Building 1. A worker exposed to the average measured external gamma radiation level ($33 \text{ } \mu\text{R/hr}$) for 2000 hr/yr would receive an integrated dose equivalent of approximately 66 mrem/yr.

Building 2A

This building was constructed after control of the site was assumed by the Canon Development Company. It connects the pre-existing Buildings 2 and 3. It measures approximately 92 ft x 29.5 ft.

Floor and lower wall measurements as well as external gamma values one meter above the floor in Building 2A are given in Table 14; overhead contamination levels are shown in Table 15. The latter set of data indicates little overhead contamination. Values from Table 14 that are above guidelines, displayed in Fig. 9, show that direct alpha measurements exceed the guideline ($300 \text{ dpm}/100 \text{ cm}^2$) over a large fraction of the floor area but on none of the wall surfaces. The measured beta-gamma dose rate exceeds the guideline value (0.20 mrad/hr) in many of the survey blocks in rows 6, 7, 8, and 9 (Fig. 9), near the center of the building. G-M survey meter data indicate that the elevated beta-gamma dose rates in this area are attributable chiefly to gamma radiation;

as discussed later in the section on subsurface soil sampling, these elevated readings are probably produced mostly by contamination beneath the floor. Exposure to the average measured external gamma radiation level (55 $\mu\text{R/hr}$) for 2000 hr/yr would result in an integrated dose equivalent of approximately 110 mrem/yr.

Building 3

This building was constructed in 1920 during the latter part of the Standard Chemical Company radium extraction operation, and it is a one-story building with block walls and wood framing. The roof is made of corrugated metal, wood, and tarpaper. It measures 92 ft x 38 ft (3496 ft^2), and it was used as a machine shop during the Vitro era.¹⁶

Contamination measurements on the floor and lower walls of Building 3, as well as external gamma measurements one meter above the floor, are shown in Table 16, while in Table 17 the corresponding overhead measurements are recorded. Above guidelines values from Table 16, displayed in Fig. 10, show that directly measured alpha contamination on a large fraction of the floor, as well as on a considerable fraction of the wall surfaces, exceeds the guideline (300 dpm/100 cm^2). The beta-gamma measurements exceeded the guideline value (0.20 mrad/hr) in nine survey blocks. Beta-gamma contamination near the east entrance (survey blocks E3, E4, and F3) are due principally to beta radiation. The average measured external gamma radiation level at 1 m was approximately 45 $\mu\text{R/hr}$; exposure to this level for 2000 hr each year would lead to an annual integrated dose equivalent of approximately 90 mrem/yr.

Directly measured alpha contamination (Table 17) was above the guideline value ($300 \text{ dpm}/100 \text{ cm}^2$) at half the overhead locations surveyed. The highest contamination levels were found on old wood surfaces of plates or stringers. Beta-gamma levels were relatively low with a maximum dose rate of 0.15 mrad/hr .

Building 7

This structure, used as a warehouse during Vitro operations, with concrete block walls, steel framing, concrete floor, and corrugated metal roof, was constructed in 1950. It measures $54 \text{ ft} \times 123 \text{ ft}$ with a floor area of 6466 square feet.¹⁶

Measurements of alpha and beta-gamma contamination on the floor and lower walls of Building 7, and the external gamma radiation levels at one meter above the floor, are displayed in Table 18 while overhead contamination measurements are recorded in Table 19. None of the overhead contamination values were above guidelines but the measurements on the floor and lower walls, shown in Fig. 11, demonstrate that contamination on a large fraction of the floor, as well as part of the lower walls, is above the guidelines for both alpha and beta-gamma radiation. The maximum measured external gamma radiation level at 1 m was $220 \text{ } \mu\text{R/hr}$, and the average external gamma level at 1 m was approximately $80 \text{ } \mu\text{R/hr}$. Assuming an exposure time of 2000 hr/yr , the maximum and average measured external gamma levels would lead to integrated dose equivalents of approximately 440 mrem/yr and 160 mrem/yr , respectively.

The data in Table 18, in conjunction with closed-window G-M survey meter data not shown, show a very interesting contamination pattern.

For example, in survey block B3 the directly measured alpha level was 160 dpm/100 cm² while a maximum beta-gamma radiation level (G-M survey meter with open window) of 8.5 mrad/hr was observed. However, the closed-window G-M meter reading showed that less than 10% of the beta-gamma contamination (as previously defined) could be attributed to gamma radiation. This observation is supported by the relatively low (35 μ R/hr) external gamma level in this survey block. In other survey blocks showing high beta-gamma levels, the gamma component varied from 6 to 10%. In contrast, contaminated spots in some survey blocks, such as G7 where the alpha contamination was very high, showed relatively little beta-gamma contamination and the gamma component here represented about 25% of the total. At other spots with high alpha contamination and varying beta-gamma levels, the gamma component was in the range 30 to 55% and, at one spot in the F10 survey block, gamma radiation made up 100% of the beta-gamma contamination. Two of the wall survey blocks (A8 and G9) showed high alpha contamination but relatively low beta-gamma levels.

Surveyors reported that there was visible grime on the floor of Building 7, mostly dust, metal shavings, and oil or grease. One possible explanation of the observations reported in the previous paragraph is that, in some locations, the dirt or grease covered the radioactive contamination well enough to prevent counting of the alpha radiation but not the beta-gamma radiation. In other places that show high alpha and low gamma contamination, the radioactive material is presumably not covered by building grime. Likely alpha sources are ²³⁸U and ²³⁰Th.

The latter isotope decays to ^{226}Ra , an alpha emitter with a long half-life, but ^{238}U has several beta-emitting daughters with relatively short half-lives that could account for the observed beta emissions.

It is also worth mentioning that Building 7 served as a warehouse during Vitro operations and materials with uranium and different associated radioactivities may have been stored in various parts of the building.

Building 9

This building was constructed in two steps. The west end, used for pilot plant work during Vitro operations, measures 31 ft x 68 ft (2108 ft²)¹⁶, while an addition to the west end, built during the Canon Industrial Park era, measures 43 ft x 40.6 ft (1750 ft²). A 30-ft extension of this addition on the north wall of the building houses a 300-ft² office area shown in Fig. 12. This figure also displays the over-guideline alpha and beta-gamma measurements in this building recorded in Tables 20 and 22 for the east (new section) and west (old section), respectively.

Overhead contamination measurements are found in Tables 21 and 23.

There are no large differences in the alpha contamination of the two sections of this building but all over-guideline beta-gamma contamination in the building was found in the west section. The highest beta-gamma dose rates (survey blocks C7, D4, D6) are due principally to beta radiation. The average external gamma radiation level at 1 m was approximately 40 $\mu\text{R/hr}$; this would lead to an integrated dose equivalent of approximately 80 mrem/yr, assuming an exposure time of 2000 hr/yr. None of the overhead measurements in the east section of the building exceed guidelines. About 40% of the alpha measurements in the west section were over 300 dpm/100 cm² but all of the beta-gamma measurements were below 0.20 mrad/hr.

Building 10

This structure, built in 1957, is a two-story, concrete block building with steel framing, concrete floor, and precast slab roof (covered with tar and gravel). It measures 142 ft x 175 ft and it has a total floor area of 45,160 ft², making it the largest building in the Canon Industrial Park. Part of the second level does not have usable floors. Building 10 was labeled "metal recovery" in a 1968 list of buildings on the site,¹⁶ presumably indicating its function during Vitro operations.

Table 24 contains data on directly measured alpha and beta-gamma contamination on the floor and lower walls of Building 10, first level, and also the external gamma radiation levels measured one meter above the floor. Measurements made on overhead surfaces of the first level are recorded in Table 25 while measurements made on interior dividing walls are displayed in Table 26. Figure 13 shows the first level grid scheme and also the directly measured alpha contamination values on the floor and lower walls that are 300 dpm/100 cm² or above, as well as drain locations. Beta-gamma measurements from Table 24 that are 0.20 mrad/hr or higher are displayed in Fig. 14. Comparison of Figs. 13 and 14 shows that above-guideline levels of alpha contamination are widespread and that the above-guideline values for beta-gamma contamination are largely concentrated in the northwest corner of the building. There is no obvious correlation between the two types of contamination measurements.

The average of the observed external gamma radiation levels at 1 m above the floor on the first level was approximately 35 μ R/hr, and the

maximum observed level was 310 $\mu\text{R/hr}$ in survey block Q6. Exposure to 310 $\mu\text{R/hr}$ for 2000 hr would result in a one-year, on-the-job dose of approximately 620 mrem, and exposure to 35 $\mu\text{R/hr}$ for 2000 hr/yr would result in an annual dose of approximately 70 mrem.

Examination of the open- and closed-window G-M survey meter readings shows an interesting pattern: the gamma fraction of the beta-gamma radiation seems to fall, in a majority of the highly-contaminated survey blocks in the northeast corner of the building, either below 10% or close to 40%. Since high alpha contamination is also observed in this area, the low gamma levels at the surface in some survey blocks probably indicate the presence of uranium; the higher gamma levels in some survey blocks probably are due, at least in part, to large quantities of ^{226}Ra underneath the building under these blocks (see the section on subsurface soil contamination).

Measurements of contamination on overhead surfaces, recorded in Table 25, show that over-guideline alpha levels are present on a few of the horizontal surfaces with a maximum observed value of 420 dpm/100 cm^2 ; none of the vertical surfaces exceeded the alpha contamination guidelines. Beta-gamma contamination was low on overhead surfaces throughout the first level of the building with only one location, the overhead beam in the R5 survey block, showing over-guideline values on both horizontal and vertical surfaces.

Surface contamination measurements on interior dividing walls displayed in Table 26 show that only three of the measured alpha levels were above the guideline value with a maximum of 570 dpm/100 cm^2 .

Also, only one beta-gamma measurement (survey block S6) showed an above-guideline reading (0.25 mrad/hr).

Contamination measurements made on the floor and lower wall surfaces of Building 10, second level, along with the external gamma radiation values measured at one meter above the floor, are given in Table 27. Overhead contamination measurements in the same area are displayed in Table 28. Alpha data from Table 27 that are above the guideline figure ($300 \text{ dpm}/100 \text{ cm}^2$) are shown in Fig. 15 while Fig. 16 shows beta-gamma values from the same table that are above the guideline (0.20 mrad/hr). Comparison of the data in Figs. 15 and 16 with the corresponding figures for the first floor shows a striking similarity in distribution. Alpha contamination is rather widespread while high beta-gamma levels are found mainly in the northwestern corner of the building. It should be noted that this area is open to the first floor through the large central opening and through the open areas at the north end of the building where there is a ramp between the first and second level. Variations in the gamma fraction of the beta-gamma radiation, deduced from open and closed-window G-M survey meter readings, resemble those observed in the first level data discussed before.

The average external gamma radiation level at 1 m on the second level was approximately $20 \text{ } \mu\text{R/hr}$, which is equivalent to an integrated dose equivalent of 40 mrem/yr , assuming an exposure time of 2000 hr/yr . Since the extent of surface contamination is not too different on the two levels, the high gamma measurements in the northwest corner of the first level can most likely be attributed to subsurface contamination known to exist in this area.

The overhead contamination measurements displayed in Table 28 show that the contamination levels are below guideline values with a few exceptions, notably the window ledge in the K1 survey block and the ceiling, beam, and upper wall surfaces in survey block T4.

Building 11

This is a one-story, concrete block building with steel framing, a concrete floor and a corrugated metal roof. It was constructed in 1956, and it measures 40 ft x 90 ft. It was used as a boiler house during the latter part of Vitro operations but the boilers were removed before 1962.

Floor and lower wall surface contamination measurements, as well as external gamma measurements one meter above the floor, are contained in Table 29. Table 30 records measurements of alpha and beta-gamma contamination on wall surfaces 15 ft above floor level while measurements made in and above floor drains are shown in Table 31.

Above-guideline values from Table 29, both alpha and beta-gamma, are displayed in Fig. 17. Although it is clear from this figure that alpha contamination is widespread, with only 10% of the floor survey blocks below the guide figure, the beta-gamma contamination level was above the guideline figure (0.20 mrad/hr) in only four survey blocks, with a maximum of 0.90 mrad/hr. None of the measured contamination values on the upper walls, shown in Table 30, were near guideline levels. The contamination readings in and over the floor drains, given in Table 31, are not excessively high.

Building 15

This is a small (44-ft x 55-ft), one-story building with corrugated metal walls and roof and a concrete floor, constructed in 1958. It was used at one time as a railroad car shed.¹⁶

Floor and lower wall data for Building 15 are recorded in Table 32 while results of overhead contamination measurements are shown in Table 33. The above-guideline data displayed in Fig. 18 show that alpha contamination is rather general on both floor and lower walls but beta-gamma radiation is above the guideline (0.20 mrad/hr) in only four survey blocks, with a maximum of 0.40 mrad/hr. External gamma radiation levels are rather uniform in the building, ranging from 55 to 100 μ R/hr with an average of 66 μ R/hr; exposure to this average gamma radiation level for 2000 hr/yr would result in an integrated dose equivalent of approximately 130 mrem/yr. The high alpha contamination levels noted in Table 32 and Fig. 18 are reflected in the overhead contamination data, Table 33, but none of the overhead beta-gamma measurements were above the guideline.

Building 16

This is a one-story building constructed in 1958 with concrete block and corrugated asbestos walls, steel framing, concrete floor and precast concrete slab roof covered with tar and gravel. It has a floor area of 7239 ft² (57 ft x 127 ft). Its previous use is not shown in the 1968 building list.¹⁶

Table 34 shows the floor and lower wall data while Table 35 contains the corresponding overhead contamination measurements for Building 16.

One difference that will be noted in comparing Table 35 with the corresponding tables for buildings previously discussed is that it contains data on transferable surface contamination. Although smear samples were routinely obtained and counted for transferable alpha and beta contamination in the previously discussed buildings, all alpha contamination measurements were below $20 \text{ dpm}/100 \text{ cm}^2$ and transferable beta contamination was below $100 \text{ dpm}/100 \text{ cm}^2$. However, this was not true for Building 16 or for Building 19 discussed below. It is apparent from Fig. 19 that transferable alpha contamination is above the guideline value ($20 \text{ dpm}/100 \text{ cm}^2$) in a number of survey blocks and that most of the floor surfaces as well as lower walls show directly measured alpha contamination levels above $300 \text{ dpm}/100 \text{ cm}^2$ with a maximum value of $40,000 \text{ dpm}/100 \text{ cm}^2$ in the B6 survey block. Transferable alpha measurements ranged up to $140 \text{ dpm}/100 \text{ cm}^2$. This value was measured in the C6 block where the directly measured alpha contamination was only $260 \text{ dpm}/100 \text{ cm}^2$ and the beta-gamma value was 0.10 mrad/hr . Although beta-gamma contamination is rather widespread in this building, with a maximum measured level of 2.1 mrad/hr , the transferable beta measurements were all below the guideline value. The average of the external gamma measurements was approximately $45 \text{ } \mu\text{R/hr}$. Exposure to this gamma radiation level for 2000 hr/yr would result in an integrated dose equivalent of approximately 90 mrem/yr .

Comparison of the open- and closed-window G-M survey meter readings in high-contamination areas showed a low gamma fraction in all but a few of the cases examined.

Building 18

This is a two-story building constructed in 1952 with concrete block walls, steel framing, concrete floors, and corrugated metal roof. The floor space is 4840 ft² (44 ft x 55 ft). It was designated Building 13 during Vitro operations and is labelled "furnace area" in the 1968 building list.¹⁶

Figure 20 shows a floor plan of Building 18, first level, with drain locations (numbers within circles) and survey points (numbers within squares) in parts of the building that received less detailed attention than the south section discussed below. The survey data obtained at the numbered points are given in Table 36.

Table 37 shows the results of direct alpha and beta-gamma contamination measurements on the floor and lower walls of the south section of Building 18, first level, along with external gamma radiation measurements made 1 m above the floor. Above-guideline data from Table 37, shown in Fig. 21, demonstrate that alpha and beta-gamma contamination is widespread. As usual, not all the survey locations with high alpha readings show high beta-gamma levels but, with only two exceptions (blocks C5 and H1), high beta-gamma values are associated with high direct alpha measurements. The pattern in regard to fraction of the gamma component of the beta-gamma contamination is no different from that observed in other buildings except that, where it was noted that moderately high readings were found over a whole survey block, the gamma component was higher than in those areas showing higher levels of beta-gamma contamination. External gamma radiation levels averaged approximately

65 $\mu\text{R/hr}$. Exposure to this level for 2000 hr/yr would result in an integrated dose equivalent of approximately 130 mrem/yr.

Overhead direct measurements recorded in Table 38 showed very high levels of alpha contamination on both horizontal and vertical surfaces with a maximum reading of 10,000 dpm/100 cm^2 (H6 beam horizontal surface). None of the horizontal surface alpha readings and only one vertical surface reading was less than 300 dpm/100 cm^2 . The maximum beta-gamma dose rate (0.60 mrad/hr) occurred at the same location as the maximum alpha measurement but the same beta-gamma reading was also obtained on the horizontal beam surface in block E10. Included among the overhead surfaces are some wood surfaces which may indicate that parts of the building existed during Standard Chemical Company operations.

Transferable alpha measurements shown in Table 39 were also above the guideline value of 20 dpm/100 cm^2 on about half the surfaces monitored, with a maximum reading of 400 dpm/100 cm^2 . Transferable beta readings up to 250 dpm/100 cm^2 were also observed; this was the highest transferable beta contamination level found at this site.

Direct measurements of alpha contamination made at floor drains in Building 18, first level, and gamma measurements made at and below surface level, are shown in Table 40. The measured surface alpha values are below the guidelines figure of 300 dpm/100 cm^2 .

Direct measurements of alpha and beta-gamma contamination on the floor and lower wall surfaces of the second level of Building 18, south section, given in Table 41, show widespread alpha contamination, but only four survey blocks show beta-gamma levels of 0.20 mrad/hr

or higher. The maximum external gamma value shown in the last column of Table 41 is 40 $\mu\text{R/hr}$. Exposure to this level for 2000 hr would result in an integrated dose equivalent of approximately 80 mrem. Above guideline values from Table 41 are shown in Fig. 22.

Directly measured alpha and beta-gamma contamination measurements on overhead surfaces in the same area, in Table 42, show above-guidelines alpha levels at most of the locations monitored, with a maximum value of 2500 dpm/100 cm^2 . Only three beta-gamma measurements were above 0.20 mrad/hr, with a maximum of 0.40 mrad/hr. Transferable surface contamination measurements recorded in Table 43 show nine survey blocks with 20 dpm/100 cm^2 transferable alpha contamination or higher but only one location where the transferable beta contamination exceeded 100 dpm/100 cm^2 .

Building 19

This is a one-story, concrete block building, with approximately 6900 ft^2 floor space. It was built after the Canon Development Company acquired the site. Table 44 records direct alpha and beta-gamma measurements made at the center of survey blocks on the floor and lower walls of Building 19 and external gamma radiation measurements made 1 m above the floor. Also exhibited in this table are data on transferable surface contamination shown by random smears. Over-guideline values from Table 44 for directly measured alpha and beta-gamma contamination, as well as for transferable alpha contamination, are displayed in Fig. 23. The latter data are in parentheses, and beta-gamma values of 0.20 mrad/hr or higher are shown in the numerator where they appear. It is apparent

from Fig. 23 and Table 44 that directly measured alpha contamination above the guideline level of $300 \text{ dpm}/100 \text{ cm}^2$ is rather general with readings up to $2800 \text{ dpm}/100 \text{ cm}^2$. A rather large number of survey blocks also showed transferable alpha contamination at levels of $20 \text{ dpm}/100 \text{ cm}^2$ or higher, including several where the directly measured alpha contamination was below $300 \text{ dpm}/100 \text{ cm}^2$. As shown by Fig. 23, above-guideline measurements of beta-gamma contamination are concentrated in the north end of the building with a maximum reading, in blocks B12 and B13, of 0.40 mrad/hr . External gamma radiation levels averaged approximately $65 \text{ } \mu\text{R/hr}$. Exposure to this level for 2000 hr would result in an integrated dose equivalent of approximately 130 mrem .

Results of a rather limited survey of overhead contamination in Building 19 are shown in Table 45. None of the directly measured beta-gamma values were above the guideline figure, 0.20 mrad/hr . All but two of the directly measured alpha contamination measurements are above the guideline figure of $300 \text{ dpm}/100 \text{ cm}^2$. The maximum value is $570 \text{ dpm}/100 \text{ cm}^2$. Transferable surface alpha contamination exceeded $20 \text{ dpm}/100 \text{ cm}^2$ at half the points surveyed, with a maximum of $35 \text{ dpm}/100 \text{ cm}^2$.

New material measurements

It was considered likely, based on the radon and radon daughter measurements (summarized in Table 6), that a significant fraction of directly measured alpha contamination in buildings was due to radon daughters attached to surfaces. An experiment was conducted in order to get an indication of how large a contribution radon daughters made to the measured alpha contamination.

The procedure used in this experiment was to first find, by using the alpha survey meter, locations in each building where the alpha contamination on the floor surface was considered representative of that in the building. Next, part of the floor area was covered by several different types of clean materials including steel, paper, cardboard, wood, tile and cement. After periods of time ranging up to three weeks direct alpha measurements were made on these materials, referred to here as new surfaces. Also, a number of direct measurements were made of alpha contamination within a 4-ft radius and the results of these measurements are recorded in the first two columns of Table 46. No significant differences were noted among the various material surfaces monitored (either on the site or during similar experiments conducted at ORNL) and, consequently, the results are combined to give the figures in the fourth and fifth columns of Table 46. Finally, the average new surface value in each location was divided by the corresponding average value measured on the nearby floor and multiplied by 100 to give the percent contribution of the radon daughter alpha activity to the total alpha contamination measured on the nearby floor; this is recorded in the sixth column of Table 46.

The radon concentration in buildings is known to be affected by a number of factors in addition to the quantity of ^{226}Ra , the parent of ^{222}Rn , present. The rate of air exchange (ventilation) and weather conditions which affect the radon concentration in the ventilation air are probably the principal factors controlling variations in the radon level within buildings and these vary, in general, with the season.

Therefore, too much quantitative significance should not be attached to the figures in the sixth column of Table 46. The figures, however, do show that the radon daughter contribution to the measured direct alpha contamination values is a significant factor in a majority of the buildings and, in some buildings may constitute most of the observed surface alpha radiation.

Analysis of Water and Soil Samples from Buildings

Drain sediments

Samples of sediment found in drains in Building 1, 2, 10, 11, and 16 were analyzed and the results are recorded in Table 47. The concentration of the various nuclides varies widely in these samples and it is clear that equilibrium between ^{238}U and its daughter products does not exist. Since these sediments have been in contact with varying amounts of water for long time periods, and different uranium-containing materials (processed uranium and raw ore) may be represented, the variation in activity ratios is not surprising.

Water and suspended soils

Water samples were removed from drains in Building 1, 2, 10, 11, and 18 for analysis and, in addition, surface and bottom water samples were taken from a large pit below Building 19 that contains 12 ft of water. These samples were filtered and separate analyses of the suspended solids and water were made. The results are recorded in Table 48. Non-equilibrium activity ratios for ^{238}U and its daughters are found for most of the samples analyzed. The high concentration of ^{226}Ra , ^{230}Th , and ^{210}Pb in the sediment from the bottom water sample in Building 19 is

particularly noteworthy. It is thought that uranium ore was unloaded from railroad cars into this pit prior to processing for extraction of uranium.

Three water samples listed in Table 48, one sample from drain No. 4 in Building 10, and two samples from the pit in Building 19, show ^{226}Ra concentrations near the CG_w for ^{226}Ra (0.03 pCi/ml) stated in ERDAM 0524 and 10 CFR 20, Appendix B.

Miscellaneous solid samples

Results of analyses of a variety of solid materials removed from interior surfaces in Buildings 7, 9, 11, 16, and 18 are shown in Table 49. The uranium concentration varies from the background level found in soil samples to a maximum of 1530 pCi/g. The very high ^{230}Th and ^{226}Ra concentrations observed in the wall surface samples taken in Building 7 are particularly interesting. These nuclides decay to give ^{222}Rn , but, since the quantity of the material present was not measured, its contribution to the radon concentration in air in Building 7 is not known. The high concentration of ^{238}U and relatively low concentration of daughter products in the last two samples listed in Table 49 seem to indicate contamination of these samples with purified uranium.

Airborne Contamination

Analysis of filters used to collect airborne nuclides in Buildings 2, 3, 10, 11, 16, and 18 was performed and the results are presented in Table 50 in terms of air concentrations in pCi/ml. Also, the non-occupational maximum permissible air concentrations (CG_a) are shown in the same units (see Appendix IV). Air samples collected in Buildings 2,

10, and 16 showed ^{230}Th concentrations above CG_a levels. It is estimated that a single, annual 2000 hr exposure to the highest airborne ^{230}Th concentration measured (2.1×10^{-7} pCi/ml in Buildings 10 and 16) would result in a critical organ (bone) dose of equivalent approximately 30 mrem the first year and a dose commitment of approximately 2.8 rem over a period of 50 years. This is calculated using the methods and assumptions of Ref. 17.

Results of the Survey Outdoors on the Site

Contamination on roofs of buildings

To determine the extent of contamination on roofs resulting from radioactive particles settling from the air, two of the larger buildings, 10 and 16, were selected for roof surveys. Direct measurements of alpha and beta-gamma contamination levels were made at several randomly selected points on the roofs of these buildings.

The roof of Building 10 is flat and covered with gravel and tar, except for an area approximately 60 ft x 60 ft in the northwest corner of the building which is part of the original concrete roof. There are 15 capped and 3 open vents, most of them located near the center. In the southeast corner there are two raised areas: the first, which is over blocks D14, D15, E14, and E15, shown in Fig. 13, is 10 ft above the main roof; and the second, which is over blocks B14, B15, C14, and C15, is 20 ft above the main roof. Beta-gamma dose rates of 0.05 mrad/hr and direct alpha contamination levels of less than 100 dpm/100 cm^2 were measured over the entire roof area with the following exceptions: (1) alpha contamination levels of approximately 200 dpm/100 cm^2 by direct

reading were found in the southeast corner over blocks B12 and B13 shown in Fig. 13; (2) alpha contamination levels of approximately 350 dpm/100 cm² by direct reading were found on the concrete portion of the roof in the northwest corner over block 5Q shown in Fig. 13; (3) a beta-gamma dose rate of 0.90 mrad/hr (principally from beta radiation) and an alpha contamination level of 1100 dpm/100 cm² by direct reading were found on the concrete portions of the roof in the northwest corner over blocks S2, S3, T2, and T3 shown in Fig. 13; and (4) a beta-gamma dose rate of 1.3 mrad/hr (principally from beta radiation) and an alpha contamination level of 1600 dpm/100 cm² by direct reading were measured on the concrete portion of the roof in the northwest corner over blocks S2 and T5 shown in Fig. 13.

The roof of Building 16 is also flat and covered with gravel and tar. There are four fans located on the east-west center axis of the building. Measurements were made at randomly selected locations. Five of the twelve points checked showed a beta-gamma dose rate greater than 0.1 mrad/hr; one point measured 0.35 mrad/hr. This last reading was taken at a point where the gravel and tar had been scraped away. Eleven of the twelve points checked showed an alpha contamination level greater than 100 dpm/100 cm² by direct reading; three of the points measured exceeded 1000 dpm/100 cm². The highest alpha contamination level observed was 5000 dpm/100 cm². Each of the four fans showed a beta-gamma dose rate of approximately 0.15 mrad/hr and alpha contamination levels ranging from 150 dpm/100 cm² to 600 dpm/100 cm².

Contamination on ramps and pads adjacent to or near buildings

Spot checks made on the concrete ramps and pads adjacent to or near the buildings revealed widespread contamination on the loading dock on the east side of Building 7, on the loading pad on the east side of Building 9, on the ramp between Buildings 9 and 10, and on the remaining foundation of the former Building 4. Consequently these areas were given thorough surveys.

On the loading dock adjacent to Building 7, external gamma measurements were made at 10 nearly uniformly spaced points. These measurements ranged from 60 to 140 $\mu\text{R/hr}$ and averaged 100 $\mu\text{R/hr}$. Beta-gamma dose rates ranged from 0.05 to 0.10 mrad/hr over most of the dock but were as high as 1.2 mrad/hr at isolated spots along the eastern edge of the dock. Direct alpha readings averaged up to 260 dpm/100 cm^2 on some portions of the dock.

The loading pad adjacent to Building 9 showed beta-gamma dose rates in the range 0.20 to 0.60 mrad/hr uniformly across the western two-thirds of the pad. Direct alpha measurements on the pad ranged from 100 to 1100 dpm/100 cm^2 . External gamma radiation levels at 1 m ranged from 80 to 160 $\mu\text{R/hr}$.

On the ramp between Buildings 9 and 10, beta-gamma dose rates were uniform near 0.10 mrad/hr, direct alpha measurements ranged from 150 to 900 dpm/100 cm^2 , and external gamma radiation levels averaged 35 $\mu\text{R/hr}$.

The foundation of the former Building 4 showed beta-gamma dose rates at 1 cm from the surface as high as 6 mrad/hr, with the highest reading observed above an old drain. Measurements inside this drain were as high as 12 mrad/hr. External gamma measurements at 1 m on and near this ramp generally ranged from 100 to 300 $\mu\text{R/hr}$.

Beta-gamma dose rates at 1 cm above the surface

The area outdoors on the site was divided into survey blocks by the 50-ft-square grid indicated in Fig. 2. Beta-gamma dose rates were measured at 1 cm above the surface at each of the grid points, and the maximum beta-gamma dose rate at 1 cm was determined for each survey block by scanning. Grid-point measurements are reported in Table 51, and those maximum beta-gamma dose rates exceeding 0.20 mrad/hr are shown in the appropriate survey block in Fig. 24. The grid-point measurements should provide an unbiased, representative sampling of beta-gamma dose rates on the site. In Parcel A (see Fig. 2), beta-gamma dose rates at 1 cm exceeded 0.20 mrad/hr at approximately 50% of the grid points. Beta-gamma dose rates on this parcel are very nonuniform; this is evident from the variation in maximum dose rates among the different survey blocks (Fig. 24). Beta-gamma dose rates in Parcel A were as high as 25 mrad/hr and exceeded 0.20 mrad/hr at some point in approximately 90% of the survey blocks in that parcel. A large portion of Parcel B is covered by 8 to 12 ft of fill dirt (Fig. 2) which consists, at least in part, of dredgings from Chartiers Creek. Beta-gamma dose rates in Parcel B exceeded 0.20 mrad/hr in some areas of this fill dirt (Figs. 2 and 24) and on much of the surface not covered by the fill dirt. Beta-gamma dose rates at 1 cm exceeded 0.20 mrad/hr over a large section of Parcel C near Strabane Avenue (Fig. 24) and were as high as 17 mrad/hr. In the southeast corner of Parcel C, beta-gamma dose rates were near background levels.

The ratio of open- and closed-window G-M meter readings taken at 1 cm above the surface was used as an aid in determining extensive areas on the site where a significant portion of the beta-gamma dose rate is a result of beta radiation. Since an open- (or closed-) window G-M meter reading at some point may vary 10 to 20% simply from normal fluctuations of the indicator on the meter, only those open-to-closed ratios exceeding 1.25 were interpreted as indicating significant beta radiation. Those extensive areas in which most open-to-closed ratios exceeded 1.25 are indicated in Fig. 25. It should be emphasized that Fig. 25 represents a generalization concerning beta radiation levels outdoors on the site; each of the areas indicated by shading in Fig. 25 contains some points at which there is apparently little beta radiation; and on the remainder of the property (the unshaded portion of Fig. 25) there are numerous isolated spots at which there is elevated beta radiation.

External gamma radiation levels at 1 m above the surface

Measurements of external gamma radiation levels outdoors on the site, made at 1 m above each of the grid points shown in Fig. 2, are reported in Table 51. External gamma levels at 1 m above the surface, measured approximately 10 ft from the outer walls of Buildings 1, 2, 2A, 3, 7, 9, 10, 11, 15, 16, 18, and 19, are shown in Fig. 26. Radiation intensity profiles for Parcels A, B, and C are displayed in Figs. 27, 28, and 29, respectively. These profiles reflect average external gamma radiation levels for the areas indicated and should not be interpreted as showing point-by-point radiation levels. On most of Parcel A, external gamma radiation levels at 1 m above the surface were in the range 100 to

300 $\mu\text{R/hr}$. The highest external gamma radiation levels on Parcel A (up to 1600 $\mu\text{R/hr}$) were measured northeast of Building 19 (Fig. 27) in an area which formerly contained several piles of waste residues generated during uranium (and possibly, radium) extraction operations. External gamma radiation levels at 1 m were in the range of 40 to 150 $\mu\text{R/hr}$ over most of Parcel B but were as high as 330 $\mu\text{R/hr}$ at isolated points (see Table 52 and Figs. 2 and 28). Parcel C is the former lagoon area which was used for several years for disposal of liquid wastes. It can be seen from Figs. 4 and 29 that the highest external gamma radiation levels at 1 m in this parcel (up to 780 $\mu\text{R/hr}$) are in the area where the wastes entered the lagoon, and that the radiation levels decrease gradually (to less than 50 $\mu\text{R/hr}$) from this area to Chartiers Creek.

Surface soil contamination

Surface soil samples were taken in Parcels A, B, and C at the locations shown in Figs. 30, 31, and 32, respectively. Concentrations of ^{226}Ra , ^{238}U , and ^{227}Ac measured in these samples are reported in Table 52. Considering the method by which sampling locations on Parcel A were chosen (see the section on Survey Methods), it can be concluded from the results in Table 52 that given almost any location in this parcel, concentrations of ^{226}Ra and ^{238}U , far exceeding the average background concentrations (1.2 and 1.3 pCi/g, respectively) are present in surface soil within a few feet of that location. The concentration of ^{226}Ra was at least an order of magnitude above background in more than 90% of the surface samples taken in Parcel A, and 5 samples showed a ^{226}Ra concentration of 1000 pCi/g or more. The concentration of ^{238}U

exceeded 10,000 pCi/g in 3 surface samples from Parcel A. At location 31 shown in Fig. 30, the concentration of ^{238}U in soil taken from the surface to a depth of 3 in. was 51,000 pCi/g. This location was chosen for sampling because of the high beta-gamma dose rate (5 mrad/hr) and the high ratio of beta to gamma radiation at the surface in an area of approximately 1000 cm². Elevated concentrations of ^{227}Ac , a daughter of ^{235}U , were also found in several surface samples taken on Parcel A. It should be noted that surface contamination in this parcel appears to be very nonuniform, and that much of the elevated external gamma radiation at 1 m on this parcel is attributable to subsurface contamination.

The concentration of ^{226}Ra in surface samples taken at random locations in Parcels B and C (Table 52) follows much the same pattern as the external gamma radiation levels at 1 m above the surface in those parcels (see Figs. 28 and 29). In the area in Parcel C showing external gamma levels up to 780 $\mu\text{R/hr}$ at 1 m, the ^{226}Ra concentration in surface soil was as high as 1600 pCi/g.

Subsurface soil contamination

Holes were augered at the 88 locations shown in Fig. 33, and gamma radiation as a function of depth was determined in these auger holes using NaI scintillation probes. Furthermore, soil samples were taken from many of the auger holes at the point of maximum contamination as indicated by the scintillation probe "loggings." A combination of soil sample analyses and scintillation probe loggings was used to determine the extent of radium contamination in subsurface soil at auger hole locations. Measurements and estimates concerning the extent of the

contaminated soil, the depth of maximum contamination, the ^{226}Ra concentration at the point of maximum contamination, and the average ^{226}Ra concentration in the contaminated region in each auger hole are presented in Table 53. The procedure used to obtain estimates of ^{226}Ra concentrations at points where no soil samples were taken is explained in Appendix III. Concentrations of ^{238}U and ^{227}Ac in soil samples taken from the auger holes are reported in Table 54; for ease of comparison with ^{238}U and ^{227}Ac , ^{226}Ra concentrations in these samples, although already listed in Table 53, are listed again in Table 54.

The information obtained from auger hole loggings applies principally to ^{226}Ra contamination, and it occasionally involves large errors. In order to determine more precisely the nature and extent of the contamination at some auger hole locations (1, 10, 12, 17, 22, 30, 41, 48, 59, 70, 77, 78, and 81 shown in Fig. 33), a core hole was drilled within a few feet of the auger hole and soil samples were taken at 6-in. or 1-ft intervals. In addition, samples were taken from core holes drilled through the floors in Buildings 2A, 10, and 18 at the points B1 through B5 shown in Fig. 34. All core hole samples were analyzed for ^{226}Ra , ^{238}U , and ^{227}Ac ; the results for outdoor core hole samples are reported in Table 55, and the results for samples taken from core holes inside buildings are given in Table 56.

Some of the auger hole locations were chosen because of high radiation levels above the surface at those points; however, most of the locations were chosen at random. The information in Table 53 suggests, then, that at almost any point on the site (except for part of the fill dirt on

Parcel B) a layer of contaminated soil can be found within a few feet of the surface. (The term "contaminated soil" indicates that the soil shows activities of ^{226}Ra and/or other radionuclides which are too high to be attributable to normal terrestrial radioactivity.) In Parcel A, maximum gamma radiation levels in the auger holes were measured at an average depth of 1.5 ft, and the layer of contaminated soil generally extended from near the surface to a depth of less than 8 ft, and usually less than 4 ft (see Tables 53, 54, and 55).

Since uranium ore has been handled on the site, and since the site has been used for both radium processing and uranium processing, it is not surprising that the ratio of ^{226}Ra activity to ^{238}U activity in sub-surface soil varies radically from point to point. Samples taken from a core hole near location 1 showed up to 1200 pCi of ^{238}U per gram as compared with a maximum ^{226}Ra concentration of 100 pCi/g (see Fig. 33 and Table 54). Similarly, samples from auger holes 2 and 4 (Fig. 33 and Table 54) showed considerably higher activities of ^{238}U than ^{226}Ra . On the other hand, in samples from nearby auger holes 3 and 5 (near Building 1, see Fig. 33 and Table 54) ^{238}U and ^{226}Ra were in approximate equilibrium. At location 5, at a depth of approximately 3 ft, a tank filled with water and sludge was pierced by the drill. The tank measured approximately 4.5 ft from top to bottom. A sludge sample taken from the bottom of the tank contained 2500 pCi of ^{226}Ra per gram and 2800 pCi of ^{238}U per gram. A soil sample taken 1.5 ft above the tank contained 2900 pCi of ^{226}Ra per gram and 2600 pCi of ^{238}U per gram. Auger holes 36 and 37 near Building 7 also showed approximately equal activities of ^{238}U and ^{226}Ra .

A sample taken from auger hole 35 (Table 54) next to Building 9 showed an approximate 4 to 1 ratio of ^{226}Ra activity to ^{238}U activity (110 pCi of ^{226}Ra per gram and 29 pCi of ^{238}U per gram). Samples from a core hole at location 10 (Fig. 33) contained up to 850 pCi of ^{226}Ra per gram and up to 450 pCi of ^{238}U per gram (see Table 55). In the area of the old "Plant No. 2" shown in Fig. 3, the highest ^{226}Ra and ^{238}U concentrations (300 pCi/g and 580 pCi/g, respectively) were measured in a sample taken at a depth of approximately 8 in. at location 15 (Fig. 33). At location 19, near the northeast corner of Building 18, the auger brought up some small pieces of contaminated wood which were possibly from an old wooden drain used during the ^{226}Ra separation period. A sample consisting principally of soil taken from a depth of 1.5 to 2.0 ft from this auger hole showed a ^{226}Ra concentration of 720 pCi/g and a ^{238}U concentration of 520 pCi/g (Table 54). Samples from a core hole drilled at location 22 (Fig. 33 and Table 55) showed maximum ^{226}Ra and ^{238}U concentrations of 2600 pCi/g and 280 pCi/g, respectively. Subsurface samples taken along the railroad spur between Buildings 10 and 15 and subsurface samples taken around Buildings 15, 19, and 16 exhibited the same variation in the activity ratio of ^{238}U to ^{226}Ra which was discussed earlier. Subsurface samples taken in the section of Parcel A north of Buildings 15, 16, and 19 and east of the railroad spur generally showed much higher activities of ^{226}Ra (up to 3000 pCi/g at location 41) than of ^{238}U (see Tables 54 and 55). This is not surprising since there were formerly several piles of uranium tailings in this area. A few feet from location 41 (Fig. 33), the external gamma radiation level at 1 m

above the surface was approximately 1600 $\mu\text{R/hr.}$ Digging in this area revealed a "sump hole" near the surface. The beta-gamma dose rate in this sump hole at a depth of 2 ft below the surface was approximately 80 $\mu\text{R/hr.}$ Two concrete troughs led from the sump hole, one toward the northwest corner of Building 10, and the other in the general direction of location 51 shown in Fig. 33. An auger hole drilled at location 25 (Fig. 33) between Buildings 10 and 11 revealed a material resembling uranium tailings and extending to a depth of approximately 3.5 ft. An analysis of this material revealed a ^{226}Ra concentration of 5670 pCi/g (Table 53). Since gamma radiation measurements indicated that the material extended under the northwest corner of Building 10, a hole was drilled through the floor of Building 10 at location B2 shown in Fig.

34. Samples taken at depths of 1.0 to 3.5 ft from this core hole revealed a maximum ^{226}Ra concentration of 3800 pCi/g and a maximum ^{238}U concentration of 300 pCi/g (see Table 56). Samples taken from hole B3 (Fig. 34) drilled near the southwest corner of Building 10 showed considerably higher ^{238}U activity (up to 410 pCi/g) than ^{226}Ra activity (see Table 56).

Holes were also drilled through the floors of Building 2A (locations B4 and B5, Fig. 34) and Building 18 (location B1, Fig. 34) in areas where direct meter readings had indicated possible subsurface contamination. The drilling in Building 2A was largely unsuccessful, since it was discovered that the present concrete floor had been poured over an old concrete floor. The samples designated B4 and B5 in Table 56 consisted partly of concrete from the old floor. These samples show ^{226}Ra concen-

trations of 220 pCi/g and 63 pCi/g, respectively. The subsurface soil at location B1 in Building 18 contained up to 520 pCi of ^{226}Ra per gram and 820 pCi of ^{238}U per gram.

In Parcel B, there appeared to be a 2- to 6-ft layer of contaminated soil which is under approximately 8 to 9 ft of fill dirt on the part of the parcel shaded in Fig. 2 and near the surface on the remainder of the parcel (see Table 53). It is estimated that the ^{226}Ra concentration exceeds 1000 pCi/g at some subsurface points on this parcel (see Table 53). The ratio of ^{226}Ra activity to ^{238}U activity in subsurface samples taken from Parcel B was generally 1.0 or higher. Auger hole 75 is thought to be near an old open drain which carried liquid wastes from the uranium processing operations to Parcel C; a sample from this auger hole showed 930 pCi of ^{226}Ra per gram, 88 pCi of ^{238}U per gram, and 290 pCi of ^{227}Ac per gram (Table 54).

Recall that Parcel C is the former lagoon area which was used as a depository for liquid wastes during uranium recovery operation and possibly during radium recovery operations. Since a highly contaminated mucky material was discovered a few feet below the surface near the center of this parcel, extensive precautions had to be taken when drilling in order to avoid creating a surface contamination problem. Consequently, only two holes (77 and 81, Fig. 33) were drilled away from the perimeter of Parcel C; however, 7 auger holes (82 through 88, Fig. 33) were drilled along Chartiers Creek and along the southern boundary of Parcel C to investigate whether the liquid residues have been leaching out of Parcel C. The scintillation probe loggings indicated that the contaminated

soil at location 77 extended from near the surface to a depth of approximately 16 ft, and a layer of muck extended from 2.5 to 6.0 ft. Samples of the muck taken at location 77 contained up to 15,000 pCi of ^{226}Ra per gram, 600 pCi of ^{238}U per gram, and 1700 pCi of ^{227}Ac per gram (Table 55). At location 81 the muck was encountered at a depth of 3.5 ft and extended at least to 7.5 ft. Samples of the muck taken at location 81 contained up to 17,000 pCi of ^{226}Ra per gram, 1000 pCi of ^{238}U per gram, and 2500 pCi of ^{227}Ac per gram (Table 55). It appears from the scintillation probe loggings that the soil at a depth of 5 to 10 ft below the surface at locations 82 and 83 (Fig. 33) contains high concentrations of ^{226}Ra . It is estimated that the maximum contamination at each location is at 8 ft, and that the maximum ^{226}Ra concentrations at locations 82 and 83 are 2000 pCi/g and 340 pCi/g, respectively. Three holes (locations 89, 90, 91 shown in Fig. 33) were drilled to depths of approximately 2 ft outside the southern boundary of Parcel C. The scintillation probe readings in the 3 holes were similar; a sample taken from hole 90 contained 13 pCi of ^{226}Ra per gram, 49 pCi of ^{238}U per gram, and 5 pCi of ^{227}Ac per gram, and a sample taken from hole 91 contained 14 pCi of ^{226}Ra per gram, 47 pCi of ^{238}U per gram, and 5.6 pCi of ^{227}Ac per gram (see Table 54). The scintillation probe loggings for holes 84, 85, 86, and 87 along Chartiers Creek indicated that the ^{226}Ra concentrations in that area are no higher than 18 pCi/g.

Analyses of water samples taken from auger holes

Water samples were taken from many of the onsite auger holes and were analyzed for ^{238}U and ^{226}Ra . The results of these analyses are

given in Table 57 for locations shown in Fig. 33. Several samples showed ^{226}Ra concentrations above the RCG for water (0.03 pCi/ml) given in 10 CFR 20, Appendix B and ERDAM 0524. All samples showed ^{238}U concentrations below the RCG_w (40 pCi/ml).

Results of Offsite Measurements

External gamma radiation levels at 1 m above the surface

External gamma radiation measurements at 1 m above the surface were made at grid points outdoors in the area just south of the site, including Penn Central Railroad property (see Fig. 2). The results of this survey are reported in Table 58. The maximum external gamma reading was 2000 $\mu\text{R/hr}$ and was taken at grid point 2+50, R50 (see Fig. 2). Moreover, a beta-gamma dose rate of 15.0 mrad/hr was measured 1 cm from the surface near this grid point.

External gamma radiation measurements at 1 m above the surface were taken at randomly selected locations in each of the lots numbered (or lettered) in Figs. 35 through 38; the results of this survey are reported in Table 59. The relationship of the site to each of these areas is shown in Fig. 39. The average external gamma level at 1 m measured on the property along Latimer Avenue was 22 $\mu\text{R/hr}$; this is twice the average background level measured in the Canonsburg area. The highest observed reading in the Latimer Avenue area was 100 $\mu\text{R/hr}$; this was measured above a brick walk in the north end of Lot 4 (see Fig. 35). In the lots surveyed in the Strabane Avenue area (see Fig. 36), the average external gamma level at 1 m was found to be 17 $\mu\text{R/hr}$. The highest observed reading was 73 $\mu\text{R/hr}$, found at the east end of lot 109. The average of

the external gamma readings taken along West Pike Street (see Fig. 37) was 10 $\mu\text{R/hr}$; this figure is within the range of background levels measured in the Canonsburg area. No readings taken in this area exceeded 15 $\mu\text{R/hr}$. The external gamma radiation levels at 1 m measured along Wilson Avenue were near the background level with the exception of the measurement of 36 $\mu\text{R/hr}$ observed at location K shown in Fig. 38.

Offsite soil and water samples

Offsite soil samples were taken at random locations and were analyzed for ^{226}Ra , ^{238}U , and ^{227}Ac . The results of these analyses are reported in Table 60. The highest concentrations of these radionuclides were found along Chartiers Creek, at locations G and Q (see Table 60 and Fig. 39). Concentrations well above background levels were also found in residential areas at locations J, K, N, O, and R. Offsite water samples were taken at several points in Chartiers Creek. Concentrations of ^{226}Ra , ^{210}Pb , and ^{230}Th in these samples (and in sediment filtered from the water) are reported in Table 62.

Offsite measurements of radon concentrations in air

Radon concentrations were measured at several locations off the site, and at two outdoor locations on the site. The results of these measurements are reported in Table 61 with references to Fig. 39. The highest offsite concentrations (up to 14.4 pCi/liter) were measured in the two indoor locations. Readings as high as 5.5 pCi/liter were observed outdoors with the weather shields in place over the Wrenn Chambers as described in the "Survey Methods" section of this report. Since background radon concentrations are generally much less than 1 pCi/liter,

the radon concentrations measured off the site could be the result of atmospheric transport of radon from the site. (Radon concentrations as high as 69 pCi/liter were measured outdoors on the site with the weather shields in place over the Wrenn Chambers.) Since elevated concentrations of ^{226}Ra were found in soil at some offsite locations, it is possible that offsite ^{226}Ra contamination is contributing to the elevated radon concentrations measured off the site.

SUMMARY

A radiological survey of the Canon Industrial Park was conducted in two phases during the period April through July, 1977. Phase I consisted of measurement of radon and radon daughter concentrations in air in the buildings and the results indicate radon and daughter levels far above guidelines stated in 10 CFR 20 and 10 CFR 712 (see Table 6 and Appendix IV). Phase II consisted of measurement of surface and subsurface contamination levels on and near the site, measurement of radiation levels above the surfaces on and near the site, and measurement of radon concentrations near the site.

This site was used from 1911 to 1922 to extract radium from carnotite ore, from 1930 to 1942 to extract radium and uranium salts from onsite residues and carnotite ore, and from 1942 to 1957 to recover uranium from various ores and scrap materials. Operations began on the western side of the site, and expansion of buildings and operations from west to east on the site was preceded by the dumping of huge quantities of radioactive wastes. Eventually, radioactive residues containing widely varying concentrations of ^{226}Ra , ^{230}Th , ^{238}U , and other radionuclides

from the ^{238}U and ^{235}U chains were present at various depths over almost the entire site; and it appears that almost all of the buildings on the site are either built over, or are adjacent to, deposits of radium-bearing residues. Samples taken underneath Building 10, for example, showed ^{226}Ra concentrations as high as 3800 pCi/g, and some surface or subsurface samples collected beneath or near Buildings 1, 2A, 3, 7, 9, 11, 15, 16, 18, and 19 contained more than 100 pCi of ^{226}Ra per gram. It is not surprising, then, that radon daughter concentrations as high as 0.50 Working Levels (WL) and radon concentrations as high as 227 pCi/liter were measured in the buildings during this survey (see Tables 5 and 6).

On the interior surfaces of Buildings 1, 2, 2A, 3, 7, 9, 10, 11, 15, 16, and 19, alpha and/or beta-gamma contamination levels exceeded NRC guidelines at some points. It appears that at many of these points a large fraction (in some cases, nearly all) of the surface contamination is actually attached radon daughters. Nevertheless, because of the large quantities of ^{226}Ra and/or ^{230}Th found in drains, on some building surfaces, and outdoors throughout the site, it must be assumed that ^{226}Ra and ^{230}Th are the most prominent radionuclides when applying NRC guidelines. Transferable alpha contamination levels exceeded the NRC guideline for ^{226}Ra and ^{230}Th (20 dpm/100 cm²) at several points in Buildings 16 and 19. Transferable alpha and beta contamination levels were low on most interior surfaces on the site. In Building 1, alpha contamination levels exceeded 300 dpm/100 cm² by direct reading over a large fraction of the floor and lower wall surfaces. Beta-gamma dose rates on the floor were as high as 1.8 mrad/hr, and at some points a

large fraction of the beta-gamma dose rates was attributable to beta radiation. External gamma radiation levels on the first level were as high as 0.22 mR/hr. The surfaces on the second level of Building 1 appeared to be relatively uncontaminated except for some alpha contamination apparently due to radon daughters. It is estimated that radon daughter concentrations on both levels of Building 1 could increase to nearly 1 WL when the building is closed tightly. In Building 2, alpha contamination levels exceeded 300 dpm/100 cm² by direct reading at some points on the floor. Building 2A is apparently built over an old concrete pad which is contaminated with ²²⁶Ra and other radionuclides along a strip approximately 20 ft wide and extending from Building 2 to Building 3 (rows 6, 7, 8, and 9 in Fig. 9). Beta-gamma dose rates (principally from gamma radiation) were as high as 0.80 mrad/hr along this strip. Radon apparently emanates through the floor in this area, and the ²²⁶Ra contamination beneath the floor could also be contributing to high radon daughter concentrations in the offices in the adjacent Building 3, since radon follows the least resistant path and can easily penetrate the wooden floors in those offices. It was estimated that the radon daughter concentrations in Buildings 2 and 2A could exceed 0.50 WL under some conditions, and this concentration was actually measured in the offices in Building 3. A large fraction of the floor, wall, and ceiling surfaces in Building 3 showed directly measured alpha contamination levels which exceed NRC guidelines. Beta-gamma dose rates on the floor of Building 3 were as high as 1.3 mrad/hr. Building 7 was used as a warehouse during the uranium processing period and the surfaces

in this building are contaminated by ^{230}Th and other radionuclides in some places. Directly measured alpha contamination levels as high as 22,000 dpm/100 cm^2 and beta-gamma dose rates as high as 8.5 mrad/hr (principally from beta radiation) were observed on the floor and lower walls of this building. The maximum external gamma radiation measured at 1 m in Building 7 was 0.22 mR/hr. It is estimated that the radon daughter concentration in Buildings 7 and 9 could exceed 1 WL when the buildings are tightly closed. In Building 9, directly measured alpha contamination levels exceeded 300 dpm/100 cm^2 at points in both the new (east) section of the building and in the old (west) section. Beta-gamma dose rates did not exceed 0.20 mrad/hr in the new section but were as high as 2.0 mrad/hr in the old section. Building 10 showed high levels of surface and subsurface contamination on both the first and second levels, particularly in the northwest corner of the building, which is apparently built over uranium tailings. Beta-gamma dose rates as high as 6.0 mrad/hr, with significant contributions from both beta and gamma radiation, were measured in that area, and the radon concentration in that area exceeded 120 pCi/liter in one office. In Building 11, alpha contamination levels exceeded 300 dpm/100 cm^2 over much of the floor, and elevated beta-gamma dose rates (up to 0.90 mrad/hr) were measured at some points. The maximum potential radon daughter concentration in Building 11 is estimated to be approximately 2 WL. Buildings 15, 16, and 19 were reportedly constructed after termination of uranium processing on the site. These buildings were built in an area containing large quantities of waste residues, and the surfaces of each of these

buildings now show alpha and beta-gamma contamination levels exceeding NRC guidelines. In fact, the highest direct reading of alpha contamination in Building 16 was 40,000 dpm/100 cm². The maximum potential radon daughter concentrations in Buildings 15, 16, and 19 are estimated to be approximately 0.3, 1.6, and 0.9 WL, respectively. The old (south) section of Building 18 showed alpha contamination levels as high as 10,000 dpm/100 cm² by direct reading and beta-gamma dose rates as high as 2.5 mrad/hr. A significant portion of the elevated beta-gamma dose rates in this section are from surface contamination, although there also appears to be high levels of gamma radiation resulting from contamination beneath the floor. Radon daughter concentrations in the old section of Building 18 could be high as 0.7 WL when the building is closed tightly. The new (north) section of Building 18 showed relatively little surface contamination.

Beta-gamma dose rates at 1 cm from the surface outdoors on the site were as high as 25 mrad/hr, and external gamma radiation levels at 1 m were as high as 1.6 mR/hr. Both of these maximum readings were observed in an area north of Buildings 15, 16, and 19 that formerly contained several piles of waste residues which were removed in 1957. Numerous points in Parcel A showed beta-gamma dose rates exceeding 1 mrad/hr. These elevated beta-gamma dose rates are mainly attributable, it appears, to large quantities of radium-bearing materials within 1.5 ft of the surface. It appears that, at one time, the top foot or more of soil in most of Parcel B was highly contaminated; however, a large part of this parcel is now covered by several feet of fill dirt. Parcel C was once

used as a depository for liquid wastes from uranium recovery operations. There remains a mucky material which showed concentrations of ^{226}Ra and ^{238}U as high as 17,000 pCi/g and 1000 pCi/g, respectively, and which was within a few feet of the surface at two sampling points. External gamma radiation levels above the surface on Parcel C decrease gradually from a maximum of 0.78 mR/hr near Strabane Avenue to less than 0.05 mR/hr near Chartiers Creek. Soil sample analyses indicate that there is considerable surface contamination in the area in Parcel C showing highest gamma radiation levels.

Exploratory measurements made near the site revealed elevated radiation levels above the surface, elevated radionuclide concentrations in soil, and elevated radon concentrations in air at some nearby offsite locations. For example, in the unoccupied area near the Penn Central Railroad just south of Parcel A, beta-gamma dose rates at 1 cm were as high as 15 mrad/hr and external gamma radiation levels were as high as 2 mR/hr. It is estimated that, at approximately 0.5 ft below the surface near the railroad spur south of Building 7, the ^{226}Ra concentration may be 7000 pCi/g or higher. A soil sample taken from a garden east of Strabane Avenue showed 110 pCi of ^{226}Ra per gram and 22 pCi of ^{238}U per gram. Radon concentrations in air measured in two garages near the site exceeded the maximum permissible concentration (MPC_a , or RCG_a) of 3.0 pCi/liter stated in 10 CFR 20, Appendix B.

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Fig. 1. Aerial view of Canon Industrial Park.

Fig. 2. Scaled drawing of the Canon Industrial Park site and grid used for outdoor survey.

BUILDINGS APPROXIMATELY TO SCALE

- A - PLANT No. 2
- B - R-1 BUILDING
- C - SHOP & STORES
- D - SERVICE BUILDING
- E - OFFICE & LABORATORY
- F - GUARD HOUSE
- G - CHROME
- H - SHED
- I - BOILER HOUSE
- J - PLANT No. 1
- K - PILOT PLANT
- L - WAREHOUSE
- M - METER ROOM

Fig. 3. Vitro Manufacturing Company buildings in April, 1956.

ORNL-DWG. 77-14384

Fig. 4. Unscaled sketch of Vitro site in 1948 showing relative locations of dumps and liquid disposal area according to Bruce Wallace. (Department of Genetics, Carnegie Institute of Washington, Cold Springs Harbor, New York. "A Preliminary Report on the Chemical Dump of the Vitro Mfg. Co., Canonsburg, Pa. undated report.)

Fig. 5. Maximum direct measurements of alpha contamination (300 dpm/100 cm² or higher) on floor and lower wall surfaces in Building 1, first level.

ORNL-DWG 77-15646

④ DRAIN LOCATION AND NUMBER
MEASUREMENTS IN MRAD/HR

Fig. 6. Maximum direct measurements of beta-gamma contamination (0.20 mrad/hr or higher) on floor and lower wall surfaces in Building 1, first level.

ORNL-DWG 77-15653

Fig. 7. Directly measured beta-gamma contamination (mrad/hr) on floor and lower wall surfaces and external gamma (μR/hr) measured 1 m above the floor in Building 1, second level.

① DRAIN LOCATION AND NUMBER

MEASUREMENTS IN DPM/100 CM²

Fig. 8. Maximum direct measurements of alpha contamination (300 dpm/100 cm² or higher) on floor and lower wall surfaces in Building 2.

ORNL-DWG 77-15642

$$\frac{\text{X.XX}}{\text{XXX}} = \frac{\beta\gamma \text{ (0.20 MRAD/HR OR HIGHER)}}{\alpha \text{ (300 DPM/100 CM}^2 \text{ OR HIGHER)}}$$

Fig. 9. Maximum direct measurements of beta-gamma contamination (numerator, where it appears) and alpha contamination on floor and lower wall surfaces in Building 2A.

① DRAIN LOCATION AND NUMBER

$\frac{x.xx}{xxx} = \frac{\beta\gamma \text{ (0.20 MRAD/HR OR HIGHER)}}{\alpha \text{ (300 DPM/100 CM}^2 \text{ OR HIGHER)}}$

Fig. 10. Maximum direct measurements of beta-gamma contamination (numerator, where it appears) and alpha contamination on floor and lower wall surfaces in Building 3.

Fig. 11. Maximum direct measurements of beta-gamma contamination (numerator, where it appears) and alpha contamination on floor and lower wall surfaces in Building 7.

ORNL-DWG 77-15634

X.XX = $\beta\gamma$ (0.20 MRAD/HR OR HIGHER)
 XXX = α (300 DPM/100 CM² OR HIGHER)

Fig. 12. Maximum direct measurements of beta-gamma contamination (numerator, where it appears) and alpha contamination on floor and lower wall surfaces in Building 9.

Fig. 13. Maximum direct measurements of alpha contamination ($300 \text{ dpm}/100 \text{ cm}^2$ or higher) on floor and lower wall surfaces in Building 10, first level.

Fig. 14. Maximum direct measurements of beta-gamma contamination (0.20 mrad/hr or higher) on floor and lower wall surfaces in Building 10, first level.

NR= NO READING

MEASUREMENTS IN DPM/100 CM²

ORNL-DWG 77-15647

READINGS GIVEN IN MRAD/HR

Fig. 16. Maximum direct measurements of beta-gamma contamination (0.20 mrad/hr or higher) on floor and lower wall surfaces in Building 10, second level.

④ DRAIN LOCATION AND NUMBER

X.XX $\beta\gamma$ (0.20 MRAD/HR OR HIGHER)XXX α (300 DPM/100 CM² OR HIGHER)

NR=NO READING

Fig. 17. Maximum direct measurements of beta-gamma contamination (numerator, where it appears) and alpha contamination on floor and lower wall surfaces in Building 11.

$$\frac{X.XX}{XXX} = \frac{\beta\gamma \text{ (0.20 MRAD/HR OR HIGHER)}}{\alpha \text{ (300 DPM/100 CM}^2 \text{ OR HIGHER)}}$$

Fig. 18. Maximum direct measurements of beta-gamma contamination (numerator, where it appears) and alpha contamination on floor and lower wall surfaces in Building 15.

Fig. 19. Maximum direct measurements of beta-gamma contamination (numerator, where it appears) and alpha contamination on floor and lower wall surfaces in Building 16.

Fig. 20. Floor plan of Building 18, first level, showing drain locations in the original building and survey points in the new section of the building.

Fig. 21. Maximum direct measurements of beta-gamma contamination (numerator, where it appears) and alpha contamination on floor and lower wall surfaces in Building 18, first level, south section.

ORNL-DWG 77-15649

Fig. 22. Maximum direct measurements of beta-gamma contamination (numerator, where it appears) and alpha contamination on floor and lower wall surfaces in Building 18, second level, south section.

Fig. 24. Maximum beta-gamma dose rate in each survey block in which some measurement exceeded 0.20 mrad/hr.

Fig. 25. Larger areas on and near the site showing elevated beta radiation levels.

g. 26. External gamma measurements (in $\mu R/hr$) at 1 m above the surface outdoors near buildings.

Fig. 27. Profile of average gamma radiation levels at 1 m above the surface in Parcel A.

Fig. 28. Profile of average external gamma radiation levels at 1 m above surface in Parcel B.

ORNL DWG 77-15658

Fig. 29. Profile of average external gamma radiation levels at 1 m above surface in Parcel C.

Fig. 30. Surface soil sample locations in Parcel A.

Fig. 31. Surface soil sample locations in Parcel B.

Fig. 32. Surface soil sample locations in Parcel C.

Fig. 33. Auger hole locations outdoors on and near the site.

Fig. 34. Locations inside buildings where core holes were drilled through floors.

SCALE
100 ft

ORNL DWG 77-16719

Fig. 35. Offsite locations near Latimer Avenue.

ORNL DWG 77-16720

Fig. 36. Offsite locations in the Strabane Avenue area.

ORNL DWG 77-16721

Fig. 37. Offsite locations along West Pike Street.

ORNL DWG 77-16722

Fig. 38. Offsite locations along Wilson Avenue.

Fig. 39. Locations of offsite soil samples and radon measurements.

Table 1. Number of workers in buildings of former Vitro plant, and current use of each building^a

Building no.	Approximate no. of employees	Approximate no. of hours per week per employee	Building use
1 - upper level	8	40	offices and storage
1 - upper level	2	8	
1 - lower level	varies	varies	
2 and 2A	2	40	packaging and storage
2 and 2A	1	15	
3	5	40	fabrication and offices
3	1	60	
3	1	10	
3	1	25	
3	7	15	
7	11	40	machine shop
7	2	20	
9	5	40	machine shop
10 - lower	12	40	offices, main- tenance, repair fabrication
10 - upper	2	44	
10 - upper	3	40	
11	varies	varies	varies
15	2	40	truck repair
16 and 19	20	40	metalizing operation
18 - upper	1	50	metal works and fabrication
18 - upper	2	20	
18 - new section	1	40	motor freight terminal
18 - new section	3	45	
18 - new section	14	15	

^aThe occupancy and use of some of these buildings change frequently. The information presented here is from April, 1977.

Table 2. Locations at which radon and radon daughters were measured, sampling time for Wrenn Chamber measurements, and number of individual radon daughter measurements at each location

Building	Location ^a	Time of continuous sampling (hr)	Number of individual radon daughter measurements
1, first level	B10	42	4
1, first level	C3	42	4
1, second level	Room 3B	46	3
1, second level	Room 4A	46	3
1, second level	Room 6B	46	4
1, second level	Room 7	48	0
1, second level	Room 7	48	4
1, second level	Room 6A	46	4
2	B2	46	3
2	F7	46	3
2A	E14	46	3
2A	E6	46	3
3	B7	72	2
3	B4	72	2
3	E9	11	2
3	E6	11	2
7	C12	96	4
7	C4	96	3
9, east end	E5	22	4
9	Room 1	22	4
9, west end	E6	72	4
9, west end	E2	72	4
10, first level	S2	28	3
10, first level	P3	38	3
10, first level	J14	44	3
10, first level	F14	44	3
10, second level	L12	45	3
10, second level	K3	45	3
11	G15	73	2
11	G3	73	2
15	C5	22	1
15	C2	28	3
16	office, first level	42	2
16	B3	42	2
16	F6	22	2
16	F9	22	2
16	office, second level	10	2
16	B3	10	1
16	F8	27	2
18, first level	office, new section	24	2
18, first level	outside office, new section	24	2
18, second level	H10	23	2
18, second level	F4	23	2

^a Locations refer to survey blocks shown in scaled drawings of buildings (see figures).

Table 3. Estimated^a average daytime radon daughter concentrations

Building		²²² Rn daughter concentration (WL)	Average daytime ²²² Rn concentration (pCi/liter)
1	Upstairs	0.12	28.4
	Downstairs	0.16	39.3
2		0.07	16.6
2A		0.07	16.8
3		0.43	106.5
7		0.14	34.2
9		0.21	51.0
10		0.15	38.3
11		0.21	50.8
13		0.06	14.6
16		0.16	38.4
18	Eng. Metals	0.12	30.8
	CCC Trucking	0.01 ^b	2.6
19		0.08	18.6

^aUsing ratios Rn : RaA ; RaB : RaC = 1 : 0.83 : 0.43 : 0.27 and average (daytime) ²²²Rn concentrations.

^bIncludes office.

Table 4. Estimated^a average 24-hr radon daughter concentrations

Building		Estimated average ^{222}Rn daughter concentration (24-hr)	24-hr average ^{222}Rn concentration (pCi/liter)
1	Upstairs	0.27	42.8
	Downstairs	0.50	78.5
2		0.16	25.8
2A		0.16	24.4
3		0.68	107.5
7		0.26	40.2
9		0.28	43.3
10		0.20	30.7
11		0.50	78.9
15		0.10	15.6
16		0.22	34.0
18	Eng. Metals	0.21	32.3
	CCC Trucking	0.01	2.1
19		0.27	41.7

^a Using ratios $\text{Rn} : \text{RaA} : \text{RaB} : \text{RaC} = 1 : 0.92 : 0.67 : 9.54$ which is average of ratios "observed" at site and ratios $1 : 1.0 : 0.9 : 0.8$ for sealed room (Toth).

Table 5. Estimated maximum (24-hr) radon daughter concentrations using maximum measurement for each building and ratios
 $Rn : RaA : RaB : RaC = 1 : 1.0 : 0.9 : 0.8$

Building	Estimated maximum (WL)	Maximum ^{222}Rn (pCi/liter)	Time measured	Location
1 Upstairs	0.79	91.7	7:10 a.m.	TMR office
Downstairs	0.99	115.0	12:54 p.m.	front room
2	0.71	82.3	7:32 a.m.	large open area
2A	0.53	61.3	6:31 a.m.	back, north corner
3	1.76	205.4	6:55 a.m.	secy's office
7	1.04	121.4	6:17 a.m.	back, north corner
9	1.50	174.6	4:50 a.m.	empty office
10	1.05	121.9	5:45 p.m.	secy's office
11	1.95	227.0	2:17 a.m.	corner next to garage door
15	0.27	31.6	2:45 a.m.	next to rest room
16	1.64	191.4	6:10 a.m.	Crile's office
18 Eng. Metals	0.68	79.8	7:05 a.m.	shop
CCC Trucking	0.06	6.5	8:30 a.m.	office
19	0.85	99.0	6:45 a.m.	center of west wall

Table 6. Summary of radon daughter measurements and estimates

Building	Measured ^a av (WL)	Estimated ^b daytime av (WL)	Estimate ^c 24-hr av (WL)	Estimated ^d maximum potential (WL)	Measured ^e maximum (WL)
1 Upstairs	0.11	0.12	0.27	0.79	0.23
Downstairs	0.06	0.16	0.50	0.99	0.08
2	0.07	0.07	0.16	0.71	0.15
2A	0.04	0.07	0.16	0.53	0.07
3	0.23	0.43	0.68	1.76	0.50
7	0.15	0.14	0.26	1.04	0.33
9	0.12	0.21	0.28	1.50	0.22
10	0.07	0.15	0.20	1.05	0.30
11	0.16	0.21	0.50	1.95	0.34
15	0.04	0.06	0.10	0.27	0.06
16	0.16	0.16	0.22	1.64	0.43
18 Eng. Metals	0.08	0.12	0.21	0.68	0.13
CCC Trucking	0.01	0.01	0.01	0.06	0.03
19	0.06	0.08	0.27	0.85	0.08

^aAll measurements were in daytime, often with doors and windows open.

^bUsing Rn:RaA:RaB:RaC = 1:0.83:0.43:0.27 ("observed" onsite).

^cUsing Rn:RaA:RaB:RaC = 1:0.92:0.67:0.54 (average of "observed" and Toth's "sealed room" ratios of 1:1.0:0.9:0.8).

^dUsing 1:1.0:0.9:0.8.

^eMeasured in daytime.

Table 7. Alpha, beta-gamma and external gamma radiation levels in Building 1, first level, including floor and lower wall surfaces

Survey block shown in Fig. 5	At center of block		At maximum beta-gamma point		External gamma-- radiation level
	Alpha contamination level (dpm/100 cm ²)	Beta-gamma dose-rate at 1 cm (mrad/hr)	Alpha contamination level (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	at 1 m above surface at center of block ² (μ R/hr)
A 2	210	0.07	NR ^a	NR	NA ^b
3	210	0.06	NR	NR	NA
4	310	0.05	NR	NR	NA
5	160	0.06	NR	NR	NA
6	360	0.09	NR	NR	NA
7	360	0.05	NR	NR	NA
8	620	0.05	NR	NR	NA
9	310	0.06	NR	NR	NA
10	360	0.07	NR	NR	NA
11	310	0.08	NR	NR	NA
12	310	0.10	NR	NR	NA
13	260	0.10	NR	NR	NA
B 1	310	0.07	NR	0.08	NA
2	470	0.07	NR	0.12	34
3	620	0.09	NR	0.15	40
4	310	0.08	NR	0.12	45
5	260	0.15	570	0.15	70
6	310	0.13	470	0.21	80
7	420	0.10	NR	0.13	70
8	880	0.15	520	0.20	80
9	470	0.13	620	0.35	90
10	470	0.15	830	0.30	100
11	260	0.10	8000	1.00	70
12	880	0.10	1100	0.25	100
13	420	0.12	1500	0.30	100
14	260	0.08	NR	NR	NA
C 1	470	0.06	NR	0.06	NA
2	310	0.05	NR	0.08	35
3	420	0.08	NR	0.08	40
4	620	0.08	NR	0.10	30
5	360	0.10	NR	0.18	35
6	620	0.13	780	0.21	45
7	210	0.13	2100	0.40	60
8	940	0.18	940	0.40	100
9	1200	0.40	880	0.50	130
10	780	0.30	940	0.30	110
11	780	0.30	420	0.50	160
12	420	0.35	570	0.50	220
13	470	0.28	620	0.30	220
14	360	0.08	NR	NR	NA

Table 7. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 1, first level, including floor and lower wall surfaces

Survey block shown in Fig. 5	At center of block		At maximum beta-gamma point		External gamma radiation level
	Alpha contamination level (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha contamination level (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	at 1 m above surface at center of block (μR/hr)
D 1	210	0.04	NR	NR	NA
2	360	0.08	NR	0.18	NA
3	210	0.10	520	0.23	45
4	520	0.07	NR	0.07	45
5	570	0.05	NR	0.10	29
6	360	0.13	NR	0.18	29
7	360	0.23	940	0.30	55
8	1200	0.15	380	1.30	65
9	570	0.25	1600	0.40	95
10	570	0.12	NR	0.10	85
11	570	0.12	NR	0.12	75
12	310	0.05	NR	0.05	60
13	680	0.03	NR	0.03	45
14	310	0.05	NR	NR	45
E 1	360	0.05	NR	NR	NA
2	360	0.08	360	0.27	40
3	520	0.05	520	0.21	50
4	420	0.05	NR	0.05	60
5	730	0.06	NR	0.08	22
6	360	0.05	NR	0.05	30
7	470	0.10	NR	0.10	65
8	1400	0.40	1100	0.40	80
9	940	0.30	1100	1.00	150
10	880	0.15	NR	NR	80
11	490	0.10	650	0.20	90
12	620	0.08	NR	NR	60
13	470	0.03	NR	NR	45
14	520	0.05	NR	NR	35
F 2	310	0.05	NR	NR	NA
3	360	0.05	NR	NR	NA
4	210	0.04	NR	NR	NA
5	310	0.03	NR	NR	NA
6	210	0.05	NR	NR	NA
7	210	0.06	NR	NR	NA
8	780	0.13	NR	NR	NA
9	520	0.10	NR	NR	NA
10	650	0.10	NR	NR	NA
11	620	0.07	NR	NR	NA
12	360	0.10	NR	NR	NA
13	420	0.06	NR	NR	NA

^aNR = no reading.

^bNA = not applicable.

Table 8. Alpha and beta-gamma contamination on interior dividing walls in Building 1, first level

Block No. shown in Fig. 5	Wall location blocks shown in Fig. 5	Directly measured contamination at center of block	
		Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
C 2	2 and 3	620	0.05
C 3	2 and 3	570	0.05
D 3	2 and 3	420	0.06
E 2	2 and 3	360	0.10
E 3	2 and 3	600	0.05
D10	D and E	420	0.07
E10	D and E	420	0.07
E 9 - E10	E9 - E10	420	0.07
E 8 - E 9	E8 - E 9	570	0.12
E 8	7 and 8	570	0.10
D 8	7 and 8	680	0.07
C 8	7 and 8	360	0.09
D 8	7 and 8	520	0.07
B 7	7 and 8	420	0.05
C 7	7 and 8	310	0.08
D 7	7 and 8	570	0.07
E 7	7 and 8	520	0.10

Table 9. Alpha and beta-gamma contamination on overhead surfaces in Building 1, first level^a

Survey block in Fig.5	Horizontal surface		Vertical surface		Ceiling surface	
	Direct alpha measurement ^b (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement ^b (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement ^b (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
A 2	NR	NR	520	0.06	NR	NR
3	NR	NR	680	0.07	NR	NR
8	NR	NR	NR	0.11	NR	NR
10	NR	NR	NR	0.15	NR	0.15
12	NR	NR	1000	0.14	NR	0.14
B 2	1100	0.06	470	0.05	470	0.08
4	940	0.05	680	0.05	NR	NR
5	NR	NR	NR	NR	680	0.06
6	620	0.06	680	0.05	780	0.10
7	680	0.05	520	0.05	730	0.06
8	1200	0.11	1200	0.11	830	0.11
10	1200	0.11	1200	0.10	1400	0.10
11	830	0.15	830	0.13	830	0.13
12	NR	NR	NR	NR	880	NR
1	NR	NR	520	0.06	NR	NR
2	1300	0.06	310	0.06	260	0.08
4	NR	NR	NR	NR	520	0.06
7	1000	0.06	470	0.08	730	0.09
8	1000	0.08	1000	0.05	940	0.05
9	1100	0.13	1400	0.13	1000	0.13
13	1000	0.08	730	0.08	940	0.08
D 3	780	0.10	680	0.06	360	0.09
4	570	0.05	570	0.05	NR	NR
5	730	0.05	620	0.05	NR	NR
7	1100	0.06	880	0.04	680	0.08
8	1300	0.10	1300	0.08	1300	0.08
11	1200	0.13	1200	0.10	1200	0.10
E 5	780	0.06	680	0.04	520	0.06
7	880	0.08	880	0.08	730	0.08
9	NR	NR	NR	0.15	NR	0.15
11	1000	0.08	1000	0.09	880	0.09
F 6	NR	NR	NR	NR	620	0.05
9	NR	NR	NR	0.15	NR	0.15
12	1000	0.09	1100	0.10	NR	0.10

^aMeasurements were made on walls above the 6 ft. level overhead beam and the concrete ceiling, all of which had been painted.

^bMeasurements made with the alpha scintillation meter in air at overhead locations with a 50 cm detection surface were as high as 500 dpm, showing that a significant fraction of the measured values are attributable to radon and its daughters.

Table 10. Radioactivity in drains in Building 1, first level

Drain No. (see fig. 5)	Gamma radiation level (μR/hr)				Direct alpha measurement 5 cm above drain (dpm/100 cm ²)	Transferable contamination ^a (dpm/100 cm ²)	
	1 m above drain	Top of drain	Below surface			Alpha	Beta
			15 cm	50 cm			
1	20	25	75	125	680	<10	110
2	25	35	125	270	210	<10	110
3	20	20	55	125	13,000	60	190
4	75	125	370	825	1,000	20	80
5	90	50	220	270	420	45	170
6	45	45	185	210	570	45	170

^aSmears were made within 15 cm of top of drain.

Table 11. Alpha, beta-gamma and external gamma radiation levels in Building 2, including floor and lower wall surfaces

Survey block shown in Fig. 8	Directly measured contamination of center of block		Directly measured contamination of surface at maximum beta-gamma point		External gamma radiation level at 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	210	0.04	No reading	0.05	Not applicable to walls
3	50	0.05	NR	0.05	NA
4	100	0.06	NR	0.06	NA
5	NR	NR	NR	NR	NA
6	210	0.05	NR	0.05	NA
7	100	0.05	NR	0.05	NA
8	100	0.04	NR	0.04	NA
9	310	0.04	NR	0.05	NA
10	100	0.05	NR	0.05	NA
11	100	0.05	NR	0.05	NA
12	210	0.05	NR	0.05	NA
13	160	0.04	NR	0.04	NA
14	50	0.05	NR	0.05	NA
15	210	0.05	NR	0.05	NA
16	100	0.05	NR	0.05	NA
B 1	0	0.05	NR	0.05	NA
2	160	0.08	NR	0.05	31
3	310	0.05	NR	0.04	29
4	160	0.08	NR	0.08	31
5	NR	NR	NR	NR	16
6	620	0.10	NR	NR	20
7	260	0.06	NR	0.06	26
8	260	0.05	NR	0.05	25
9	420	0.08	NR	0.08	25
10	420	0.05	NR	0.06	34
11	360	0.08	NR	0.08	42
12	160	0.06	NR	0.06	34
13	210	0.05	NR	0.05	26
14	160	0.05	NR	0.05	25
15	310	0.05	NR	0.05	26
16	260	0.05	NR	0.05	29
17	260	0.05	NR	0.05	NA
C 1	0	0.05	NR	0.05	NA
2	260	0.04	NR	0.08	29
3	100	0.04	NR	0.04	31

Table 11. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 2, including floor and lower wall surfaces

Survey block shown in Fig. 8	Directly measured contamination of center of block		Directly measured contamination of surface at maximum beta-gamma point		External gamma radiation level at 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
4	100	0.05	NR	0.05	25
5	780	0.04	NR	0.08	20
6	680	0.06	NR	0.08	25
7	520	0.05	NR	0.08	29
8	470	0.06	NR	0.08	35
9	520	0.13	NR	0.13	44
10	260	0.08	NR	0.10	42
11	210	0.03	NR	0.08	35
12	360	0.08	NR	0.08	25
13	420	0.10	NR	0.08	26
14	160	0.06	NR	0.08	22
15	50	0.05	NR	0.05	31
16	160	0.05	NR	0.05	31
17	160	0.05	NR	0.05	NA
D 1	50	0.06	NR	0.06	NA
2	420	0.08	NR	0.08	34
3	780	0.08	NR	0.08	26
4	520	0.06	NR	0.06	22
5	520	0.09	NR	0.09	20
6	570	0.08	NR	0.08	25
7	730	0.08	NR	0.08	26
8	470	0.08	NR	0.08	34
9	420	0.09	NR	0.09	44
10	310	0.08	NR	0.08	42
11	260	0.06	NR	0.06	35
12	310	0.08	NR	0.08	34
13	620	0.08	NR	0.08	40
14	310	0.08	NR	0.08	42
15	420	0.08	NR	0.08	42
16	210	0.06	NR	0.06	34
17	0	0.05	NR	0.05	NA
E 1	50	0.07	NR	0.07	NA
2	260	0.09	NR	0.09	40
3	160	0.08	NR	0.08	31
4	210	0.13	NR	0.08	25

Table 11. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 2, including floor and lower wall surfaces

Survey block shown in Fig. 8	Directly measured contamination of center of block		Directly measured contamination of surface at maximum beta-gamma point		External gamma radiation level at 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
5	570	0.08	NR	0.08	20
6	210	0.08	NR	0.13	26
7	260	0.08	NR	0.08	26
8	470	0.14	NR	0.15	29
9	310	0.09	NR	0.10	44
10	160	0.08	NR	0.08	40
11	160	0.08	NR	0.08	31
12	160	0.05	NR	0.08	34
13	210	0.10	NR	0.10	47
14	160	0.08	NR	0.13	44
15	160	0.08	210	0.23	38
16	50	0.05	NR	0.05	40
17	50	0.05	NR	0.05	NA
F 1	100	0.05	NR	0.05	NA
2	310	0.05	NR	0.05	38
3	100	0.09	NR	0.15	38
4	260	0.10	NR	0.10	33
5	260	0.08	NR	0.10	29
6	420	0.05	NR	0.05	29
7	210	0.05	NR	0.05	27
8	160	0.10	NR	NR	33
9	100	0.12	NR	0.12	36
10	360	0.07	NR	0.07	33
11	210	0.05	NR	0.05	29
12	160	0.05	NR	0.05	36
13	100	0.09	NR	NR	47
14	210	0.09	NR	NR	38
15	160	0.13	NR	0.18	60
16	160	0.09	NR	0.08	42
17	50	0.04	NR	NR	NA
G 1	NR	NR	NR	NR	NA
2	160	0.05	NR	0.05	29
3	360	0.05	NR	0.05	25
4	160	0.10	NR	0.10	NR
5	310	0.06	NR	NR	38

Table 11. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 2, including floor and lower wall surfaces

Survey block shown in Fig. 8	Directly measured contamination of center of block		Directly measured contamination of surface at maximum beta-gamma point		External gamma radiation level at 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
6	260	0.09	NR	0.12	42
7	420	NR	NR	NR	31
8	360	0.12	NR	NR	34
9	210	0.05	NR	NR	35
10	310	NR	NR	NR	35
11	160	0.05	NR	0.05	25
12	260	NR	NR	NR	NR
13	NR	NR	NR	NR	31
14	160	0.09	NR	0.12	36
15	160	0.10	NR	0.10	47
16	50	0.06	NR	0.06	42
17	50	0.07	NR	NR	NA
H 1	NR	NR	NR	NR	NA
2	100	0.05	NR	0.05	NA
3	50	0.07	NR	0.07	NA
4	210	0.05	NR	0.05	NA
5	100	0.08	NR	0.08	NA
6	50	NR	NR	NR	NA
7	160	NR	NR	NR	NA
8	100	0.05	NR	NR	NA
9	160	NR	NR	NR	NA
10	100	NR	NR	NR	NA
11	50	0.05	NR	0.05	NA
12	100	NR	NR	NR	NA
13	0	0.05	NR	0.05	NA
14	260	0.05	NR	0.05	NA
15	160	0.04	NR	0.04	NA
16	160	0.05	NR	0.05	NA
17	NR	NR	NR	NR	NA

Table 12. Alpha and beta-gamma contamination
on overhead surfaces in Building 2^a

Survey block shown in Fig. 8	Horizontal surface		Vertical surface	
	Direct alpha measurement (mrad/hr)	Beta-gamma dose rate at 1 cm (dpm/100 cm ²)	Direct alpha measurement (mrad/hr)	Beta-gamma dose rate at 1 cm (dpm/100 cm ²)
B 2	360	0.05	260	NR ^b
6	210	0.03	50	NR
9	50	0.03	160	NR
13	50	0.05	210	NR
15	160	0.06	160	NR
D 2	156	0.05	160	NR
6	104	0.03	160	NR
8	100	0.05	160	NR
12	260	0.06	160	NR
15	260	0.04	310	NR
E 4	160	0.03	360	0.03
F11	100	0.04	180	0.02
13	260	0.05	260	0.03
15	80	0.03	50	0.06
H 6	100	0.05	30	0.04

^aThe overhead surfaces in this building are relatively new. In each of the survey squares in which overhead measurements were made, a vertical surface (such as upper walls or sides of beams) and a horizontal surface (such as the ceiling surface or a horizontal surface of a beam) were selected for alpha and/or beta-gamma measurements.

^bNR = no reading.

Table 13. Radioactivity in drains 1 in Building 2

Drain No. (see Fig. 8)	1 m above drain	Gamma radiation level ($\mu\text{R/hr}$)			Direct alpha reading at 5 cm above drain	Transferable contamination ^a (dpm/100 cm ²)	
		Top of drain	15 cm below surface	25-100 cm below surface		Alpha	Beta
1	45	35	90	220	75	< 20	0
2	35	35	90	160	2000	< 20	0
3	27	27	40	130	100	< 20	0
4	55	80	90	NR ^b	700	NR	NR
5	45	80	280	440	100	< 20	0
6	27	35	NR	80	3000	< 20	0

^aSmears were made within 15 cm of top of drain.

^bNR=no reading.

Table 14. Alpha, beta-gamma and external gamma radiation levels in Building 2A, including floor and lower wall surfaces

Survey ck shown Fig. 9	Directly measured contami- nation at center of block		Directly measured contami- nation of block surface at maximum beta-gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	0	0.04	NR ^a	0.04	NA ^b
3	0	0.05	NR	0.05	NA
4	50	0.05	NR	0.05	NA
5	50	0.10	NR	0.10	NA
6	NR	NR	NR	NR	NA
7	50	0.09	NR	0.09	NA
8	100	0.06	NR	0.06	NA
9	160	0.08	NR	0.08	NA
10	100	0.06	NR	0.06	NA
11	100	0.04	NR	0.04	NA
12	160	0.05	NR	0.05	NA
	50	0.04	NR	0.04	NA
14	0	0.04	NR	0.04	NA
15	100	0.03	NR	0.03	NA
16	50	0.04	NR	0.04	NA
B 1	NR	0.04	NR	0.04	NA
2	160	0.13	NR	0.13	26
3	260	0.14	NR	0.14	49
4	260	0.14	NR	0.14	71
5	1000	NR	NR	0	85
6	520	0.25	460	0.50	89
7	470	0.10	680	0.80	67
8	940	0.15	1400	0.28	51
9	620	NR	NR	0	78
10	520	NR	NR	NR	44
11	940	0.15	NR	0.15	40
12	1200	0.10	NR	0.10	40
13	230	0.08	NR	0.08	35
14	210	0.05	NR	0.05	34
15	160	0.04	NR	0.04	25
16	260	0.03	NR	0.03	25
17	100	0.03	NR	0.03	NA
C 1	100	0.04	NR	0.04	NA
2	260	0.07	NR	0.07	29
3	0	0.05	NR	0.05	38
4	360	NR	NR	NR	44
	260	NR	NR	NR	49

^aNR = no reading.

^bNA = not applicable to walls.

Table 14. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 2A, including floor and lower wall surfaces

Survey block shown in Fig. 9	Directly measured contami- nation at center of block		Directly measured contami- nation of block surface at maximum beta-gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
6	570	0.50	570	0.80	180
7	1000	0.25	470	0.5	100
8	470	0.13	1400	NR	100
9	730	0.35	940	0.8	120
10	440	0.15	NR	0.15	76
11	260	NR	NR	NR	35
12	940	0.10	NR	0.10	38
13	890	0.07	NR	0.07	35
14	100	NR	NR	NR	NR
15	210	NR	NR	NR	25
16	0	NR	NR	0.03	25
17	0	NR	NR	0.03	NA
D 1	50	0.05	NR	0.05	NA
2	100	0.05	NR	0.05	40
3	260	0.05	NR	0.05	40
4	160	0.06	NR	0.10	40
5	780	0.12	NR	0.07	56
6	520	0.35	570	NR	130
7	620	0.15	420	0.35	100
8	1100	0.10	NR	0.25	100
9	520	0.50	520	0.25	150
10	1090	0.18	NR	0.10	60
11	520	0.10	NR	0.08	38
12	260	0.09	NR	0.08	38
13	310	0.10	NR	0.05	40
14	160	0.07	NR	0.07	40
15	NR	NR	NR	NR	29
16	160	NR	NR	NR	22
17	NR	NR	NR	NR	NA
E 1	0	0.05	NR	0.05	NA
2	210	0.05	NR	0.05	34
3	160	0.05	NR	0.05	38
4	210	0.10	NR	0.10	44
5	260	0.07	NR	0.07	53
6	260	NR	NR	NR	85
7	730	0.35	730	0.50	127
8	680	0.25	680	0.35	116
9	780	0.25	780	0.25	73
10	420	0.10	NR	0.10	49

Table 14. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 2A, including floor and lower wall surfaces

Survey block shown Fig. 9	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta-gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
11	470	0.08	NR	0.08	34
12	470	0.08	NR	0.08	34
13	620	0.05	NR	0.05	40
14	160	0.04	NR	0.04	25
15	100	0.03	NR	0.03	22
16	260	0.03	NR	NR	22
17	NR	0.03	NR	NR	NA
F 1	50	0.05	NR	0.05	NA
2	NR	NR	NR	NR	34
3	260	0.15	NR	0.15	49
4	210	NR	NR	NR	44
5	990	0.13	NR	0.13	34
6	470	0.15	NR	0.15	60
	1500	0.23	1200	0.23	85
8	990	0.20	680	0.20	67
9	830	0.14	NR	0.14	44
10	360	0.10	NR	0.10	38
11	260	0.10	NR	0.10	35
12	260	0.10	NR	0.10	34
13	310	0.15	NR	0.15	38
14	310	0.05	NR	0.05	22
15	160	0.03	NR	0.03	22
16	200	0.03	NR	0.03	25
17	260	0.03	NR	0.03	NA
G 2	160	0.06	NR	0.06	NA
3	210	0.05	NR	0.05	NA
4	100	0.06	NR	0.09	NA
5	100	0.06	NR	0.06	NA
6	50	0.10	NR	0.10	NA
7	50	0.09	NR	0.14	NA
8	0	0.06	NR	0.06	NA
9	100	0.15	NR	0.15	NA
10	50	0.05	NR	0.05	NA
11	210	0.05	NR	0.05	NA
12	50	0.04	NR	0.04	NA
13	100	0.08	NR	0.08	NA
14	50	0.08	NR	0.08	NA
15	50	0.05	NR	0.05	NA
	160	0.05	NR	0.05	NA

Table 15: Alpha and beta-gamma contamination
on overhead surfaces in Building 2A.

Block No. (see Fig. 9)	Horizontal surfaces		Vertical surfaces	
	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Direct alpha dose rate at 1 cm (mrad/hr)
D 3	210	0.05	100	0.05
5	210	0.10	50	0.10
7	260	0.13	50	0.13
C11	420	0.06	50	0.06
E 3	100	0.05	100	0.05
5	160	0.08	50	0.08
6	310	0.10	100	0.10
9	50	0.05	210	0.05
12	50	0.06	0	0.06
F14	210	0.05	100	0.05

Table 16. Alpha, beta-gamma and external gamma radiation levels in Building 3, including floor and lower wall surfaces

Survey block shown in Fig. 10	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta-gamma point		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	210	0.05	NR	0.05	Not applicable
3	310	0.04	NR	0.04	NA
4	260	0.04	NR	0.04	NA
5	210	0.05	NR	0.05	NA
6	310	0.05	NR	0.05	NA
7	NR	NR	NR	NR	NA
8	780	0.05	NR	0.05	NA
9	360	0.05	NR	NR	NA
10	60	0.05	NR	NR	NA
11	100	0.04	NR	NR	NA
12	100	0.04	NR	NR	NA
13	100	0.05	NR	NR	NA
14	310	NR	NR	NR	NA
15	310	0.05	NR	NR	NA
16	420	0.06	NR	NR	NA
B 1	260	0.05	NR	0.05	NA
2	260	0.06	NR	0.06	49
3	210	0.05	NR	0.13	44
4	570	0.05	NR	0.08	40
5	570	0.05	NR	0.05	38
6	730	0.05	NR	0.05	35
7	310	0.05	NR	0.05	38
8	1800	0.13	NR	0.13	34
9	310	0.10	NR	0.10	26
10	420	0.08	NR	0.08	26
11	210	0.10	NR	0.15	29
12	210	0.09	NR	0.09	34
13	470	0.10	NR	0.10	38
14	310	0.05	NR	NR	34
15	260	0.06	NR	0.06	38
16	310	0.15	NR	NR	44
17	210	0.05	NR	NR	NA
C 1	160	0.05	NR	0.05	NA
2	360	0.08	NR	0.08	49
3	520	0.06	NR	0.06	49
4	310	0.06	NR	0.06	44
5	420	0.04	NR	0.08	44
6	210	0.06	NR	0.06	44
7	360	0.13	NR	0.08	35

Table 16. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 3, including floor and lower wall surfaces

Survey block shown in Fig. 10	Directly measured contami- nation at center of block		Directly measured contami- nation of block surface at maximum beta-gamma point		External gamma radiation leve 1 m above floc (μ R/hr)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
8	520	0.13	NR	NR	29
9	570	0.06	NR	NR	22
10	210	0.09	NR	0.10	44
11	210	0.10	NR	0.10	58
12	210	0.10	NR	0.10	44
13	360	0.05	NR	0.10	40
14	210	0.05	NR	0.08	40
15	360	0.08	NR	0.10	40
16	360	0.10	NR	0.10	51
17	260	0.06	NR	0.06	NA
D 1	210	0.04	NR	0.13	NA
2	360	0.10	NR	0.08	51
3	260	0.10	NR	0.06	49
4	210	0.05	NR	0.10	40
5	210	0.09	NR	0.05	44
6	470	0.05	NR	0.10	44
7	260	0.08	NR	0.15	29
8	360	0.10	NR	0.25	25
9	520	0.18	310	0.11	26
10	310	0.11	NR	0.10	60
11	210	0.10	NR	0.15	60
12	260	0.15	NR	0.15	40
13	260	0.15	NR	0.14	47
14	310	0.10	NR	0.08	44
15	260	0.08	NR	0.08	51
16	260	0.08	NR	0.08	49
17	50	0.08	NR	0.08	NA
E 1	260	0.13	NR	0.13	NA
2	420	0.18	NR	0.18	89
3	730	0.25	2200	0.75	56
4	570	0.20	2000	1.25	51
5	470	0.13	NR	0.18	73
6	160	0.08	NR	0.13	58
7	730	0.08	NR	0.10	53
8	520	0.08	NR	0.08	40
9	620	0.08	NR	0.10	44
10	360	0.08	NR	0.13	51
11	520	0.10	NR	0.13	53
12	420	0.15	NR	0.15	58
13	360	0.15	210	0.25	76
14	360	0.06	NR	0.15	38

Table 16. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 3, including floor and lower wall surfaces

Survey block shown in Fig. 10	Directly measured contami- nation at center of block		Directly measured contami- nation of block surface at maximum beta-gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
15	620	0.13	NR	0.15	38
16	320	0.13	NR	0.15	56
17	160	NR	NR	NR	NA
F 1	100	0.13	NR	0.13	NA
2	360	0.15	NR	0.15	71
3	730	0.18	1700	0.60	35
4	470	0.13	NR	0.13	34
5	360	0.13	NR	NR	40
6	310	0.15	NR	0.15	53
7	210	0.18	1200	0.50	71
8	570	0.15	1200	0.35	34
9	310	0.10	NR	0.10	44
10	940	0.13	NR	0.13	49
11	470	0.11	NR	0.11	53
12	310	0.09	NR	0.09	49
13	470	0.10	NR	0.10	55
14	420	0.09	NR	0.09	49
15	210	0.13	NR	0.13	60
16	990	0.18	NR	0.18	34
17	210	NR	NR	NR	NA
G 1	210	0.18	NR	NR	NA
2	1900	0.09	NR	0.10	57
3	360	NR	NR	NR	34
4	NR	NR	NR	NR	34
5	NR	NR	NR	NR	NR
6	NR	NR	NR	NR	44
7	520	0.15	1700	0.35	34
8	780	0.05	2200	0.25	40
9	670	0.13	NR	0.13	34
10	670	0.09	NR	0.09	34
11	420	0.13	NR	0.13	34
12	520	0.05	NR	NR	40
13	310	0.05	NR	NR	31
14	1200	0.09	NR	0.09	31
15	570	0.05	NR	NR	29
16	620	0.04	NR	0.05	34
17	160	0.06	NR	0.06	NA
H 2	420	0.10	NR	0.15	NA
3	160	NR	NR	NR	NA

Table 16. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 3, including floor and lower wall surfaces

Survey block shown in Fig. 10	Directly measured contami- nation at center of block		Directly measured contami- nation of block surface at maximum beta-gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
4	NR	NR	NR	NR	NA
5	NR	NR	NR	NR	NA
6	780	NR	NR	NR	NA
7	210	0.05	NR	NR	NA
8	520	0.08	NR	NR	NA
9	310	0.06	NR	0.10	NA
10	210	0.05	NR	NR	NA
11	210	0.06	NR	NR	NA
12	420	0.08	NR	NR	NA
13	160	0.08	NR	NR	NA
14	470	0.07	NR	NR	NA
15	210	0.06	NR	NR	NA
16	160	0.06	NR	NR	NA

Table 17. Alpha and beta-gamma contamination on overhead surfaces in Building 3

Block No. (see Fig. 10)	Direct measurement of alpha contamination (dpm/100 cm ²)		Beta-gamma dose rate at 1 cm (mrad/hr)
	Vertical beam surfaces	Ceiling and horizontal beam surfaces	
B 12	100	100	0.05
C 15	160	260	0.04
D 4	620	1200	0.15
8L ^a	360	730	0.10
8R ^b	360	940	0.15
10	260	260	0.18
E 3L	310	290	0.08
3R	310	260	0.10
5L	470	360	0.13
5R	50	50	0.08
6L	100	570	0.08
6R	50	50	0.08
8L	160	210	0.08
8R	100	160	0.08
10	470	730	0.10
12	290	230	0.08
G 2	780	2000	0.08
16	100	100	0.05

^aLow part of overhead beams.

^bTop part of overhead beams.

Table 18. Alpha, beta-gamma and external gamma radiation levels in Building 7 including floor and lower wall surfaces

Survey block shown in Fig. 11	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	100	0.05	100	0.45	NA ^a
3	100	0.08	NR ^b	0.08	NA
4	200	0.13	NR	0.13	NA
5	210	0.13	NR	0.13	NA
6	50	0.13	NR	0.13	NA
7	160	0.05	NR	0.10	NA
8	2100	0.15	2600	0.23	NA
9	100	0.15	210	0.23	NA
10	310	0.15	NR	0.15	NA
11	100	0.15	NR	0.15	NA
12	420	0.15	NR	0.15	NA
13	520	0.28	520	0.28	NA
B 1	210	0.05	NR	0.05	NA
2	620	0.10	1100	0.10	40
3	160	0.10	160	8.5	35
4	220	0.18	260	6.0	45
5	260	1.8	160	2.0	40
6	210	0.10	830	3.5	50
7	1500	0.35	940	0.50	75
8	880	0.25	1200	1.5	70
9	620	0.30	620	2.8	100
10	310	0.25	260	3.0	130
11	260	0.25	210	0.35	120
12	1500	0.20	1100	0.70	130
13	990	0.60	1500	0.75	220
14	160	0.15	NR	0.15	NA
C 1	50	0.05	NR	0.05	NA
2	1100	0.09	NR	0.09	35
3	470	0.08	NR	0.15	40
4	310	0.13	360	0.35	60
5	420	0.15	1500	1.3	80
6	420	0.13	310	1.3	75
7	1170	0.13	620	0.30	70
8	620	0.30	2600	3.5	50
9	260	0.08	730	0.65	55
10	310	0.11	310	0.20	55
11	210	0.15	260	0.33	90
12	570	0.15	100	0.20	85
13	570	0.40	210	1.0	170

Table 18. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 7, including floor and lower wall surfaces

Survey block shown in fig. 11	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
14	100	0.12	100	0.30	NA
D 1	310	0.12	100	0.30	NA
2	470	0.10	NR	0.10	45
3	830	0.11	680	0.25	85
4	470	0.20	730	0.55	95
5	680	0.15	360	0.35	110
6	260	0.15	360	0.25	80
7	1100	0.11	620	0.25	60
8	620	0.13	520	0.25	60
9	520	0.11	1100	0.27	65
10	830	0.14	NR	0.14	65
11	520	0.15	NR	0.15	80
12	310	0.15	570	0.23	100
	160	0.18	100	0.75	200
14	50	0.15	NR	0.15	NA
E 1	50	0.14	NR	0.04	NA
2	160	0.06	NR	0.06	26
3	160	0.15	1000	0.40	60
4	310	0.10	470	0.40	60
5	360	0.13	100	0.50	65
6	260	0.18	160	0.35	75
7	1400	0.13	940	0.23	80
8	1100	0.25	830	0.25	60
9	570	0.08	1800	0.33	50
10	470	0.15	260	0.50	50
11	310	0.18	1400	0.50	65
12	420	0.15	830	0.5	75
13	310	0.35	1300	1.3	170
14	100	0.15	NR	0.15	NA
F 1	50	0.04	NR	0.04	NA
2	360	0.06	NR	0.06	29
3	420	0.05	NR	0.05	45
4	260	0.18	780	0.30	65
5	780	0.13	NR	0.13	55
6	310	0.15	280	0.25	80
7	1800	0.20	5000	0.30	80
8	1100	0.15	2500	0.20	75
9	2200	0.08	3800	0.20	60
10	5000	0.25	2700	0.50	120

Table 18. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 7, including floor and lower wall surfaces

Survey block shown in Fig. 11	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
11	3900	0.35	4200	0.75	70
12	360	0.15	NR	0.15	65
13	260	0.20	470	1.0	200
14	210	0.10	NR	0.10	NA
G 2	50	0.06	NR	0.06	NA
3	160	0.13	NR	0.13	NA
4	160	0.10	NR	0.10	NA
5	50	0.10	NR	0.10	NA
6	100	0.06	NR	0.06	NA
7	360	0.11	22,000	0.25	NA
8	420	0.13	1000	0.50	NA
9	5300	0.15	1400	0.40	NA
10	470	0.18	NR	0.18	NA
11	470	0.10	420	0.20	NA
12	50	0.10	NR	0.10	NA
13	210	0.23	210	0.20	NA

^aNA = not applicable.

^bNR = no reading.

Table 19. Alpha and beta-gamma contamination on overhead surfaces in Building 7

Survey block shown in Fig. 11	Surface	Horizontal surface		Vertical surface	
		Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
A 6	wall	NR ^a	NR	50	0.08
11	wall	NR	NR	0	0.10
B 2	wall	NR	NR	100	0.05
6	beam	160	0.07	NR	NR
11	heater	260	0.10	NR	NR
12	beam	260	0.10	NR	NR
14	wall	NR	NR	0	0.15
C 3	beam	50	0.05	NR	NR
4	ceiling	50	0.08	NR	NR
7	beam	210	0.11	NR	NR
D 1	wall	NR	NR	50	0.05
4	heater	50	0.05	NR	NR
10	beam	210	0.06	NR	NR
E 3	beam	50	0.07	NR	NR
8	beam	160	0.08	NR	NR
10	beam	100	0.11	NR	NR
12	beam	50	0.09	NR	NR
14	wall	NR	NR	0	0.10
7	wall	NR	NR	0	0.05
9	wall	NR	NR	100	0.04

^aNR = no reading.

Table 20. Alpha, beta-gamma and external gamma radiation levels in east section of Building 9, including floor and lower wall surfaces

Survey block shown in Fig. 12	Directly measured contamination at center of block		Directly measured contamination at center of block surface at maximum beta-gamma point		External gamma radiation level at 1 m above surface
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	210	0.10	NR ^a	0.10	NA ^b
3	620	0.10	NR	0.10	NA
4	210	0.07	NR	0.07	NA
5	260	0.08	NR	0.08	NA
B 1	160	0.08	NR	0.08	NA
2	360	0.10	NR	0.10	45
3	310	0.10	NR	0.10	40
4	260	0.12	NR	0.12	45
5	50	0.07	NR	0.07	40
6	210	0.13	NR	0.13	NA
C 1	210	0.06	NR	0.06	NA
2	100	0.08	NR	0.08	26
3	210	0.07	NR	0.09	35
4	360	0.05	NR	0.08	35
5	310	0.06	NR	0.11	60
6	260	0.11	NR	0.11	NA
D 1	360	0.04	NR	0.04	NA
2	310	0.08	NR	0.08	29
3	260	0.09	NR	0.09	35
4	260	0.05	NR	0.05	40
5	260	0.05	NR	0.08	40
6	260	0.08	NR	0.08	NA
E 1	80	0.05	NR	0.05	NA
2	420	0.08	NR	0.08	30
3	570	0.10	NR	0.06	30
4	1300	0.05	NR	0.05	29
5	210	0.05	NR	0.05	35
6	210	0.05	NR	0.05	NA
F 1	100	0.06	NR	0.05	NA
2	260	0.06	NR	0.05	35
3	160	0.04	NR	0.03	35
4	210	0.05	NR	0.05	22
5	520	0.05	NR	0.03	22
6	100	0.05	NR	0.05	NA
G 2	210	0.04	NR	0.04	NA
3	360	0.05	NR	0.05	NA
4	160	0.04	NR	0.03	NA
5	100	0.05	NR	0.03	NA

^aNR = no reading.

^bNA = Not applicable to walls.

Table 21. Alpha and beta-gamma contamination on overhead surfaces in east section of Building 9

Survey block shown in fig. 12	Surface	Horizontal surface		Vertical surface	
		Alpha (dpm/100 cm ²)	Beta-gamma (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma (mrad/hr)
A 2	high wall	NA ^a	NA	100	0.04
A 2	low wall	NA	NA	210	0.05
D 2	old wall, low	210	0.06	NA	NA
D 2	old wall, high	NR ^b	0.15	NA	NA
F 3	wall	NA	NA	100	0.04
F 3	ceiling	100	0.04	NA	NA
F 5	wall	NA	NA	60	0.05
F 5	ceiling	160	0.03	NA	NA

A = Not applicable.

^bNR = No reading.

Table 22. Alpha, beta-gamma and external gamma radiation levels in west section of Building 9, including floor and lower wall surfaces

Survey block shown in Fig. 12	Directly measured contamination at center of block		Contamination of block surface at maximum beta-gamma point		External gamma radiation level above 1 (μR/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma (mrad/hr)	
A 2	100	0.06	NR ^a	0.10	NA ^b
3	160	0.03	NR	0.13	NA
4	210	0.03	NR	0.14	NA
5	100	0.04	NR	0.13	NA
6	260	0.03	NR	0.07	NA
7	210	0.05	470	0.23	NA
8	260	0.05	NR	0.08	NA
B 1	160	0.08	NR	0.08	NA
2	160	0.10	260	0.23	30
3	420	0.15	NR	0.15	35
4	210	0.10	360	0.28	30
5	310	0.13	NR	0.15	35
6	210	0.05	NR	0.05	35
7	160	0.10	NR	0.10	45
8	520	0.10	680	0.35	35
9	620	0.06	NR	0.06	NA
C 1	160	0.06	NR	0.06	NA
2	210	0.15	NR	0.15	40
3	310	0.13	360	0.23	50
4	310	0.18	100	0.21	60
5	210	0.09	NR	0.09	35
6	210	0.10	NR	0.10	30
7	470	0.09	620	0.70	45
8	160	0.10	NR	0.10	35
9	210	0.04	NR	0.04	NA
D 1	310	0.08	NR	0.10	NA
2	420	0.13	NR	0.15	60
3	100	0.07	NR	0.15	40
4	100	0.10	470	0.50	45
5	210	0.08	NR	0.08	29
6	100	0.08	1200	2.0	35
7	570	0.10	680	0.23	40
8	520	0.10	NR	0.10	35
9	360	0.05	NR	0.05	NA
E 2	50	0.06	NR	0.11	NR
3	260	0.07	NR	0.06	NR
4	100	0.06	NR	0.09	NR
5	100	0.03	NR	0.06	NR
6	260	0.08	NR	0.08	NR
7	160	0.08	NR	0.10	NR
8	310	0.05	NR	0.05	NR

^aNR = No reading.

^bNA = Not applicable to walls.

Table 23. Alpha and beta-gamma contamination on overhead surfaces in west section of Building 9

Survey block shown in Fig. 12	Surface	Horizontal surface		Vertical surface	
		Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
A 2		NR ^a	NR	210	0.05
5	wall	NR	NR	160	0.05
7	wall	NR	NR	310	0.09
B 1	high wall, ledge	310	NR	310	NR
2	ceiling	160	0.04	NR	NR
3	ceiling	50	0.08	NR	NR
3	beam	100	0.08	100	0.04
5	ceiling	360	0.04	NR	NR
5	beam	260	0.08	100	0.08
7	ceiling	210	0.05	NR	NR
C 1	high wall	260	0.08	440	0.08
5	beam	210	0.07	420	0.07
5	ceiling	210	0.13	160	0.13
7	ceiling	210	0.08	NR	0.08
9	wall	NR	NR	160	0.06
9	ceiling	360	0.04	NR	NR
D 2	wall	520	0.10	620	0.10
9	wall	310	0.05	520	0.05
9	ceiling	360	0.04	260	0.04
E 2	ceiling	260	0.06	210	0.06
5	ceiling	310	0.05	420	0.05
6	wall	NR	NR	260	0.06
6	ceiling	440	0.04	160	0.04
8	ceiling	360	0.04	260	0.04

^aNR = No reading.

Table 24. Alpha, beta-gamma and external gamma radiation levels in Building 10, first level, including floor and lower wall surfaces

Survey block shown in Fig. 13	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta-gamma point		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	210	0.06	NR ^a	0.06	NA ^b
3	100	0.06	NR	0.06	NA
4	50	0.05	100	0.25	NA
5	210	0.06	NR	0.08	NA
6	100	0.04	NR	0.04	NA
7	50	0.04	NR	NR	NA
8	50	0.04	NR	0.05	NA
9	50	0.04	NR	0.04	NA
10	50	0.04	NR	0.04	NA
11	0	0.04	NR	0.04	NA
12	0	0.04	NR	0.04	NA
13	50	0.04	NR	0.04	NA
14	0	0.04	NR	0.04	NA
15	50	0.04	NR	0.04	NA
B 1	310	0.05	NR	0.05	NA
2	130	0.04	NR	0.04	20
3	100	0.04	NR	0.04	20
4	730	0.04	NR	0.04	22
5	420	0.06	NR	0.06	22
6	210	0.06	NR	0.15	20
7	100	0.05	NR	0.08	20
8	990	0.04	NR	0.04	20
9	2100	0.03	NR	0.03	10
10	1900	0.04	NR	0.04	9
11	1600	0.04	NR	0.04	8
12	0	0.04	NR	0.04	12
13	50	0.04	NR	0.04	14
14	160	0.04	NR	0.04	10
15	260	0.03	NR	0.03	13
16	50	0.03	NR	0.03	NA
C 1	100	0.05	NR	0.05	NA
2	210	0.04	NR	0.05	22
3	100	0.04	NR	0.04	20
4	160	0.04	NR	0.10	20
5	50	0.04	NR	0.10	20
6	100	0.08	NR	0.10	20
7	400	0.09	NR	0.15	20
8	1100	0.05	NR	0.10	22
9	930	0.05	360	0.23	12
10	1100	0.05	NR	0.05	9

Table 24. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, first level, including floor and lower wall surfaces

Survey block shown in Fig. 13	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
11	50	0.04	NR	0.05	9
12	0	0.04	NR	0.04	9
13	0	0.04	NR	0.04	10
14	160	0.04	NR	0.04	11
15	160	0.03	NR	0.03	14
16	50	0.03	NR	0.03	NA
D 1	50	0.04	NR	0.04	NA
2	420	0.06	NR	0.06	35
3	100	0.04	NR	0.04	20
4	8000	0.05	1000	0.25	21
5	570	0.06	NR	0.13	22
6	210	0.04	NR	0.05	20
7	470	0.04	NR	0.07	20
8	1000	0.04	NR	0.06	12
9	1000	0.04	NR	0.10	11
10	160	0.05	NR	0.05	13
11	470	0.04	NR	0.04	10
12	50	0.06	NR	0.06	10
13	360	0.04	NR	0.10	10
14	2300	0.06	NR	0.06	9
15	2100	0.03	NR	0.03	12
16	0	0.03	NR	0.03	NA
E 1	0	0.08	NR	0.08	NA
2	210	0.08	NR	0.25	35
3	210	0.05	NR	0.05	22
4	1000	0.11	NR	0.18	22
5	310	0.13	NR	0.13	22
6	160	0.05	NR	0.10	20
7	50	0.05	NR	0.05	22
8	100	0.05	NR	0.08	14
9	100	0.05	NR	0.05	14
10	100	0.03	NR	0.10	13
11	100	0.03	NR	0.09	12
12	520	0.05	NR	0.05	10
13	260	0.08	NR	0.08	9
14	1600	0.08	NR	0.08	8
15	230	0.04	NR	0.10	10
16	0	0.03	NR	0.03	NA
F 1	310	0.03	NR	0.05	NA
2	990	0.13	NR	0.13	22
3	1300	0.13	4700	0.23	20
4	260	0.08	NR	0.08	13

Table 24. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, first level, including floor and lower wall surfaces

Survey block shown in Fig. 13	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
5	420	0.08	NR	0.08	14
6	940	0.06	NR	0.23	22
7	50	0.04	NR	NR	20
8	160	0.08	NR	0.08	16
9	470	0.06	NR	0.06	13
10	310	0.04	NR	0.06	12
11	110	0.03	NR	0.05	11
12	730	0.05	NR	0.08	9
13	210	0.03	NR	0.09	9
14	1800	0.04	NR	0.06	10
15	2600	0.07	NR	0.07	12
16	0	0.04	NR	0.04	NA
G 1	1400	0.05	NR	0.05	NA
2	1200	0.05	NR	0.05	10
3	4700	0.10	1300	0.21	18
4	680	0.08	NR	0.08	18
5	260	0.08	NR	0.18	22
6	260	0.08	NR	0.08	22
7	160	0.08	NR	NR	14
8	520	0.08	NR	0.08	12
9	310	0.03	NR	0.10	11
10	420	0.04	NR	0.04	13
11	370	0.03	NR	0.04	11
12	680	0.03	NR	0.04	9
13	360	0.03	NR	0.03	8
14	1400	0.04	NR	0.04	7
15	260	0.02	NR	0.02	14
16	50	0.03	11,000	0.20	NA
H 1	0	0.04	NR	0.04	NA
2	260	0.05	NR	0.05	11
3	2700	0.06	NR	0.06	14
4	310	0.08	NR	0.08	22
5	310	0.06	NR	0.10	35
6	50	0.08	NR	0.15	22
7	160	0.08	NR	0.08	14
8	160	0.05	NR	0.05	12
9	0	0.05	NR	0.05	12
10	50	0.04	NR	0.04	13
11	260	0.04	NR	0.04	8

Table 24. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, first level, including floor and lower wall surfaces

Survey block shown in Fig. 13	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
12	260	0.04	NR	0.04	8
13	260	0.03	NR	0.03	8
14	260	0.05	NR	0.05	10
15	160	0.05	NR	0.05	14
16	50	0.05	NR	0.05	NA
I 1	50	0.05	NR	0.05	NA
2	430	0.05	NR	0.05	NA
3	260	0.05	NR	0.05	12
4	210	0.09	NR	0.09	22
5	470	0.08	NR	0.11	29
6	310	0.09	NR	0.15	26
7	260	0.08	NR	0.08	13
8	520	0.05	NR	0.05	13
9	160	0.08	NR	0.08	13
10	520	0.05	NR	0.05	11
11	620	0.05	NR	0.08	11
12	1500	0.05	NR	0.05	7
13	780	0.10	NR	0.10	8
14	360	0.10	NR	0.10	9
15	420	0.10	NR	0.10	17
16	50	0.10	NR	0.10	NA
J 1	210	0.04	NR	0.04	NA
2	420	0.04	NR	0.04	12
3	360	0.04	NR	0.04	13
4	620	0.07	NR	0.15	22
5	210	0.07	NR	0.15	35
6	260	0.10	NR	0.15	26
7	160	0.08	NR	0.15	13
8	310	0.05	NR	0.05	16
9	520	0.05	NR	0.05	14
10	NR	0.05	NR	0.05	13
11	100	0.05	NR	0.05	10
12	470	0.05	NR	0.05	4
13	1100	0.05	NR	0.05	9
14	470	0.04	NR	0.10	10
15	1400	0.04	NR	0.15	17
16	360		NR	NR	NA
K 1	0	0.04	NR	0.04	NA
2	100	0.04	NR	0.08	22
3	210	0.08	980	1.60	29

Table 24. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, first level, including floor and lower wall surfaces

Survey block shown in Fig. 13	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
4	210	0.05	360	0.80	30
5	420	0.20	420	0.35	40
6	310	0.03	NR	0.17	35
7	420	0.06	NR	0.06	22
8	160	0.03	NR	0.03	13
9	NR	0.03	NR	0.03	10
10	NR	NR	NR	NR	8
11	470	0.04	NR	0.04	12
12	360	0.05	NR	0.05	7
13	990	0.05	NR	0.05	10
14	260	0.05	NR	0.05	11
15	210	0.05	NR	0.05	35
16	0	0.06	NR	0.06	NA
L 1	50	0.20	620	3.0	NA
2	420	0.20	620	0.40	35
3	520	0.50	7700	5.0	35
4	230	0.50	5100	1.50	50
5	2000	0.35	2000	0.75	55
6	420	0.10	570	0.18	35
7	310	0.09	NR	0.09	26
8	420	0.06	NR	0.06	14
9	260	0.06	NR	0.06	13
10	160	0.04	NR	0.04	11
11	210	0.04	NR	0.04	9
12	570	0.04	NR	0.05	7
13	780	0.03	NR	0.03	8
14	420	0.03	NR	0.03	12
15	360	0.03	NR	0.05	22
16	210	0.05	NR	0.10	NA
M 2	0	0.09	NR	0.09	NA
3	NR	0.04	NR	0.04	NA
4	NR	0.06	NR	0.06	NA
5	NR	0.06	NR	0.06	NA
6	50	0.06	NR	0.06	NA
7	0	0.03	NR	0.03	NA
8	0	0.03	NR	0.03	NA
9	0	0.03	NR	0.03	NA
10	0	0.03	NR	0.03	NA
11	0	NR	NR	0.03	NA

Table 24. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, first level, including floor and lower wall surfaces

Survey block shown in fig. 13	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
12	50	0.03	NR	0.03	NA
13	50	0.03	NR	0.03	NA
14	0	0.04	NR	0.04	NA
15	0	0.04	NR	0.04	NA
N 2	50	0.06	NR	0.10	NA
3	360	0.06	NR	0.06	NA
4	0	0.06	NR	0.06	NA
5	210	0.07	NR	0.07	NA
6	50	0.07	NR	0.10	NA
7	160	0.07	NR	0.18	NA
8	160	0.06	NR	0.06	NA
9	160	0.05	NR	0.05	NA
10	160	0.04	NR	0.04	NA
11	50	0.03	NR	0.05	NA
12	0	0.03	NR	0.03	NA
13	0	0.03	NR	0.05	NA
14	100	0.03	NR	0.05	NA
15	50	0.04	NR	0.05	NA
O 1	100	0.05	NR	0.05	NA
2	520	0.13	360	0.80	35
3	210	0.30	470	0.35	50
4	990	0.25	1200	0.75	60
5	2200	0.33	2200	0.33	80
6	830	0.40	1600	0.70	100
7	1090	0.33	1500	0.50	70
8	620	0.05	NR	0.08	30
9	1100	0.04	NR	0.04	11
10	880	0.04	NR	0.04	11
11	980	0.05	NR	0.05	12
12	620	0.04	NR	0.04	13
13	670	0.08	NR	0.13	11
14	310	0.08	NR	0.08	14
15	310	0.05	NR	0.05	29
16	160	0.08	NR	0.08	NA
P 1	50	0.05	NR	0.05	NA
2	990	0.28	1000	0.25	45
3	470	0.18	620	0.75	60
4	1500	0.20	1700	0.20	65

Table 24. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, first level, including floor and low wall surfaces

Survey block shown in Fig. 13	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
5	1400	1.25	2600	6.0	90
6	1500	0.40	1300	0.60	220
7	930	0.50	940	0.50	130
8	570	0.05	NR	0.10	25
9	730	0.07	NR	0.10	13
10	1200	0.05	NR	0.05	12
11	420	0.08	NR	0.08	11
12	160	0.07	NR	0.07	13
13	360	0.04	NR	0.04	12
14	160	0.07	NR	0.07	16
15	360	0.06	NR	0.06	22
16	100	0.04	NR	0.04	NA
Q 1	100	0.05	NR	0.05	NA
2	360	0.30	830	0.20	50
3	420	0.10	830	0.20	60
4	310	0.25	360	0.30	75
5	260	0.15	1100	4.0	95
6	990	1.0	3000	1.25	310
7	2000	0.40	940	0.60	220
8	150	0.05	NR	0.05	35
9	1100	0.05	NR	0.05	22
10	2000	0.05	NR	0.05	16
11	1200	0.04	NR	0.04	13
12	830	0.05	NR	0.05	20
13	310	0.05	NR	0.05	18
14	210	0.05	NR	0.05	18
15	260	0.05	NR	0.05	20
16	420	0.05	NR	0.05	NA
R 1	50	0.05	NR	0.05	NA
2	360	0.30	880	0.40	65
3	730	0.30	830	0.40	80
4	360	0.40	520	0.80	70
5	680	4.0	1200	5.0	80
6	1000	0.5	470	0.25	220
7	680	0.4	780	0.50	160
8	NR	NR	NR	NR	NR
9	NR	NR	NR	NR	NR
10	NR	NR	NR	NR	NR
11	NR	NR	NR	NR	NR

Table 24. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, first level, including floor and lower wall surfaces

Survey block shown in Fig. 13	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
12	160	0.15	NR	0.15	26
13	310	0.15	NR	0.15	29
14	620	0.10	NR	0.15	25
15	420	0.15	990	0.35	25
16	310	0.06	NR	0.06	NA
S 1	310	0.05	NR	0.10	NA
2	160	0.15	160	0.25	80
3	310	0.15	210	0.23	85
4	360	0.18	260	0.28	90
5	360	0.23	420	0.28	120
6	310	0.35	470	0.50	150
7	260	0.25	260	0.25	220
8	260	0.05	NR	0.05	40
9	470	0.30	470	0.30	55
10	360	0.15	620	0.25	26
11	260	0.10	570	0.30	25
12	420	0.05	NR	0.10	25
13	260	0.06	NR	0.10	25
14	470	0.08	NR	0.13	22
15	680	0.06	NR	NR	20
16	160	0.08	NR	NR	NA
T 1	360	0.10	NR	0.10	NA
2	360	0.15	NR	0.15	65
3	420	0.08	NR	0.13	40
4	570	0.15	260	0.35	35
5	680	0.15	780	0.23	65
6	470	0.22	NR	0.15	150
7	620	0.19	620	0.23	95
8	210	0.15	NR	NR	20
9	360	0.15	730	0.50	45
10	570	0.08	NR	0.15	26
11	360	0.10	NR	NR	25
12	160	0.08	NR	0.08	35
13	360	0.08	NR	0.08	29
14	260	0.06	NR	0.06	26
15	990	0.08	NR	0.08	35
16	100	0.06	NR	NR	NA
J 2	260	0.10	NR	0.10	NA
3	310	0.08	NR	0.08	NA

Table 24. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, first level, including floor and lower wall surfaces

Survey block shown in Fig. 13	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation lev 1 m above flo (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
4	210	0.08	NR ^a	NR	NA ^b
5	260	0.10	NR	0.10	NA
6	260	0.10	NR	0.10	NA
7	310	0.10	NR	0.10	NA
8	50	0.06	NR	0.06	NA
9	100	0.06	NR	0.04	NA
10	210	0.04	NR	0.06	NA
11	100	0.05	NR	0.10	NA
12	100	0.05	NR	0.05	NA
13	310	0.08	NR	0.08	NA
14	210	0.06	NR	0.10	NA
15	100	0.06	NR	0.10	NA

^aNR - No reading

^bNA - Not applicable to walls

Table 25. Alpha and beta-gamma contamination on
overhead surfaces in Building 10,
first level

Survey block shown in Fig. 13	Surface	Horizontal surface		Vertical surface	
		Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
V9 A 1	beam	50	0.03	50	0.04
01 3	wall	NA ^a	NA	160	0.06
11	wall	50	0.03	50	0.02
B 3	beam	50	0.03	50	0.04
4	ceiling	50	0.03	NR ^b	NR
6	beam	160	0.04	0	0.03
8	ceiling	50	0.03	NA	NA
10	beam	100	0.03	50	0.02
12	ceiling	0	0.02	NA	NA
C 1	wall	NA	NA	0	0.04
2	beam	50	0.03	0	0.03
3	beam	0	0.03	0	0.02
4	beam	310	0.05	0	0.02
6	ceiling	50	0.03	NA	NA
8	beam	210	0.02	0	0.02
10	ceiling	50	0.03	NA	NA
12	beam	160	0.01	50	0.03
14	ceiling	50	0.03	NR	0.03
14	beam	160	0.03	50	0.03
E12	ceiling	160	0.02	NR	0.02
12	beam	160	0.02	0	0.02
F 2	ceiling	0	NR	NA	NA
2	beam	100	0.02	0	0.02
13	ceiling	0	0.02	NR	0.02
13	beam	0	0.02	0	0.02
G 4	ceiling	0	0.03	NR	0.03
4	beam	260	0.03	100	0.04
14	ceiling	0	0.04	NR	0.04
14	beam	100	0.04	0	0.04
H 5	beam	100	0.04	0	0.04
5	ceiling	0	0.04	NR	0.04
13	ceiling	100	0.03	NR	0.02
13	beam	50	0.02	0	0.02
I 2	ceiling	50	0.04	NR	0.04
2	beam	0	0.04	100	0.04
4	ceiling	0	0.04	NR	0.04
4	beam	160	0.04	100	0.04
5	ceiling	50	0.04	0	0.04
5	beam	100	0.04	50	0.04
J 3	ceiling	310	0.04	NR	0.04
3	beam	260	0.04	50	0.04
4	ceiling	0	0.06	0	0.06
4	beam	360	0.06	160	0.06

Table 25. (cont.) Alpha and beta-gamma contamination
on overhead surfaces in Building 10,
first level

Survey block shown in Fig. 13	Surface	Horizontal surface		Vertical surface	
		Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
14	ceiling	100	0.03	NR	0.03
14	beam	100	0.03	100	0.03
K 5	ceiling	0	0.25	NR	0.25
5	beam	100	0.05	50	0.05
13	ceiling	50	0.03	NR	0.03
13	beam	160	0.03	100	0.03
14	ceiling	0	0.04	0	0.04
14	beam	0	0.04	0	0.04
L 2	ceiling	50	0.04	0	0.04
2	beam	160	0.04	50	0.13
O 2	ceiling	100	0.04	NA	NA
2	beam	420	0.08	160	0.03
6	ceiling	100	0.13	NA	NA
6	beam	420	0.13	100	0.13
10	ceiling	100	0.02	NA	NA
10	beam	100	0.02	100	0.02
13	ceiling	100	0.02	NA	NA
13	beam	160	0.04	100	0.02
15	ceiling	100	0.03	NA	NA
15	beam	260	0.03	100	0.03
Q 7	ceiling	310	0.15	NA	NA
7	beam	310	0.23	160	0.15
13	ceiling	NR	0.02	NA	NA
13	beam	260	0.02	160	0.02
R 2	ceiling	50	0.08	NA	NA
2	beam	160	0.05	160	0.06
5	ceiling	100	0.15	NA	NA
5	beam	260	0.40	210	0.25

^aNA = not applicable.

^bNR = no reading.

Table 26. Alpha and beta-gamma contamination on interior dividing walls in Building 10, first level

Survey block shown in Fig. 13	Directly measured contamination at center of block	
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
Wall between blocks Q and R		
Q 8	360	0.05
9	0	0.05
10	210	0.04
12	260	0.04
13	210	0.04
14	570	0.03
15	260	0.04
R 8	0	0.12
9	210	0.08
10	50	0.12
11	0	0.05
12	50	0.03
13	0	0.06 ^a
14	250	NR ^a
15	0	NR
Wall between blocks R and S (office area)		
S 2	100	0.06
3	210	0.08
4	160	0.15
5	160	0.13
6	100	0.25
7	100	0.15

^aNR = No reading.

Table 27. Alpha, beta-gamma and external gamma radiation levels in Building 10, second level, including floor and lower wall surfaces

Survey block shown in Fig. 15	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above surface (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 4	0	0.03	NR ^a	0.03	NA ^b
5	0	0.03	NR	0.05	NA
6	0	0.03	NR	0.05	NA
7	0	0.05	NR	0.05	NA
8	0	NR	NR	NR	NA
9	0	NR	NR	NR	NA
10	0	0.04	NR	0.04	NA
11	0	0.04	NR	0.04	NA
12	50	0.03	NR	0.03	NA
13	0	0.02	NR	0.03	NA
14	0	0.03	NR	0.03	NA
15	50	0.05	NR	0.05	NA
B 4	160	0.08	NR	0.10	20
5	520	0.08	NR	0.08	18
6	210	0.06	NR	0.10	20
7	470	0.13	NR	0.18	18
8	100	NR	NR	NR	NR
9	0	NR	NR	NR	NR
10	160	0.05	NR	NR	NR
11	470	0.05	NR	NR	11
12	830	0.05	NR	0.05	16
13	310	0.08	NR	0.08	16
14	NR	NR	NR	NR	18
15	NR	NR	NR	NR	20
16	0	0.03	NR	0.07	NA
C 4	570	0.05	NR	0.05	18
5	570	0.07	NR	0.07	16
6	280	0.06	NR	0.12	16
7	310	0.10	NR	0.10	16
8	620	0.06	NR	NR	13
9	2800	0.06	NR	NR	16
10	680	0.05	NR	NR	13
11	1300	0.04	NR	NR	13
12	940	0.04	NR	0.04	13
13	1000	0.04	NR	0.04	11
14	NR	NR	NR	NR	13
15	NR	NR	NR	NR	20

^aNR = No reading.

^bNA = Not applicable to walls.

Table 27. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, second level, including floor and lower wall surface

Survey block shown in Fig. 15	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above surface (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
16	100	0.06	NR	0.06	NA
D12	260	0.05	NR	0.05	16
13	210	0.05	NR	0.08	16
14	160	0.03	NR	NR	16
15	470	0.03	NR	NR	16
16	0	0.03	NR	0.03	NA
E12	160	0.05	NR	0.10	16
13	210	0.07	NR	0.07	16
14	520	0.03	NR	NR	16
15	1000	0.03	NR	NR	16
16	0	0.03	NR	0.03	NA
F 1	50	0.06	NR	0.06	NA
2	50	0.03	NR	0.04	14
3	260	0.03	NR	0.05	12
4	570	0.08	NR	0.25	14
5	520	0.05	NR	0.08	14
5W ^c	0	0.04	NR	0.04	NA
12	620	0.05	NR	0.05	16
13	100	0.07	NR	0.07	16
G 1	100	0.05	NR	0.05	NA
2	210	0.03	NR	0.05	13
3	160	0.03	NR	0.05	11
4	680	0.08	NR	0.10	13
5	570	0.08	NR	0.10	10
5W	50	0.04	NR	0.04	NA
12	620	0.05	NR	0.05	16
13	260	0.04	NR	0.04	16
H 1	0	0.05	NR	0.05	NA
2	100	0.05	NR	0.05	12
3	100	0.04	NR	0.05	13
4	940	0.08	NR	0.10	13
5	470	0.10	NR	0.10	14
5W	0	0.04	NR	0.04	NA
12	470	0.05	NR	NR	NA
13	160	0.07	NR	0.07	16
I 1	100	0.09	NR	0.05	NA
2	50	0.03	NR	0.05	12
3	50	0.04	NR	0.05	12

^cW = interior wall surface.

Table 27. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, second level, including floor and lower wall surface

Survey block shown in Fig. 15	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above surface ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
4	160	0.04	NR	0.10	13
5	730	0.10	9600	0.25	13
5W	0	0.04	NR	0.04	NA
12	260	0.04	NR	0.08	16
13	310	0.04	NR	0.04	16
J 1	100	0.05	NR	NR	NA
2	100	0.04	NR	0.05	11
3	50	0.03	NR	0.05	12
4	260	0.07	NR	0.11	12
5	680	0.5	NR	0.10	13
5W	0	0.04	NR	0.04	NA
12	360	0.03	NR	0.03	16
13	150	0.06	NR	0.06	16
K 1	50	0.05	NR	0.05	NA
2	420	0.09	NR	0.09	14
3	310	0.23	1200	0.31	13
4	160	0.10	NR	0.15	14
5	160	0.08	NR	0.13	14
5W	50	0.04	NR	0.04	NA
12	260	0.05	NR	0.05	16
13	100	0.05	NR	0.05	16
L 1	100	0.05	NR	0.05	NA
2	2300	0.40	3600	5.5	17
3	940	0.15	520	1.9	16
4	470	0.05	NR	0.16	13
5	520	0.13	NR	0.23	13
5W	0	0.04	NR	0.04	NA
12	420	0.05	NR	0.05	16
13	50	0.05	NR	0.05	16
M 2	50	0.05	NR	0.05	NA
3	50	0.05	NR	0.05	NA
4	160	0.05	NR	0.05	NA
5	0	0.05	NR	0.05	NA
12	50	0.03	NR	0.03	NA
13	0	0.04	NR	0.04	NA
N 2	100	0.02	NR	0.02	NA
3	50	0.05	NR	0.05	NA
4	50	0.02	NR	0.02	NA
5	50	0.02	NR	0.02	NA
6	0	0.03	NR	0.03	NA

Table 27. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, second level, including floor and lower wall surface

Floor block in	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above surface ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
7	0	0.03	NR	0.03	NA
8	100	0.03	NR	0.03	NA
9	50	0.03	NR	0.03	NA
10	50	0.03	NR	0.03	NA
11	50	0.03	NR	0.03	NA
12	0	0.03	NR	0.03	NA
13	0	0.03	NR	0.03	NA
14	0	0.03	NR	0.03	NA
15	50	0.03	NR	0.03	NA
	50	0.10	100	0.35	NA
	620	0.18	420	0.23	14
3	620	0.26	470	0.55	16
4	1510	1.0	1200	1.50	22
5	730	0.75	1700	1.25	22
6	680	0.23	990	0.75	26
7	360	0.25	470	0.35	25
8	210	0.03	NR	0.05	13
9	210	0.03	NR	0.03	12
10	0	0.04	NR	0.04	12
11	1200	0.04	NR	0.07	10
12	210	0.05	NR	0.06	14
13	50	0.04	NR	0.06	18
14	260	0.03	NR	0.06	18
15	50	0.03	NR	0.03	22
16	50	0.06	NR	0.06	NA
P 1	50	0.05	100	0.50	NA
2	1100	0.18	1100	2.50	20
3	100	0.20	100	1.75	20
4	620	0.25	620	1.0	29
5	780	0.30	780	1.25	30
6	830	0.40	830	0.75	35
7	680	0.25	680	1.0	35
8	100	0.03	NR	0.50	16
9	210	0.04	NR	0.33	20
10	210	0.03	NR	0.05	13
	160	0.05	NR	0.08	13
12	1600	0.05	1600	0.35	20
13	360	0.05	NR	0.08	20
14	210	0.05	NR	0.05	22
15	470	0.03	NR	0.03	25

Table 27. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 10, second level, including floor and lower wall surface

Survey block shown in Fig. 15	Directly measured contamination at center		Directly measured contamination of block gamma point		External gamma radiation level 1 m above surface (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
16	160	0.04	NR	0.10	NA
Q 1	310	0.10	210	0.40	NA
2	780	0.15	1000	0.30	20
3	310	0.23	NR	NR	18
4	1100	0.20	620	0.50	25
5	1300	1.25	2000	1.00	35
6	730	0.30	730	0.30	45
7	680	0.18	780	0.23	35
8	0	0.04	NR	0.04	13
9	210	0.04	NR	0.04	13
10	100	0.04	NR	0.04	13
11	100	0.04	NR	0.04	16
R 1	160	0.09	210	0.23	NA
2	1200	0.13	470	0.30	20
3	310	0.18	NR	NR	13
4	100	0.50	730	0.50	22
5	520	0.68	880	0.50	35
6	210	0.16	570	0.75	45
7	420	0.20	730	0.50	40
8	260	0.15	360	0.23	30
9	260	0.10	160	0.23	25
10	310	0.15	310	0.15	26
11	260	0.18	260	0.19	26
S 1	50	0.08	160	0.50	NA
2	2800	0.20	2100	3.8	22
3	NR	NR	NR	NR	22
4	520	0.40	490	0.60	18
5	730	0.30	680	0.60	26
6	620	0.23	620	0.23	29
7	1000	0.20	620	0.50	30
T 1	160	0.10	420	0.20	NA
2	4100	0.30	4100	0.30	22
3	1200	0.50	620	0.50	22
4	210	0.15	730	0.50	20
5	620	0.40	680	5.0	26
6	260	0.25	260	0.25	26
7	680	0.35	680	0.35	35
U 2	160	0.10	NR	0.10	NA
3	100	0.08	100	0.75	NA
4	160	0.12	880	1.2	NA
5	470	0.25	2000	0.60	NA
6	50	0.13	NR	0.13	NA
7	370	0.25	50	1.0	NA

Table 28. Alpha and beta-gamma contamination on overhead surfaces in Building 10, second level

Survey block shown in fig. 15	Surface	Horizontal surface		Vertical surface	
		Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
A 6	wall	NR ^a	NR	0	0.03
15	wall and beam	50	0.03	0	0.03
B 4	beam	100	0.04	50	0.03
7	beam	50	0.06	0	0.06
12	beam	50	0.04	0	0.04
14	beam	100	0.03	0	0.03
15	beam	50	0.03	0	0.03
C 4	ceiling	50	0.03	0	0.02
6	beam	100	0.03	50	0.03
8	ceiling	0	0.03	0	0.03
9	beam	50	0.02	0	0.04
12	ceiling	0	0.03	0	0.03
13	beam	100	0.02	50	0.02
F 1	wall	NR	NR	100 ^b	0.03
2	ceiling	50	0.03	NA ^b	NA
2	beam	100	0.03	0	0.03
G 4	ceiling	0	0.04	NA	NA
4	beam	160	0.08	0	0.04
H 3	ceiling	0	0.03	NA	NA
3	beam	420	0.03	50	0.03
I 4	ceiling	50	0.03	NA	NA
4	beam	100	0.03	50	0.03
13	ceiling	0	0.03	NA	0.03
J 1	wall	NR	NR	260	0.05
K 1	window ledge	1100	0.30	NA	NA
2	ceiling	0	0.03	NA	NA
2	beam	160	0.03	50	0.03
4	ceiling	0	0.03	NA	NA
4	beam	0	0.03	0	0.03
13	beam	50	0.04	50	0.04
L 1	window ledge	260	0.50	NA	NA
1	wall	NA	NA	0	0.03
2	ceiling	0	0.05	NA	NA
2	beam	160	0.10	0	0.10
4	ceiling	50	0.04	NA	NA
4	beam	260	0.07	50	0.07
5	ceiling	100	0.03	NA	NA
5	beam	210	0.08	50	0.03
6	ceiling	0	0.03	NA	NA
6	beam	50	0.05	50	0.05
7	ceiling	260	0.04	NA	NA
7	beam	160	0.06	50	0.04
9	ceiling	50	0.03	NA	NA
9	beam	50	0.03	50	0.03

^a NR = No reading.^b NA = Not applicable to ceiling.

Table 28. (cont.) Alpha and beta-gamma contamination on overhead surfaces in Building 10, second level

Survey block shown in Fig. 15	Surface	Horizontal surface		Vertical surface	
		Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
12	ceiling	100	0.05	NA	NA
12	beam	100	0.03	50	0.03
13	ceiling	50	0.03	NA	NA
13	beam	50	0.02	0	0.02
P 5	ceiling	100	0.04	NA	NA
5	beam	210	0.04	100	0.05
7	ceiling	50	0.04	NA	NA
7	beam	50	0.04	50	0.04
9	ceiling	100	0.03	NA	NA
9	beam	160	0.03	0	0.03
11	ceiling	50	0.03	NA	NA
11	beam	100	0.03	100	0.03
13	ceiling	100	0.03	NA	NA
13	beam	160	0.03	100	0.03
15	ceiling	160	0.05	NA	NA
15	beam	160	0.03	160	0.03
Q 2	ceiling	100	0.04	NA	NA
2	beam	260	0.11	0	0.07
R 4	ceiling	50	0.06	NA	NA
4	beam	160	0.18	50	0.08
6	ceiling	160	0.06	NA	NA
6	beam	210	0.07	100	0.06
S 2	ceiling	0	0.05	NA	NA
2	beam	160	0.05	50	0.05
6	wall, small room	NA	NA	160	0.10
6	ceiling	0	0.04	NA	NA
6	beam	210	0.08	0	0.04
T 2	ceiling	0	0.04	NA	NA
2	beam	210	0.10	100	0.05
4	ceiling	4300	0.80	NA	NA
4	beam	520	3.3	260	0.40
4	wall	NA	NA	210	0.30

Table 29. Alpha, beta-gamma and external gamma radiation levels in Building 11, including floor, and lower wall surfaces

Survey block shown in Fig. 17	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	340	0.05	330	0.08	NA ^a
3	310	0.05	330	0.08	NA
4	290	0.04	260	0.08	NA
5	1200	0.05	260	0.08	NA
6	340	0.04	300	0.10	NA
7	340	0.04	310	0.10	NA
8	290	0.04	260	0.10	NA
9	260	0.03	250	0.08	NA
10	700	0.05	580	0.08	NA
11	680	0.05	240	0.08	NA
12	260	0.05	200	0.09	NA
13	940	0.04	510	0.08	NA
14	230	0.04	140	0.08	NA
15	550	0.04	500	0.08	NA
16	290	0.04	290	0.10	NA
B 1	210	0.05	620	0.10	NA
2	1100	0.10	650	0.90	27
3	1100	0.10	NR ^b	0.10	27
4	1100	0.10	NR	0.10	27
5	1400	0.10	NR	0.10	27
6	2200	0.10	1100	0.20	22
7	1500	0.10	NR	0.10	27
8	620	0.10	NR	0.10	27
9	490	0.08	NR	0.08	22
10	520	0.05	NR	0.05	22
11	470	0.08	NR	0.08	22
12	1200	0.05	NR	0.05	22
13	1200	0.05	NR	0.05	22
14	730	0.05	NR	0.05	22
15	940	0.05	NR	0.05	22
16	1000	0.10	NR	0.05	27
17	360	0.03	NR	0.10	NA
C 1	470	0.05	NR	0.05	NA
2	420	0.08	1100	0.10	22
3	620	0.08	720	0.10	24
4	360	0.05	NR	0.08	22
5	570	0.08	NR	0.05	22
6	880	0.08	NR	0.08	22
7	310	0.08	NR	0.08	22
8	360	0.05	NR	0.05	22
9	570	0.05	NR	0.05	22
10	260	0.05	NR	0.05	18

Table 29. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 11, including floor and lower wall surfaces

Survey block shown in Fig. 17	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
11	310	0.05	NR	0.05	18
12	160	0.08	NR	0.08	18
13	570	0.04	NR	0.04	18
14	470	0.05	310	0.10	16
15	420	0.05	NR	0.05	16
16	720	0.05	NR	0.05	16
17	210	0.05	NR	0.05	NA
D 1	310	0.05	NR	0.04	NA
2	1000	0.05	NR	0.50	22
3	880	0.05	NR	0.05	22
4	830	0.05	NR	0.05	22
6	830	0.05	NR	0.05	22
7	420	0.04	NR	0.04	22
8	570	0.08	NR	0.08	22
9	1200	0.04	NR	0.04	18
10	880	0.05	NR	0.05	18
11	520	0.05	NR	0.05	18
12	310	0.05	NR	0.05	18
13	520	0.05	NR	0.05	18
14	680	0.05	NR	0.05	18
15	550	0.05	NR	0.05	18
16	990	0.05	680	0.10	18
17	310	0.07	NR	0.07	NA
E 1	310	0.04	NR	0.04	NA
2	520	0.05	NR	0.05	20
3	470	0.05	NR	0.05	22
4	470	0.05	NR	0.05	22
5	420	0.05	NR	0.05	22
6	470	0.08	NR	0.08	24
7	470	0.05	NR	0.05	22
8	210	0.05	NR	0.05	16
9	570	0.05	NR	0.05	18
10	260	0.05	NR	0.05	14
11	310	0.03	NR	0.03	14
12	420	0.05	NR	0.05	16
13	370	0.05	NR	0.05	14
14	360	0.05	730	0.10	14
15	210	0.05	NR	0.05	14
16	570	0.05	NR	0.05	14
17	420	0.03	NR	0.03	NA

Table 29. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 11, including floor and lower wall surfaces

Survey block shown in Fig. 17	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
F 1	160	0.04	NR	0.04	NA
2	420	0.05	NR	0.05	27
3	1800	0.08	NR	0.08	35
4	310	0.05	NR	0.05	35
5	620	0.05	NR	0.05	35
6	310	0.05	NR	0.05	35
7	260	0.08	NR	0.08	29
8	420	0.05	NR	0.05	27
9	1000	0.08	NR	0.08	30
10	520	0.08	NR	0.08	27
11	620	0.08	NR	0.08	27
12	160	0.08	NR	0.08	27
13	310	0.05	NR	0.05	27
14	260	0.05	NR	0.05	24
15	310	0.05	NR	0.05	27
16	780	0.05	NR	0.05	27
17	160	0.05	NR	0.05	NA
G 1	570	0.03	NR	0.03	NA
2	NR	NR	NR	NR	NA
3	570	0.05	NR	0.05	33
4	830	0.08	NR	0.08	33
5	570	0.05	NR	0.05	27
6	570	0.05	NR	0.05	27
7	620	0.05	NR	0.05	27
8	470	0.05	NR	0.05	22
9	570	0.05	NR	0.05	22
10	830	0.04	NR	0.04	22
11	880	0.08	NR	0.08	22
12	520	0.05	NR	0.05	27
13	830	0.05	NR	0.05	27
14	880	0.05	730	0.25	27
15	780	0.05	NR	0.05	27
16	680	0.08	NR	0.08	27
17	360	0.07	NR	0.07	NA
H 2	680	0.05	NR	0.05	NA
3	520	0.06	NR	0.06	NA
4	260	0.03	NR	0.03	NA
5	680	0.07	NR	0.07	NA
6	210	0.04	NR	0.04	NA

Table 29. (cont.) Alpha, beta-gamma and external gamma radiation levels in Building 11, including floor and lower wall surfaces

Survey block shown in Fig. 17	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
7	360	0.06	NR	0.06	NA
8	420	0.07	NR	0.07	NA
9	310	0.04	NR	0.04	NA
10	210	0.05	NR	0.05	NA
11	210	0.04	NR	0.04	NA
12	360	0.04	NR	0.04	NA
13	210	0.04	NR	0.04	NA
14	360	0.06	NR	0.06	NA
15	730	0.05	NR	0.05	NA
16	420	0.05	NR	0.05	NA

^aNA = Not applicable.

^bNR = No reading.

Table 30. Alpha and beta-gamma contamination on
Building 11 walls 15 ft. above floor
level

Block No. shown in Fig. 17	Directly measured contamination (single points)	
	Alpha	Beta-gamma
	(dpm/100 cm ²)	dose rate at 1 cm (mrad/hr)
A 3	160	0.04
4	100	0.04
9	210	0.05
10	210	0.05
14	160	0.09
15	160	0.09
C17	160	0.05
D17	160	0.05
E17	210	0.05
F 1	210	0.08
17	210	0.05
G 1	160	0.08
17	160	0.08
H 2	180	0.08
5	130	0.04
7	100	0.04
8	210	0.03
11	130	0.03
12	210	0.03
13	160	0.03
14	160	0.03
15	260	0.06

Table 31. Radioactivity in drains in Building 11

Drain No. (see Fig. 17)	Direct alpha measurement 10 cm above drain (dpm/100 cm ²)	Direct gamma measure- ment in drains within 15 cm of surface (μR/hr)	Concentration of nuclides in drain sediment (pCi/g)		
			²²⁶ Ra	²³⁸ U	²³⁰ Th
1	1000	90	16	14	91
2	160	220 ^a	310	91	920
3	50	45	No sediment found		
4	210	220	No sediment found		
5	50	220	No sediment found		
6	Plugged - No measurements made				

^a measured at surface of drain.

Table 32. Alpha, beta-gamma and external gamma radiation levels in Building 15, including floor and lower wall surfaces

Survey block shown in Fig. 18	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	310	0.25	NR ^a	NR	NA ^b
3	470	0.16	NR	NR	NA
4	680	0.13	NR	NR	NA
5	1400	0.18	NR	NR	NA
6	1000	0.14	NR	NR	NA
7	880	0.15	NR	NR	NA
B 1	Door - no measurements				
2	570	0.05	360	0.23	70
3	310	0.05	NR	0.08	60
4	260	0.07	NR	0.12	60
5	360	0.08	NR	0.10	60
6	420	0.05	7000	0.20	60
7	570	0.07	5000	0.40	100
8	100	0.10	NR	NR	NA
C 1	Door - no measurements				
2	260	0.07	NR	NR	80
3	100	0.09	NR	0.10	60
4	420	0.05	NR	0.10	55
5	470	0.05	NR	0.11	55
6	470	0.05	NR	0.14	55
7	570	0.10	1200	0.30	80
8	100	0.15	NR	NR	NA
D 2	50	0.05	NR	NR	NA
3	420	0.05	NR	NR	NA
4	990	0.05	NR	NR	NA
5	470	0.05	NR	NR	NA
6	830	0.07	NR	NR	NA
7	50	0.10	NR	NR	NA

^aNR = No reading.

^bNA = Not applicable to walls.

Table 33. Alpha and beta-gamma contamination
on overhead surfaces in Building 15

Survey block shown in Fig. 18	Surface	Horizontal surface		Vertical surface	
		Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
A 5	beam	570 ^b	0.10	NR ^a	NR
5	wall	NA	NA	100	0.10
B 1	wall	NA	NA	210	0.08
2	beam	730	0.08	0	0.08
2	ceiling	0	0.10	NA	NA
3	beam	100	0.09	160	0.10
3	ceiling	50	0.09	NA	NA
5	beam	310	0.08	50	0.08
5	ceiling	50	0.08	NA	NA
7	beam	0	0.13	680	0.11
7	ceiling	0	0.13	NA	NA
C 1	wall	NA	NA	210	0.08
2	beam	1400	0.08	50	0.08
2	ceiling	50	0.10	NA	NA
3	beam	940	0.08	360	0.08
3	ceiling	50	0.08	NA	NA
5	beam	1000	0.11	100	0.06
5	ceiling	50	0.06	NA	NA
7	beam	100	0.13	2300	0.10
7	ceiling	50	0.13	NA	NA
8	wall	1600	0.18	100	0.10
D 4	beam	1100	0.10	NR	NR
4	wall	NA	NA	310	0.10

^aNR = No reading.

^bNA = Not applicable to walls or to ceiling.

Table 34. Directly measured alpha, beta-gamma, and external gamma radiation levels and transferable surface contamination in Building 16, including floor and lower wall surfaces.

Survey block shown in Fig. 19	Directly measured contamination at center of block		Directly measured contamination at maximum beta-gamma point		Transferable contamination shown by random smears		External gamma radiation level at 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta (dpm/100 cm^2)	
A 2	100	0.05	NR ^a	NR	< 20	< 100	NA ^b
3	470	0.03	NR	NR	< 20	< 100	NA
4	210	0.03	NR	NR	< 20	< 100	NA
5	730	0.03	NR	NR	< 20	< 100	NA
6	50	0.15	NR	NR	< 20	< 100	NA
7	420	0.10	NR	NR	< 20	< 100	NA
8	50	0.05	NR	NR	< 20	< 100	NA
9	570	0.10	NR	NR	< 20	< 100	NA
B 1	260	0.05	NR	NR	< 20	< 100	NA
2	420	0.05	NR	NR	< 20	< 100	24
3	730	0.03	NR	NR	30	< 100	35
4	310	0.03	NR	NR	25	< 100	30
5	420	0.03	NR	NR	< 20	< 100	35
6	7100	0.20	40,000	0.65	< 20	< 100	110
7	680	0.15	NR	NR	40	< 100	55
8	470	0.10	NR	NR	35	< 100	40
9	310	0.10	730	1.3	< 20	< 100	55
10	470	0.10	NR	NR	NR	NR	NA
C 1	50	0.05	NR	NR	< 20	< 100	NA
2	310	0.05	NR	NR	80	< 100	24
3	360	0.03	NR	NR	< 20	< 100	27
4	260	0.05	NR	NR	60	< 100	40
5	780	0.03	NR	NR	25	< 100	40
6	260	0.10	NR	NR	140	< 100	50
7	780	0.18	NR	NR	< 20	< 150	50

^aNR = No reading.

^bNA = Not applicable to walls.

Table 34. (cont.) Directly measured alpha, beta-gamma and external gamma radiation levels and transferable surface contamination in Building 16, including floor and lower wall surfaces

Survey block shown in Fig. 19	Directly measured contamination at center of block		Directly measured contamination at maximum beta-gamma point		Transferable contamination shown by random smears		External gamma radiation level at 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta (dpm/100 cm^2)	
8	830	0.05	620	0.60	50	< 150	45
9	470	0.13	420	1.3	< 20	< 150	45
10	620	0.10	NR	NR	< 20	< 150	NA
D 1	160	0.04	NR	NR	< 20	< 100	NA
2	990	0.05	1100	0.18	< 20	< 100	35
3	830	0.05	2400	0.40	< 20	< 100	35
4	570	0.05	NR	0.13	< 20	< 100	40
5	830	0.04	NR	0.08	50	< 100	35
6	880	0.06	NR	NR	25	< 100	45
7	880	0.10	NR	0.13	< 20	< 100	50
8	730	0.08	3400	2.0	50	< 100	50
9	730	0.04	NR	1.0	< 20	< 100	35
10	100	0.25	2000	2.1	< 20	< 150	NA
E 1	310	0.05	NR	NR	25	< 100	NA
2	830	0.05	NR	NR	25	< 100	30
3	1400	0.08	NR	0.18	< 20	< 100	35
4	570	0.05	NR	0.08	< 20	< 100	45
5	570	0.06	NR	NR	< 20	< 100	40
6	420	0.05	NR	0.08	< 20	< 100	45
7	420	0.08	2700	0.60	< 20	< 100	40
8	570	0.08	1200	1.3	< 20	< 100	55
9	100	0.09	1500	0.50	< 20	< 100	NA
10	570	0.10	1000	0.40	< 20	< 100	NA
F 1	630	0.05	NR	NR	< 20	< 100	NA
2	160	0.05	NR	NR	< 20	< 100	50
3	260	0.15	NR	NR	< 20	< 100	45

Table 34. (cont.) Directly measured alpha, beta-gamma and external gamma radiation levels and transferable surface contamination in Building 16, including floor and lower wall surfaces

Survey block shown in Fig. 19	Directly measured contamination at center of block		Directly measured contamination at maximum beta-gamma point		Transferable contamination shown by random smears		External gamma radiation level at 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta (dpm/100 cm ²)	
4	220	0.10	NR	NR	< 20	< 100	55
5	260	0.18	NR	NR	< 20	< 100	40
7	470	0.10	NR	NR	50	< 100	35
8	360	0.30	1800	1.3	< 20	< 100	40
9	260	0.10	NR	NR	< 20	< 100	45
10	420	0.10	NR	NR	< 20	< 100	NA
G 2	880	0.05	NR	NR	< 20	< 100	NA
3	520	0.15	NR	NR	< 20	< 100	NA
4	2600	0.50	2600	0.50	< 20	< 100	NA
5	5400	0.50	5400	0.50	< 20	< 200	NA
6	2200	0.10	NR	NR	< 20	< 200	NA
7	470	0.08	NR	NR	< 20	< 200	NA
8	420	0.05	NR	NR	< 20	< 200	NA
9	360	0.10	NR	NR	< 20	< 200	NA

Table 35. Alpha and beta-gamma contamination and transferable surface contamination on overhead surfaces in Building 16

Survey block shown in Fig. 19	Surface	Horizontal surface		Vertical surface		Transferable surface contamination shown by random smears	
		Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta (dpm/100 cm ²)
B 6	ceiling	50	0.08	NA ^a	NR ^b	< 20	< 100
C 6	beam	50	0.10	NR	0.10	< 20	< 100
6	ceiling	100	0.08	NR	NR	< 20	< 100
D 2	beam	360	0.08	NR	0.08	35	< 100
2	ceiling	50	0.08	NR	NR	35	< 100
3	beam	NR	0.08	NR	0.08	50	< 100
3	ceiling	1600	0.08	NR	NR	50	< 100
4	beam	1400	0.08	NR	0.08	25	< 100
4	ceiling	NR	0.08	NR	NR	25	< 100
5	beam	160	0.10	NR	0.10	25	< 100
5	ceiling	50	NR	NR	NR	25	< 100
6	beam	100	0.08	NR	0.08	< 20	< 100
E 3	beam	360	0.08	210	0.08	< 20	< 100
3	ceiling	210	0.06	NR	NR	< 20	< 100
4	beam	940	0.08	100	0.08	< 20	< 100
4	ceiling	100	0.06	NR	NR	< 20	< 100
F 4	beam	1100	0.13	160	0.13	< 20	< 100
4	ceiling	0	0.10	NR	NR	< 20	< 100

^aNA = Not applicable to ceiling.

^bNR = No reading.

Table 36. Directly measured alpha and beta-gamma contamination and external gamma radiation measurements at selected survey points in the north and central sections of Building 18, first level

Survey point shown in Fig. 20	Alpha contamination level (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	External gamma radiation level at 1 m above floor (μR/hr)
1	50	0.04	NR ^a
2	0	0.04	NR
3	50	0.04	NR
4	0	0.04	NR
5	0	0.04	NR
6	0	0.04	NR
7	0	0.04	NR
8	50	0.04	NR
9	50	0.04	NR
10	50	0.04	NR
11	0	0.04	NR
12	0	0.04	NR
13	0	0.04	NR
14	50	0.04	NR
15	50	0.05	35
16	160	0.05	30
17	100	0.05	35
18	100	0.10	30
19	160	0.04	35
20	210	0.04	35
21	160	0.04	30
22	100	0.08	25
23	210	0.03	35
24	100	0.04	30
25	160	0.05	30
26	160	0.05	35
27	260	0.08	35
28	50	0.08	40

^aNR = No reading.

Table 37. Alpha, beta-gamma and external gamma radiation levels in south end of Building 18, first level, including floor and lower wall surfaces

Survey block shown in Fig. 20	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	730	0.13	2300	2.5	NA ^a
3	1400	0.08	1400 ^b	0.03	NA
4	990	0.05	NR	0.15	NA
5	160	0.05	NR	NR	NA
6	210	0.10	NR	0.15	NA
7	420	0.10	NR	0.15	NA
8	NR	NR	NR	NR	NA
9	NR	NR	NR	NR	NA
10	310	0.10	NR	0.15	NA
B 1	420	0.09	1200	0.25	NA
2	720	0.15	10,000	1.8	30
3	830	0.13	470	0.13	35
4	1500	0.18	1500	2.3	40
5	570	0.10	NR	0.10	60
6	310	0.18	830	0.30	110
7	470	0.30	1100	0.35	110
8	310	0.50	390	0.50	110
9	520	0.40	1700	0.45	60
10	260	0.13	NR	0.13	55
11	100	0.06	NR	0.06	NA
C 1	50	0.09	NR	0.16	NA
2	100	0.10	NR	0.10	35
3	260	0.08	NR	0.15	45
4	260	0.13	730	0.35	45
5	100	0.12	260	0.25	50
6	210	0.25	360	0.25	65
7	50	0.35	50	0.35	105
8	100	0.40	310	0.40	40
9	310	0.40	160	0.50	105
10	680	0.25	NR	NR	105
11	160	0.06	260	0.20	NA
D 1	470	0.08	NR	0.20	NA
2	210	0.08	NR	0.08	35
3	210	0.08	NR	0.08	40
4	260	0.18	NR	0.18	60
5	360	0.16	NR	0.16	80
6	520	0.20	360	0.25	120
7	160	0.35	NR	NR	100

^aNA = Not applicable to walls.

^bNR = No reading.

Table 37. (cont.) Alpha, beta-gamma and external gamma radiation levels in south end of Building 18, first level including floor and lower wall surfaces

Survey block shown in Fig. 20	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	
8	100	0.30	NR	NR	100
9	210	0.35	NR	NR	85
10	NR	NR	NR	NR	55
11	630	NR	NR	NR	NA
E 1	260	0.04	NR	NR	NA
2	260	0.08	NR	0.08	40
3	260	0.09	NR	0.09	40
4	310	0.13	NR	0.13	40
5	210	0.12	NR	0.12	65
6	520	0.30	310	0.30	90
7	830	0.25	1900	0.30	130
8	620	0.30	8000	0.40	120
9	680	0.13	290	0.50	100
10	NR	NR	NR	NR	55
11	260	NR	NR	NR	NA
F 1	210	0.04	NR	0.15	NA
2	260	0.06	NR	0.06	30
3	210	NR	NR	NR	30
4	160	0.10	NR	0.10	45
5	160	0.13	780	0.25	80
6	160	0.23	730	0.30	120
7	160	0.25	360	0.40	135
8	260	0.25	570	0.40	120
9	310	0.50	8000	1.0	85
10	NR	NR	NR	NR	55
11	210	NR	NR	NR	NA
G 1	160	0.05	NR	0.05	NA
2	260	0.04	NR	0.04	26
3	100	0.04	NR	0.04	26
4	260	NR	NR	0.15	30
5	260	0.10	NR	0.10	45
6	210	0.10	470	0.40	90
7	260	0.20	570	0.40	100
8	470	0.13	210	0.25	60
9	1300	0.18	NR	NR	55
10	2200	0.50	NR	NR	50
11	520	0.10	NR	NR	NA

Table 37. (cont.) Alpha, beta-gamma and external gamma radiation levels in south end of Building 18, first level including floor and lower wall surfaces

Survey block shown in Fig. 20	Directly measured contamination at center of block		Directly measured contamination of block surface at maximum beta- gamma point		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
H 1	210	0.03	NR	0.20	NA
2	570	0.08	NR	NR	27
3	470	0.15	1800	0.40	27
4	210	NR	NR	NR	29
5	1200	NR	NR	NR	45
6	570	NR	NR	NR	55
7	NR	NR	NR	NR	NR
8	1500	NR	NR	NR	60
9	NR	NR	NR	NR	29
10	1900	NR	NR	NR	NR
11	310	NR	NR	NR	NA
I 2	420	0.05	NR	NR	NA
3	210	0.07	NR	NR	NA
4	420	0.08	NR	NR	NA
5	730	NR	NR	NR	NA
6	360	NR	NR	NR	NA
7	100	NR	NR	NR	NA
8	NR	NR	NR	NR	NA
9	NR	NR	NR	NR	NA
10	NR	NR	NR	NR	NA

Table 38. Alpha and beta-gamma contamination on overhead surfaces in south end of Building 18, first level

Survey block shown in Fig. 20	Surface	Horizontal surface		Vertical surface	
		Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
B 2	beam	990	0.04	620	0.04
3	old concrete, overhead	3700	0.06	NR ^a	NR
4	beam	830	0.09	990	0.05
5	new concrete, overhead	360	0.08	NR	NR
6	beam	1000	0.21	1100	0.10
10	beam	1700	0.26	940	0.09
C 2	beam	990	0.14	620	0.04
5	beam	1300	0.29	1000	0.15
5	overhead concrete	730	0.16	NR	NR
7	beam	570	0.19	420	0.13
8	beam	2200	0.40	520	0.11
10	beam	1400	0.23	520	0.05
D 2	old concrete, overhead	680	0.06	NR	NR
3	beam	730	0.06	520	0.04
5	overhead concrete	680	0.24	NR	NR
6	beam	1300	0.19	620	0.08
7	beam	1600	0.40	680	0.14
8	beam	1800	0.28	570	0.10
E 4	old concrete, overhead	NR	NR	310	0.06
5	overhead concrete	680	0.14	NR	NR
6	beam	880	0.25	470	0.06
9	beam	1100	0.25	470	0.16
10	beam	2800	0.60	520	0.14
F 3	beam	680	0.05	160	0.05
4	beam	420	0.11	420	0.07
6	beam	1800	0.15	620	0.09
9	old wood overhead	2500	0.18	8300	0.23
10	beam	5100	0.20	520	0.09
G 4	beam	3400	0.16	620	0.05
4	old wood ceiling	6400	0.16	NR	NR
4	old wood overhead	NR	NR	5100	0.22
5	old wood overhead	5100	0.18	NR	NR
6	beam	2700	0.28	940	0.10
8	beam	1800	0.18	570	0.05
10	old wood overhead	1500	0.11	730	0.10
H 6	beam	10,000	0.60	1800	0.09
8	beam	3100	0.23	420	0.06
9	old wood overhead	5800	0.23	NR	NR
10	beam	7700	0.50	880	0.05

^aNR = No reading.

Table 39. Transferable surface contamination on overhead surfaces in south end of Building 18, first level

Block No. shown in Fig. 21	Surface	Contamination measurements (dpm/100 cm ²)	
		Alpha	Beta
A 2	wall	< 20	< 100
B 1	wall	< 20	< 100
2	ceiling	< 20	< 100
4	beam	< 20	< 100
5	ceiling	< 20	< 100
6	beam	< 20	< 100
8	beam	< 20	< 100
9	ceiling	< 20	< 100
10	beam	< 20	< 100
11	wall	< 20	< 100
C 3	ceiling	< 20	< 100
8	beam	< 20	< 100
D 5	beam	25	< 100
8	beam	25	< 100
E 3	ceiling	< 20	< 100
4	beam	35	130
6	beam	25	< 200
7	ceiling	< 20	< 200
8	ceiling	< 20	< 100
9	beam	25	< 100
F 9	wood ceiling	170	190
G10	wood ceiling	230	250
11	wall	120	< 100
H 3	wood ceiling	< 20	< 100
4	beam	400	< 150
6	wood ceiling	85	< 150
8	beam	160	< 100
9	wood ceiling	180	< 100
I 4	wall	45	< 150
6	wall	45	< 150

Table 40. Radioactivity in drains in south end of Building 18,
first level

Drain No. (see Fig. 21)	Direct alpha at 3 to 10 cm above drain (dpm/100 cm ²)	Direct gamma at drain surface (μR/hr)	Direct gamma at 25 to 60 cm below surface (μR/hr)
1	200	NR	670
2	NR	90	NR
3	NR	110	NR
4	200	35	270
5	200	35	NR
6	NR	220	NR
7	NR	NR	440

Table 41. Alpha, beta-gamma and external gamma radiation levels in south end of Building 18, second level, including floor and lower wall surfaces

Survey block shown in Fig. 21	Directly measured contamination at center of block		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
A 2	520	0.07	NA ^a
3	620	0.07	NA
4	570	0.07	NA
5	570	0.07	NA
6	570	0.07	NA
7	470	0.07	NA
8	520	0.07	NA
9	420	0.07	NA
10	310	0.07	NA
B 1	420	0.12	NA
2	1200	0.08	40
3	620	0.10	29
4	780	0.08	29
5	830	0.06	29
6	8000	0.06	29
7	1200	0.10	29
8	2500	0.07	27
9	1100	0.07	29
10	730	0.05	30
11	780	0.07	NA
C 1	360	0.13	NA
2	470	0.08	29
3	420	0.07	29
4	830	0.13	29
5	830	0.07	29
6	880	0.13	29
7	730	0.10	29
8	1600	0.05	35
9	1200	0.05	30
10	940	0.08	40
11	1200	0.07	NA
D 1	470	0.10	NA
2	420	0.05	27
3	420	0.10	27
4	730	0.10	25
5	360	0.20	27
6	1000	0.15	27
7	420	0.10	27
8	2300	0.09	29

^aNA = Not applicable to walls.

Table 41. (cont.) Alpha, beta-gamma and external gamma radiation levels in south end of Building 18, second level, including floor and lower wall surfaces

Survey block shown in Fig. 21	Directly measured contamination at center of block		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
9	1600	0.25	35
10	2700	0.40	40
11	570	0.15	NA
E 1	360	0.15	NA
2	260	0.06	29
3	470	0.05	27
4	520	0.08	27
5	620	0.14	27
6	520	0.15	35
7	730	0.11	27
8	1000	0.50	27
9	830	0.06	27
10	360	0.09	40
11	880	0.15	NA
F 1	310	0.13	NA
2	680	0.05	29
3	420	0.06	30
4	470	0.05	30
5	570	0.06	29
6	680	0.07	35
7	620	0.05	35
8	470	0.08	40
G 1	570	0.13	NA
2	940	0.05	27
3	520	0.05	29
4	520	0.03 ^b	27
5	730	NR ^b	27
6	520	0.04	30
7	680	0.03	35
8	680	0.04	40
H 1	520	0.13	NA
2	420	0.05	27
3	570	0.05	27
4	470	0.04	27
5	NR	NR	29
6	570	0.05	29
7	310	0.05	27
8	570	0.04	27
I 2	420	0.13	NA
3	520	0.13	NA

^bNR = No reading.

Table 41. (cont.) Alpha, beta-gamma and external gamma radiation levels in south end of Building 18, second level, including floor and lower wall surfaces

Survey block shown in Fig. 21	Directly measured contamination at center of block		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	
4	620	0.13	NA
5	620	0.13	NA
6	470	0.13	NA
7	830	0.13	NA
8	730	0.15	NA

^aNA = not applicable to walls.

^bNR = no reading.

Table 42. Alpha and beta-gamma contamination on overhead surfaces in Building 18; second level

Survey block shown in Fig. 22	Surface	Horizontal surface		Vertical surface	
		Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Direct alpha measurement (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)
A 2	beam	NR ^a	NR	420	NR
B 4	beam	440	0.18	310	0.08
6	beam	420	0.25	130	0.08
8	beam	NR	0.18	520	0.08
C 1	beam	NR	NR	730	NR
2	ceiling ^b	NR	NR	940	NR
2	ceiling ^c	NR	NR	570	NR
4	beam	2300	NR	570	NR
6	beam	1500	0.18	210	0.05
8	beam	360	0.25	80	0.05
10	beam	NR	NR	360	0.05
10	ceiling ^b	180	0.06	NR	NR
D 4	beam	NR	NR	2500	NR
5	beam	730	0.08	420	0.05
6	beam	470	0.08	210	0.05
E 1	beam	NR	NR	520	NR
2	ceiling ^b	NR	NR	1400	NR
4	beam	1600	0.10	570	0.04
5	beam	1800	0.09	NR	NR
8	beam	340	0.18	160	0.08
10	beam	NR	0.10	NR	0.15
11	ceiling ^c	NR	NR	310	NR
11	beam	NR	NR	360	NR
F 4	beam	2200	0.08	420	0.06
6	beam	1900	0.40	310	0.05
10	beam	NR	NR	260	0.05
10	ceiling	180	0.05	NR	NR

^aNR = No reading.^bCeiling (underside of roof) with blown insulation.^cCeiling (underside of roof) without insulation.

Table 43. Transferable surface contamination on overhead surfaces in south end of Building 18, second level

Block No. shown in Fig. 22	Surface	Transferable surface contamination shown by random smears (dpm/100 cm ²)	
		Alpha	Beta
A 2	wall	< 20	< 100
3	window ledge	20	< 100
8	wall	< 20	< 100
B 2	ceiling	< 20	< 100
4	beam	< 20	< 100
4	ceiling	< 20	< 100
9	ceiling	< 20	< 100
C 1	wall	< 20	< 100
2	ceiling	< 20	< 100
6	beam	< 20	< 100
6	ceiling	< 20	< 100
8	beam	< 20	< 100
9	ceiling	< 20	< 100
D 6	ceiling	25	< 100
6	beam	< 20	< 100
9	beam	< 20	< 100
11	wall	< 20	< 100
E 1	wall	< 20	< 100
1	window ledge	20	< 100
2	ceiling	< 20	< 100
4	beam	< 20	< 100
4	ceiling	45	< 100
F 4	beam	90	< 100
6	beam	20	< 100
6	ceiling	< 20	< 100
8	beam	< 20	< 100
8	ceiling	< 20	< 100
G 1	wall	< 20	< 100
2	ceiling	25	< 100
6	beam	35	< 100
6	ceiling	25	110
8	beam	20	< 100
8	ceiling	< 20	< 100
H 4	beam	55	130
4	ceiling	20	< 100
8	beam	< 20	< 100
8	ceiling	< 20	< 100
I 3	wall	< 20	< 100
7	wall	< 20	< 100

Table 44. Alpha, beta-gamma and external gamma radiation levels and transferable surface contamination in Building 19, including floor and lower wall surfaces

Survey block shown in Fig. 23	Directly measured contamination at center of block		Transferable contamination shown by random smears		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta (dpm/100 cm ²)	
A 2	0	0.05	< 20	< 200	NA ^a
3	50	0.04	25	< 200	NA
4	100	0.05	< 20	< 200	NA
5	50	0.04	< 20	< 200	NA
6	50	0.05	< 20	< 200	NA
7	260	0.04	< 20	< 100	NA
8	50 _b	0.05 _b	< 20	< 100	NA
9	100 _b	0.23 _b	< 20	< 100	NA
10	50	0.23	< 20	< 100	NA
11	10	0.20	< 20	< 100	NA
12	50	0.20	< 20	< 100	NA
13	10	0.20 _b	25	< 100	NA
B 1	50	0.13 _b	< 20	< 100	NA
2	470	0.09	< 20	< 100	55
3	520	0.05 _b	< 20	< 100	30
4	570	0.10 _b	< 20	< 100	45
5	310	0.10 _b	< 20	< 100	45
6	260	0.18 _b	< 20	< 100	45
7	360	0.08	< 20	< 100	45
8	570	0.08 _b	< 20	< 100	60
9	830	0.10 _b	< 20	< 100	55
10	1300	0.07 _b	< 20	< 100	55
11	1100	0.13 _b	25	< 100	55
12	1700 _b	0.40 _b	< 20	< 100	55
13	1800 _b	0.40 _b	< 20	< 100	100
14	450	0.23	< 20	< 100	NA
C 1	0	0.13 _b	< 20	< 100	NA
2	160	0.12 _b	35	< 100	65
3	420	0.08 _b	< 20	< 100	30
4	160	0.10 _b	< 20	< 100	45
5	160	0.06	< 20	< 100	45
6	0	0.09	< 20	< 100	55
7	260	0.07	< 20	< 100	60
8	310	0.08 _b	< 20	< 150	65
9	260	0.18 _b	< 20	< 150	50
10	420	0.15 _b	< 20	< 150	60
11	310	0.08	25	< 150	45

^aNA = not applicable to walls.

^bMaximum observed contamination in block.

Table 44. (cont.) Alpha, beta-gamma and external gamma radiation levels and transferable surface contamination in Building 19, including floor and lower wall surfaces

Survey block shown in Fig. 23	Directly measured contamination at center of block		Transferable contamination shown by random smears		External gamma radiation level 1 m above floor ($\mu\text{R/hr}$)
	Alpha (dpm/100 cm^2)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm^2)	Beta (dpm/100 cm^2)	
12	1400	0.25	< 20	< 150	100
13	1100	0.15	30	< 100	95
14	50	0.28	< 20	< 100	NA
D 1	50	0.10	20	< 100	NA
2	100	0.08	25	< 100	45
3	940	0.10	< 20	< 100	50
4	940	0.05	25	< 100	50
5	210	0.10	30	< 150	60
6	470	0.06	< 20	< 150	60
7	310	0.10	< 20	< 150	65
8	830	0.09	25	< 150	75
9	830	0.12	< 20	< 150	75
10	680	0.10	25	< 100	75
11	570	0.05	< 20	< 100	70
12	940	0.18 ^a	< 20	< 100	70
13	2800 ^a	0.23 ^a	< 20	< 100	100
14	1000	0.3	30	< 100	NA
E 1	160	0.05	< 20	< 100	NA
2	620	0.08	< 20	< 100	55
3	680	0.10 ^a	30	< 100	50
4	680	0.10 ^a	30	< 100	55
5	730	0.13 ^a	< 20	< 100	60
6	570	0.08	< 20	< 100	60
7	780	0.15 ^a	< 20	< 100	60
8	680	0.10	< 20	< 100	65
9	620	0.30 ^a	30	< 100	95
10	570	0.10	25	< 100	80
11	680	0.13	< 20	< 100	90
12	940	0.18 ^a	35	< 100	105
13	1900 ^a	0.23 ^a	< 20	< 100	110
14	1100	0.18 ^a	60	< 100	NA
F 1	160	0.15 ^a	35	< 100	NA
2	730	0.10 ^a	< 20	< 100	55
3	1300	0.09 ^a	< 20	< 100	40
4	570	0.10 ^a	< 20	< 100	45
5	360	0.15 ^a	< 20	< 100	45

Table 44. (cont.) Alpha, beta-gamma and external gamma radiation levels and transferable surface contamination in Building 19, including floor and lower wall surfaces

Survey block shown in Fig. 23	Directly measured contamination at center of block		Transferable contamination shown by random smears		External gamma radiation level 1 m above floor (μ R/hr)
	Alpha (dpm/100 cm ²)	Beta-gamma dose rate at 1 cm (mrad/hr)	Alpha (dpm/100 cm ²)	Beta (dpm/100 cm ²)	
6	570	0.18 ^a	< 20	< 100	65
7	620	0.13	< 20	< 100	75
8	780	0.15 ^a	< 20	< 100	80
9	900 ^a	0.30 ^a	35	< 100	95
10	880	0.12	35	< 100	85
11	780	0.18	< 20	< 100	120
12	1500 ^a	0.20 ^a	< 20	< 100	105
13	2400 ^a	0.25 ^a	< 20	< 100	125
14	50	0.18	< 20	< 100	NA
G 2	50	0.06	< 20	< 100	NA
3	100	0.05	< 20	< 100	NA
4	50	0.05	65	< 100	NA
5	NR	NR	< 20	< 100	NA
6	420	0.05	< 20	< 100	NA
7	260	0.06	40	< 100	NA
8	210	0.10	< 20	< 100	NA
9	50	0.15	30	< 100	NA
10	100	0.15	25	< 100	NA
11	0	0.20	< 20	< 100	NA
12	50	0.15	< 20	< 100	NA
13	50	0.20	< 20	< 100	NA

Table 45. Alpha and beta-gamma contamination on overhead wall surfaces in Building 19

Wall location (see Fig. 23)	Directly measured contamination		Transferable surface 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)
Northwest	200	0.10	< 20	< 150
Northeast	310	0.14	< 20	< 150
Southwest	360	0.06	25	< 150
Southeast	570	0.05	35	< 150
Center-west	420	0.06	< 20	< 150
Center-east	470	0.13	35	< 150
High wall-B5	100	0.05	NR ^a	NR
High wall-B6	160	0.05	NR	NR

^aNR = No reading

Table 46. Comparison of directly measured alpha contamination on new surfaces with that on the nearby floor

Building No.	Direct alpha measurements (dpm/100 cm ²)				Average alpha on new surfaces
	On nearby floor surfaces		On new material surfaces		Average alpha on nearby floor
	Maximum	Average	Maximum	Average	(Percent)
1(east room, first floor)	1200	950	620	460	48
1(west room, first floor)	1200	580	1200	520	90
2	140	110	100	60	55
2A	290	220	100	50	23
3	740	370	190	120	32
7	290	230	190	120	52
9	430	230	380	200	87
10	720	280	190	100	36
11	290	240	190	100	36
15	1500	1200	50	40	3
16	960	350	70	40	11
18	240	150	240	190 ^a	100 ^a
19	2000	1400	220	80	6

^aThe difference between this measurement and the average measurement on the nearby floor is not considered significant and they are assumed to be equal in calculating the fraction.

Table 47. Analysis of sediment from floor drains in various buildings

Building No.	Drain No.	Figure No.	Nuclide Concentration (pCi/g)			
			^{226}Ra	^{230}Th	^{238}U	^{210}Pb
1	1	5	6.3	13	27	120
1	3	5	3.3	49	46	140
1	5	5	3.2	11	41	34
1	6	5	30	470	270	75
2	4	8	6.8	21	5.3	26
10	5	13	3.4	30	2.5	17
10	12	13	26	180	34	15
11	1	17	16	93	25	16
11	2	17	310	920	14	230
16	3	19	44	900	51	54

Table 48. Analysis of water and suspended sediment samples from various buildings

Building No.	Drain No.	Figure No.	Sample type	Nuclide concentration (pCi/g or pCi/ml)			
				^{226}Ra	^{230}Th	^{210}Pb	^{238}U
1	4	5	water sediment	2.5×10^{-3} 13	1.2×10^{-3} 110	7×10^{-3} 100	0.003 0.03
2	sewer	8	water sediment	3×10^{-3} 45	$< 1 \times 10^{-3}$ 38	$< 2 \times 10^{-3}$ 45	0.02 0.06
10	4	13	water sediment	1×10^{-2} 44	5×10^{-4} 250	1.4×10^{-2} 55	0.20 0.11
10	6	13	water sediment	5×10^{-4} 1.3	5×10^{-4} 2.1	2×10^{-3} 10	0.10 0.05
10	13	13	water sediment	2×10^{-4} 2.1	$< 1 \times 10^{-3}$ 7.5	1×10^{-3} 12	0.03 0.07
11	5	17	water sediment	1×10^{-3} 1.1	2×10^{-3} 8.7	$< 1 \times 10^{-3}$ 1.7	0.03 0.22
	5	20	water sediment	1×10^{-3} 4.9	3×10^{-4} 5.0	$< 1 \times 10^{-3}$ 3.7	0.02 1.0
19	large pit, surface	23	water sediment	1.1×10^{-2} No sample	1.1×10^{-2}	3×10^{-3}	0.26 0.35
19	large pit, bottom	23	water sediment	1.9×10^{-2} 630	5×10^{-4} 5400	2×10^{-3} 730	0.16 8.2

Table 49. Analysis of miscellaneous solid samples from interior building surfaces

Building No.	Sample material	Sample location (see Fig. no.)	Nuclide concentration ^a (pCi/g)			
			²²⁶ Ra	²³⁰ Th	²¹⁰ Pb	²³⁸ U
7	ceiling insulation	E 8 (Fig. 11)	1.2	4.1	5	1.4
7	contaminated black wall surface	G 7 (Fig. 11)	190	2.8x10 ⁴	ND ^b	360
7	contaminated wall surface	G 8 (Fig. 11)	67	2.8x10 ⁴	ND	270
7	contaminated wall surface	G 9 (Fig. 11)	4.0	4.6x10 ⁴	67	640
9	worm bedding dirt ^c		0.8	1.5	6	0.3
9	ceiling insulation	F 2 (Fig. 12)	0.08	0.5	1	13
11	overhead insulation		0.7	5.6	11	1.2
16	insulation		2.8	10	33	1.4
18	ceiling insulation	second level C 2 (Fig. 22)	1.4	7.8	< 3	14
18	ceiling insulation	second level D 8 (Fig. 22)	7.1	38	34	39
18	dirt	first level B 6 and C 6 (Fig. 21)	8.1	18	30	39
18	mortar-concrete	first level, wall A 2 and A 3 (Fig. 21)	6.5	13	13	1530
18	tar	first level, overhead wood beam (Fig. 21)	1.1	2.1	50	1140

^aNuclides leached from samples with nitric acid.^bND = Not determined.^cNot part of building surfaces.

Table 50. Airborne nuclide concentrations in buildings

Building No.	Sampler location	Volume of air sampled (10^3 ml)	Nuclide Concentration (pCi/ml)			
			^{210}Pb	^{226}Ra	^{230}Th	^{238}U
2	Southeast corner	1.58	1.3×10^{-7}	4.5×10^{-8}	2.0×10^{-7}	1.8×10^{-7}
3	Northeast corner	4.39	2.0×10^{-9}	1.4×10^{-8}	6.2×10^{-8}	2.3×10^{-8}
10	First level, North end	1.59	1.2×10^{-7}	8.1×10^{-8}	3.1×10^{-9}	1.7×10^{-7}
10	First level, South end	3.44	3.4×10^{-8}	1.8×10^{-8}	7.9×10^{-8}	2.9×10^{-8}
10	First level, South end, L4	1.51	7.2×10^{-8}	5.2×10^{-8}	2.1×10^{-7}	7.7×10^{-8}
11	Southwest corner	1.53	4.4×10^{-9}	3.7×10^{-9}	1.8×10^{-8}	3.5×10^{-7}
16	Northeast corner	1.53	7.1×10^{-8}	5.1×10^{-8}	2.1×10^{-7}	7.6×10^{-8}
19	Northeast corner	1.53	4.4×10^{-9}	3.7×10^{-9}	1.8×10^{-8}	3.5×10^{-7}
Non-occupational CG_a			4×10^{-6} (soluble)	2×10^{-6} (insoluble)	8×10^{-8} (soluble)	2×10^{-6} (insoluble)

Table 51. Beta-gamma dose rates at 1 cm and external gamma radiation levels at 1 m above grid points, outdoors on the site

Coordinates shown in Fig. 2		Beta-gamma dose rate	External gamma
Base line	Left (L) or Right (R)	at 1 cm above surface (mrad/hr)	radiation level at 1 m above surface (μ R/hr)
0 + 0	0	0.30	140
0 + 50	0	0.13	90
0 + 50	L 50	0.16	110
0 + 50	L 100	0.50	130
1 + 0	0	0.25	130
1 + 0	L 50	0.15	80
1 + 0	L 100	0.10	90
1 + 0	L 150	0.18	120
1 + 0	L 200	0.28	120
1 + 50	0	0.15	150
1 + 50	L 50	0.14	100
1 + 50	L 100	0.28	140
1 + 50	L 150	0.13	110
1 + 50	L 200	0.30	160
1 + 50	L 300	0.34	130
2 + 0	0	0.08	95
2 + 0	L 100	0.30	80
2 + 0	L 150	0.06	65
2 + 0	L 195	0.15	85
2 + 0	L 250	0.21	65
2 + 0	L 400	0.13	95
2 + 0	L 450	0.04	35
2 + 50	0	0.35	330
2 + 50	L 200	0.10	60
2 + 50	L 250	0.14	100
2 + 50	L 350	0.18	100
2 + 50	L 400	0.08	85
2 + 50	L 450	0.15	110
2 + 50	L 500	0.40	190
2 + 50	L 550	0.05	50
3 + 0	L 0	0.70	280
3 + 0	L 350	0.23	140
3 + 0	L 400	0.29	170
3 + 0	L 450	0.17	110
3 + 0	L 500	0.09	65
3 + 0	L 550	0.09	80
3 + 0	L 600	0.25	140
3 + 0	L 650	0.08	60
3 + 50	0	0.16	140
3 + 50	L 50	0.40	210
3 + 50	L 300	0.35	180
3 + 50	L 400	0.11	95

Table 51. (cont.) Beta-gamma dose rates at 1 cm and external radiation levels at 1 m above grid points, outdoors on the site

Base line	Coordinates shown in Fig. 2		Beta-gamma dose rate at 1 cm above surface (mrad/hr)	External gamma radiation level at 1 m above surface (μ R/hr)
	Left (L) or Right (R)			
3 + 50	L	450	0.10	55
3 + 50	L	500	0.09	50
3 + 50	L	550	0.10	70
3 + 50	L	600	0.45	270
3 + 50	L	650	0.40	210
4 + 0		0	0.40	220
4 + 0	L	50	0.20	150
4 + 0	L	100	0.40	220
4 + 0	L	150	1.40	NR
4 + 0	L	300	0.10	100
4 + 0	L	350	0.20	NR
4 + 0	L	400	0.10	70
4 + 0	L	550	0.06	40
4 + 0	L	600	0.21	130
4 + 0	L	650	0.28	130
+ 50		0	0.12	110
+ + 50	L	50	0.23	160
4 + 50	L	100	0.12	80
4 + 50	L	150	0.50	150
4 + 50	L	200	0.45	280
4 + 50	L	250	1.00	360
4 + 50	L	300	0.09	120
4 + 50	L	350	0.11	100
4 + 50	L	400	0.11	120
4 + 50	L	450	0.11	100
4 + 50	L	500	0.07	35
4 + 50	L	600	1.00	330
4 + 50	L	650	0.24	160
4 + 50	L	700	0.11	75
5 + 0		0		220
5 + 0	L	50	0.28	180
5 + 0	L	250	0.45	280
5 + 0	L	300	0.50	280
5 + 0	L	350	0.15	180
5 + 0	L	400	0.20	200
5 + 0	L	450	0.10	80
5 + 0	L	500	0.08	65
5 + 0	L	550	0.10	75
5 + 0	L	600	0.10	110
5 + 0	L	650	0.19	110
+ + 0	L	700	0.25	130
+ 50		0	0.45	
5 + 50	L	50	0.80	
5 + 50	L	150	1.10	440

Table 51. (cont.) Beta-gamma dose rates at 1 cm and external gamma radiation levels at 1 m above grid points, outdoors on the site

Coordinates shown in Fig. 2		Beta-gamma dose rate at 1 cm above surface (mrad/hr)	External gamma radiation level at 1 m above surface (μ R/hr)
Base line	Left (L) or Right (R)		
5 + 50	L 200	0.18	190
5 + 50	L 250	1.35	670
5 + 50	L 300	1.30	440
5 + 50	L 350	0.75	420
5 + 50	L 400	0.28	220
5 + 50	L 450	0.13	120
5 + 50	L 500	0.45	130
5 + 50	L 550	0.10	90
5 + 50	L 600	0.40	160
5 + 50	L 650	0.09	100
5 + 50	L 700	0.09	65
6 + 0	0	0.18	200
6 + 0	L 150	0.55	280
6 + 0	L 200	1.15	500
6 + 0	L 250	0.29	330
6 + 0	L 300	0.80	440
6 + 0	L 350	0.13	160
6 + 0	L 400	1.10	440
6 + 0	L 450	0.23	320
6 + 0	L 500	0.40	440
6 + 0	L 550	0.25	170
6 + 0	L 600	0.12	100
6 + 0	L 650	0.09	70
6 + 0	L 700	0.11	85
6 + 50	0	0.13	130
6 + 50	L 50	0.23	160
6 + 50	L 100	0.12	110
6 + 50	L 150	0.55	310
6 + 50	L 200	0.40	310
6 + 50	L 250	5.00	1600
6 + 50	L 300	0.33	220
6 + 50	L 350	0.30	220
6 + 50	L 400	0.16	180
6 + 50	L 450	0.27	190
6 + 50	L 500	0.30	270
6 + 50	L 550	1.30	620
6 + 50	L 600	0.23	200
6 + 50	L 650	0.08	85
6 + 50	L 700	0.08	95
7 + 0	0	0.29	330
7 + 0	L 50	0.70	390
7 + 0	L 100	0.30	360
7 + 0	L 150	0.30	310
7 + 0	L 200	0.30	330

Table 51. (cont.) Beta-gamma dose rates at 1 cm and external gamma radiation levels at 1 m above grid points, outdoors on the site

Coordinates shown in Fig. 2		Beta-gamma dose rate at 1 cm above surface (mrad/hr)	External gamma radiation level at 1 m above surface (μ R/hr)
Base line	Left (L) or Right (R)		
7 + 0	L 250	0.90	510
7 + 0	L 300	0.90	290
7 + 0	L 350	0.30	360
7 + 0	L 400	0.13	130
7 + 0	L 450	0.13	120
7 + 0	L 500	0.13	140
7 + 0	L 550	0.23	220
7 + 0	L 600	0.30	270
7 + 0	L 650	0.28	220
7 + 0	L 700	0.05	55
7 + 0	L 750	0.06	50
7 + 50	0	0.30	280
7 + 50	L 50	0.30	240
7 + 50	L 100	0.40	280
7 + 50	L 150	0.23	220
7 + 50	L 200	0.60	380
7 + 50	L 250	0.23	280
7 + 50	L 300	0.35	270
7 + 50	L 350	0.25	220
7 + 50	L 400	0.60	280
7 + 50	L 450	1.00	400
7 + 50	L 500	0.15	120
7 + 50	L 550	0.13	95
7 + 50	L 600	0.06	75
7 + 50	L 650	0.05	50
7 + 50	L 700	0.05	50
7 + 50	L 750	0.50	330
8 + 0	0	0.15	180
8 + 0	L 50	0.20	220
8 + 0	L 100	0.23	200
8 + 0	L 150	0.13	220
8 + 0	L 200	0.50	280
8 + 0	L 250	0.23	330
8 + 0	L 300	0.60	470
8 + 0	L 350	1.10	440
8 + 0	L 400	0.11	130
8 + 0	L 450	0.06	80
8 + 0	L 500	0.07	70
8 + 0	L 550	0.08	60
8 + 0	L 600	0.06	55
8 + 0	L 650	0.06	45
8 + 0	L 700	0.05	45

Table 51. (cont.) Beta-gamma dose rates at 1 cm and external gamma radiation levels at 1 m above grid points, outdoors on the site

Coordinates shown in Fig. 2		Beta-gamma dose rate at 1 cm above surface (mrad/hr)	External gamma radiation level at 1 m above surface (μ R/hr)
Base line	Left (L) or Right (R)		
8 + 0	L 750	0.35	310
8 + 0	L 770	0.10	160
8 + 50	0	0.35	310
8 + 50	L 50	0.30	300
8 + 50	L 100	0.23	160
8 + 50	L 150	0.23	220
8 + 50	L 200	0.65	240
8 + 50	L 250	1.05	730
8 + 50	L 300	0.13	310
8 + 50	L 350	0.10	140
8 + 50	L 400	0.08	95
8 + 50	L 450	0.08	70
8 + 50	L 500	0.05	60
8 + 50	L 550	0.05	55
8 + 50	L 600	0.05	45
8 + 50	L 650	0.03	45
8 + 50	L 700	0.04	65
8 + 50	L 750	0.40	310
8 + 50	L 780	0.08	110
9 + 0	0	0.06	80
9 + 0	L 50	0.20	140
9 + 0	L 100	0.30	270
9 + 0	L 150	0.13	220
9 + 0	L 220	0.12	130
9 + 0	L 250	0.13	200
9 + 0	L 300	0.13	130
9 + 0	L 350	0.08	90
9 + 0	L 400	0.05	55
9 + 0	L 450	0.05	55
9 + 0	L 500	0.06	50
9 + 0	L 550	0.05	45
9 + 0	L 600	0.04	45
9 + 0	L 650	0.04	55
9 + 0	L 700	0.23	220
9 + 0	L 750	0.70	330
9 + 0	L 800	0.13	200
9 + 50	0	0.15	200
9 + 50	L 50	0.15	180
9 + 50	L 100	0.10	110
9 + 50	L 150	0.13	130
9 + 50	L 200	0.40	330
9 + 50	L 250	0.15	120
9 + 50	L 300	0.13	120

Table 51. (cont.) Beta-gamma dose rates at 1 cm and external gamma radiation levels at 1 m above grid points, outdoors on the site

Coordinates shown in Fig. 2		Beta-gamma dose rate at 1 cm above surface (mrad/hr)	External gamma radiation level at 1 m above surface (μ R/hr)
Base line	Left (L) or Right (R)		
9 + 50	L 350	0.09	85
9 + 50	L 400	0.05	55
9 + 50	L 450	0.05	45
9 + 50	L 500	0.05	45
9 + 50	L 550	0.05	45
9 + 50	L 600	0.05	40
9 + 50	L 650	0.18	110
9 + 50	L 700	0.20	200
9 + 50	L 750	0.50	220
9 + 50	L 800	0.05	60
10 + 0	R 50	0.04	55
10 + 0	0	0.04	65
10 + 0	L 50	0.06	120
10 + 0	L 100	1.25	780
10 + 0	L 150	0.10	270
10 + 0	L 200	0.15	200
10 + 0	L 250	0.10	120
10 + 0	L 300	0.30	200
10 + 0	L 350	0.18	130
10 + 0	L 400	0.13	95
10 + 0	L 450	0.05	45
10 + 0	L 500	0.05	45
10 + 0	L 550	0.04	45
10 + 0	L 600	0.18	85
10 + 0	L 650	0.10	70
10 + 0	L 700	0.13	100
10 + 0	L 750	0.30	100
10 + 50	R 50	0.03	50
10 + 50	0	0.05	55
10 + 50	L 50	0.10	75
10 + 50	L 100	0.28	200
10 + 50	L 150	0.40	340
10 + 50	L 200	0.40	310
10 + 50	L 250	0.10	120
10 + 50	L 300	0.08	90
10 + 50	L 350	0.28	170
10 + 50	L 400	0.18	140
10 + 50	L 450	0.15	110
10 + 50	L 500	0.05	60
10 + 50	L 550	0.08	60
10 + 50	L 600	0.06	45
11 + 0	R 50	0.03	45
+ 0	0	0.03	50

Table 51. (cont.) Beta-gamma dose rates at 1 cm and external gamma radiation levels at 1 m above grid points, outdoors on the site

Coordinates shown in Fig. 2		Beta-gamma dose rate at 1 cm above surface (mrad/hr)	External gamma radiation level at 1 m above surface (μ R/hr)
Base line	Left (L) or Right (R)		
11 + 0	L 50	0.05	85
11 + 0	L 100	0.13	110
11 + 0	L 150	0.13	120
11 + 0	L 200	0.18	240
11 + 0	L 250	0.40	220
11 + 0	L 300	0.09	100
11 + 0	L 350	0.08	75
11 + 0	L 400	0.30	270
11 + 0	L 450	0.25	200
11 + 0	L 500	0.20	120
11 + 0	L 550	0.21	220
11 + 50	R 50	0.03	40
11 + 50	0	0.03	45
11 + 50	L 50	0.05	60
11 + 50	L 100	0.10	90
11 + 50	L 150	0.10	110
11 + 50	L 200	0.15	210
11 + 50	L 250	0.40	220
11 + 50	L 300	0.11	100
11 + 50	L 350	0.09	90
11 + 50	L 400	0.25	160
11 + 50	L 450	0.33	220
11 + 50	L 500	0.18	130
12 + 0	R 50	0.03	35
12 + 0	0	0.03	45
12 + 0	L 50	0.05	55
12 + 0	L 100	0.05	70
12 + 0	L 150	0.05	70
12 + 0	L 200	0.18	160
12 + 0	L 250	0.10	85
12 + 0	L 300	0.15	140
12 + 0	L 350	0.05	55
12 + 0	L 400	0.10	80
12 + 0	L 450	0.13	120
12 + 0	L 490	0.06	35
12 + 50	R 50	0.03	35
12 + 50	0	0.02	35
12 + 50	L 50	0.03	40
12 + 50	L 100	0.03	40
12 + 50	L 150	0.04	50
12 + 50	L 200	0.05	60
12 + 50	L 250	0.11	70

Table 51. (cont.) Beta-gamma dose rates at 1 cm and external gamma radiation levels at 1 m above grid points, outdoors on the site

Coordinates shown in Fig. 2		Beta-gamma dose rate at 1 cm above surface (mrad/hr)	External gamma radiation level at 1 m above surface (μ R/hr)
Base line	Left (L) or Right (R)		
12 + 50	L 300	0.08	70
12 + 50	L 350	0.15	90
12 + 50	L 400	0.05	40
13 + 0	R 50	0.03	20
13 + 0	0	0.04	35
13 + 0	L 50	0.03	30
13 + 0	L 100	0.03	35
13 + 0	L 150	0.04	35
13 + 0	L 200	0.05	40
13 + 0	L 250	0.06	45
13 + 0	L 300	0.04	45
13 + 0	L 350	0.03	35

Table 52. Concentrations of ^{226}Ra , ^{238}U , and ^{227}Ac in surface soil samples

Location shown in Fig. 30-32	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)
1	1,150	790	150
2	30	28	4.0
3	20	20	ND ^a
4	100	ND	ND
5	16	19	ND
6	12	17	ND
7	63	130	20
8	6.2	8.7	ND
9	91	ND	ND
10	4.2	8.8	1.5
11	25	59	3.8
12	12	ND	ND
13	110	ND	18
14	500	200	ND
15	350	120	120
16	19	21	6.0
17	130	ND	ND
18	25	66	12
19	160	210	45
20	15	ND	7.4
21	8.6	1.6	ND
22	1,300	210	140
23	180	ND	120
24	1,000	190	140
25	120	14	18
26	74	8.6	8.2
27	99	270	21
28	140	85	ND
29	98	460	30
30	170	7,200	66
31	ND	51,000	250
32	250	15,300	750
33	830	180	60
34	4,000	ND	520
35	4,200	ND	4,500
36	320	1,100	140
37	72	22,000	ND
38	47	2,500	ND
39	48	ND	ND
40	1,600	ND	ND
41	7.8	ND	ND
42	270	ND	ND
43	390	49	ND
44	80	ND	ND

^aND - concentration not determined.

Table 52. (cont.) Concentrations of ^{226}Ra , ^{238}U , and ^{227}Ac in surface soil samples

Location shown in Fig. 30-32	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)
45	20	ND	ND
46	15	4.7	ND
47	2.1	ND	ND
48	5.4	ND	ND
49	1.3	ND	ND
50	2.1	ND	ND
51	1.8	1.3	ND
52	3.0	ND	ND
53	3.7	1.4	ND
54	1.5	ND	ND
55	47	ND	ND
56	10	3.8	1.0
57	17	ND	ND
58	8.0	8.2	ND
59	22	ND	8.9
60	45	ND	19.1
61	2.6	2.1	ND
62	3.5	ND	ND
63	240	ND	ND
64	14	21	2.2
65	3.3	3.8	ND
66	1.8	2.1	ND
67	7.1	ND	1.4
68	4.1	ND	ND
69	5.5	ND	ND
70	3.5	ND	ND
71	100	ND	ND
72	11	ND	ND
73	90	ND	ND
74	4.7	ND	ND

Table 53. Extent of ^{226}Ra contamination in subsurface soil at auger hole locations

Auger hole location shown in Fig. 33	Estimated extent of contaminated soil (ft)	Depth of maximum contamination (ft)	Measured (M) or estimated (E) ^{226}Ra concentration at point of maximum contamination (pCi/g)	Estimated average ^{226}Ra concentration in contaminated region in hole (pCi/g)
1	0 - 2.0	1.5	82 (M)	40
2	0 - 2.0	1.5	7.8 (M)	6
3	0.5 - 1.5	1.0	45 (M)	25
4	0 - 2.0	1.0	32 (M)	20
5	0 - 8.0	1.5	2,900 (M)	no estimate ^a
6	0 - 1.5	1.0	71 (M)	45
7	0 - 1.0	0.5	10 (E)	5
8	0 - 2.0	1.0	24 (M)	15
9	0 - 2.0	1.0	420 (M)	250
10	0.5 - 2.5	1.5	160 (M)	95
11	0.5 - 2.5	1.5	130 (M)	100
12	1.0 - 4.0	3.0	140 (E)	90
13	0 - 1.0	0.5	300 (M)	200
14	0.5 - 1.0	0.5	4.0 (E)	4
15	0 - 2.5	0.5	300 (M)	180
16	None			
17	0 - 2.5	2.0	80 (M)	55
18	0 - 3.5	3.0	21 (M)	20
19	0 - 3.0	2.0	720 (M)	370
20	1.0 - 3.5	2.5	280 (M)	130
21	1.0 - 4.0	1.5	99 (M)	50
22	1.0 - 2.5	1.5	320 (M)	200
23	0 - 3.5	2.0	96 (M)	40
24	1.0 - 3.0	2.0	360 (M)	200
25	0 - 3.5	2.0	5,700 (M)	3,300
26	0 - 5.0	3.0	170 (E)	110
27	0 - 6.0	0.5	76 (M)	26
28	0 - 5.0	3.0	900 (E)	490
29	0 - 3.0	1.5	57 (M)	40
30	0 - 2.0	1.0	220 (M)	150
31	0 - 2.5	1.5	410 (M)	220
32	0 - 3.0	1.5	18 (M)	10
33	0 - 6.0	5.0	250 (E)	120
34	0 - 2.0	1.0	38 (E)	28
35	0 - 2.0	1.5	110 (M)	72
36	0 - 3.0	surface	67 (M)	43
37	0 - 4.0	1.0	120 (M)	57
38	0 - 4.0	3.0	900 (E)	360
39	0 - 12.0	4.0	900 (E)	320

^aA tank, 4.5 ft. from top to bottom and filled with contaminated water, was drilled into at approximately 3 feet below the surface.

Table 53. (cont.) Extent of ^{226}Ra contamination in subsurface soil at auger hole locations

Auger hole location shown in Fig. 33	Estimated extent of contaminated soil (ft)	Depth of maximum contamination (ft)	Measured (M) or estimated (E) ^{226}Ra concentration at point of maximum contamination (pCi/g)	Estimated average ^{226}Ra concentration in contaminated region in hole (pCi/g)
40	0 - 4.0	2.0	150 (E)	100
41	0 - 3.0	2.0	2,100 (M)	1,000
42	No log			
43	0 - 3.5	2.0	170 (E)	95
44	0 - 2.5	2.0	19 (E)	14
45	0 - 5.0	4.0	24 (E)	16
46	0 - 2.0	1.5	280 (E)	200
47	0 - 3.0	1.5	800 (E)	420
48	0 - 2.0	1.0	750 (M)	330
49	0 - 2.0	1.0	1,700 (M)	920
50	1.0 - 3.0	2.5	28 (E)	22
51	0 - 3.5	2.5	420 (E)	170
52	0 - 3.0	1.0	850 (M)	450
53	0 - 5.0	0.5	110 (M)	56
54	0 - 7.0	3.0	600 (E)	330
55	0 - 0.5	surface	92 (E)	88
56	None			
57	0 - 2.0	0.5	7,000 (E)	4,500
58	None			
59	0 - 3.0	2.0	160 (E)	96
60	0 - 1.5	1.0	28 (E)	18
61	No log			
62	0 - 1.5	0.5	34 (E)	25
63	0 - 1.5	1.0	8.0 (E)	7
64	0 - 3.0	2.5	8.0 (E)	7
65	0 - 5.0	4.5	180 (E)	100
66	0.5 - 2.5	1.5	480 (M)	290
67	0.3 - 1.0	0.5	18 (E)	13
68	0 - 0.5	surface	160 (E)	160
69	0 - 2.0	0.5	240 (E)	140
70	4.0 - 18.0	8.0	1,050 (E)	550
71	8.0 - 14.0	10.0	154 (E)	69
72	7.0 - 12.0	11.0	10 (E)	6
73	9.0 - 10.5	10.0	26 (E)	14
74	9.5 - 12.0	11.0	250 (E)	110
75	8.5 - 12.0	11.0	450 (E)	250
76	9.0 - 11.0	10.5	180 (E)	140
77	0 - 16.0	4.0	15,000 (M)	no estimate
78	0 - 2.0	0.5	60 (E)	44
79	0 - 2.0	1.0	80 (E)	45
80	0 - 2.0	1.0	18 (E)	14

Table 53. (cont.) Extent of ^{226}Ra contamination in subsurface soil at auger hole locations

Auger hole location shown in Fig. 33	Estimated extent of contaminated soil (ft)	Depth of maximum contamination (ft)	Measured (M) or estimated (E) ^{226}Ra concentration at point of maximum contamination (pCi/g)	Estimated average ^{226}Ra concentration in contaminated region in hole (pCi/g)
81	3.0 - 18.0	8.0	17,000 (M)	no estimate
82	6.0 - 10.0	8.0	2,000 (E)	860
83	0 - 9.0	8.0	340 (E)	82
84	None			
85	4.0 - 6.5	6.0	6.0 (E)	5
86	2.5 - 5.0	3.5	18 (E)	12
87	0 - 6.0	0.5	7.0 (E)	4
88	5.0 - 7.5	7.0	12 (E)	9

Table 54. Concentrations of ^{226}Ra , ^{238}U , and ^{227}Ac in soil samples taken from auger holes

Location shown in Fig. 33	Depth (ft)	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)
1	1.5	82	95	9.8
2	1.7	7.8	42	0.8
3	1.0	45	34	ND
4	1.0	32	142	ND
5	1.5	2,900	2,600	ND
6	0 - 1.0	71	120	ND
8	0 - 1.0	24	133	3.4
9	1 - 1.5	420	210	ND
10	1.0 - 2.0	160	340	27
11	1.0 - 5.0	130	360	43
13	0.7 - 8.0	300	300	30
15	0.7	300	580	87
17	2.0	80	200	ND
18	1.0	21	43	2.1
19	1.5 - 2.0	720	520	61
20	2.0	280	24	109
21	1.5	99	116	160
22	1.5 - 2.0	320	92	ND
23	2.0	96	81	ND
24	2.0 - 2.5	360	1,800	48
25	0.7 - 3.5	5,700	ND	420
27	0.5	76	66	29
29	1.5	57	104	11
30	1.0	220	330	51
31	1.5	410	5,200	ND
32	1.5	18	68	11
35	1.0 - 1.5	110	29	ND
36	0 - 1.0	67	71	4.3
37	1.0	120	110	ND
41	0 - 2.5	2,100	908	140
48	0 - 1.5 ^a	750	37	71
49	0 - 1.5 ^a	1,700	81	130
52	0 - 2.0 ^a	850	85	350
53	0 - 1.5 ^a	106	56	53
66	0 - 2.5 ^a	480	170	69
70	4.0 - 18.0 ^a	205	240	16
74	9.0 - 12.0 ^a	21	15	ND
75	8.0 - 12.0 ^a	930	88	290
76	8.0 - 12.0 ^a	102	48	91
77	2.5 - 6.0 ^a	15,000	600	1,700
77	2.5 - 6.0 ^a	10,000	350	850
83	0 - 6.0 ^a	28	66	7.9
85	0 - 8.0 ^a	2.3	7.2	ND
86	2.0 - 6.0 ^a	8.6	76	1.8
87	0 - 4.0 ^a	7.0	1.2	ND

^aDepth is inexact since sample is composite sample taken from soil brought up by auger.

Table 54. (cont.) Concentrations of ^{226}Ra , ^{238}U , and ^{227}Ac in soil samples taken from auger holes

Location shown in Fig. 33	Depth (ft)	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)
88	0 - 8.0 ^a	3.2	4.6	1.4
90	0 - 1.5 ^a	13	49	5.0
91	0 - 1.5 ^a	11	26	1.8
92	0 - 1.5 ^a	14	47	5.6

Table 55. Concentrations of ^{226}Ra , ^{238}U , and ^{227}Ac in soil samples taken from core holes outdoors

Location shown in Fig. 33	Depth (ft)	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)
1	0 - 0.5	24	ND ^a	ND
	0.5 - 1.0	19	105	ND
	1.0 - 1.5	100	1200	ND
	1.5 - 2.0	95	120	ND
	2.0 - 3.0	2.3	5.3	ND
	3.0 - 4.0	2.0	8.6	ND
	4.0 - 5.0	1.8	3.4	ND
	5.0 - 6.0	1.3	2.0	ND
	6.0 - 7.5	1.2	1.5	ND
10	0 - 0.5	48	104	14.0
	0.5 - 1.0	5.7	7.0	1.9
	1.0 - 1.5	630	420	46
	2.5 - 3.5	850	190	ND
	3.5 - 4.5	78	450	5.0
	4.5 - 5.5	480	200	36
	5.5 - 6.5	110	230	ND
12	0 - 1.0	4.8	5.9	ND
	1.0 - 2.0	72	45	ND
	2.0 - 3.0	150	200	18
	3.0 - 4.0	130	260	17
	4.0 - 5.0	7.0	46	0.73
	5.0 - 6.0	1.8	47	0.83
17	0 - 1.0	43	31	11
	1.0 - 2.0	15	35	4.0
	2.0 - 3.0	14	12	ND
	3.0 - 4.0	2.0	2.4	ND
	4.0 - 5.0	1.1	1.3	ND
	5.0 - 5.5	1.0	1.0	ND
22	0 - 0.5	7.2	12.0	1.2
	0.5 - 1.0	ND	5.1	ND
	1.0 - 1.5	53	42	ND
	1.5 - 2.0	630	280	86
	2.0 - 2.5	2600	180	400
	2.5 - 3.0	11.0	68	ND
	3.0 - 3.5	5.1	54	ND
	3.5 - 4.0	ND	8.0	ND
	4.0 - 4.5	3.8	4.1	ND
	4.5 - 5.0	4.7	11	ND
	5.0 - 5.5	14.0	17.0	ND
	5.5 - 6.5	2.6	4.3	ND
30	0 - 1.0	120	240	ND
	1.0 - 2.0	1900	3400	210
	5.5 - 6.5	39	160	ND

Table 55. (cont.) Concentrations of ^{226}Ra , ^{238}U , and ^{227}Ac in soil samples taken from core holes outdoors

Location shown in Fig. 33	Depth (ft)	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)
41	0 - 1.0	33	6.8	ND
	1.0 - 1.5	810	310	63
	1.5 - 2.0	3000	1200	ND
	2.0 - 3.0	23	11	4.4
	3.0 - 4.0	3.8	3.3	1.4
	4.0 - 5.0	22	10	ND
	5.0 - 6.0	1.6	1.0	ND
48	0 - 0.5	3.2	1.7	1.0
	0.5 - 1.0	410	120	130
	1.0 - 1.5	13	31	ND
	1.5 - 2.0	9.3	9.1	ND
	2.0 - 2.5	3.7	4.5	ND
	3.0 - 3.5	3.2	2.8	ND
	3.5 - 4.0	1.9	3.3	ND
	4.0 - 4.5	2.0	2.7	ND
	4.5 - 5.0	1.1	1.1	ND
	5.0 - 5.5	0.7	0.8	ND
	5.5 - 6.0	1.4	1.1	ND
	6.0 - 7.0	0.8	0.8	ND
59	0 - 1.0	260	510	ND
	1.0 - 2.0	170	62	34
	2.0 - 3.0	65.0	62	9.4
	3.0 - 4.0	8.5	48	ND
	4.0 - 5.0	1.5	16	ND
70	0 - 1.5	21	2.0	ND
	1.5 - 2.3	2.7	1.7	ND
	2.3 - 3.0	5.9	4.0	ND
	5.0 - 6.5	550	450	ND
	10.1 - 10.7	31	46	ND
	10.7 - 11.2	7.2	30	ND
	11.2 - 12.8	5.8	8.8	ND
	15.7 - 16.1	0.4	2.8	ND
	17.6 - 18.6	13	2.7	ND
77	2.5 - 6.0	15,000	600	1700
	2.5 - 6.0	10,000	350	850
78	0 - 1.0	380	305	88
	1.0 - 2.0	68	40	18
	2.0 - 3.0	13	12	2.5
	3.0 - 4.5	4.4	11	1.4
	4.5 - 5.5	4.4	14	ND
	5.5 - 6.5	1.0	8.5	ND
	6.5 - 8.0	1.0	9.0	ND

Table 55. (cont.) Concentrations of ^{226}Ra , ^{238}U , and ^{227}Ac in soil samples taken from core holes outdoors

Location shown in Fig. 33	Depth (ft)	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)
81	3.2 - 4.2	14,900	ND	ND
	4.7 - 5.0	14,600	560	ND
	7.0 - 7.6	14,300	750	ND
	7.6 - 8.8	17,000	610	2,500
	8.0 - 9.2	11,000	ND	ND
	9.2 - 10.2	14,000	490	1,600
	10.2 - 11.2	5,000	1,000	1,500
	11.2 - 12.2	700	ND	87
	12.2 - 13.0	4,000	ND	50
	14.7 - 15.1	170	9.9	ND
	16.7 - 17.1	27	10.8	ND
	17.4 - 17.9	11	3.2	1.7

^aND = concentration not determined.

Table 56. Concentrations of ^{226}Ra , ^{238}U , and ^{227}Ac in soil samples taken from core holes drilled through floors in buildings

Location shown in Fig. 34	Depth (ft)	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)
B - 1	0.5 - 1.0	60	30	ND ^a
	1.0 - 2.0	480	450	ND
	2.0 - 2.8	380	600	ND
	2.8 - 3.3	350	820	ND
	3.3 - 4.0	520	200	ND
	4.0 - 6.0	2.4	15	ND
	6.0 - 7.5	5.7	15	ND
B - 2	0.5 - 1.0	36	67	ND
	1.0 - 2.0	2,200	300	410
	2.0 - 3.5	3,800	210	540
	3.5 - 4.5	6.4	17	ND
	4.5 - 5.0	10	43	2.1
B - 3	0.5 - 1.0	34	61	7.1
	1.0 - 2.0	6.2	28	1.2
	2.0 - 3.5	33	140	ND
	3.5 - 5.0	34	410	12
B - 4	0.4 - 1.0	220	150	135
B - 5	0.5 - 0.8	63	60	ND

^aND = concentration not determined.

Table 57. Analyses of water samples taken from auger holes

Location shown in Fig. 33	^{238}U (pCi/ml)	^{226}Ra (pCi/ml)
1	0.01	< 0.10
5	0.92	0.14
9	0.34	< 0.10
18	0.38	< 0.10
20	0.01	0.24
27	1.08	< 0.10
28	0.82	0.19
30	0.62	< 0.10
33	0.12	< 0.10
34	0.01	0.10
37	0.23	0.20
39	2.06	< 0.10
53	0.65	< 0.10
55	0.04	< 0.10
59	< 0.01	< 0.10
60	0.02	0.39
64	< 0.01	< 0.10
65	0.04	< 0.10
69	0.01	< 0.10
71	0.74	0.22
73	0.02	< 0.10
75	0.28	< 0.10
78	0.05	< 0.10
80	0.08	< 0.10
82	0.03	< 0.10
84	< 0.01	< 0.10
85	< 0.01	< 0.10
86	< 0.01	< 0.10
87	0.03	0.12
88	0.11	< 0.10
RCG _w (soluble)	40	0.03

Table 58. Beta-gamma dose rates at 1 cm and external gamma radiation levels at 1 m above grid points, outdoors in area just south of site, including railroad

Coordinates shown in Fig. 2		Beta-gamma dose rate	External gamma
Base line	Left (L) or Right (R)	at 1 cm from surface (mrad/hr)	radiation level at 1 m above surface (μ R/hr)
0 + 0	R 50	0.08	70
0 + 0	R 100	0.13	600
0 + 50	R 50	0.04	600
0 + 50	R 100	0.06	710
1 + 0	R 50	0.09	840
1 + 0	R 100	0.10	1160
1 + 50	R 50	0.15	120
1 + 50	R 100	0.15	270
2 + 0	R 50	0.50	560
2 + 50	R 50	7.50	2000
2 + 50	R 100	0.28	330
3 + 0	R 50	0.18	130
3 + 0	R 100	0.28	130
3 + 50	R 50	0.15	130
3 + 50	R 100	0.08	65
4 + 0	R 50	0.18	130
4 + 0	R 100	0.08	70
4 + 50	R 50	0.10	100
4 + 50	R 100	0.05	45
5 + 0	R 50	0.13	120
5 + 0	R 100	0.04	50
5 + 50	R 50	0.18	130
5 + 50	R 100	0.05	75
6 + 0	R 50	0.10	120
6 + 0	R 100	1.10	75
6 + 50	R 50	1.10	100
6 + 50	R 100	1.10	100
7 + 0	R 50	0.13	130
7 + 0	R 100	0.50	330
7 + 50	R 50	0.13	120
7 + 50	R 100	0.13	110
8 + 0	R 50	0.10	100
8 + 0	R 100	0.08	110
8 + 50	R 50	0.08	80

Table 59. External gamma radiation levels^a at 1 m above the surface at offsite locations

Lot No.	Maximum observed external gamma radiation level at 1 m indoors ($\mu\text{R/hr}$)	Average observed external gamma radiation level at 1 m outdoors ($\mu\text{R/hr}$)	Maximum observed external gamma radiation level at 1 m outdoors ($\mu\text{R/hr}$)	Location of maximum observed gamma radiation level outdoors
Latimer Avenue area - lots shown in Fig. 35				
2	17	25	38	North end of lot
3	11	49	100	Brick walk from rear door
4	13	35	60	North end of lot
6		27 ^b	27	North end of lot
7	10			
8	10	16 ^b	16	South end of lot
9	24	22	27	North end of lot
10		22 ^b	22	South end of lot
11		20 ^b	20	South end of lot
12		22 ^b	22	South end of lot
13		18 ^b	18	South end of lot
14		22 ^b	22	South end of lot
15		22 ^b	22	South end of lot
16	14	24	33	North end of lot
17	9	14 ^b	14	South end of lot
18		24	33	South end of lot
21		12 ^b	12	South end of lot
22	10	12	12	North end of lot
23		12	17	South end of lot
24	17	16	18	South end of lot
Strabane Avenue area - lots shown in Fig. 36				
101	10	12	13	Northwest end of lot
102	9	18	29	Along Chartiers Creek on church property
103		12 ^b	12	East end of lot
104		11 ^b	11	East end of lot

^aGamma radiation levels were measured at random locations.

^bOnly one reading was recorded.

Table 59. (cont.) External gamma radiation levels^a at 1 meter above the surface at offsite locations

Lot No.	Maximum observed external gamma radiation level at 1 m indoors ($\mu\text{R/hr}$)	Average observed external gamma radiation level at 1 m outdoors ($\mu\text{R/hr}$)	Maximum observed external gamma radiation level at 1 m outdoors ($\mu\text{R/hr}$)	Location of maximum observed gamma radiation level outdoors
105		10 ^b	10	East end of lot
106		12	14	West end of lot
107		12	14	West end of lot
108		14	16	East end of lot
109	10	50	73	East end of lot
110		17	20	East end of lot
111		16	17	West end of lot
112		22	22	West end of lot
113		23	23	West end of lot
114		12 ^b	12	East end of lot
115		17 ^b	17	West end of lot
116	9	17 ^b	17	West end of lot
117		10 ^b	10	East end of lot
118	8			
119	9	14 ^b	14	On Southwest corner of lot 118
120		10 ^b	10	North end of lot
121		16	20	East end of lot
122	10	17	17	South end of lot
123		22 ^b	22	Garage to lot 123
124	8	19	21	South end of lot
125	8	19	22	South end of lot

West Pike Avenue area - lots shown in Fig. 37

201	12	14	East end of lot
202	13	15	South end of lot
203	10	12	South end of lot
204	10	11	South end of lot
205	10	12	South end of lot
206	10	12	South end of lot

Table 59. (cont.) External gamma radiation levels^a at 1 meter above the surface at offsite locations

Lot No.	Maximum observed external gamma radiation level at 1 m indoors ($\mu\text{R/hr}$)	Average observed external gamma radiation level at 1 m outdoors ($\mu\text{R/hr}$)	Maximum observed external gamma radiation level at 1 m outdoors ($\mu\text{R/hr}$)	Location of maximum observed gamma radiation level outdoors
207		< 10	10	Southwest end of lot
208		10	10	South end of lot
209	8	< 10	10	South end of lot
210		< 10	10	South end of lot
Wilson Avenue area - lots shown in Fig. 38				
A		< 10 ^b	< 10	See Fig. 38
B		< 10 ^b	< 10	See Fig. 38
C		< 10 ^b	< 10	See Fig. 38
D		10 ^b	10	See Fig. 38
E		< 10 ^b	< 10	See Fig. 38
F		< 10 ^b	< 10	See Fig. 38
G		< 10 ^b	< 10	See Fig. 38
H		< 10 ^b	< 10	See Fig. 38
I		< 10 ^b	< 10	See Fig. 38
J		< 10 ^b	< 10	See Fig. 38
K		36 ^b	36	See Fig. 38

Table 60. Concentrations of ^{226}Ra , ^{238}U , ^{227}Ac in offsite soil samples

Location shown in Fig. 39	Comments	External gamma radiation level at 1 m ($\mu\text{R/hr}$)	External gamma radiation level at surface ($\mu\text{R/hr}$)	^{226}Ra concentration (pCi/g)	^{238}U concentration (pCi/g)	^{227}Ac concentration (pCi/g)
A	Chartiers Creek, left bank	9		1.1	4.3	ND ^a
B	Chartiers Creek, left bank	9		1.1	0.9	ND
C	Chartiers Creek, left bank	27		9.4	1.6	ND
D	Chartiers Creek, right bank	44		2.5	1.1	ND
E	Chartiers Creek, right bank	9		1.2	1.7	ND
F	Chartiers Creek, right bank			7.7	6.0	1.9
G	Chartiers Creek, right bank			200	660	ND
H	Chartiers Creek, ~2 mi. downstream from "G" at Hahn Rd.			1.6	1.4	ND
I	Chartiers Creek, downstream from "H"			1.3	1.4	ND
J		17	67	99	20	ND
K	Lot No. 3 (see Fig. 35) North end of lot		49	22	43	1.6
L	Lot No. 6 (see Fig. 35) North end of lot			2.4	4.1	0.6

^a ND = Concentration was not determined.

Table 60. (cont.) Concentrations of ^{226}Ra , ^{238}U , ^{227}Ac in offsite soil samples

Location shown in Fig. 39	Comments	External gamma radiation level at 1 m ($\mu\text{R/hr}$)	External gamma radiation level at surface ($\mu\text{R/hr}$)	^{226}Ra concentration (pCi/g)	^{238}U concentration (pCi/g)	^{227}Ac concentration (pCi/g)
M	Lot No. 125 (see Fig. 36) south end of lot	17		6.9	11	ND
N	Lot No. 109 (see Fig. 36) east end of lot, near garden	46		68	24	ND
O	Lot No. 109 (see Fig. 36) east end of lot, in garden	73	130	110	22	ND
P	at Chartiers Creek, left bank			1.9	2.5	ND
Q	at Chartiers Creek, right bank (taken from a concrete cask with a wooden liner found near the creek)			3100	61	330
R	Lot No. 1 (see Fig. 35) north end of lot, in garage		62	30	96	22
S	Between railroad and parcel C			2.4	4.8	1.0

Table 6. Radon concentrations measured outdoors, both on and off the site

Location shown in Fig. 39	Comments	Date (1977)	Number of readings ^a	Average ²²² Rn concentration (pCi/liter)	Maximum ²²² Rn concentration (pCi/liter)	Time maximum ²²² Rn concentration was measured
1	Building 4 pad, on site	June 7-11	324	2.5	10	4:17 am, June 8
2	East side of Bldg. 16, on site	June 11-13	160	17	69	10:51 pm, June 11
3	Catholic church, corner of Hutchison Ave., and West Pike St.	June 13-14	78	1.3	3.0	5:19 am, June 14
4	Lot No. 101, outdoors, off site (see Fig. 36)	June 14-16	164	2.1	5.5	6:37 am, June 15
5	Lot No. 101 indoors, off site (see Fig. 36)	June 16-17	84	2.1	5.8	7:34 am, June 17
6	Garage on Lot. No. 1, off site (see Fig. 35)	June 17-18	72	8.6	14.4	6:52 am, June 18

^aReadings were taken in pairs (using two Wrenn chambers) at 2000 second intervals. The numbers in this column represent the total number of readings taken.

Table 62. Analyses of offsite water samples and sediment

Location shown in Fig. 39	Water			Sediment		
	^{226}Ra (pCi/ml)	^{210}Pb (pCi/ml)	^{230}Th (pCi/ml)	^{226}Ra (pCi/g)	^{210}Pb (pCi/g)	^{230}Th (pCi/g)
A	$5 \times 10^{-4} \pm 100\%$	$4 \times 10^{-3} \pm 65\%$	$2 \times 10^{-4} \pm 140\%$	$5 \pm 100\%$	< 34	$0.90 \pm 300\%$
B	$3 \times 10^{-4} \pm 120\%$	$2 \times 10^{-3} \pm 120\%$	$2 \times 10^{-4} \pm 150\%$	$2 \pm 100\%$	< 5.4	$5 \pm 60\%$
C	$2 \times 10^{-4} \pm 125\%$	$5 \times 10^{-3} \pm 60\%$	$5 \times 10^{-4} \pm 100\%$	$2 \pm 200\%$	< 51	$2 \pm 250\%$
E	$3 \times 10^{-4} \pm 130\%$	$1 \times 10^{-3} \pm 110\%$	$2 \times 10^{-4} \pm 120\%$	$36 \pm 75\%$	< 86	$45 \pm 70\%$
Ditch 25 ft west of point E	$4 \times 10^{-3} \pm 100\%$	$8.6 \times 10^{-3} \pm 350\%$	$9 \times 10^{-4} \pm 100\%$	3.1 ± 0.3	$24 \pm 45\%$	$56 \pm 2\%$
RCG _w (soluble)	3×10^{-2}	1×10^{-1}	2	--	--	--

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APPENDIX I

DESCRIPTION OF RADIATION SURVEY METERS,
SMEAR COUNTERS, AND TECHNIQUES FOR THE
MEASUREMENT OF RADON AND RADON
DAUGHTER CONCENTRATIONS IN AIR

RADIATION SURVEY METERS

Alpha Survey Meters

The type of alpha survey meter used at the Vitro 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. 1-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-Muller (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 2000 cpm per mR/hr for surfaces contaminated with ^{226}Ra in equilibrium with ^{238}U and 2300 cpm per mR/hr for surfaces contaminated with initially pure uranium. The lower figure was routinely applied. The closed-window (gamma) calibration factor, determined by use of a NBS standard ^{226}Ra source, was 3200 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 $\mu\text{R/hr}$ to several hundred $\mu\text{R/hr}$. This instrument is calibrated at ORNL with an NBS standard ^{226}Ra source. Typical calibration factors are of the order of 300 cpm/ μR per 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.

detector. The potential between this aluminized mylar film and the hemispherically shaped wire screen creates a strong electric field which serves to attract the charged ions. The ions thus attracted remain on the surface of the mylar film and continue their radioactive decay to other radon daughters. The principal radiation detected by a radon monitor of this type is the alpha particles from RaA and RaC'.

The Wrenn Chambers were calibrated on the site by comparison with the Lucas flasks described below. In order to observe any differences in response of the six Wrenn Chambers used on this site when exposed to the same concentration of radon, the six chambers were placed close together on the ground floor of Building 1 and were operated simultaneously for a period of 24 hr. The results of this comparison are shown in Fig. I-F. The observed differences were compensated for in the calibration factors for the different instruments.

The Wrenn Chambers are attached to a counter which records automatically the radon concentration at intervals of 2000 sec. Some radon and progeny from previous 2000 sec counts remain in the Wrenn Chamber; hence each reading actually represents a concentration which has been integrated over a period of 2 to 4 hr. Fig. I-G shows typical twenty-four hour integrated concentrations measured with a Wrenn Chamber in Building 9 on this site.

Lucas Chamber

A Lucas Chamber (Fig. I-H) consists of a 95-ml glass flask, coated inside with a uniform layer of zinc sulfide. For measurements of radon concentration in the air, the flask is evacuated to a pressure of 50 microns. The flask is then taken to a location where a sample is desired

I-E). The electronics package consisted of a preamplifier, a 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 ($\sim 2 \text{ mg/cm}^2$) 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.

TECHNIQUES FOR THE MEASUREMENT OF RADON AND RADON DAUGHTERS IN AIR

Wrenn Chambers

The Wrenn Chamber operates on the principle that RaA ions are positively charged. Radon is allowed to diffuse through a foam rubber covered hemispherically shaped metal screen, which filters radon daughters. As radon decays, after diffusing into the cavity, RaA ions are attracted to a thin aluminized mylar film which is stretched over a zinc sulfide scintillation

and the collection value is opened. After collection of air in the flask, sample counting is delayed 3 to 4 hours to allow the radon daughters to attain equilibrium. Alpha particles from the radon daughters produce scintillations in the zinc sulfide. The sample is normally counted for 1000 seconds with a photomultiplier tube assembly. A calibration performed at ORNL using a known radon concentration indicated that the conversion factor is 2.02 pCi/l per cpm. After the sample has been counted, the flask is again evacuated to 50 microns to prevent contamination.

Technique for the Measurement of ^{222}Rn Progeny Concentrations in Air

An alpha spectrometry technique has been refined by Kerr^(I-1, I-2) for the measurement of ^{222}Rn progeny concentrations in air. From one integral count of the ^{218}Po alpha activity and two integral counts of the ^{214}Po alpha activity, the concentrations in air of ^{218}Po , ^{214}Bi and ^{214}Pb may be calculated.

Particulate ^{222}Rn daughters attached to airborne dust are collected on a membrane filter with a pore size of 0.4 microns. A sampling time of 5 minutes and a flow rate of 12 LPM are used. This filter sample is then placed under a silicon surface barrier detector and counted. The detector and counting system used for radon daughter measurements are shown in Fig. I-1. Usually, counting of this kind is performed with a vacuum between the sample and the detector which requires a complicated sample holder and time-consuming sample changing methods. Experiments at this laboratory have shown that ease in sample handling is obtained with little loss in resolution when helium is used as a chamber fill gas.^(I-3) In this counter, helium is flowed between the diode and the filter sample,

which are separated by a distance of 0.5 cm. One integral count of the ^{218}Po alpha activity is obtained from 2 to 12 minutes, and two integral counts of the ^{214}Po activity are obtained from 2 to 12 minutes and 15 to 30 minutes, respectively. All counting intervals are referenced to $t = 0$ at the end of sampling.

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

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

where

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

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

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

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

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

$$y = e^{-ax} [y_0 + \int F(x) e^{ax} dx] .$$

From the general form of the solution, specific equations can be obtained describing the number of each ^{222}Rn decay product collected on the filter as a function of time. Also by letting $v = 0$ in Eq. (1), a set of equations describing the decay on the filter of each ^{222}Rn progeny can be obtained. The equations describing the decay of ^{222}Rn progeny on the filter can be integrated and related to the integral counts obtained experimentally. Values for the total activities of ^{218}Po , ^{214}Pb , and ^{214}Bi

on the filter at the end of sampling are obtained by applying matrix techniques. The airborne concentrations are obtained by solving the equations describing the atom collection rates on the filter. A computer program has been written to perform these matrix operations, to calculate the air concentrations of the radon progeny, and to estimate the accuracy of the calculated concentrations.

REFERENCES FOR APPENDIX I

- I-1. G. D. Kerr, Measurement of Radon Progeny Concentrations in Air by Alpha-Particle Spectrometry, ORNL/TM-4924 (July 1975).
- I-2. G. D. Kerr, "Measurement of Radon Progeny Concentrations in Air," *Trans. Am. Nuc. Soc.* 17, 541 (1973).
- I-3. 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).

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

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

Fig. I-D. Gamma scintillation survey meter.

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

Fig. I-F. Intercomparison of the response of six Wrenn chambers exposed for 21 hours in a ground floor area of Building 1.

Fig. I-G. Typical diurnal variation of radon concentration in Building 9.

Fig. I-H. Lucas Chamber.

Fig. I-I. System used for measurement of radon daughter concentrations.

APPENDIX II

DESCRIPTION OF Ge(Li) DETECTOR AND SOIL COUNTING PROCEDURES

DESCRIPTION OF Ge(Li) DETECTOR SYSTEM

A holder for twelve 30-cm³ polyethylene bottles (standard containers for liquid scintillation samples) and a background shield have been designed for use with a 50-cm³ Ge(Li) detector system in laboratory counting of radioactivity in environmental samples (see Figs. II-A, II-B). 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-cm³ sample and a graded shield developed for use with the system, it is possible to measure 1 pCi/g of ²³²Th or ²²⁶Ra with an error of $\pm 10\%$ or less and ²²⁷Ac within an error of $\pm 30\%$.

Pulses are sorted by a 4096-channel analyzer (see Fig. II-C), stored on magnetic tape, and subsequently entered into a computer program which uses an iterative least squares method to identify radionuclides corresponding to those gamma-ray lines found in the sample. The program, which is accessible through a remote terminal, relies on a library of radioisotopes which contains approximately 700 isotopes and 2500 gamma-rays and which runs continuously on the IBM-360 system at ORNL. In identifying and quantifying ²²⁶Ra, six principal gamma-ray lines are analyzed. Most of these are from ²¹⁴Pb and correspond to 295, 352, 609, 1120, 1765, and 2204 KeV. An estimate of the concentration of ²³⁸U is obtained from an analysis of the 93 KeV line from its daughter ²³⁴Th.

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

Fig. II-B. Ge(Li) detector system.

Fig. II-C. 4096-channel analyzer.

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APPENDIX III

PROCEDURE FOR ESTIMATING ^{226}Ra CONTAMINATION LEVELS FROM SCINTILLATION PROBE LOGGINGS

Since the gamma radiation intensity in subsurface soil contaminated with ^{226}Ra and other radionuclides from the ^{238}U chain depends chiefly on the concentrations of ^{226}Ra and daughters present, gamma scintillation probe loggings in auger holes can be used to estimate ^{226}Ra concentrations in subsurface soil. Errors occur in such estimates when the ratios of ^{226}Ra activity to the activity of the other radionuclides varies significantly from point to point. At the Canonsburg site, an attempt was made to minimize this source of error by applying the following procedure. Whenever the point with the highest gamma radiation level within an auger hole H was within reach, a soil sample was taken at that point and was analyzed for ^{226}Ra . The number N_H of pCi $^{226}\text{Ra}/\text{g}$ per cpm on the scintillation counter was determined for that point, and the average ^{226}Ra concentration A in the contaminated region was estimated by the formula $A = N_H B$, where B was the average gamma radiation intensity (in cpm) in the contaminated zone. (The contaminated zone itself was estimated from a graph showing gamma radiation intensity vs. depth.) Hence, instead of assuming that the ratios of activities of radionuclides on the entire site were nearly constant, it was assumed only that the ratios of activities of radionuclides above and below the sampling point were nearly constant.

For auger holes from which no samples were taken, the following approach was applied. Using information from sampled auger holes, a "best-fitting" curve $y = f(x)$ was determined where x is the measured scintillation probe reading and y is the measured radium concentration at the same point in the same auger hole. Then maximum and average

^{226}Ra concentrations in each unsampled auger hole were estimated using this curve and the maximum and average scintillation probe counts in the unsampled auger hole.

The methods described above were checked using loggings and ^{226}Ra analyses for core holes on the Canonsburg site. (Recall that core holes differ from auger holes in that core holes are sampled at frequent intervals.) Estimates of ^{226}Ra concentrations based on this procedure were generally correct within a factor of 2.

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APPENDIX IV

PERTINENT RADIOLOGICAL REGULATIONS, STANDARDS AND GUIDELINES

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

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

November 1976

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

1. The licensee shall make a reasonable effort to eliminate residual contamination.
2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table I prior to applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.
3. The radioactivity on the interior surfaces of pipes, drain lines, or ductwork shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or ductwork. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.
4. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated with materials in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer of premises to another organization continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such request must:
 - a. Provide detailed, specific information describing the premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.
 - b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.

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

^aWhere surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

^bAs 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.

^cMeasurements 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.

TABLE IV-1 (cont'd.)

- ^dThe maximum contamination level applies to an area of not more than 100 cm².
- ^eThe amount of removable radioactive material per 100 cm² of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.
- ^fThe 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 IV-2 or Table IV-3. (Table IV-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 IV-2

SURFACE CONTAMINATION LIMITS

The levels may be averaged* 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 ** is $2 \times 10^{-13} \text{ Ci/m}^3$ or less or for which the nonoccupational MPC *** is $2 \times 10^{-7} \text{ Ci/m}^3$ or less; includes Ac-227; Am ^w -241; -242m, -243; Cf-249; -250, -251, -252; Cm-243, -244, -245, -246, -247, -248; I-125, -129; Np-237; Pa-231; Pb-210; Pu-238, -239 -240, -242, -244; Ra-226, -228; Th-228, -230.****	100	20
Group 2: Those nuclides not in Group 1 for which the nonoccupational MPC ** is $1 \times 10^{-12} \text{ Ci/m}^3$ or less or for which the nonoccupational MPC *** is $1 \times 10^{-6} \text{ Ci/m}^3$ or less; includes Es-254; Fm-256; I-126, -131, -133; Po-210; Ra-223; Sr-90; Th-232; U-232.****	1,000	200
Group 3: Those nuclides not in Group 1 or Group 2.	5,000	1000

*See note following Table 2 on application of limits.

**MPC : 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 Part 20 Appendix B Table 2, Column 1.)

***MPC : Maximum Permissible Concentration in Water applicable to members of the public.

****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 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 1.

TABLE IV-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 * provided the maximum activity in any area of 100 cm^2 is less than 3 times the limit value.

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

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

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

- From measurements of a representative number, n, of sections, it is determined that $1/n \sum Si > L$, where Si is the dpm/100 cm^2 determined from measurement of section i; or
- On surfaces less than 1 m^2 , it is determined that $1/n \sum Si > AL$, where A is the area of the surface in units of m^2 ; or
- It is determined that the activity of all isolated spots or particles in any area less than 100 cm^2 exceeds 3L.

SURGEON GENERAL'S GUIDELINES
Part 712
Grand Junction Remedial Action Criteria

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

PART 712 - GRAND JUNCTION
REMEDIAL ACTION CRITERIA

712.1 Purpose

(a) The regulations in this part establish the criteria for determination by ERDA of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colo., to radiation emanating from uranium mill tailing which have been used as construction-related material.

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

713.2 Scope

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

712.3 Definitions

As used in this part:

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

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

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

(d) "ERDA" means the Energy Research and Development Administration or duly authorized representative thereof.

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

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

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) Averaging the results of 6 air samples, each of at least 100 hours duration, and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

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

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

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

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

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

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

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

712.4 Interpretations

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

712.5 Communications

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

712.6 General radiation exposure level criteria for remedial action

The basis for undertaking remedial action shall be the applicable

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

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

712.7 Criteria for determination of possible need for remedial action

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

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

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

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

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

(1) For dwellings and schoolrooms:

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

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

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

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

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

(2) For other structures: (i) An external gamma radiation level of 0.15 mR/hr. above background averaged on a room-by-room basis.

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

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

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

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

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

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

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

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

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

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

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

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

712.10 Selection of appropriate remedial action

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

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

ENVIRONMENTAL PROTECTION AGENCY
Title 40-Part 141
Drinking Water Regulations-Radionuclides

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

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

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

- (a) Combined ^{226}Ra and ^{228}Ra - 5 pCi/liter.
- (b) Gross alpha particle activity (including ^{226}Ra but excluding radon and uranium) - 15 pCi/liter.

APPENDIX V

EVALUATION OF RADIATION EXPOSURES
AT THE FORMER VITRO RARE
METALS PLANT

SEP 18 1978

EVALUATION OF RADIATION EXPOSURES AT
THE VITRO RARE METALS PLANT,
CANONSBURG, PENNSYLVANIA

The U. S. Department of Energy has determined that the Canonsburg Industrial Park in Canonsburg, Pennsylvania, is presently contaminated with radioactive residues resulting from previous uses of this property. Private firms extracted radium and uranium for commercial purposes during the period 1911 through 1942. Uranium recovery work for the Atomic Energy Commission was later conducted by the Vitro Corporation in the 1940's and 1950's. No work involving radioactive materials has been performed at this site for about twenty years.

Extraction of radioactive materials at the Canonsburg site apparently began on the western side of the property, and expansion from west to east was preceded by the dumping of large quantities of ore wastes. Eventually, radioactive residues containing widely varying concentrations of radium, thorium, and uranium and other naturally-occurring radionuclides were deposited at various depths over almost the entire site. It appears that all of the existing buildings are either built over, or are adjacent to, soils containing elevated quantities of radium. There are 12 occupied buildings on the 18-acre industrial park, accommodating a working population of approximately 125 full- and part-time employees, a few of whom sometimes work outdoors.

The contamination from previous operations is producing radiation exposures to employees working at this industrial park. These exposures come from two primary sources: inhalation of radon gas and its decay products which remain in air, 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 inhalation and direct gamma radiation.

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

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

Employees at the Canonsburg Industrial Park are, in many cases, receiving exposures which exceed guidelines for limiting exposure to the general public. Furthermore, although employees at this site do not perform work related to the nuclear industry, in some cases their exposures approach or exceed occupational limits established to protect nuclear industry workers. Exposures of workers at the industrial park are compared numerically with guidelines and background radiation in the accompanying Table 1.

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^a of uranium-238, one half curie will remain after 4.5 billion years. After 9 billion years, this would only be one-fourth curie of uranium-238, etc. 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 2 until stable lead-206 is formed. The "decay product" listed in Table 2 is the radiation produced as the parent decays.

Exposure from Inhalation of Radionuclides in Air

The deposits of radium-bearing residues in soil are the indirect sources of most of the radiation exposure of persons on the site. As may be seen in Table 2, radium-226 changes to radon-222 as a result of radioactive decay. Radon-222 is an inert gas which can emanate from the ground and enter buildings by diffusion through floors. If not diluted by additional ventilation air, the concentration can build up in closed areas of the buildings. As indicated in Table 1, workers on this site are exposed to average radon concentrations which are generally higher than the level suggested for continuous exposure to the general population and which range to more than three times the recommended maximum concentration for occupational exposure for radiation workers. Guidelines discussed here are those given in Federal Regulation 10 CFR 20.^b

^aA curie is a unit defined for expressing the amount of radioactivity present in a substance; one curie of uranium-238 represents 3.7×10^{10} disintegrations per second. Because of the long half-life of uranium-238, a curie is represented by 6600 pounds of that material. On the other hand, a curie of thorium-234, the daughter of uranium-238 is represented by only four one hundred thousandths of one gram due to its short half-life of 24 days.

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

Radioactive decay of radon-222 is rapid (days) and its decay gives rise to other short-lived radionuclides as shown in Table 2. Background concentrations of radon daughters both inside and outside structures are typically less than 0.01 working level (WL). (Working level is a unit used to measure the exposure for the short-lived radon daughter products; it was developed originally as a guide for exposure of uranium miners.)

The radon daughter product concentrations measured in buildings at the Canonsburg Industrial Park exceed the guide value of 0.03 WL given in Federal Regulation 10 CFR 712.^c This value is based on a recommendation of the Surgeon General for exposure to radon daughter products in structures (other than dwellings or schools) built on or with radium-bearing residues from the extraction of uranium from ores such as at the Canonsburg Industrial Park site. Workers within the buildings at the Canonsburg site are exposed to radon daughter concentrations in air that are up to 14 times higher than the guide value.

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

^cTitle 10, Code of Federal Regulations, Part 712, is a document published by the Energy Research and Development Administration (now Department of Energy) and may be found in the Federal Register.

Direct Gamma-Ray Exposure

That fraction of the radon-222 which decays before rising into the atmosphere may lead to elevated gamma radiation levels because, as shown in Table 2, some of its daughters emit gamma-rays. (Gamma-rays are a penetrating radiation like X-rays.) The maximum gamma radiation level at one meter above the floor at any point in any building was 310 microRoentgen/hour. Outdoors, the average gamma radiation levels at one meter above the ground ranged from 100 to 190 microRoentgen/hour, (when averaged over the three individual tracts of land), and the maximum external gamma level at one meter above the ground outdoors was 1600 microRoentgen/hour. For comparison, a typical chest X-ray (according to Department of Health, Education, and Welfare data) might yield an exposure of about 27,000 microRoentgen. The National Council on Radiation Protection and Measurements has recommended a maximum annual whole-body exposure of 500,000 microRoentgen/year to an individual continually exposed in the general population; this would correspond to exposure to 250 microRoentgen/hour for 2000 exposure hours. It is possible that some worker or workers on the site are receiving an average exposure from gamma radiation that is above the federal guideline for the general public although it appears that most, and possibly all, workers on the site are receiving average gamma exposures that are below this guideline. The guideline for exposure to an individual in the general public is ten times lower than guidelines established for a worker in the nuclear industry.

Other Considerations of Exposure

In almost all areas of this site, the soil is contaminated with radium-226 to the extent that radon daughter concentrations in air in structures built in these areas would exceed the Surgeon General's

guidelines. Use of this site or of the residues on this site for residential or agricultural purposes could lead to radiation exposures much more significant than those which presently exist.

At the present time, residents in the immediate vicinity of the Canonsburg Industrial Park are subject to a small increase in exposure to radon which emanates from residues on the site and which is transported in the atmosphere to areas off the site. The concentration of radon decreases quickly with distance, and results, in general, in exposures less than two times the natural background level at distances of about 200 meters from the site boundary.

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 non-smoker.

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 Canonsburg site.

The normal annual death rate from lung cancer for all population groups in Washington County (as of 1970) is 22.2 deaths per 100,000 population. At the same time, the annual death rate from lung cancer for all population groups in the United States and the state of Pennsylvania are 21.1 and 21.5 deaths per 100,000 population, respectively. A one-year exposure to the guideline value for uranium miners

(0.33 working level for 2000 hours) might increase the risk of death due to lung cancer by approximately four percent.

The annual death rate from all types of cancer among all population groups in Washington County (as of 1970) is 159 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 Pennsylvania are 151 and 160 per 100,000 population, respectively. A one-year exposure to penetrating gamma radiation of 500,000 microRoentgen might increase the risk of death due to all types of cancer by about one-tenth of a percent. Exposures in excess of these guideline values would be expected to result in proportionately higher increases in risk. Consequently, any action taken to reduce either the rate or the duration of radiation exposures would also reduce the risk attendant to that exposure.

Remedial Measures

Guidelines quoted in this paper which have been established for occupational exposure of radiation workers (who voluntarily choose employment in that industry) are based on the philosophy that the benefit to the worker (gainful employment) far outweighs any risk associated with occupational radiation exposure. Exposures to workers at the Canonsburg Industrial Park are involuntary and are unrelated to their normal jobs; no discernable benefits can be attributed to these exposures. Consequently, the risks associated with the exposures appear to be unwarranted.

A number of control measures are possible to reduce the exposure of people working at the Canonsburg Industrial Park. The most immediate

remedy is to improve ventilation in closed areas of buildings where radon and its daughter products can accumulate in stagnant air. Other measures include restricting the working time of people at the site in areas having high concentrations of radon daughter products. 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. The DOE is now actively evaluating alternatives under a priority program designed to assure adequate protection of the working population.

SUMMARY

In summary, the Canonsburg Industrial Park is contaminated with residues containing naturally occurring radionuclides. This contamination is producing radiation exposures to employees working at this site. Furthermore, these exposures approach, and in many cases exceed, scientifically-based guidelines. These employees did not knowingly incur such exposure and are receiving no benefits from their involuntary exposures to radiation; the risk of cancer may be elevated somewhat by these exposures. Consequently, remedial measures are in order. The DOE has developed a coordinated plan which addresses the specific problems at the Canonsburg Industrial Park. Currently, work is underway to implement the elements of this plan.

TABLE 1
SUMMARY OF EXPOSURE DATA AT CANONSBURG INDUSTRIAL PARK,
CANONSBURG, PENNSYLVANIA

Exposure Source	Background Levels	Guideline Value for General Public	Guideline Value for Radiation Workers	Average Levels at Canonsburg Site
Radon in air	Less than 1 picocurie ^a per liter of air	Continuous exposure to 3 picocurie per liter of air	Exposure for 40 hours to 30 picocuries per liter of air	Average daytime concentration ranged from 2.6 to 106.5 picocurie per liter of air
Radon daughters in air	Less than 0.01 "working-level" ^b	0.01 working level for residences and school rooms, and 0.03 working level for other structures.	0.33 working level for uranium miners exposed for 40 hours per week and 50 weeks per year.	Average daytime concentration ranged from 0.01 working level to 0.43 working level.
Gamma radiation from decay products of radium and uranium contamination	11 micro-Roentgens ^c per hour in the Canonsburg area.	0.5 Roentgens per year for an individual; equivalent to 250 microRoentgens per hour above natural background for 40 hours per week and 50 weeks per year.	5 Roentgens per year	Average gamma radiation levels 1 meter above the floor or ground ranged from 23 to 80 microRoentgens per hour. Some spots up to 1600 microRoentgens per hour were observed outside buildings.

^aThe picocurie is a unit which was defined for expressing the amount of radioactivity present in a substance.

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

^cThe 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.

TABLE 2
Uranium-238 decay series

Parent	Half-life	Decay products	Daughter
uranium-238	4.5 billion years	alpha	thorium-234
thorium-234	24 days	beta, gamma	protactinium-234
protactinium-234	1.2 minutes	beta, gamma	uranium-234
uranium-234	250 thousand years	alpha	thorium-230
thorium-230	80 thousand years	alpha	radium-226
radium-226	1600 years	alpha	radon-222
radon-222	3.8 days	alpha	polonium-218
polonium-218*	3 minutes	alpha	lead-214
lead-214*	27 minutes	beta, gamma	bismuth-214
bismuth-214*	20 minutes	beta, gamma	polonium-214
polonium-214*	$\frac{2}{10,000}$ second	alpha	lead-210
lead-210	22 years	beta	bismuth-210
bismuth-210	5 days	beta	polonium-210
polonium-210	140 days	alpha	lead-206
lead-206	stable	none	none

*Short-lived radon daughters.