Formerly Utilized MED/AEC Sites Remedial Action Program

Radiological Survey of the St. Louis Airport Storage Site, St. Louis, Missouri

September 1979

Final Report

Prepared for

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

Available from:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price: **Printed Copy:** $ 7.25
Microfiche: $ 3.00

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 Engineer 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 decontamination work done at the time nuclear activities ceased is adequate by current guidelines.

This report contains the results of a radiological survey to determine the current radiological conditions at the former St. Louis Airport Storage Site, St. Louis, Missouri.

The report further documents the present radiological condition at the St. Louis Airport Site within the realm of today's sophisticated instrumentation and the impact on any future area development.

The results of this survey indicate that there are elevated levels of one or more radionuclides in both the on and off site environments. Therefore, based on the results of this survey and previous radiological data remedial measures should be considered to preclude any future concern of inadvertent radiation exposure to people.

The work reported in this document was conducted by the following members of the Health and Safety Research Division, Oak Ridge National Laboratory, Oak Ridge, Tenn:

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ABSTRACT

The results of two radiological surveys of the St. Louis-Lambert Airport property, formerly known as the Atomic Energy Commission (AEC) Airport Storage Site, St. Louis, Missouri, are presented in this report. These surveys were conducted over the 21.7-acre area on which uranium- and radium-bearing waste materials were stored from the 1940's to the late 1960's. The surveys included direct measurements of beta-gamma radiation at the ground surface and external gamma radiation at 1 m above the ground throughout the site and adjacent drainage systems; determination of uranium, actinium, and radium concentrations in samples of soil from the surface and from holes bored at locations on and near the site; determination of radionuclide concentrations in groundwater and surface water samples; measurement of radon flux from the ground surface; and measurements of ^{222}Rn in air at accessible locations nearest the site. The second (or followup) survey was designed to support an environmental characterization survey and to provide a basis for comparison of changes in site conditions associated with known changes in topography. Results of these surveys indicate that some offsite drainage pathways are becoming contaminated, probably by runoff from the site; no migration of ^{222}Rn from the site was observed.

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*Research sponsored by the Division of Environmental Control Technology, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

INTRODUCTION

At the request of the Department of Energy (DOE), (then the Energy Research and Development Administration – ERDA), Oak Ridge Operations, a radiological survey was conducted at the St. Louis-Lambert Airport property, St. Louis, Missouri. This 21.7-acre tract of land is bordered on the north and east by Brown Road, on the south by the Norfolk and Western Railroad, and on the west by Coldwater Creek (see Fig. 1). The site was used as a storage area for residues generated by the Mallinckrodt Chemical Works during their uranium-processing operations from 1946 to 1953. Some contaminated rubble was known to have been buried in the western end of the site. An inventory of the materials and their approximate uranium content is given in Table 1. Also given in this table is a list of the original structures and other facilities on site. This inventory was made as a part of a radiological survey conducted by the U.S. Atomic Energy Commission (AEC) in November of 1965 prior to the removal of the residue piles and disposal of structures. Since that time, access to the site has been controlled by the Airport Manager, thus barring casual entry.

During 1966 and 1967 the residues were sold and removed from the site. Except for the area where barium sulfate residues (referred to as "airport cake" or AJ-4 residues) were located, the removal of residue piles restored all areas to a condition where the radiation level at the ground surface was less than 1 mrad/hr. In the AJ-4 area, the surface beta-gamma dose rate was about 3 mrad/hr due to residual contamination.[1] As stated in the acquisition permit of November 10, 1969, the St. Louis-Lambert Airport Authority agreed to decontaminate this property. In an

agreement with the U.S. Government, it was required that the barium sulfate residue be removed to an abandoned quarry at Weldon Springs, Missouri, and that all structures on site except the fence be razed. Building rubble which was to be buried onsite included a storage shed, truck wash pad, and a concrete storage pit. Also, a minimum of one foot of clean fill was to be placed over the entire site. This work was performed,[2] and in December 1969, a radiation survey[3] was made according to the criteria stated in Appendix II of the acquisition permit. During this survey, eleven areas (ranging in size from 10 ft^2 to 50,000 ft^2) were found where gamma radiation levels exceeded 1 mR/hr. Additional fill (2 to 3 ft) was placed over these areas to achieve acceptable radiation levels.[2] Clean fill elevations were then described by a topographical survey conducted in October 1971.[2] Subsequently, a radiation survey was conducted in November 1971 to document the radiological condition of the entire site.[2] It was found that ground surface dose rates were generally less than 0.05 mrad/hr; certain isolated areas which exceeded 0.2 mrad/hr were documented; no readings exceeded 1.0 mrad/hr.

The present survey was performed to characterize the existing radiological status of the property. It was conducted by members of the Health and Safety Research Division of the Oak Ridge National Laboratory during the weeks of November 14, 1976 and August 28, 1978. The earlier survey included the following measurements:

1) beta-gamma dose rates at 1 cm above the surface and external gamma radiation levels at the surface and at 1 m above the surface throughout the site and at selected off-site locations;

2) concentrations of ^{226}Ra, ^{238}U, and ^{227}Ac in surface and subsurface soil on and off the site;

3) concentrations of ^{226}Ra, ^{238}U, ^{230}Th, and ^{210}Pb in Coldwater Creek and in groundwater on site;

4) gamma radiation levels at various depths in auger holes drilled on the site, as a means of estimating the ^{226}Ra concentrations at these locations; and

5) external gamma radiation levels at 1 m above the surface and concentrations of radionuclides in surface soil at selected background locations within the state of Missouri.

The follow-up survey conducted in 1978 was designed to provide supplementary data to an environmental survey* conducted simultaneously and to provide a basis for comparison between site conditions in 1976 and the present. The later survey included the following measurements:

1) rate of emanation of ^{222}Rn from the ground surface;

2) concentration of airborne ^{222}Rn at selected off-site locations;

3) radionuclide concentrations in soil and water in drainage pathways adjacent to the site;

4) gamma radiation levels at various depths in auger holes drilled on and off the site as a means of estimating the ^{226}Ra concentrations at these locations; and

5) concentrations of ^{238}U, ^{230}Th, ^{226}Ra, and ^{210}Pb in groundwater taken from holes drilled on and off the site.†

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*Performed by Weston Environmental Consultants, West Chester, Pennsylvania.

†Analyses performed by Radiation Management Corporation, Philadelphia, Pennsylvania.

RADIOLOGICAL SURVEY TECHNIQUES

Measurement of Beta-Gamma Dose Rates and Gamma Radiation Levels

The entire site was divided into 100 ft × 100 ft "survey blocks" by the rectangular grid system shown in Fig. 2. During the 1976 survey, a 50-ft grid system was used at the west end of the site as shown in Fig. 2. Furthermore, the earlier survey also used a fine grid system shown in Fig. 3; this fine grid system covered an area of about 47,500 ft^2 where contaminated materials are known to be buried.

Beta-gamma dose rates were measured 1 cm above the ground surface using a Geiger-Mueller (G-M) survey meter (described in Appendix I). Gamma radiation levels were measured at 1 m above the surface by means of a portable gamma scintillation (NaI crystal) survey meter (described in Appendix I). All direct survey meter readings reported in this document represent gross readings; background radiation levels have not been subtracted. Similarly, background levels have not been subtracted from radionuclide concentrations measured in environmental samples.

During the 1976 survey, beta-gamma dose rates and gamma radiation levels were measured at the grid points shown in Fig. 2. Each block of the fine grid system shown in Fig. 3 was scanned using the scintillation survey meter. Beta-gamma dose rate readings were taken at the points where the gamma radiation level was a maximum inside each block. During the 1978 survey, beta-gamma dose rates and gamma radiation levels were measured at the numbered locations shown in Fig. 4; these locations were all outside the controlled access area of the site.

Surface Soil Sampling

In 1976, surface soil samples from a depth of 0 to 1 inch were taken at grid points approximately 100 to 150 ft apart west of R 15+00, at grid points approximately 200 to 300 ft apart east of R 15+00, and at five points where insectivore* activity was noted. In addition, 15 samples were taken along the property line bordering Brown Road. Except for the five samples taken at insectivore holes, surface sampling was done systematically; sampling locations were not influenced by radiaton levels or other biasing factors.

Each sample was packaged in plastic bags for transport to Oak Ridge where they were dried for 24 hours at 110°C and pulverized to a particle size of 35 mesh (500 μm). Aliquots from each sample were transferred to 12 plastic bottles (25 ml), weighed, and counted using a Ge(Li) detector. The spectra obtained were analyzed by computer techniques. A description of the Ge(Li) detector and the soil counting techniques is given in Appendix II. Concentrations of ^{226}Ra, ^{238}U, and ^{227}Ac were determined for all samples.

In the 1978 survey surface soil samples were taken at random locations shown in Fig. 5. These samples were analyzed for ^{238}U and ^{226}Ra.

Subsurface Soil Sampling

Holes were drilled with a motorized rig at the locations shown in Fig. 6 in the 1978 survey. An 8-in. diameter auger was used to drill to depths between 15 and 33 ft. A plastic pipe with a 4-in. inside 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 horizontal row of narrow collimating slits on the side. This arrangement

*Moles, shrews, etc.

allowed measurements of gamma radiation intensities resulting from contamination within small fractions of the hole depth. Measurements were usually made at 6-in. or 1-ft. intervals. This "logging" of the core holes was done in order to define the profile of radioactivity underground and 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. A sample of potentially contaminated material was removed from the auger turnings for each hole and was returned to ORNL for analysis of ^{226}Ra and ^{238}U.

In the 1976 survey, in addition to the hole loggings, soil samples were collected using Shelby tube samplers at 8 of the 16 core hole locations. Concentrations of ^{226}Ra, ^{238}U, and ^{227}Ac were determined for these samples.

Measurement of the Flux of ^{222}Rn

Since activated charcoal readily adsorbs ^{222}Rn, an estimate of the radon flux from ground surfaces was obtained by placing canisters containing charcoal in direct contact with the ground (see ref. 4). After a period of exposure which ranged from one to two days, the canisters were removed, and the radon daughters were allowed to achieve equilibrium. The amount of radon adsorbed on activated charcoal canisters was determined by counting the gamma emissions from ^{214}Pb and ^{214}Bi using a 3 × 3-in. NaI scintillation detector coupled to a multichannel pulse height analyzer.

In the 1978 survey, canisters were distributed uniformly over the site. These modified U.S. Army M-11 gas mask canisters were twisted

into the soil to a depth of 1 cm and sealed with additional soil. A total of 10 canisters was used (see Fig. 6). These individual readings were then used to estimate the average rate of emanation of ^{222}Rn over the entire site.

Groundwater Sampling

In 1976 corings were made at 6 grid locations to a depth where groundwater was reached. At each location a 2-liter water sample was collected. These samples were analyzed at ORNL using sequential separation techniques to determine ^{238}U, ^{226}Ra, and ^{230}Th concentrations. Eight additional groundwater samples were collected in the 1978 survey. These samples were analyzed by Radiaton Management Corporation, Philadelphia, Pennsylvania, for ^{238}U, ^{226}Ra, ^{230}Th, and ^{210}Pb.

Additional Offsite Sampling and Analysis

In the 1976 survey, four water samples were taken from Coldwater Creek, which borders the west side of the site. A sample of sediment was taken from the bed of Coldwater Creek at each of the locations used for sampling water. Each sediment sample was prepared and analyzed using the soil sample analysis techniques described before. The creek water samples were analyzed using the same sequential separation techniques as for the groundwater samples. Gamma radiation levels were measured at 1 m above the creek bed at each sampling point.

Along each side of Brown Road are drainage ditches which carry runoff water westward into Coldwater Creek. The ditch adjacent to the south side of Brown Road serves as a drainage path for the former AEC storage site. This ditch is connected to the drainage ditch on the north side of the road by two culverts. The south side of the site is

drainecd by a ditch which borders the Norfolk and Western Railroad track and which also drains into Coldwater Creek (see Fig. 1).

In 1976, gamma radiation levels at 1 m and beta-gamma dose rates at 1 cm were averaged over areas of 1 m^2 centered at selected points along these drainage pathways. Also, surface soil samples were taken at five locations in the ditch north of Brown Road, and two Shelby-tube samples were taken in the ditch south of Brown Road.

In the 1978 survey, in addition to the offsite samples previously mentioned, high volume air samples were collected and the radon concentration in air was measured at the locations shown in Fig. 5. Radon concentration measurements were made using Wrenn Chambers.[5] This instrument is described in Appendix I. Filters used in the high volume air sampler were returned to ORNL and analyzed for a variety of long-lived airborne radionuclides.

On April 14, 1979, a stream sampling program was conducted in Goldwater Creek and all drainage pathways from the site. Continuous rainfall for ten hours preceeding the sampling had produced a total of 0.25 in. of precipitation. Consequently, all three drainage pathways from the site contained flowing water. Water and sediment samples were obtained from the drainage pathways and from Coldwater Creek; these samples were analyzed for a variety of radionuclides.

SURVEY RESULTS

Background Measurements

Samples of surface soil were collected at ten locations throughout Missouri as shown in Fig. 7. This material was returned to ORNL for

analysis using gamma-ray spectrometry techniques. Results of these analyses are given in Table 2. It was observed that the concentration of ^{226}Ra ranged from 0.3 to 1.3 pCi/g. The average ^{226}Ra concentration was 1.05 pCi/g with a standard deviation of 0.3 pCi/g. The range in values for ^{232}Th was 0.3 to 1.3 pCi/g; and for ^{238}U, the range was 0.3 to 1.7 pCi/g.

Background external gamma radiation levels at 1 m above the ground were measured at 4 points within 5 miles of the site. The measurements ranged from 7 to 9 μR/hr and averaged 8 μR/hr.

Background external gamma radiation levels were also measured throughout the state of Missouri at the soil sampling locations shown in Fig. 7. The average of these measurements was 6 μR/hr; the standard deviation (0) was 1.7 μR/hr.

Background beta-gamma dose rates, as measured with the G-M survey meters used on this site, typically average approximately 0.02 mrad/hr. It should be pointed out that readings at typical background levels cannot be accurately reproduced using the G-M survey meter.

As stated earlier, 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.

Surface Soil Analyses

Locations at which on-site surface soil samples were collected and the results of gamma-ray spectrometry analyses of these samples are listed in Table 3. These surface soil samples have been divided into

four groups: those taken at certain grid points used for beta and gamma-ray measurements (samples 1 through 49); those taken along a fence bounding the north side of the property (samples F1 through F15); those collected in areas excavated by insectivores (V1 through V5); and those collected in drainage ditches north and south of Brown Road (B1 through B5 and LAOS 52 through LAOS 66). The LAOS samples were taken during the 1978 survey, all others were taken during the 1976 survey.

Concentrations of ^{226}Ra, ^{238}U, and ^{227}Ac in these samples are listed in Table 3. Much of the surface soil at grid points inside the fence boundary was found to contain normal terrestrial concentrations of ^{226}Ra and ^{238}U. However, there were several grid points where the concentration of ^{226}Ra exceeded the maximum ^{226}Ra concentration observed in Missouri background samples. The range of elevated values was from approximately 1.4 pCi/g to 78 pCi/g (see samples 1 through 49 in Table 3). The highest concentration of ^{238}U in samples 1 through 49 was 260 pCi/g.

None of the background samples contained measurable quantities of ^{227}Ac, daughter of ^{231}Pa. However, ^{227}Ac was found at 18 of the 49 grid sampling locations with a range of 0.5 to 77 pCi/g. The source of the ^{227}Ac is linked to a precipitate formed in a column where uranium was stripped from diethyl ether using dilute nitric acid. This precipitate was, on occasion, removed from the column by a Sperry Filterpress.[1] This "Sperry cake" was found to be a good source of ^{231}Pa and, hence, of its daughter ^{227}Ac. The largest concentration of this radionuclide, 1100 pCi/g, was found near the area where barium sulfate cake ("airport cake") had been stored. Also, a ^{227}Ac concentration of 77 pCi/g was observed in an area where pitchblende raffinate (AM-7) had been stored.

In the 1976 survey, surface soil samples were also collected at five locations where insectivores had burrowed into the site. One such sample, V5, barely outside the fence (S5+25/R10+50), contained 1300, 420, and 1100 pCi/g, respectively of ^{226}Ra, ^{238}U, and ^{227}Ac. These concentrations of ^{226}Ra and ^{227}Ac were the highest observed among all surface soil samples. These surface samples biased by insectivore activity were all collected along the fence line at the north side of the property. Erosion of fill earth was apparent along this fence line. Insectivores have tunneled extensively in this area, and some of the excavated soil had been brought to the surface. The contamination of this excavated dirt is obvious only in sample V5. Insectivore activity did not extend more than 10 ft from any point along the fence.

In contrast to the 49 surface soil samples collected within the fenced confines of the site, practically all of the 35 samples collected outside the fenced area had elevated levels of one or more radionuclides. These samples were collected from the drainage ditches north and south of Brown Road. The range of ^{226}Ra activity in samples outside the fence but south of Brown Road ranged from 1.5 to 460 pCi/g; ^{238}U ranged from 2.6 to 890 pCi/g; ^{227}Ac ranged from less than detectable quantities to 290 pCi/g. The drainage ditch north of Brown Road had ^{226}Ra concentrations ranging from 1.4 to 120 pCi/g; ^{238}U from 3.0 to 72 pCi/g, and ^{227}Ac from less than detectable to 160 pCi/g.

Subsurface Soil Analyses

In the 1978 survey, 34 holes were drilled at random locations for the determination of subsurface contamination levels. By choosing the locations in a random manner, the results obtained may be regarded as

being truly representative of existing conditions at the site. Estimates of maximum subsurface radium concentrations as a function of depth are given in Table 4. A combination of soil sample analyses and scintillation probe "loggings" was used to estimate these concentrations. Graphs of the count rates as measured using the shielded scintillation probe vs. depth permit an accurate estimation of the depth at which the maximum ^{226}Ra concentration occurs and the thickness of the contaminated layer. Estimates of the depth of the contaminated zone and the average radium concentration within this zone are also given in Table 4.

The gamma-ray logging technique used during this survey is not specific for a given nuclide. However, some comparisons have been made between observed response of the gamma-ray logging probe and measured ^{226}Ra concentrations in soil taken from points corresponding to gamma-ray measurements. It is thus possible to make an estimate of the thickness of contaminated layers underground. The techniques used in estimating the depth and extent of contamination are explained in Appendix III.

At each of the cored holes, soil samples were taken from auger turnings removed from the contaminated zone or from the side of the hole. The concentrations of ^{238}U and ^{226}Ra in these samples are presented in Table 5.

In the 1976 survey, sixteen holes were drilled for the determination of subsurface contamination levels. Eleven of the holes (hole numbers 1 through 10 and hole number 14) were drilled in the areas of elevated gamma radiation levels observed during the 1969 AEC survey.[3] The remaining five holes were drilled near the perimeter of the site, in or near the areas on the site where highest radiation levels were measured during

the survey. Since selection of drilling locations were biased by surface radiation levels, radionuclide concentrations measured in samples taken from these holes should not be considered representative for the site. Rather, this exploratory drilling was done in an effort to find highest radionuclide concentrations in subsurface soil. Results from drilling in the 1978 survey are representative of the conditions at the site.

At 7 of the 16 cored holes in the 1976 survey, soil samples were taken for radionuclide analysis. Concentrations of ^{238}U, ^{226}Ra, and ^{227}Ac in these biased samples are given in Table 6. Estimates of ^{226}Ra concentration based on gamma logging of these 16 cored holes are given in Table 7.

External Beta-Gamma Dose Rates

The average beta-gamma dose rate at 1 cm above the surface in the 1976 survey was 0.05 mrad/hr with a range of 0.02 to 0.34 mrad/hr at grid points in the 100-ft grid area east of grid line R 15+00 (Fig. 2); 0.05 mrad/hr with a range of 0.02 to 0.23 mrad/hr at grid points in the 50-ft grid area west of grid line R 15+00 (Fig. 2); and 1.5 mrad/hr with a range of 0.24 to 4.6 mrad/hr within the fine grid blocks shown in Fig. 3. Each beta-gamma dose rate reported for the 50 and 100 ft- grid points represents the average of several readings taken over an area of 1 m^2 centered at the grid point. The beta-gamma dose rates reported for the fine grid blocks represent readings taken within each grid block in Fig. 3. Beta-gamma measurements made within the fenced area at grid points in Figs. 2 and 3 are given in Tables 8 and 9.

Beta-gamma dose rates were measured outside the fenced confines in three main areas: between the fence and Brown Road (Table 10); north of

Brown Road (Table 11); and south of the site between fence and railroad tracks (Table 12). As may be seen in these tables, surface beta-gamma dose rates were elevated in drainage areas north and south of Brown Road, ranging up to 0.34 and 1.6 mrad/hr, respectively. On the other hand, no reading exceeded 0.06 mrad/hr in the drainage area between the site's south fence and the railroad tracks.

External Gamma Radiation Levels

The average external gamma radiation level at 1 m above the surface in the 1976 survey was 16 μR/hr with a range of 4 to 71 μR/hr at grid points in the 100-ft grid area (Fig. 2); 14 μR/hr with a range of 5 to 43 μR/hr at grid points in the 50-ft grid area (Fig. 2); and 113 μR/hr with a range of 23 to 300 μR/hr within the fine grid area (Fig. 3). Detailed gamma radiation measurements for these grid points are given in Tables 8 and 9.

The numerous gamma radiation measurements which were made outside the fenced area are given in Tables 10, 11 and 12. Gamma radiation levels between the fence and Brown Road averaged 65 μR/hr and ranged up to 330 μR/hr (the highest reading obtained in these surveys) as shown in Table 10. Readings obtained north of Brown Road are listed in Table 11; these yielded an average 1-m exposure of 58 μR/hr. Measurements made south and west of the site fence are shown in Table 12; these range to values no higher than 20 μR/hr. The gamma radiation measurements at the north and south outfalls were made on the east bank of Coldwater Creek during the 1976 survey. It was noticed that the creek and both banks contained a large amount of discarded items such as 55-gal drums, tires, washing machine tubs, and various forms of scrap metal. The debris

was surveyed with a gamma scintillation survey meter; no contamination by radioactive material was observed. Water in the creek had a noticeable oil layer as did the creek bed. There was evidence of erosion of fill material at both the north and south outfalls.

It may be noticed that at some locations, such as S3+00/R4+00, the gamma radiation level at 1 m was higher than the corresponding beta-gamma dose rates measured at 1 cm above the surface. This anomaly is attributed to the abrupt changes in ground elevation. These abrupt changes, particularly in the ditches north and south of Brown Road, invalidate usual assumptions about a detection point above a flat, infinite, planar source.

Measurement points 69 and 72 which exhibit elevated gamma radiation levels in Table 11 (Fig. 4) lie about 10 ft above the other points exhibiting elevated gamma radiation. These points are along the north edge of Brown Road above the ditch where other readings were taken; a 16-in. diameter natural gas main lies below these measurement points.

Results of Radon Emanation Measurements

The rate of emanation of ^{222}Rn from ground surfaces was measured using the charcoal canister technique described in the "Radiological Survey Techniques" section. Canister locations are shown in Fig. 6; results are presented in Table 13. The average rate of emanation measured for this site is 6.3 pCi/m^2 sec. Canisters 9 and 41 could be considered as representative of the background emanation rate. It is believed that the presence of grass and roots below canister 41 may have biased this result to be lower than the actual rate. Wilkening[6] found a world-wide average ^{222}Rn emanation rate of 0.42 pCi/m^2 sec.

Concentrations of ^{222}Rn in Air

A summary of measurements of the outdoor concentration of ^{222}Rn in air is given in Table 14; locations are shown in Fig. 5. Only the Wrenn Chamber located south of the site was predominantly downwind from the site during measurements. The north location was predominantly upwind; east and west locations were predominantly crosswind.

The annual average concentrations of radon as a function of distance and direction were estimated using techniques given by Haywood et al.[7] Results are given for off-site locations in Table 15; for selected on-site locations see Table 16. These estimates indicate that measurements around the site should not be appreciably different in any direction from the site.

Concentrations of Long-Lived Radionuclides in Air

Sampling for airborne particulate matter was conducted simultaneously with the ^{222}Rn sampling. Results are shown in Table 17. General wind patterns were comparable for those described for the radon measurements. Also shown in Table 17 are the more restrictive concentration guides from 10 CFR 20 Appendix B[8] for airborne radionuclides.

Estimated annual average concentrations of airborne radionuclides at a point on-site 50 ft north of the site center are given in Table 18. These concentrations were estimated by using resuspension rates recommended by Healy[9] for wind and mechanical resuspension of particulates. Dispersion was similar to that used for radon; it was assumed that there was no plume depletion by deposition of particulates.

As may be seen in Table 18, estimated concentrations of airborne radionuclides on site will be less than 10 CFR 20[8] guidelines for continuous exposure. It was assumed that the site is undergoing mechanical

resuspension for 5% of the year. Since site access is restricted, this assumption may be unrealistically conservative.

Radionuclides in Surface and Groundwaters

Results of radionuclide analysis of water samples collected in the April 1979 stream survey are given in Table 19. Stream samples collected downstream of the site do not contain appreciably higher concentrations of radionuclides than those samples collected upstream. Although the water samples from the ditches had ^{226}Ra, ^{238}U, and possibly ^{210}Pb concentrations higher than background, all concentrations were at least an order of magnitude below the guidelines given in 10 CFR 20.[8] Although no specific analyses were performed for chemical pollutants, a noticeable oil sheen was present on Coldwater Creek between Banshee Road and Brown Road.

Sediment samples from the stream bed were also collected during the April 1979 survey. Results of analyses of these samples are shown in Table 20. No upstream sediment sample from Coldwater Creek had ^{226}Ra, ^{227}Ac, or ^{238}U concentrations appreciably different from background. However, sediments from the drainage ditches did contain slightly elevated levels of these radionuclides.

Results obtained from water and sediment samples collected during the 1976 survey are shown in Table 21. These results are compatible with those obtained in 1979. Furthermore, results from water samples taken during the 1978 survey, shown in Table 22, are also similar. All these results indicate that no detectable increase in radionuclide content of water or sediment in Coldwater Creek can be attributed to runoff from the Airport Storage Site.

Groundwater samples were obtained from drilled holes during both the 1976 and 1978 surveys. Analytical results are shown in Table 23. No sample contained a concentration of ^{238}U, ^{230}Th, ^{226}Ra, or ^{210}Pb in excess of guidelines given in 10 CFR 20.[8]

SITE TOPOGRAPHY

As an adjunct to the 1976 radiation survey and at the request of ERDA, a topographical survey was made on January 4, 1977. The purpose of obtaining elevations on the site was to determine whether there had been a change in the surface contour since the previous topographic survey in 1971. Results of the survey are presented in Fig. 8. Results of this topographic survey indicate that numerous points onsite are at lower elevations than in 1971; in some cases, the surface in 1977 was 2 ft below the 1971 elevation.

Since the 1977 survey, numerous truck loads of clean fill dirt and concrete highway rubble have been deposited on the site by the St. Louis Police Academy. Changes in surface contour between 1976 and 1978 are shown clearly in the aerial photos shown in Fig. 9.

SUMMARY

Almost half of the 49 surface soil samples taken at grid points within the fenced area contained normal terrestrial concentrations of ^{226}Ra, ^{238}U, and ^{227}Ac. The maximum concentration of ^{226}Ra was 78 pCi/g; ^{238}U-260 pCi/g; ^{227}Ac-77 pCi/g. In contrast, practically all the 35 surface soil samples collected in the drainage ditches north and south of Brown Road had elevated levels of one or more radionuclides. The maximum offsite ^{226}Ra concentration in these ditches was 460 pCi/g; ^{238}U-890 pCi/g; ^{227}Ac-290 pCi/g. Contamination of these ditches appears

to be the result of surface water erosion of contaminated material from the site.

Subsurface contamination was found at depths to 19 ft in holes drilled onsite. Offsite contamination of ditches appears to be confined to soil within a few inches of the surface.

Elevated gamma radiation levels were found at both onsite and offsite locations. The average gamma radiation level (at 1 m) inside the fenced area was about 15 μR/hr; in the ditches north of the site the average gamma level was about 60 μR/hr. These ditches are accessible to the general public; the site is not accessible. The maximum level observed inside the fenced area was 300 μR/hr; maximum in the ditches was 330 μR/hr.

Surface beta-gamma dose rates as high as 4.6 mrad/hr were measured within the fenced area. A maximum of 1.6 mrad/hr was found in the ditches north of the site. Currently applicable guidelines for surface contamination and other radiological parameters are given in Appendix IV.

The emanation of ^{222}Rn from the surface of the site was observed to be about 15 times the flux considered to be a world-wide average value. However, measurements and calculations indicate that off-site ^{222}Rn concentrations are not influenced to any extent by the Airport Storage Site.

Radionuclide concentrations in air and water samples were far below guidelines given in 10 CFR 20. Concentrations of radionuclides were above background only in storm water runoff in the ditches draining the site and in groundwater samples taken from holes drilled onsite. Radionuclide migration does not appear to be occurring as a result of groundwater movement. Surface water migration of radionuclides appears

to be occurring in the drainage ditches bordering the site; Coldwater Creek is not transporting activity away from the site at this time.

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

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8. *Standards for Protection Against Radiation*, U.S. Code of Federal Regulations, Title 10, Part 20 (April 30, 1975).

9. J. W. Healy, *A Proposed Interim Standard for Plutonium in Soils*, LA-5483-MS, Los Alamos Scientific Laboratory (January 1974).

ORNL-Photo 1821-77A

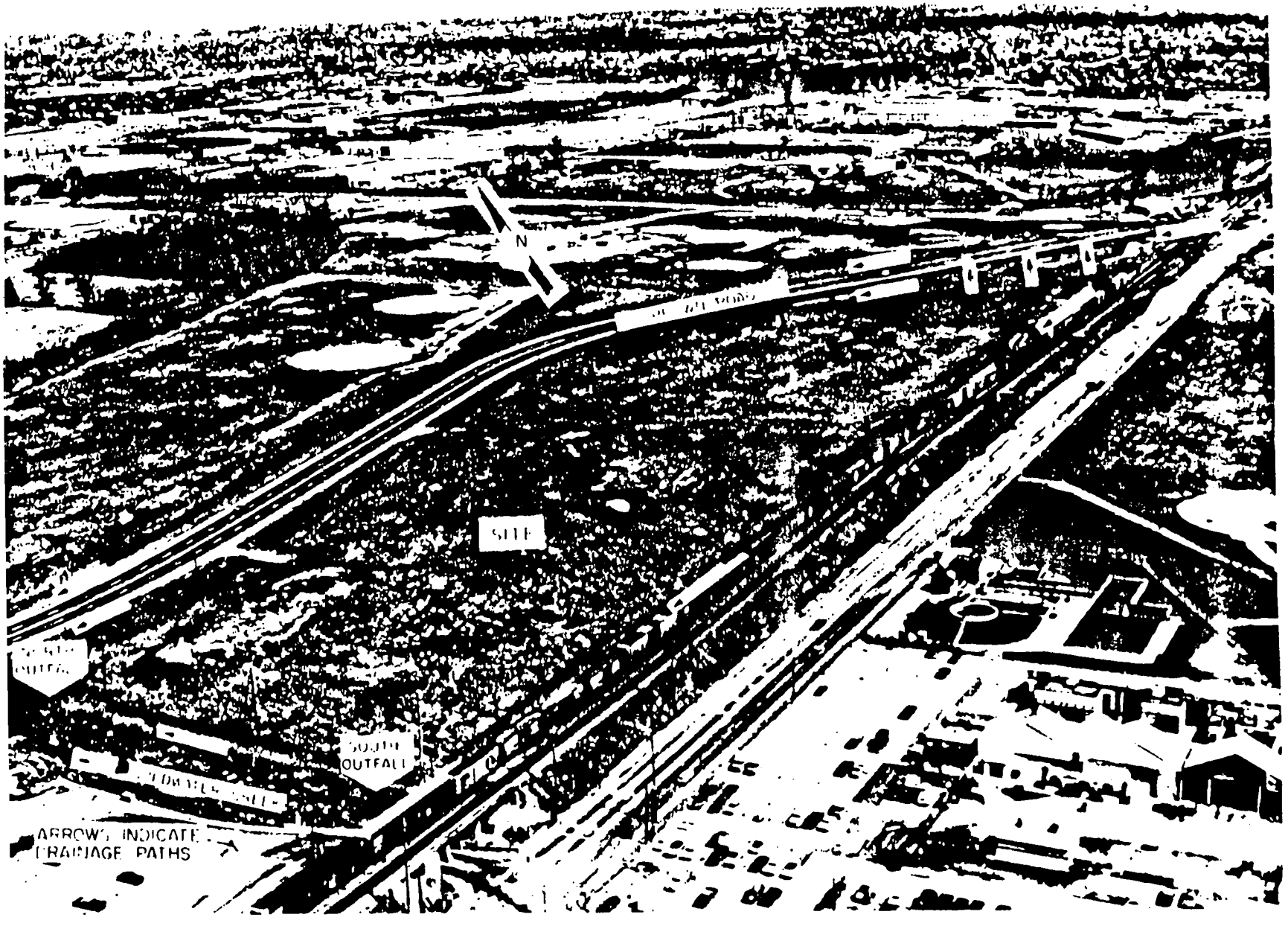


Fig. 1. Aerial view of Former AEC Storage site, St. Louis, Missouri.

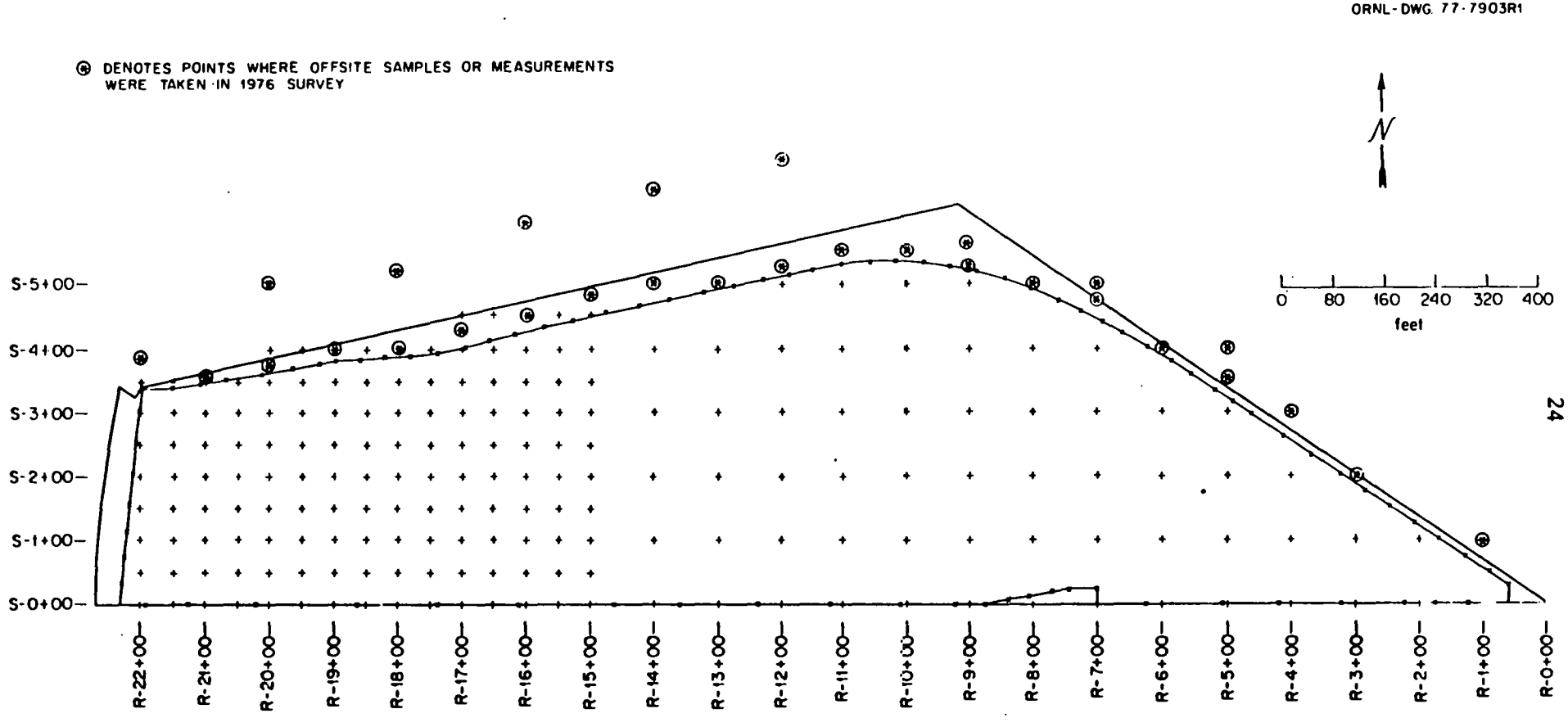


Fig. 2. Grid locations used for survey measurements at Former AEC Storage site.

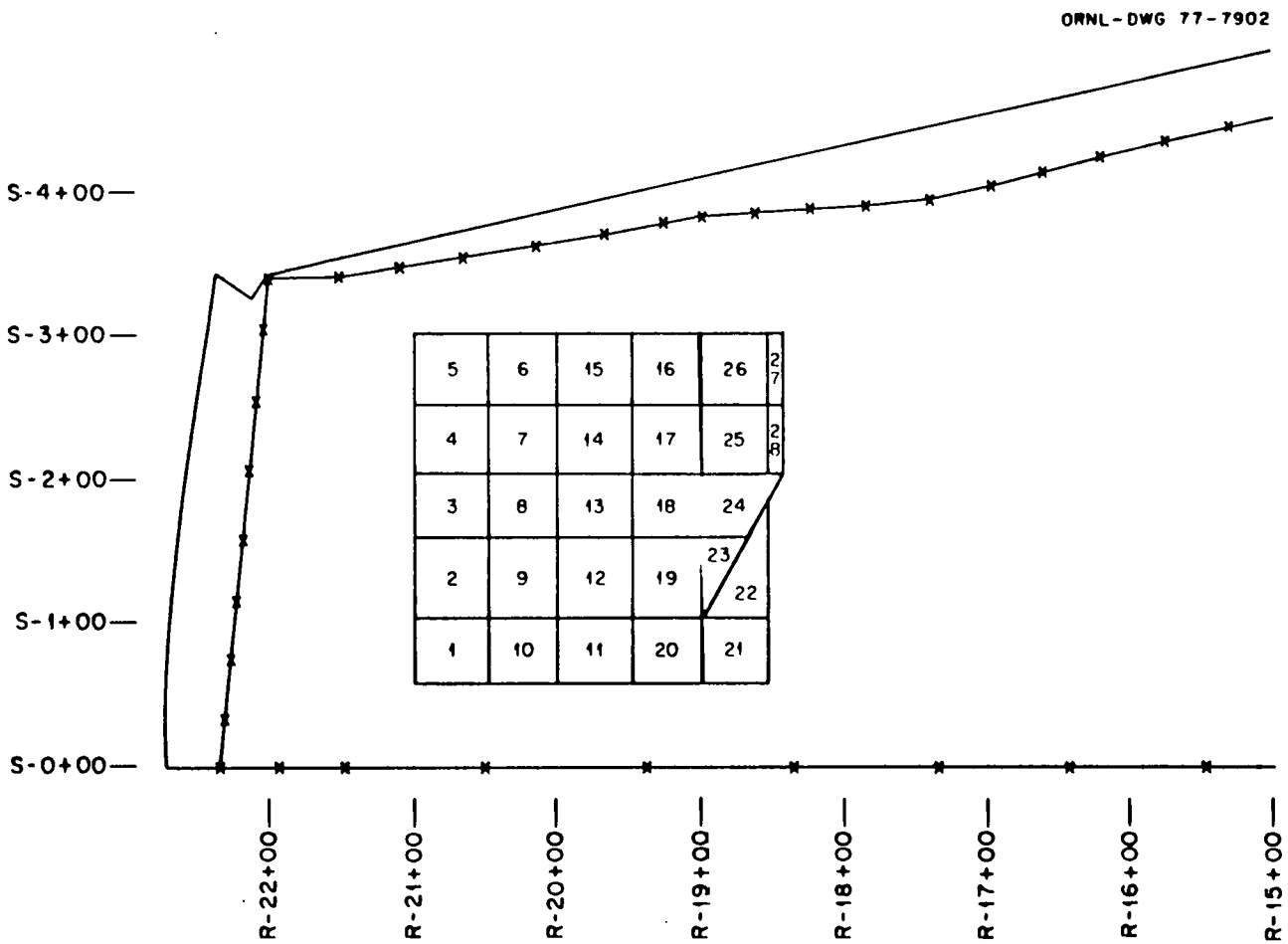


Fig. 3. Survey grid blocks in west end of Former AEC Storage site.

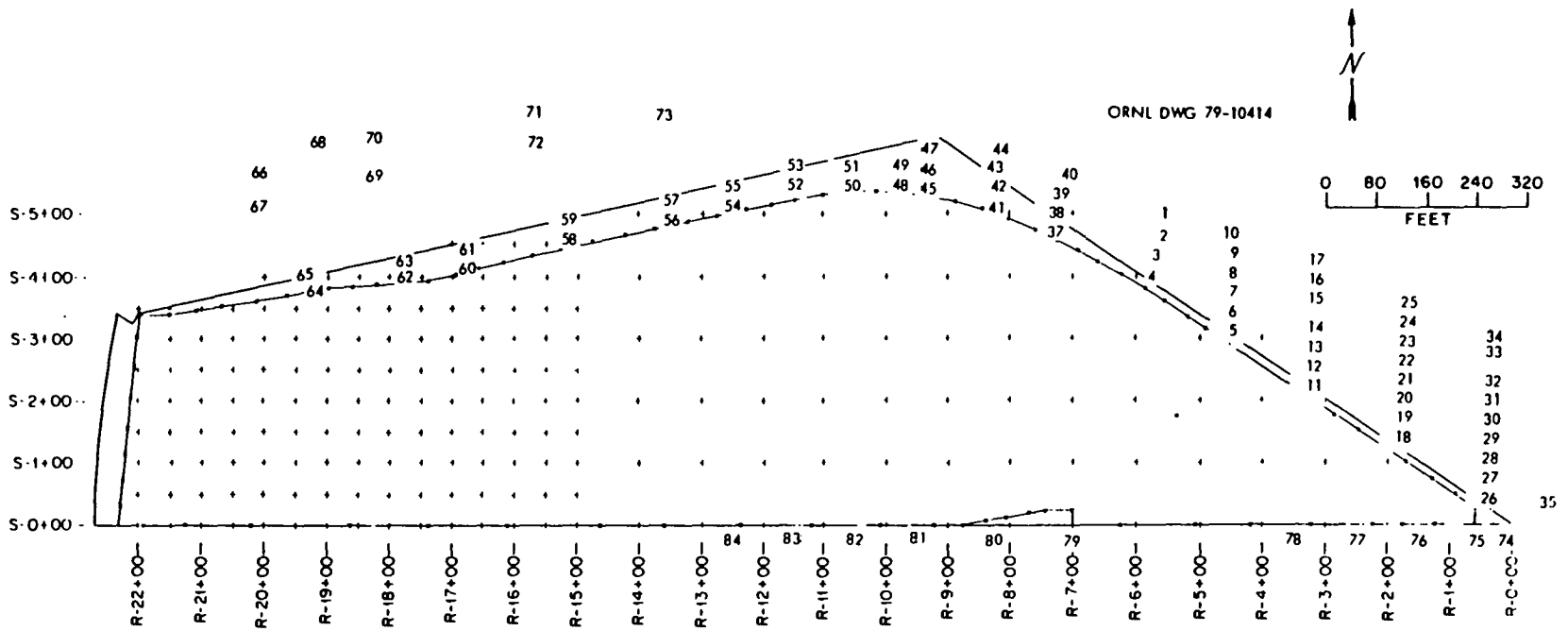


Fig. 4. Location of points where beta-gamma dose rate and gamma radiation level measurements were made during the 1978 survey.

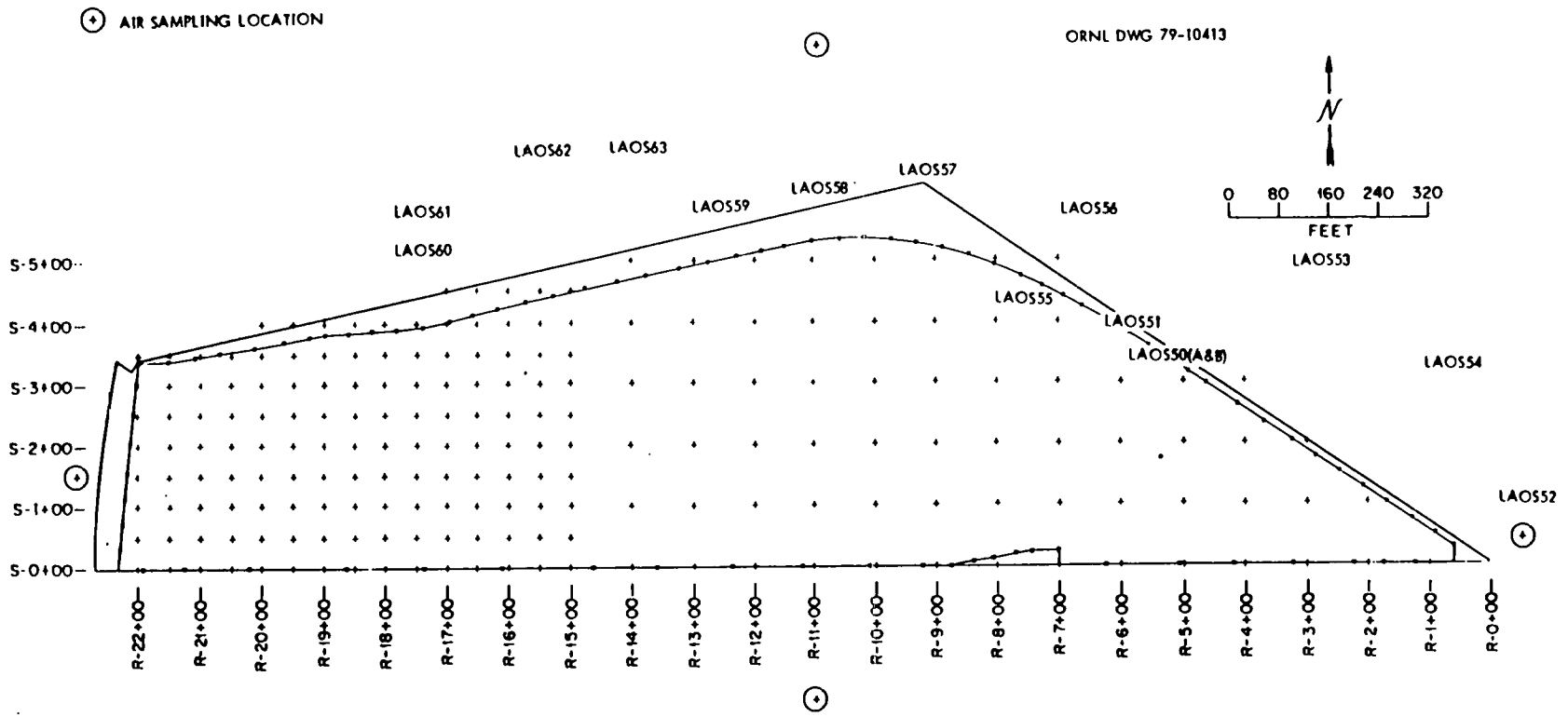


Fig. 5. Off-site soil sample and radon monitoring locations used in the 1978 survey.

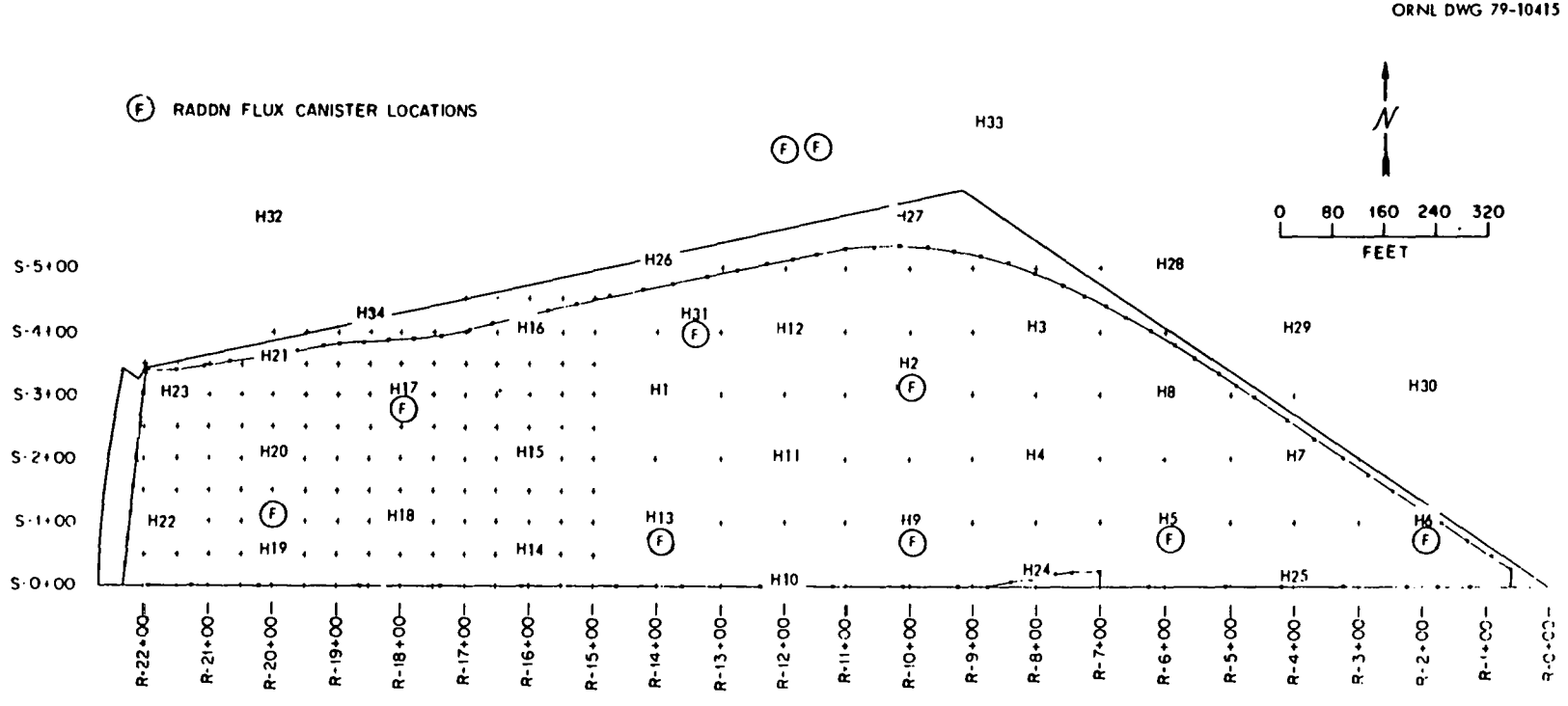


Fig. 6. Location of augered holes and radon flux canisters used in 1978 survey.

ORNL-DWG. 77-8299

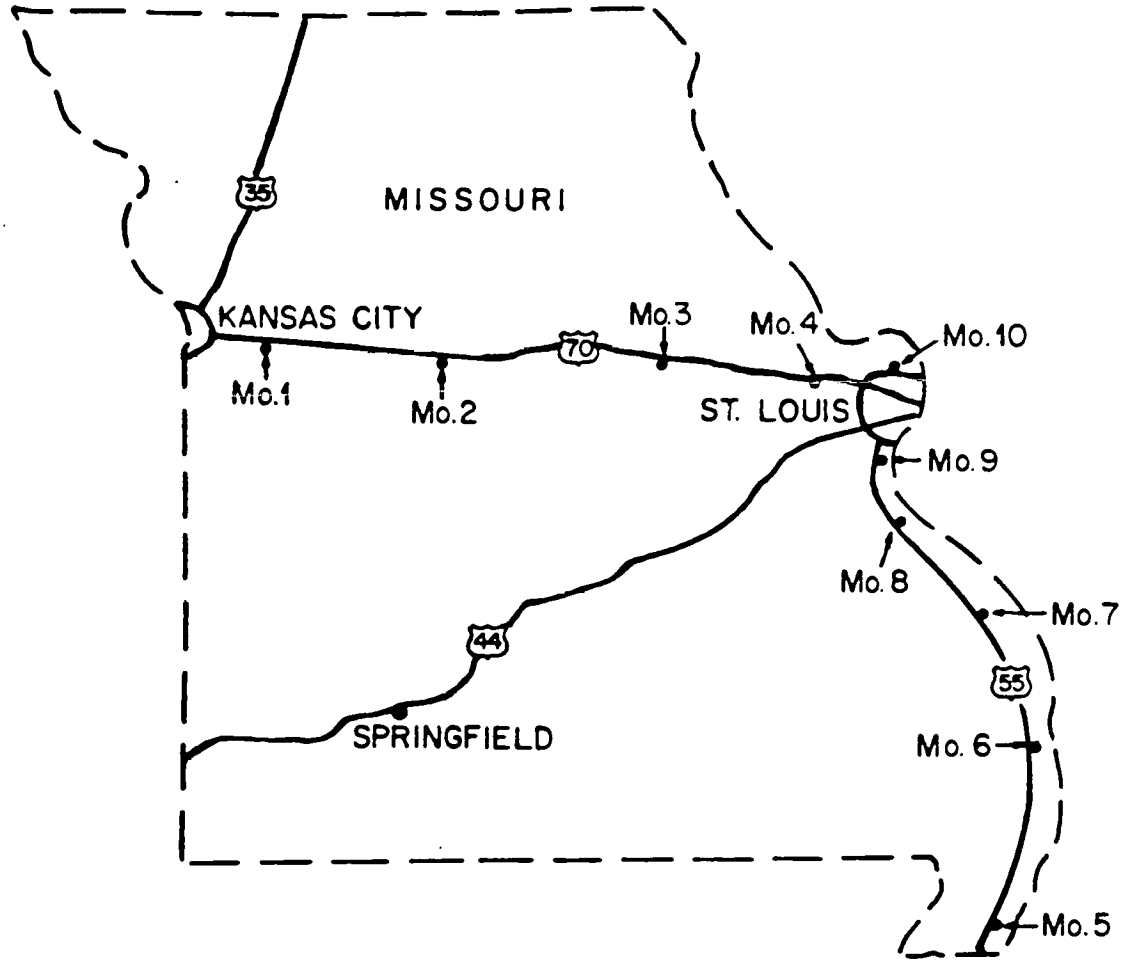


Fig. 7. Location of background soil samples in Missouri.

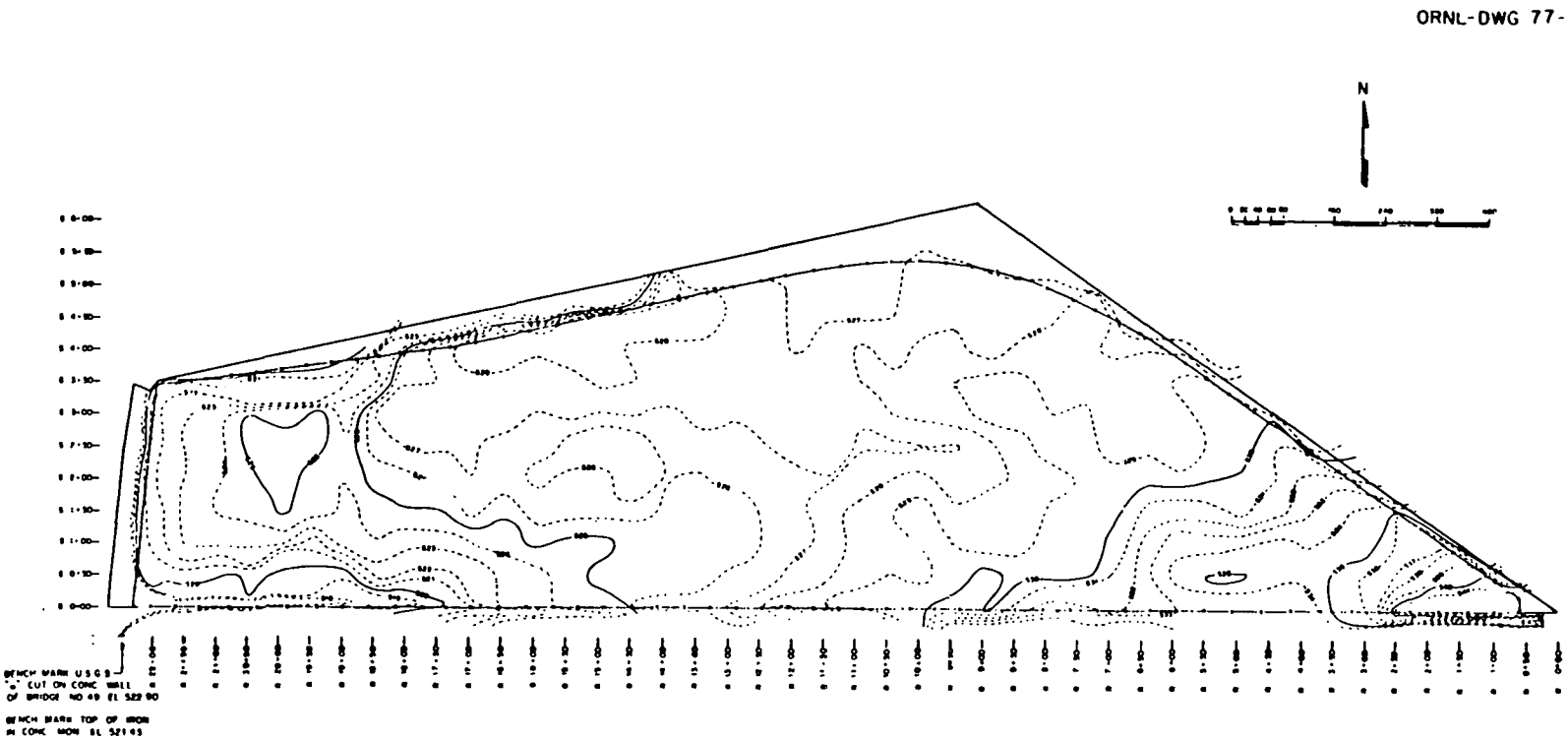
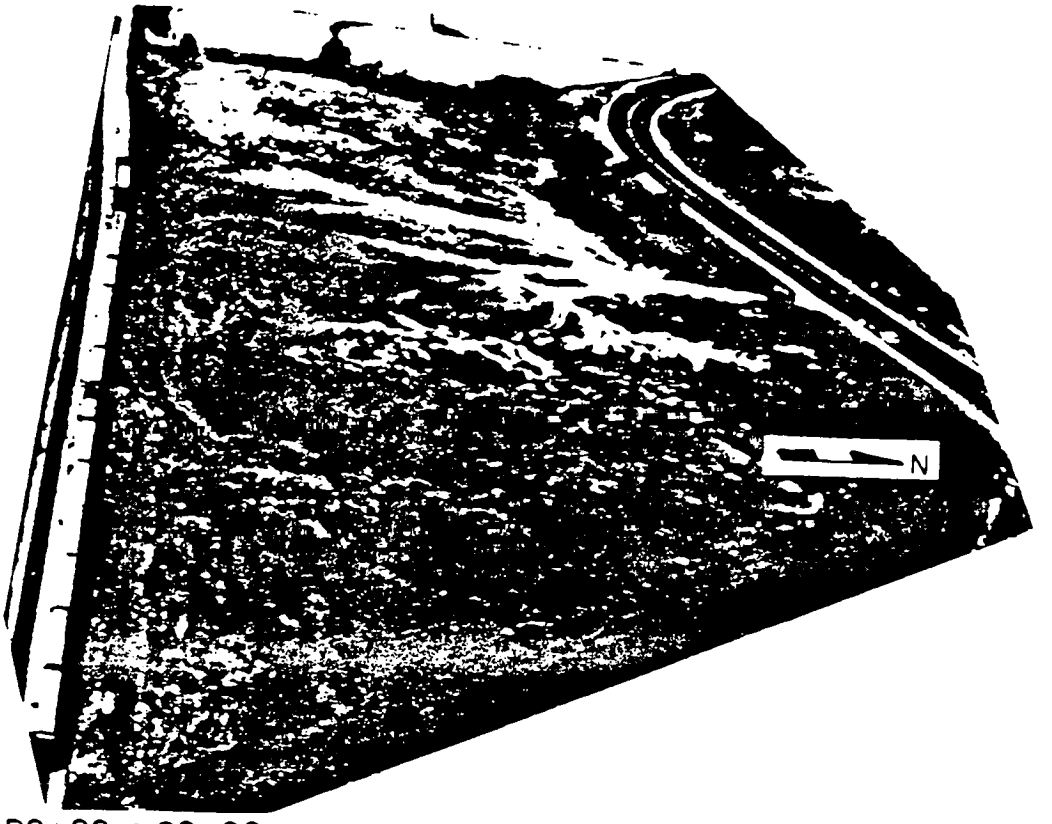
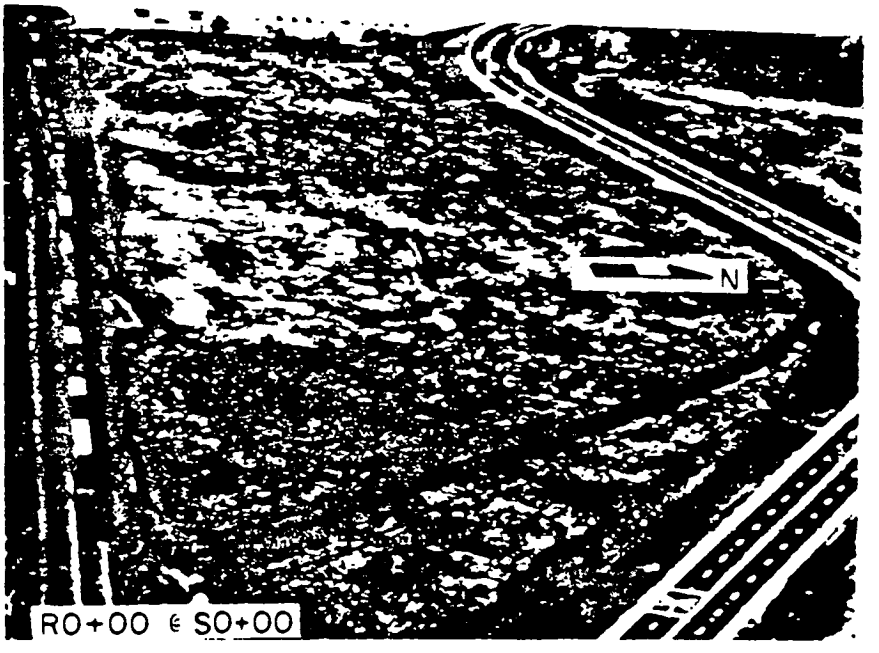


Fig. 8. Topographical survey made in January 1977.

ORNL-Photo 1854-79



Site in 1978



Site in 1976

Fig. 9. Aerial views showing differences in topography between 1976 and 1978.

Table 1. Uranium residues stored at airport site (November 1965)

Waste material	Tonnage	Uranium tonnage
Pitchblende raffinate	74,000	113
Colorado raffinate	32,500	48
Barium sulfate cake, unleached	1,500	22
Barium sulfate cake, leached	8,700	7
Miscellaneous material	350	2
C-Liner slag	4,000	49
Total	121,050	241

Structures and other facilities on site (November 1965)

Reinforced concrete pit 200 x 42 x 12 ft

Storage shed (concrete floor, transite roof)

Railroad spur

Loading platform (concrete)

Truck wash pad (concrete)

Three single-story storage shacks (wood)

Chain-link fence

Table 2. Concentration of radionuclides in Missouri background samples

Sample No.	Radionuclide concentration (pCi/g)			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
Mo1	1.3	1.3	1.7	15
Mo2	1.3	1.2	1.2	ND[a]
Mo3	1.1	1.0	1.2	8.7
Mo4	1.3	1.1	1.1	ND
Mo5	1.1	1.2	1.3	18
Mo6	0.3	0.3	0.3	11
Mo7	1.1	1.1	1.1	15
Mo8	0.8	0.8	0.8	ND
Mo9	1.1	1.1	1.1	12
Mo10	1.0	1.0	0.8	16

[a]Not determined.

Table 3. Surface soil sample analysis

Sample No.	Grid location[a]	Radionuclide concentrations (pCi/g)		
		^{226}Ra	^{238}U	^{227}Ac
1	S3+00/R22+00	1.5	1.5	0.8
2	S2+50/R22+00	1.1	1.0	NF[b]
3	S1+50/R22+00	2.8	6.0	2.6
4	S0+50/R22+00	17	13	NF
5	S0+00/R21+00	3.7	11	1.8
6	S1+00/R21+00	1.0	0.9	NF
7	S2+00/R21+00	1.0	1.0	NF
8	S3+00/R21+00	0.5	0.6	NF
9	S0+50/R20+00	1.7	3.4	NF
10	S1+50/R20+00	78	120	14
11	S2+50/R20+00	1.2	260	NF
12	S3+50/R20+00	2.2	6.8	1.1
13	S0+00/R19+00	58	66	39
14	S1+00/R19+00	2.3	2.6	NF
15	S2+00/R19+00	1.0	1.9	NF
16	S3+00/R19+00	1.5	200	NF
17	S3+50/R18+00	1.0	1.6	NF
18	S2+50/R18+00	1.4	1.6	NF
19	S1+50/R18+00	1.5	1.5	1.7
20	S0+50/R18+00	1.2	1.5	NF
21	S4+00/R17+00	0.9	1.4	NF
22	S3+00/R17+00	1.2	1.4	NF
23	S2+00/R17+00	2.3	4.1	3.1
24	S1+00/R17+00	1.1	1.3	NF
25	S0+00/R17+00	3.4	48	NF
26	S0+50/R16+00	1.4	11	NF
27	S1+50/R16+00	1.0	1.4	NF
28	S2+50/R16+00	1.2	1.6	0.9
29	S3+50/R16+00	1.1	1.3	1.7
30	S3+00/R15+00	4.1	21	NF
31	S3+00/R15+00	1.0	2.0	NF
32	S2+00/R15+00	0.9	1.1	NF
33	S1+00/R15+00	1.1	18	NF
34	S0+00/R15+00	0.9	1.3	NF
35	S3+75/R13+00	43	21	29
36	S3+00/R13+00	3.4	8.1	3.4
37	S1+00/R13+00	0.9	1.4	1.3
38	S0+00/R11+00	0.8	1.1	NF
39	S2+00/R11+00	1.0	1.1	NF
40	S4+00/R11+00	3.0	2.9	2.9
41	S1+00/R9+00	1.4	6.1	NF
42	S3+00/R9+00	4.0	11	NF

Table 3. (Continued)

Sample No.	Grid location[a]	Radionuclide concentrations (pCi/g)		
		^{226}Ra	^{238}U	^{227}Ac
43	S5+00/R9+00	25	5.9	13
44	S0+00/R7+00	3.2	7.1	4.1
45	S2+00/R7+00	39	[c]	77
46	S4+00/R7+00	1.3	2.2	NF
47	S1+00/R5+00	1.1	1.8	NF
48	S3+00/R5+00	1.1	1.6	NF
49	S0+00/R3+00	1.1	170	NF
V1[d]	S0+00/R12+00	1.4	1.4	NF
V2	S1+50/R9+00	1.2	2.3	NF
V3	S3+25/R9+25	1.1	1.5	0.5
V4[e]	S1+00/R5+00	1.1	1.8	NF
V5[f]	S5+25/R10+50	1300	420	1100
F1[g]	S3+75/R22+00	2.9	5.0	NF
F2	S3+50/R21+00	54	210	13
F3	S3+75/R20+00	110	890	24
F4	S3+90/R19+00	30	180	5.7
F5	S4+00/R18+00	52	280	17
F6	S4+25/R17+00	8.4	190	3.1
F7	S4+50/R16+00	11	75	4.4
F8	S4+75/R15+00	6.7	28	6.6
F9	S5+00/R13+00	7.1	7.0	3.6
F10	S5+50/R11+00	230	160	140
F11	S5+50/R9+00	450	240	290
F12	S4+75/R7+00	72	82	100
F13	S3+50/R5+00	120	99	130
F14	S2+00/R3+00	4.5	14	3.7
F15	S1+00/R1+00	4.9	13	8.1
B1[h]	S7+00/R12+00	94	55	160
B2	S6+50/R14+00	1.4	3.0	NF
B3	S6+00/R16+00	100	13	80
B4	S5+25/R18+00	120	72	81
B5	S5+00/R20+00	16	18	1.5
LAOS52[i]	[j]	26	600	--
LAOS53	S4+00/R3+00	3.8	2.7	--
LAOS54	S4+00/R0+50	8.9	5.9	--
LAOS55	S4+50/R7+00	160	170	--
LAOS56	S6+00/R7+00	1.5	2.6	--
LAOS57	S5+50/R9+00	460	430	--
LAOS58	S5+50/R10+50	90	43	--
LAOS59	S5+00/R13+00	74	56	--
LAOS60	S5+00/R18+00	23	39	--
LAOS61	S6+00/R18+00	91	57	--

Table 3. (Continued)

Sample No.	Grid location[a]	Radionuclide concentrations (pCi/g)		
		^{226}Ra	^{238}U	^{227}Ac
LAOS62	S6+00/R15+00	92	61	--
LAOS63	S6+00/R14+00	54	32	--
LAOS64	S4+00/R19+00	15	--	--
LAOS65	S3+50/R18+00	8.4	--	--
LAOS66	S4+50/R17+00	18	--	--

[a] See Fig. 2 for sample location.

[b] In this table, "not found" (NF) means that the activity of the sample was below the limit of detection of the system described in Appendix II.

[c] -- = this radionuclide not determined in this sample.

[d] V samples designate those taken where insectivore activity was noted.

[e] Joint sample with No. 47.

[f] This sample was taken outside the fence.

[g] Samples designate those taken along the fence at the north end of the property.

[h] B samples designate those taken in the drainage pathway north of Brown Road.

[i] LAOS samples designate those taken in ditches north of the site during the 1978 survey. See Fig. 5 for sample locations.

[j] LAOS52 was taken at east end of property on access road about 15 ft. outside fence.

Table 4. Extent of ^{226}Ra contamination in subsurface soil as estimated from gamma radiation measurements in auger holes drilled at random locations, 1978 survey.

Hole No.	Location[a]	Estimated extent of contaminated soil (ft)	Depth of maximum contamination (ft)	Estimated ^{226}Ra concentration at point of maximum contamination (pCi/g)	Estimated average ^{226}Ra concentration in contaminated region (pCi/g)
H1	S3+00/R14+00	0 - 2.0	1.0	90	40
H2	S3+50/R10+00	1.5 - 3.0	2.0	30	20
H3	S4+00/R8+00	0 - 3.0	1.5	150	60
H4	S2+00/R8+00	0 - 9.0	1.5	170	30
H5	S1+00/R6+00	2.5 - 6.0	4.5	100	40
H6	S1+00/R2+00	2.0 - 2.5	2.0	15	10
H7	S2+00/R4+00	2.5 - 4.0	3.5	30	20
H8	S3+00/R6+00	1.7 - 2.2	2.0	15	15
H9	S1+00/R10+00	1.5 - 4.0	3.0	90	30
H10	S0+10/R12+00	2 - 3.5	2.0	80	35
H11	S2+00/R12+00	0 - 12.0	1.5	180	60
H12	S4+00/R12+00	0 - 3.5	2.5	110	30
H13	S1+00/R14+00	2.0 - 3.5	2.5	60	30
H14	S0+50/R16+00	0 - 0.5	0.5	7	7
		3.5 - 6.5	5.0	300	90
H15	S2+00/R16+00	3.5 - 4.5	4.0	15	10
H16	S4+00/R16+00	0.7 - 1.2	1.0	5	5
H17	S3+00/R18+00	0 - 7.0	5.0	550	140
H18	S1+00/R18+00	4.5 - 8.0	7.0	60	20
H19	S0+65/R20+00	6.0 - 9.0	8.0	30	15
H20	S2+00/R20+00	0 - 6.5	3.5	1200	250
		13.5 - 18.5	15.0	150	40
H21	S3+40/R20+00	0 - 3.5	0.5	50	20
H22	S1+00/R21+70	3.5 - 11.0	8.5	700	250
H23	S3+00/R21+50	1.5 - 2.5	2.0	20	15
H24	S0+10/R8+00	1.0 - 2.0	1.5	15	10
H25	S0+10/R4+00	2.0 - 2.5	2.0	10	10
H26	S5+00/R14+00	0 - 0.5	0.5	20	15

Table 4. (Continued)

Hole No.	Location[a]	Estimated extent of contaminated soil (ft)	Depth of maximum contamination (ft)	Estimated ^{226}Ra concentration at point of maximum contamination (pCi/g)	Estimated average ^{226}Ra concentration in contaminated region (pCi/g)
H27	S6+00/R10+00	--	--	<5[b]	<5
H28	S5+00/R6+00	--	--	<5	<5
H29	S4+00/R4+00	--	--	<5	<5
H30	S3+00/R2+00	--	--	<5	<5
H31	S4+25/R13+25	0 - 4.0	2.5	110	30
H32	S5+50/R20+00	--	--	<5	<5
H33	S6+95/R8+80	--	--	<5	<5
H34	S4+20/R18+50	--	--	<5	<5

[a]See Fig. 6.

[b]Soil layers containing a ^{226}Ra concentration less than 5 pCi/g could not be distinguished from background in the logging technique used.

Table 5. Concentrations of ^{238}U and ^{226}Ra (pCi/g) in soil samples taken from augered holes drilled at random locations, 1978 survey

Sample designation	Location[a]	Depth of sample[b] (ft)	^{238}U (pCi/g)	^{226}Ra (pCi/g)
LAC1A	S3+00/R14+00	0 - 5	18	14
LAC2A	S3+50/R10+00	0 - 20	2.5	2.7
LAC3B	S4+00/R8+00	0 - 20	--	21
LAC4B	S2+00/R8+00	@1.5	64	140
LAC5A	S1+00/R6+00	0 - 20	22	7.7
LAC6A	S1+00/R2+00	0 - 20	35	<1
LAC7A	S2+00/R4+00	0 - 20	69	6
LAC8A	S3+00/R6+00	0 - 20	1.7	<1
LAC9A	S1+00/R10+00	0 - 20	--	2.8
LAC10B	S0+10/R12+00	@2.0	--	62
LAC11B	S2+00/R12+00	@1.5	38	130
LAC12B	S4+00/R12+00	@2.5	--	64
LAC13A	S1+00/R14+00	0 - 20	10	20
LAC14A	S0+50/R16+00	0 - 20	18	4.4
LAC15A	S2+00/R16+00	0 - 20	1.3	<1
LAC16A	S4+00/R16+00	0 - 20	--	<1
LAC17A	S3+00/R18+00	0 - 20	96	19
LAC18A	S1+00/R18+00	0 - 20	7.1	6.3
LAC19A	S0+65/R20+00	0 - 20	8.3	4.7
LAC20A	S2+00/R20+00	0 - 20	51	440
LAC21B	S3+40/R20+00	@0.5	--	35
LAC22A	S1+00/R21+70	0 - 20	18	15
LAC23A	S3+00/R21+50	0 - 20	3.6	1.3
LAC25A	S0+10/R4+00	0 - 20	4.3	<1
LAC26A	S5+00/R14+00	0 - 20	1.8	<1
LAC27A	S6+00/R10+00	0 - 20	--	<1
LAC28A	S5+00/R6+00	0 - 20	1.2	<1
LAC29A	S4+00/R4+00	0 - 20	1.4	<1
LAC30	S3+00/R2+00	0 - 20	--	<1
LAC31A	S4+25/R13+25	0 - 20	--	2.9
LAC32A	S5+50/R20+00	0 - 30	1.4	1.3
LAC33A	S6+95/R8+80	0 - 20	1.0	<1.0
LAC34A	S4+20/R18+50	0 - 20	1.1	<1.0
LAOS50A	S4+00/R5+50	0 - 0.3	390	270
LAOS50B	S4+00/R5+50	0 - 1	38	17
LAOS51	S4+00/R5+50	0 - 2	--	61

[a] See Fig. 5. and Fig. 6.

[b] Samples representing a range were composited from auger turnings. Samples representing a specific depth were removed from a side of drilled hole.

Table 6. Concentration of radionuclides in subsurface soil samples taken from biased cores from the 1976 survey

Location[a]	Depth of soil sample (ft)	Radionuclide concentrations (pCi/g) ^{226}Ra	^{238}U	^{227}Ac
Hole No. 7				
@S1+80/R20+20	0.0 - 0.5	1.0	1.1	NF[b]
	0.5 - 1.0	0.8	1.0	NF
	1.0 - 1.5	1.1	6.5	NF
	1.5 - 2.0	190	880	180
Hole No. 9				
@S0+90/R20+40	1.0 - 0.5	1.3	1.4	NF
	0.5 - 1.0	150	220	39
	2.0 - 2.5	28	49	9.5
	2.5 - 3.0	2.0	11	NF
	3.0 - 3.5	3.2	32	0.7
	3.5 - 4.0	12	70	2.3
Hole No. 10				
@S1+80/R20+75	0.0 - 0.5	2.8	5.1	16
	0.5 - 1.0	1.2	1.0	NF
	1.0 - 1.5	68	130	20
	1.5 - 2.0	2.6	300	13
	2.0 - 2.7	15	120	13
Hole No. 11				
@S0+25/R22+00	0.0 - 0.5	1.9	2.0	1.0
	0.5 - 1.0	4.1	2.4	3.4
	1.0 - 1.5	4.8	3.6	4.4
	1.5 - 2.0	1.1	1.1	NF
	2.0 - 2.5	1.6	1.9	NF
	2.5 - 3.0	1.5	1.5	0.7
	3.0 - 3.5	1.1	1.2	NF
	3.5 - 4.0	1.2	1.4	NF
Hole No. 12				
@S3+50/R21+50	0.0 - 0.5	530	82	25
	0.5 - 1.0	1000	300	45
	1.0 - 1.5	44	32	NF
	1.5 - 2.0	52	22	NF
Hole No. 15				
@S5+60/R9+20	0.0 - 0.5	3.8	4.5	3.4
	0.5 - 1.0	1.5	0.8	NF
	1.0 - 1.5	1.1	2.2	NF
	1.5 - 2.0	1.1	3.7	0.9

Table 6. (Continued)

Location [a]	Depth of soil sample (ft)	Radionuclide concentrations (pCi/g) ^{226}Ra	^{238}U	^{227}Ac
Hole No. 16 @S4+00/R5+75	0.0 - 0.5	1.6	1.3	1.0
	0.5 - 1.0	1.2	1.0	NF
	1.0 - 1.5	1.3	0.9	NF
	1.5 - 2.0	1.1	0.8	NF

[a] See Fig. 2.

[b] In this table, "not found" (NF) means that the observed activity of the sample was below the limit of detection of the gamma-ray spectroscopy system.

Table 7. Estimates of subsurface ^{226}Ra concentration from gamma logs of biased cored holes from 1976 survey

Hole No.[a]	Location	Depth over which ^{226}Ra concentration was averaged (ft)	Average ^{226}Ra concentration in contaminated zone (pCi/g)	Depth at estimated maximum radium concentration (ft)
1	S2+75/R16+10	1 - 4	11[b]	2.5 - 3.0
2	S1+75/R16+50	0 - 10	<5[b]	--
3	SO+50/R15+50	0 - 6	210	2.5 - 3.0
4	SO+80/R15+50	0 - 7	1100	3.0 - 3.5
5	S2+60/R18+25	0 - 7	550	5.0 - 5.5
6	S2+75/R18+50	0 - 5	1400	2.0 - 2.5
7	S1+80/R20+20	0 - 4	33	1.5 - 2.0
8	S1+10/R20+60	0 - 5	78	1.0 - 1.5
9	SO+90/R20+40	0 - 5	24	1.0 - 1.5
10	S1+80/R20+75	0 - 4	30	1.0 - 1.5
11	SO+25/R22+00	0 - 10	<5	--
12	S3+50/R21+50	0 - 4	46	0 - 0.5
13	S3+75/R19+40	0 - 4	11	0 - 0.5
14	S4+50/R9+25	0 - 5	64	1.5 - 2.0
15	S5+60/R9+20	0 - 8	<5	--
16	S4+00/RS+75	0 - 10	<5	--

[a] See Fig. 2.

[b] Soil layers containing a ^{226}Ra concentration less than 5 pCi/g could not be distinguished from background in the logging technique used.

Table 8. External gamma radiation levels at 1 m above the ground and beta-gamma radiation levels at 1 cm above the ground at grid points inside the fenced area

Location	External gamma radiation levels at 1 m (μR/hr)	Beta-gamma radiation levels at 1 cm (mrad/hr)
S0+00/R0+00	31	0.13
S0+00/R1+00	7	0.04
S1+00/R1+00	14	0.05
S0+00/R2+00	7	0.03
S1+00/R2+00	6	0.03
S1+25/R2+00	26	0.20
S0+00/R3+00	8	0.03
S1+00/R3+00	6	0.03
S2+00/R3+00	10	0.06
S0+00/R4+00	5	0.03
S1+00/R4+00	7	0.03
S2+00/R4+00	6	0.03
S0+00/R5+00	7	0.03
S1+00/R5+00	6	0.03
S2+00/R5+00	7	0.03
S3+00/R5+00	9	0.05
S0+00/R6+00	10	0.04
S1+00/R6+00	7	0.03
S2+00/R6+00	10	0.03
S3+00/R6+00	8	0.03
S0+00/R7+00	9	0.05
S1+00/R7+00	7	0.03
S2+00/R7+00	24	0.08
S3+00/R7+00	10	0.03
S4+00/R7+00	16	0.05
S0+00/R8+00	7	0.03
S1+00/R8+00	8	0.03
S2+00/R8+00	18	0.06
S3+00/R8+00	14	0.05
S4+00/R8+00	15	0.03
S0+00/R9+00	10	0.05
S1+00/R9+00	11	0.04
S2+00/R9+00	10	0.03
S3+00/R9+00	14	0.03
S4+00/R9+00	38	0.13
S5+00/R9+00	65	0.20
S0+00/R10+00	7	0.04
S1+00/R10+00	9	0.02
S2+00/R10+00	10	0.03
S3+00/R10+00	12	0.03
S4+00/R10+00	27	0.04
S5+00/R10+00	71	0.34
S0+00/R11+00	7	0.04

Table 8. (Continued)

Location	External gamma radiation levels at 1 m (μR/hr)	Beta-gamma radiation levels at 1 cm (mrad/hr)
S1+00/R11+00	9	0.04
S2+00/R11+00	27	0.03
S3+00/R11+00	26	0.03
S4+00/R11+00	30	0.04
S5+00/R11+00	44	0.07
S0+00/R12+00	11	0.05
S1+00/R12+00	9	0.03
S2+00/R12+00	16	0.05
S3+00/R12+00	13	0.05
S4+00/R12+00	31	0.14
S5+00/R12+00	29	0.09
S0+00/R13+00	12	0.02
S1+00/R13+00	9	0.03
S2+00/R13+00	14	0.04
S3+00/R13+00	15	0.05
S4+00/R13+00	32	0.06
S0+00/R14+00	12	0.05
S1+00/R14+00	12	0.04
S2+00/R14+00	18	0.06
S3+00/R14+00	20	0.05
S4+00/R14+00	24	0.11
S0+00/R15+00	11	0.04
S0+50.R15+00	6	0.03
S1+00/R15+00	9	0.04
S1+50/R15+00	6	0.03
S2+00/R15+00	6	0.03
S2+50/R15+00	9	0.03
S3+00/R15+00	11	0.02
S3+50/R15+00	12	0.03
S4+00/R15+00	14	0.05
S4+50/R15+00	16	0.05
S0+00/R15+50	7	0.04
S0+50/R15+50	6	0.03
S1+00/R15+50	6	0.04
S1+50/R15+50	5	0.04
S2+00/R15+50	10	0.02
S2+50/R15+50	25	0.06
S3+00/R15+50	13	0.05
S3+50/R15+50	15	0.05
S4+00/R15+50	15	0.03
S4+50/R15+50	31	0.06
S0+00/R16+00	6	0.03
S0+50/R16+00	8	0.03

Table 8. (Continued)

Location	External gamma radiation levels at 1 m (μR/hr)	Beta-gamma radiation levels at 1 cm (mrad/hr)
S1+00/R16+00	6	0.02
S1+50/R16+00	6	0.03
S2+00/R16+00	11	0.03
S2+50/R16+00	13	0.04
S3+00/R16+00	13	0.03
S3+50/R16+00	15	0.03
S4+00/R16+00	18	0.07
S4+50/R16+00	28	0.06
S0+00/R16+50	6	0.03
S0+50/R16+50	7	0.04
S1+00/R16+50	6	0.02
S1+50/R16+50	12	0.03
S2+00/R16+50	7	0.03
S2+50/R16+50	7	0.03
S3+00/R16+50	8	0.04
S3+50/R16+50	7	0.05
S4+00/R16+50	8	0.05
S4+50/R16+50	29	0.05
S0+00/R17+00	7	0.06
S0+50/R17+00	6	0.03
S1+00/R17+00	6	0.03
S1+50/R17+00	7	0.03
S2+00/R17+00	8	0.03
S2+50/R17+00	7	0.03
S3+00/R17+00	7	0.04
S3+50/R17+00	8	0.06
S4+00/R17+00	12	0.05
S4+50/R17+00	23	0.09
S0+00/R17+50	7	0.05
S0+50/R17+50	7	0.02
S1+00/R17+50	7	0.04
S1+50/R17+50	7	0.05
S2+00/R17+50	8	0.04
S2+50/R17+50	7	0.04
S3+00/R17+50	8	0.04
S3+50/R17+50	7	0.03
S4+00/R17+50	14	0.05
S0+50/R18+00	10	0.06
S1+50/R18+00	7	0.03
S1+00/R18+00	9	0.03
S1+50/R18+00	6	0.04
S2+00/R18+00	7	0.03
S2+50/R18+00	9	0.05
S3+00/R18+00	10	0.03

Table 8. (Continued)

Location	External gamma radiation levels at 1 m (μR/hr)	Beta-gamma radiation levels at 1 cm (mrad/hr)
S3+50/R18+00	9	0.02
S4+00/R18+00	15	0.04
S0+00/R18+50	32	0.17
S0+50/R18+50	7	0.03
S1+00/R18+50	8	0.02
S1+50/R18+50	10	0.05
S2+00/R18+50	9	0.05
S2+50/R18+50	10	0.05
S3+00/R18+50	26	0.07
S3+50/R18+50	20	0.05
S4+00/R18+50	17	0.06
S0+00/R19+00	43	0.23
S0+50/R19+00	20	0.06
S1+00/R19+00	9	0.03
S1+50/R19+00	8	0.04
S2+00/R19+00	8	0.03
S2+50/R19+00	13	0.06
S3+00/R19+00	20	0.11
S3+50/R19+00	27	0.09
S4+00/R19+00	29	0.07
S0+00/R19+50	39	0.20
S0+50/R19+50	18	0.06
S1+00/R19+50	32	0.11
S1+50/R19+50	12	0.03
S2+00/R19+50	9	0.04
S2+50/R19+50	10	0.04
S3+00/R19+50	11	0.04
S3+50/R19+50	29	0.07
S4+00/R19+50	20	0.06
S0+00/R20+00	30	0.11
S0+50/R20+00	37	0.10
S1+00/R20+00	30	0.07
S1+50/R20+00	39	0.06
S2+00/R20+00	18	0.04
S2+50/R20+00	16	0.03
S3+00/R20+00	15	0.05
S3+50/R20+00	26	0.06
S4+00/R20+00	19	0.05
S0+00/R20+50	29	0.14
S0+50/R20+50	20	0.05
S1+00/R20+50	18	0.04
S1+50/R20+50	46	0.19
S2+00/R20+50	73	0.20
S2+50/R20+50	13	0.05

Table 8. (Continued)

Location	External gamma radiation levels at 1 m (μR/hr)	Beta-gamma radiation levels at 1 cm (mrad/hr)
S3+00/R20+50	12	0.05
S3+50/R20+50	18	0.06
S0+00/R21+00	17	0.07
S0+50/R21+00	7	0.03
S1+00/R21+00	8	0.03
S1+50/R21+00	16	0.05
S2+00/R21+00	12	0.04
S2+50/R21+00	10	0.05
S3+00/R21+00	7	0.03
S3+50/R21+00	27	0.09
S0+00/R21+50	31	0.10
S0+50/R21+50	12	0.04
S1+00/R21+50	18	0.06
S1+50/R21+50	10	0.06
S2+00/R21+50	8	0.03
S2+50/R21+50	16	0.06
S3+00/R21+50	9	0.04
S3+50/R21+50	19	0.05
S0+00/R22+00	9	0.04
S0+50/R22+00	9	0.05
S1+00/R22+00	17	0.04
S1+50/R22+00	20	0.04
S2+00/R22+00	11	0.05
S2+50/R22+00	10	0.05
S3+00/R22+00	80	0.04
S3+50/R22+00	9	0.02

Table 9. External gamma radiation levels at 1 m above the ground and beta-gamma radiation levels at 1 cm above the ground in the fine grid area of Fig. 3

Block No.	External gamma radiation levels at 1 m (μR/hr)	Beta-gamma radiation levels at 1 cm (mrad/hr)
1	55	0.27
2	140	2.3
3	*a*	*b*
4	*a*	*b*
5	83	0.86
6	71	2.3
7	*a*	*b*
8	*a*	*b*
9	120	1.1
10	31	0.46
11	240	4.6
12	25	0.26
13	23	0.14
14	240	4.6
15	29	0.46
16	*a*	*b*
17	*a*	*b*
18	*a*	*b*
19	*a*	*b*
20	300	4.6
21	250	2.9
22	47	0.29
23	29	0.14
24	36	0.16
25	*a*	*b*
26	*a*	*b*
27	270	1.5
28	53	0.23

[a]Approximately 8 μR/hr (near background).

[b]Approximately 0.02 mrad/hr (near background).

Table 10. External gamma radiation levels and beta-gamma dose rates at locations in area outside fence on north side of site from fence to Brown Road

Location No.	Grid location	External gamma radiation level at 1 m (μR/hr)	Beta-gamma dose rate at 1 cm (mrad/hr)
1[a]	S5+00/R5+50	35	0.03
2	S4+60/R5+50	40	0.02
3	S4+20/R5+60	130	0.11
4	S4+00/R5+70	180	0.43
5	S3+00/R4+50	60	0.06
6	S3+40/R4+50	30	0.03
7	S3+75/R4+50	20	0.03
8	S4+10/R4+40	15	0.03
9	S4+40/R4+40	15	0.03
10	S4+65/R4+40	10	0.03
11	S2+25/R3+25	20	0.03
12	S2+55/R3+25	15	0.02
13	S3+00/R3+20	20	0.02
14	S3+20/R3+20	10	0.02
15	S3+55/R3+10	10	0.02
16	S4+00/R3+00	10	0.02
17	S4+20/R3+00	10	0.02
18	S1+30/R1+90	30	0.03
19	S1+60/R1+85	20	0.02
20	S4+00/R1+80	15	0.02
21	S2+30/R1+70	15	0.02
22	S2+60/R1+70	10	0.01
23	S3+00/R1+70	10	0.03
24	S3+30/R1+60	10	0.01
25	S3+60/R1+60	10	0.01
26	S0+30/R0+40	20	0.03
27	S0+60/R0+40	10	0.02
28	S1+00/R0+40	10	0.02
29	S1+20/R0+40	10	0.01
30	S1+60/R0+40	10	0.01
31	S2+00/R0+40	10	0.01
32	S2+30/R0+40	10	0.01
33	S2+70/R0+40	10	0.03
34	S3+00/R0+40	10	0.02
35	S0+30/R0-30	80	0.13
36	S1+50/R-2+40	35	0.04
37	S4+70/R7+30	220	0.50
38	S5+00/R7+25	100	0.08
39	S5+20/R7+20	40	0.05
40	S5+40/R7+10	30	0.02
41	S5+10/R8+20	150	0.29
42	S5+30/R8+20	70	0.04
43	S5+50/R8+30	45	0.03

Table 10. (Continued)

Location No.	Grid location	External gamma radiation level at 1 m (μR/hr)	Beta-gamma dose rate at 1 cm (mrad/hr)
44	S5+70/R8+10	45	0.03
45	S5+40/R9+30	330	1.6
46	S5+60/R9+30	220	0.50
47	S5+40/R9+70	85	0.03
48	S5+70/R9+70	180	0.17
49	S5+70/R9+70	95	0.13
50	S5+40/R10+60	270	0.69
51	S5+70/R10+60	130	0.11
52	S5+30/R11+50	115	0.47
53	S5+70/R11+50	70	0.08
54	S5+10/R12+50	45	0.04
55	S5+40/R12+50	130	0.15
56	S4+90/R13+60	45	0.03
57	S5+10/R13+60	65	0.07
58	S4+50/R15+20	110	0.05
59	S4+80/R15+20	70	0.09
60	S4+20/R16+80	30	0.03
61	S4+50/R16+80	30	0.05
62	S4+00/R17+80	20	0.03
63	S4+20/R17+80	25	0.02
64	S3+80/R19+20	95	NR[b]
65	S4+00/R19+30	40	NR
--	S1+40/R1+00[c]	*d*	0.02
--	S2+00/R2+00	*d*	0.03
--	S2+50/R3+00	*d*	0.04
--	S3+00/R4+00	150	0.05
--	S3+50/R5+00	*d*	0.06
--	S4+00/R5+00	190	0.29
--	S4+25/R6+00	30	0.06
--	S4+00/R6+00	120	0.57
--	S4+75/R7+00	30	0.06
--	S5+00/R7+00	140	0.46
--	S5+25/R8+00	40	0.06
--	S5+00/R8+00	110	0.46
--	S5+60/R9+00	100	0.57
--	S5+25/R9+00	240	1.4
--	S5+75/R10+00	65	0.29
--	S5+50/R10+00	90	0.29
--	S5+60/R11+00	70	0.14
--	S5+50/R11+00	230	1.0
--	S5+50/R12+00	40	0.13

Table 10. (Continued)

Location No.	Grid location	External gamma radiation level at 1 m (μR/hr)	Beta-gamma dose rate at 1 cm (mrad/hr)
--	S5+25/R12+00	35	0.07
--	S5+25/R13+00[e]	85	0.46
--	S5+00/R13+00	25	0.09
--	S5+00/R14+00	35	0.06

[a]Location numbers 1 through 65 represent measurements taken during the 1978 survey and are shown in Fig. 4. Approximate grid locations of these points are given so that comparisons with other data may be made.

[b]NR = No reading taken at this location.

[c]Locations without a designated location number were measured in the 1976 survey.

[d]Reading was approximately 8 μR/hr (near background).

[e]At this point, a drain culvert leads to ditch on north side of Brown Road.

Table 11. External gamma radiation levels and beta-gamma dose rates at locations north of Brown Road

Location No.	Grid location	External gamma radiation level at 1 m (μR/hr)	Beta-gamma dose rate at 1 cm (mrad/hr).
66[a]	S5+20/R20+20	20	0.03
67	S5+00/R20+20	NR[b]	0.05
68	S5+80/R19+30	60	0.06
69	S5+30/R18+20	60	0.08
70	S6+00/R18+20	80	NR
71	S6+60/R15+50	90	NR
72	S5+90/R15+50	45	NR
73	S6+60/R13+70	60	NR
--	S7+00/R12+00[c]	15	0.05
--	S6+50/R14+00	90	0.23
--	S6+00/R16+00	90	0.34
--	S5+25/R18+00	70	0.23
--	S5+00/R20+00	25	0.10

[a]Location nos. 66 through 73 represent measurements taken during the 1978 survey and are shown in Fig. 4. Approximate grid locations of these points are given so that comparison with other data may be made.

[b]NR = no reading taken at this location.

[c]Locations without a designated location no. were measured during the 1976 survey.

Table 12. External gamma radiation levels and beta-gamma dose rates at locations outside fence on south and west sides of site

Location No.	Grid location	External gamma radiation level at 1 m (μR/hr)	Beta-gamma dose rate at 1 cm (mrad/hr)
74[a]	S0-30/R0+00	10	NR[b]
75	S0-30/R0+50	15	NR
76	S0-30/R1+50	15	NR
77	S0-30/R2+60	10	NR
78A	S0-50/R3+60	15	NR
78B	S0-00/R3+60	20	NR
79A	S0+05/R7+00	15	NR
79B	S0-00/R7+00	20	NR
80A	S0-00/R8+20	20	NR
80B	S0-50/R8+20	10	NR
81	S0-20/R9+50	20	NR
82A	S0-50/R10+60	10	NR
82B	S0-00/R10+60	20	NR
83	S0-30/R11+60	15	NR
84	S0-30/R12+50	10	NR
--	S0-50/R0+00[c]	NR	0.05
--	S0-50/R1+00	NR	0.03
--	S0-50/R2+00	NR	0.03
--	S0-50/R3+00	NR	0.03
--	S0-50/R4+00	NR	0.03
--	S0-50/R5+00	NR	0.05
--	S0-50/R6+00	NR	0.03
--	S0-50/R7+00	NR	0.03
--	S0-50/R8+00	NR	0.06
--	S0-50/R9+00	NR	0.03
--	S0-50/R10+00	NR	0.04
--	S0-50/R11+00	NR	0.03
At North Outfall[d]		12	NR
At South Outfall[d]		18	NR

[a]Location nos. 74 through 84 represent measurements taken during the 1978 survey and are shown in Fig. 4. Approximate grid locations of these points are given so that comparison with other data may be made.

[b]NR = no reading taken at this location.

[c]Locations without a designated location no. were measured during the 1976 survey.

[d]Location as shown in Fig. 1.

Table 13. Radon emanation rates as measured using charcoal canisters

Canister No.	Location	Radon emanation rate (pCi/m^2-s)
3	S1+00, R20+00	0.28
6	S4+25, R13+25	11
7	S3+50, R10+00	2.6
9	N of Brown Road	0.78
15	S3+00, R18+00	7.7
17	S1+00, R10+00	1.0
18	S1+00, R10+00	7.2
18A	S1+00, R14+00	14
36	S1+00, R6+00	6.6
41	N of Brown Road	0.08

Table 14. Outdoor radon measurements near St. Louis Airport Site

Direction from the site	Location	Counting interval (hrs)	No. of readings	Average ^{222}Rn concentration (pCi/liter)	Maximum ^{222}Rn concentration (pCi/liter)	Time at which maximum ^{222}Rn concentration was measured
North	Across Brown Road in ballpark	6.8	14	0.36	0.99	6:26 pm
East	~50 ft. east of fence on service road	9.0	18	0.36	0.78	12:39 pm
South	~20 ft. south of railroad tracks near large bill-board	12.0	24	0.34	0.96	10:30 pm
West	Across Goldwater Creek and fence in McDonnell-Douglas parking lot	10.0	21	0.26	0.61	11:04 am

Table 15. Calculated annual average ^{222}Rn concentration as a function of distance and direction (fCi/liter) resulting from the St. Louis Airport site

Dist. from center[a] of site (mi)	Compass direction															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0.25	8.8	8.4	9.1	12.0	22.5	10.7	6.5	5.5	6.0	8.1	12.9	22.3	34.5	22.0	15.3	1.1
0.50	3.0	2.1	2.4	3.0	5.3	2.5	1.7	1.4	1.7	2.5	3.7	2.5	4.3	5.2	3.2	3.4
0.75	1.7	0.9	1.2	1.5	2.5	1.2	0.8	0.6	0.9	1.3	1.9	1.0	1.8	2.5	1.5	1.5
1.00	1.2	0.5	0.7	0.9	1.5	0.7	0.5	0.4	0.6	0.8	1.1	0.6	1.0	1.4	0.9	0.9
1.25	0.8	0.3	0.5	0.6	1.0	0.5	0.3	0.2	0.4	0.5	0.8	0.4	0.7	1.0	0.6	0.6
1.50	0.6	0.3	0.4	0.5	0.8	0.4	0.3	0.2	0.3	0.4	0.6	0.3	0.5	0.7	0.4	0.4
1.75	0.5	0.2	0.3	0.4	0.6	0.3	0.2	0.1	0.2	0.3	0.4	0.2	0.4	0.6	0.3	0.3
2.00	0.4	0.2	0.2	0.3	0.5	0.2	0.2	0.1	0.2	0.3	0.4	0.2	0.3	0.5	0.3	0.3
2.25	0.3	0.1	0.2	0.2	0.4	0.2	0.1	0.1	0.2	0.2	0.3	0.1	0.3	0.4	0.2	0.2
2.50	0.3	0.1	0.2	0.2	0.4	0.2	0.1	0.1	0.1	0.2	0.3	0.1	0.2	0.3	0.2	0.2

[a]Center of site is approximated by coordinates S2+50/R12+00.

Table 16. Calculated radon-222 concentration on the St. Louis Airport site

Distance from center of site[a] (ft)	Concentration (fCi/liter)
50	130
100	130
150	120
200	110
250	90
350	70
500	40
650	30

[a]Measured from the center of the site (S2+50/R12+00) in the northern direction.

Table 17. Concentrations of long-lived radionuclides in air (fCi/m^3) measured near the site in 1978

Location[a]	^{226}Ra	^{230}Th	^{210}Pb	^{238}U	^{227}Ac
Berkeley Park — north of site	<8	4	20	3	0.4
∿50 ft east of fence — east of site	<5	12	10	4	0.3
∿10 ft south of railroad tracks — south of site	<7	10	30	4	1.0
parking lot — west of site	<14	13	30	5	1.6
10 CFR 20 Guideline	2000 I[b]	80 S	4000 S	300 S	80 S

[a]Locations shown in Fig. 5.

[b]More restrictive guide is given: S = soluble, I = insoluble.

Table 18. Estimated annual average concentration of airborne radionuclides at grid location S3+00/R12+00 (50 ft north of site center) attributable to resuspension from site surface

Radionuclide	Estimated annual average airborne concentration (pCi/m^3) due to		10 CFR 20 guideline concentration (pCi/m^3)
	Wind resuspension	Mechanical resuspension	
^{226}Ra	1×10^{-8}	0.03	3
^{230}Th	1×10^{-8}	0.03	0.08
^{227}Ac	6×10^{-9}	0.01	0.08
^{238}U	4×10^{-8}	0.1	3
^{210}Pb	1×10^{-8}	0.03	4

Table 19. Radionuclide concentrations (pCi/liter) in offsite water samples, April 1979

Location	^{226}Ra	^{210}Pb	^{230}Th	^{227}Ac	^{238}U
Coldwater Creek samples:					
∿1.6 miles upstream of SO+00 (at old Natural Bridge Road)	<0.5	<3	<0.5	<0.5	0.4
∿60 ft upstream of SO+00	<0.5	4	<0.5	<0.5	1
at SO+00	<0.5	3	<0.9	<0.9	3
downstream at SO+95	<0.5	3	<0.5	<0.5	3
downstream at S2+00	<0.5	1	<0.9	<0.9	3
downstream at S3+10	<0.5	5	<4	<4	9
downstream at S5+00	<0.9	1	<14	<14	4
downstream at S6+00	<0.5	2	<0.9	<0.9	11
Drainage Ditch samples:					
south outfall at ∿SO+30	0.9	3	<5	<5	500
ditch on south side of Brown Road (North outfall)	1.8	11	<0.5	<0.5	3500
ditch on north side of	0.9	8	<5	<5	230
10 CFR 20 Guideline	30	100	2000	2000	40,000

Table 20. Radionuclide concentrations (pCi/g) in offsite sediment samples, April 1979

Location	^{226}Ra	^{227}Ac	^{238}U
Coldwater Creek samples:			
∿60 ft upstream of SO+00	0.72	<0.04	0.69
at SO+00	0.71	<0.04	0.69
downstream at SO+95	1.06	<0.04	0.73
downstream at S2+00	1.08	<0.04	0.73
downstream at S3+10	1.05	<0.07	1.13
downstream at S4+00	1.24	<0.3	1.08
downstream at S5+00	1.33	<0.04	1.21
downstream at S6+00	1.18	<0.04	1.57
Drainage Ditch samples:			
south outfall at ∿SO+30	2.02	<0.06	9.8
ditch on south side of Brown Road (north outfall)	3.09	0.54	15.7
ditch on north side of Brown Road	2.29	0.87	8.2

Table 21. Radionuclide concentrations in water (pCi/liter) and in sediments (pCi/g) from Coldwater Creek, 1976

Location and sample type	^{226}Ra	^{238}U	^{227}Ac	^{230}Th	^{210}Pb
50 m upstream of south outfall					
water (pCi/liter)	<0.2	1	*a*	0.03	<40
sediment (pCi/g)	0.9	0.9	<0.2	*a*	*a*
at south outfall					
water (pCi/liter)	<0.1	1	*a*	0.02	<90
sediment (pCi/g)	12	25	9	*a*	*a*
at north outfall					
water (pCi/liter)	<0.3	1	*a*	0.03	<90
sediment (pCi/g)	1.6	11	<0.5	*a*	*a*
600 m downstream of north outfall					
water (pCi/liter)	<0.1	1	*a*	0.3	<200
sediment (pCi/g)	0.9	0.7	<0.2	*a*	*a*

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

Table 22. Radionuclide concentrations (pCi/liter) in water samples, 1978 survey

Location	^{210}Pb	^{238}U
Coldwater Creek upstream from site, at Norfolk and Western RR crossing	<4	<3
Drainage ditch at SW corner of site at Coldwater Creek	<4	<3
Coldwater Creek, 100 ft N of Brown Road bridge, downstream from site	4	<3
0.74 mi downstream from site in Coldwater Creek	5	<3

Table 23. Concentration of radionuclides in groundwater samples

Sample location	Depth at which water encountered (ft)	Radionuclide concentration (pCi/liter) ^{238}U	^{230}Th	^{226}Ra	^{210}Pb
Hole No. 7[a] S1+75/R20+15	25	20	1.1	0.5	<100
Hole No. 10[a] S1+75/R20+75	20	170	1.9	--	<80
Hole No. 11[a] S0+60/R22+00	35	4	0.08	0.05	<100
Hole No. 12[a] S3+45/R21+50	35	4	<0.05	1.0	<90
Hole No. 13[a] S3+70/R19+75	25	210	1.6	0.5	<30
Hole No. 14[a] S4+50/R9+75	17	1200	0.15	9.0	<40
Hole No. 26[b] S5+00/R14+00	17	90	<0.3	1.0	<4
Hole No. 27[b] S6+00/R10+00	19	110	<0.3	1.6	<5
Hole No. 28[b] S5+00/R6+00	20	230	<0.3	<0.2	36
Hole No. 29[b] S4+00/R4+00	13	350	<0.3	<0.2	<4
Hole No. 30[b] S3+00/R2+00	20	8	<0.4	0.4	<4
Hole No. 32[b] S5+50/R20+00	19	210	<0.2	1.4	7
Hole No. 33[b] S6+95/R8+80	18	50	0.1	1.6	11
Hole No. 34[b] S4+20/R18+50	15	230	<0.3	0.1	<5

[a]Samples obtained during 1976 survey.

[b]Samples obtained during 1978 survey; these analyses were performed by Radiation Management Corporation, Philadelphia, Pennsylvania.

APPENDIX I

DESCRIPTION OF RADIATION SURVEY METERS AND WRENN CHAMBERS

RADIATION SURVEY METERS

Beta Survey Meter

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

The G-M survey meter was calibrated at ORNL for gamma radiation using an NBS standard Ra source. The gamma calibration factor is typically of the order of 2600 cpm per mR/hr.

In order to assess beta-gamma surface dose rates from uranium contaminated surfaces using this instrument, a field calibration was performed. The G-M survey meter was compared with a Victoreen Model 440 ionization chamber (see Fig. I-B) and was found to produce 1750 cpm per mrad/hr with a 25% standard deviation for a wide variety of surfaces, including concrete, wood, pavement, bricks, and steel beams.

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 × 3.8-cm NaI crystal coupled to a photomultiplier tube. This probe is connected to a Victoreen Model Thyac III ratemeter (see Fig. I-C).

This unit is capable of measuring radiation levels from a few μR/hr to several hundred μR/hr. This instrument is calibrated at ORNL with an NBS standard ^{226}Ra source. Typical calibration factors are of the order of 300 cpm per μR/hr.

TECHNIQUES FOR THE MEASUREMENT OF RADON AND RADON DAUGHTERS IN AIR

Continuous Radon Monitor

Concentrations of radon are measured using a detector developed by Wrenn et al.[I-1] This detector operates on the principle that most of the 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 in the chamber decays, after diffusing into the cavity, RaA ions are attracted to a thin aluminized mylar film which is stretched over a zinc sulfide scintillation detector. The potential between this aluminized mylar film and the hemispherically shaped wire screen creates a strong electric field which serves to attract the charged ions. The ions thus attracted remain on the surface of the mylar film and continue their radioactive decay to other radon daughters. The principal radiation detected by a radon monitor of this type is the alpha particles from RaA and RaC'. Alpha pulses are counted and integrated for a fixed period of time, usually 30 min. At the end of each timed counting period, the total count for each channel is printed automatically and the system is reset and counting for the next period is initiated.

The radon monitor in use by ORNL is similar to that developed by Wrenn. However, the scintillation detector is larger (2 in. in diam), and a provision has been made to utilize an alpha source in order to

standardize the chamber before putting it into service (see Fig. I-D). The alpha standard is inserted through a hole in the top of the chamber and rests in a fixed and repeatable position. During use of the monitor, the source access hole is plugged with a rubber stopper. An overall view of the ORNL radon monitor is shown in Fig. I-E.

MOBILE LABORATORIES

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

ORNL-Photo 6704-76

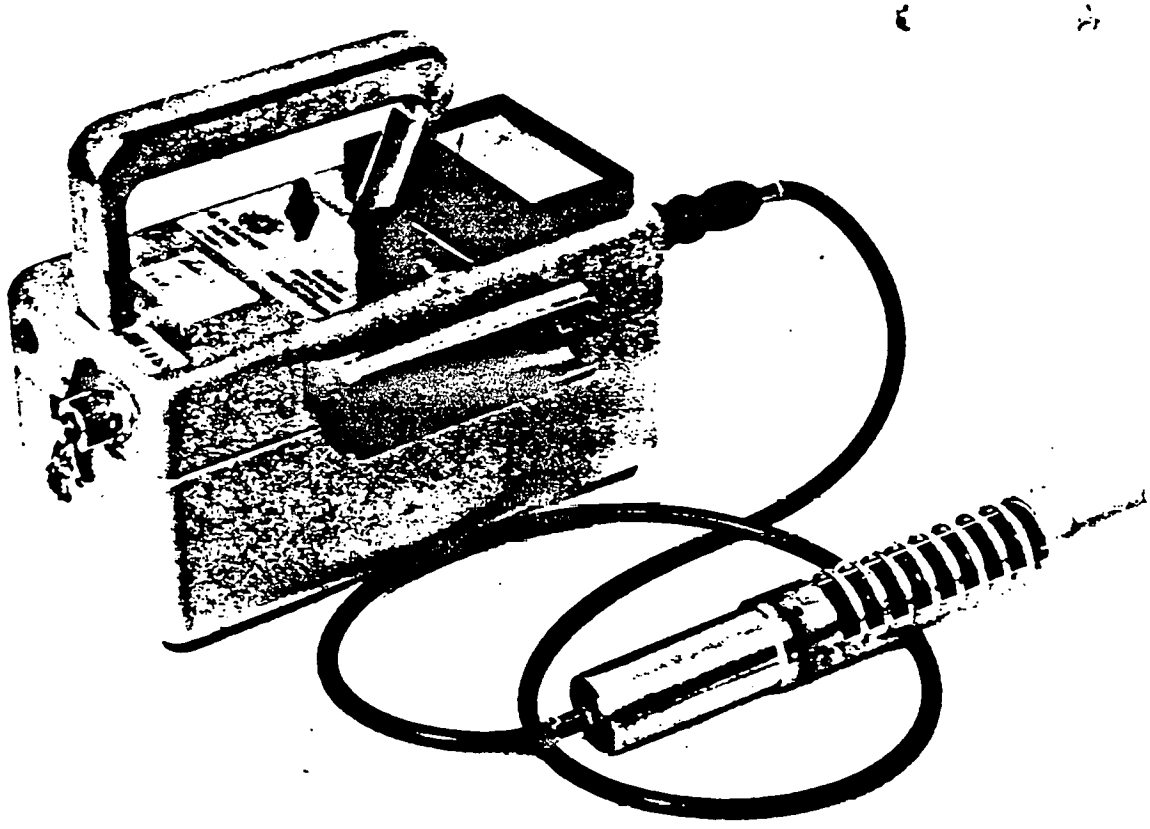


Fig. I-A. Geiger-Mueller survey meter.

ORNL-Photo 6710-76

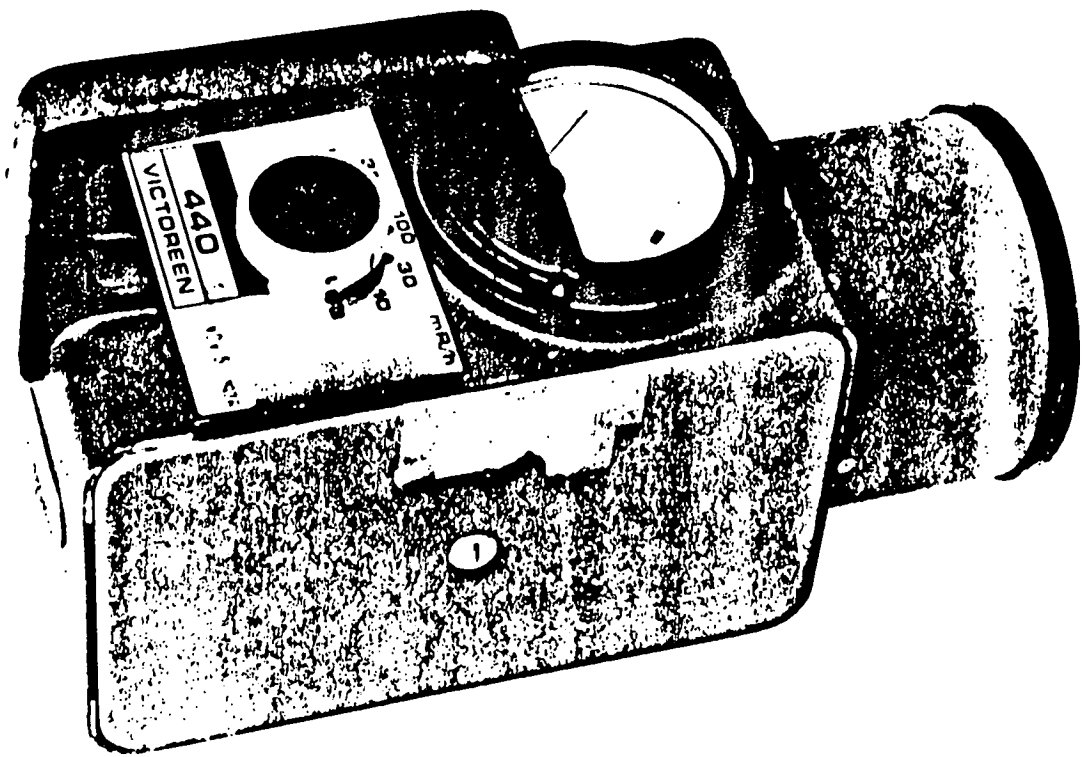


Fig. I-B. Victoreen 440 ionization chamber.

ORNL-Photo 6707-76

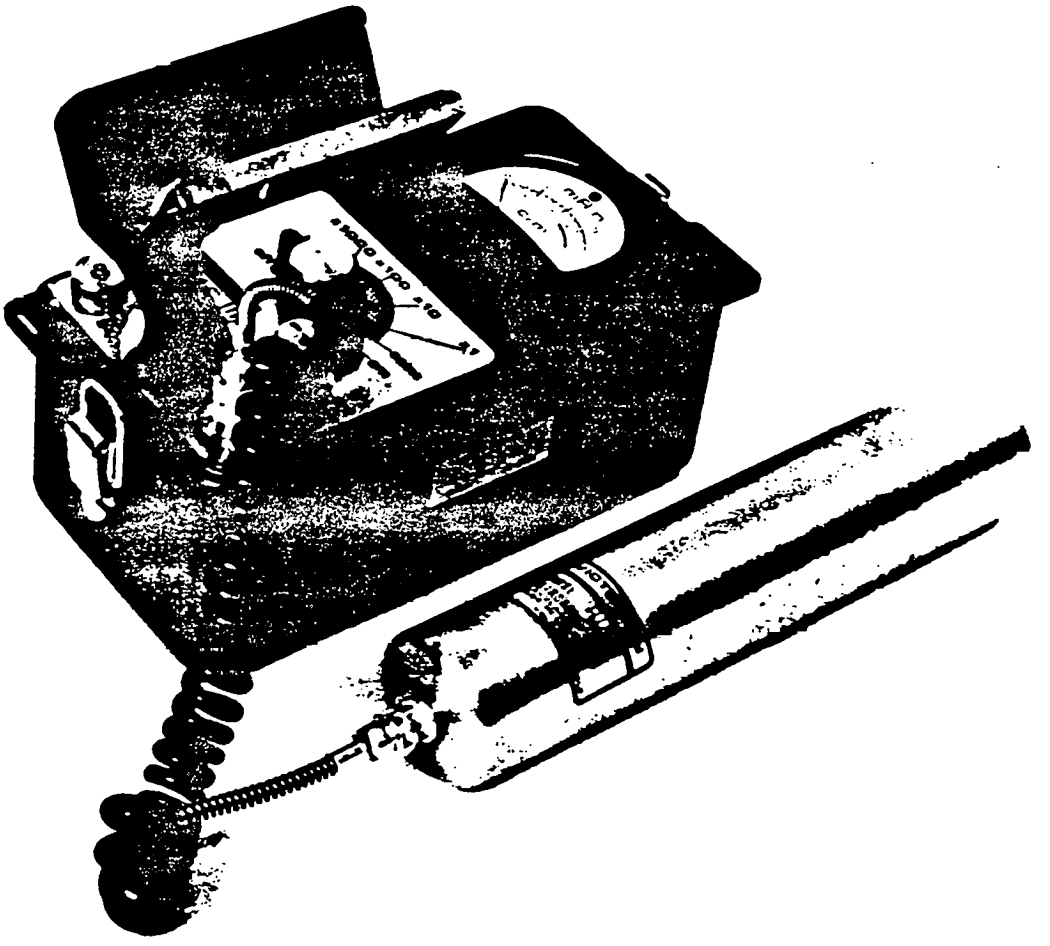


Fig. I-C. Gamma scintillation survey meter.

ORNL-Photo 0686-78

Fig. I-D. View of ionization chamber utilized in ORNL radon monitor. Shown in the photo-multiplizer housing, screen mesh hemisphere housing, and aluminized mylar covered ZnS scintillator.

ORNL-Photo 0685-78

Fig. I-E. Overall view of ORNL continuous radon monitor.

DESCRIPTION OF Ge(Li) DETECTOR SYSTEM

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

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

ORNL-Photo 2172-75

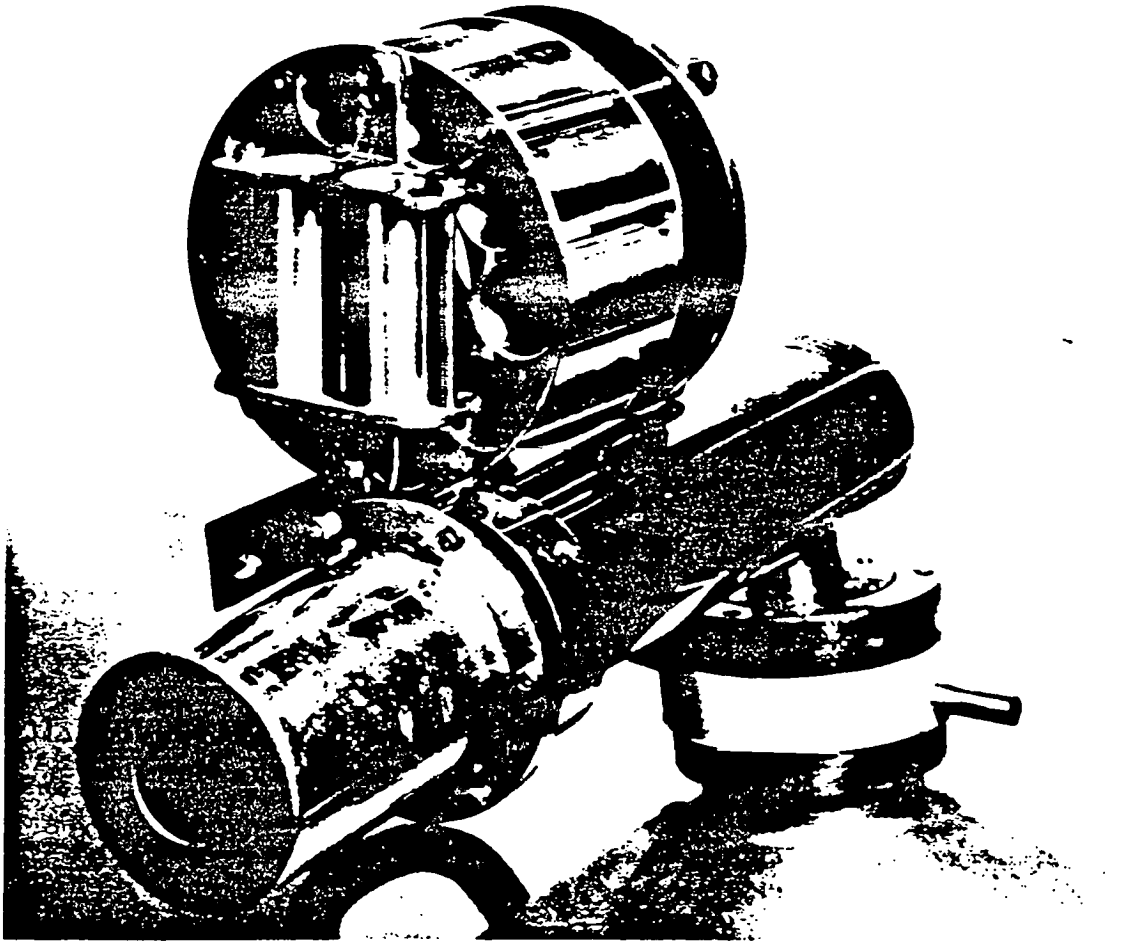


Fig. II-A. Holder for Ge(Li) detector system samples.

ORNL-Photo 6719-76

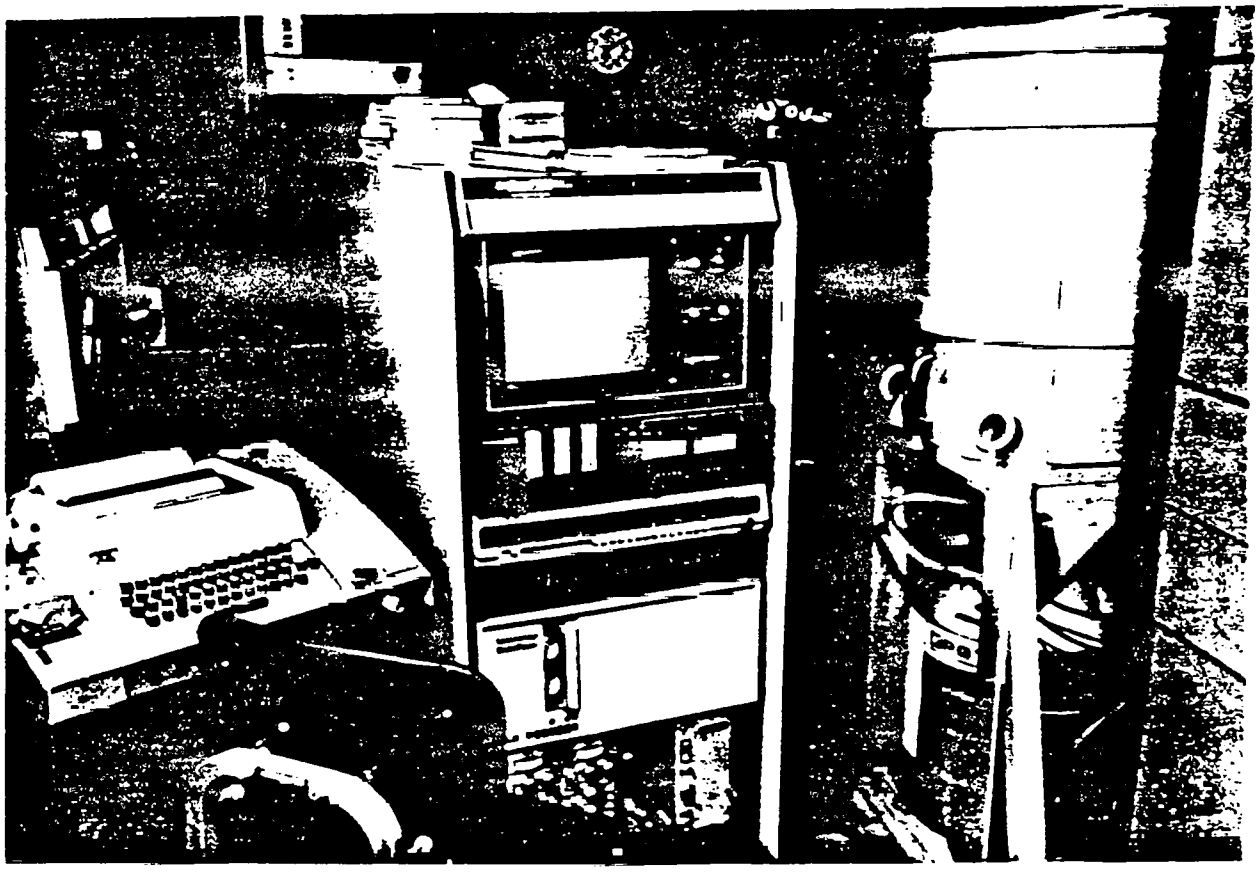


Fig. 11-8. Computer-based 4096 channel analyzer.

APPENDIX III

THE ESTIMATION OF RADIUM-226 CONCENTRATION IN SUBSURFACE SOIL

1976 SURVEY

Scintillation probe readings were used to estimate radium concentrations at points in the core holes at which no soil samples were taken. For scintillation probe readings below 20,000 cpm, estimates of radium concentrations over intervals of 1 ft were based on the formula $y = 0.12x$, where

x = scintillation probe cpm/100

y = pCi ^{226}Ra/g.

The regression line $y = 0.12x$ was determined from ten pairs (x, y) for which both the scintillation probe reading x and the radium concentration y were known. (These scintillation probe readings and soil samples were taken at points on the St. Louis-Lambert Airport site.) The estimate $y = 0.12x$ was correct within a factor of 1.63 for all ten pairs (x, y) on which it was based; the average error factor* was 1.28 ± 0.20

It was found that the regression line $y = 0.12x$ could not be used to predict radium concentrations corresponding to scintillation probe readings above 20,000 cpm. The relation $y = 0.19x$ (x, y are as above) was determined from eight pairs (x, y) measured on the St. Louis-Lambert Airport site with scintillation probe counts y greater than 20,000 cpm. The formula $y = 0.19x$ yielded radium concentrations which were correct within a factor of 2.2 for all eight pairs (x, y) on which it was based; the average error factor was 1.57 ± 0.41. In order to avoid potentially large errors for estimates of radium concentrations over small intervals, the formula $y = 0.19x$ was applied only to estimate average ^{226}Ra

*The error factor is defined as the ratio of the predicted value and the measured value, with the larger of the two as the numerator.

concentrations over large intervals in which scintillation probe readings were consistently greater than 20,000 cpm.

For each of 16 core holes drilled on the site, a graph was made of scintillation probe readings versus depth. Subsurface soil samples were taken from 8 of these core holes; and for each of these 8 core holes, a graph was made of radium concentrations as a function of depth. A comparison of the graphs of radium versus depth with the graphs of probe readings versus depth indicated that the depth at which maximum radium concentrations occur can be accurately determined from the scintillation probe readings. Furthermore, it appears that the vertical extent of the contamination can be estimated within approximately six inches from the graphs of probe readings versus depth.

1978 SURVEY

The regression line was determined from five pairs (x, y) for which both the scintillation probe reading x and the radium concentration y were known. The regression line $y = 3.9x$ was correct within a factor of 1.23 for all five pairs (x, y) on which it was based; the average error factor was 1.13 ± 0.13.

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

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

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

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

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

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

    b. Provide a detailed health and safety analysis which reflects that the residual amounts of 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 IV-1. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:

    a. Identify the premises.

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

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

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

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

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 βγ/100 cm^2	15,000 dpm βγ/100 cm^2	1,000 dpm βγ/100 cm^2

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

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

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

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

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

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

Excerpts from

Proposed

ANSI N328-197

Proposed American National Standard

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

Secretariat

Health Physics Society

Property shall not be released for uncontrolled use unless documented measurements show the total and removable contamination levels to be no greater than the values in Table 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[a] over the 1 m^2 provided the maximum activity in any area of 100 cm^2 is less than 3 times the limit value.

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

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

[b] MPC_a: Maximum Permissible Concentration in Air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as NCRP, ICRP or NRC (10 CFR 20, Appendix B, Table 2, Column 1).

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

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

TABLE 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:

a. From measurements of a representative number, n, of sections, it is determined that $1/n \sum_{i=1}^{n} Si > L$, where Si is the dpm/100 cm^2 determined from measurement of section i; or

b. On surfaces less than 1 m^2, it is determined that $1/n \sum_{i=1}^{n} Si \geq AL$, where A is the area of the surface in units of m^2; or

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

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 Energy Research and Development 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 U.S. Energy Research and Development Administration or any duly authorized representative thereof.

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

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

(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 Reguations
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

EVALUATION OF RADIATION EXPOSURES AT THE ST. LOUIS-LAMBERT AIRPORT SITE
ST. LOUIS, MISSOURI

The U. S. Department of Energy has determined that the former Atomic Energy Commission (AEC) Airport Storage Site in St. Louis, Missouri, is presently contaminated with radioactive residues. The 21.7-acre site, now a part of the St. Louis-Lambert Airport property, was used during the 1950's and 1960's for the storage of uranium- and radium-bearing residue wastes. These wastes resulted primarily from operations of the Mallinckrodt Chemical Corporation during their AEC-contracted uranium processing operations from 1946 to 1953. The tract of land is bordered on the north and east by Brown Road, on the south by tracks of the Norfolk and Western Railroad, and on the west by Coldwater Creek.

Decontamination actions at the site began in November of 1965, at which time the Atomic Energy Commission conducted a radiological survey. During 1966 and 1967, most of the residues were sold for their mineral contents and removed from the site. Most of the remaining residues (located in the western section of the site) were subsequently removed to an abandoned quarry at Weldon Springs, Missouri. All structures on the site were razed, the resulting rubble was buried on-site, and one foot of clean fill dirt was spread over the site. In December 1969 an additional two to three feet of clean soil was spread over several areas of the site to reduce the radiation levels to below guideline values. At the present, there are no structures on the site and access is controlled by the airport manager.

There is a possibility that this site may become the location for a police academy driving school. The present deed to the property is a

quit claim deed and specifies that the area be used only for airport purposes unless approved by the Federal Aviation Authority (FAA). Future uses of the site are contingent upon maintaining the radiation exposure at acceptable levels.

Contamination at the St. Louis Airport site is due to buried deposits of naturally occurring radionuclides--principally, uranium-238, radium-226, and thorium-230. This contamination will yield slight radiation exposures to persons on the site. These small radiation exposures result primarily from beta and gamma radiations emitted by the radionuclides in the soil. In addition to these direct radiation exposures, radium deposits in the soil may lead to exposures through the inhalation of radon and its short-lived daughters. The additional exposures received by other sources such as ingestion (e.g., eating or drinking on the site) are relatively small as compared with external radiation and the inhalation of radon and its short-lived daughters. A summary of radiation exposures is provided in Table V-1 along with appropriate guidelines and background values.

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

TABLE V-1

SUMMARY OF EXPOSURE DATA AT THE ST. LOUIS-LAMBERT AIRPORT SITE
ST. LOUIS, MISSOURI

Exposure Source	Background Levels	Guideline Value for General Public	Guideline Value for Radiation Workers	Average Levels at St. Louis site
Radon in air	Less than one picocurie* per liter of air	Continuous exposure to 3 picocuries per liter of air	Exposure for 40 hours per week and 50 weeks per year to 30 picocuries per liter of air	Average concentration was 0.33 picocurie per liter of air
Radon daughters in air	Less than 0.01 working level†	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	Estimated average concentration is less than 0.001 working level
Gamma radiation from daughters of radium and uranium contamination	8 micro-Roentgens‡ per hour in the St. Louis area	250 microRoentgens per hour above natural background for 40 hours per week and 50 weeks per year for an individual in the general public. This is equivalent to 0.5 Roentgen per year	2500 microRoentgens per hour for 40 hours per week and 50 weeks per year. This is equivalent to 5 Roentgens per year	Average gamma radiation level one meter above the ground was 15 micro-Roentgens per hour inside the fenced area. Average level was 60 microRoentgens per hour in the drainage ditches along either side of Brown Road

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

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

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

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.

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

Direct Beta and Gamma Ray Exposures

Nuclear Regulatory Commission (NRC) guidelines state that the combined dose from weakly penetrating beta particles and from gamma rays, measured at a distance of one centimeter from any surface, should not

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

TABLE V-2

Uranium-238 decay series

Parent	Half-life	Decay products	Daughter
uranium-238	4.5 billion years	alpha	thorium-234
thorium-234	24 days	beta, gamma	protactinium-234
protactinium-234	1.2 minutes	beta, gamma	uranium-234
uranium-234	250 thousand years	alpha	thorium-230
thorium-230	80 thousand years	alpha	radium-226
radium-226	1600 years	alpha	radon-222
radon-222	3.8 days	alpha	polonium-218
polonium-218*	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.

exceed 0.2 millirad* per hour when averaged over an area of one square meter. The combined dose rate should not exceed 1.0 millirad per hour in small areas of 100 cm^2. These guidelines are exceeded at 10 locations at the site, with individual measurements ranging up to 4.6 millirads per hour in the western half of the site. Two locations outside the fenced confines of the site in the ditch south of Brown Road exceeded these guidelines; the maximum observed in this ditch was 1.6 millirad per hour. Most of the contamination appears to be within an area of about 1.5 acres in the western half of the site. Beta-gamma exposure rates in this area averaged 1.5 millirad per hour, with several areas exceeding the guideline value of 0.2 millirad per hour when averaged over one square meter or greater.

Thus, handling the surface soil from this western area for a period of 1 hr would produce a beta-gamma dose of 1.5 millirads to the skin. For comparison, the skin dose which would be expected from a normal year's watching of color television by an adult is 1.6 millirads; for a child less than 15 years of age, the comparable dose is 3.6 millirads per year (according to the United Nations Scientific Committee on the Effects of Atomic Radiation).

As may be seen in Table V-2, several of the daughters of uranium-238 and of radium-226 emit gamma radiation (gamma rays are penetrating radiation like X-rays). Hence, the residues on this site are sources of external gamma radiation exposure. External gamma exposures measured at one meter above the ground at the St. Louis Airport Storage site ranged

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

from 4 to 330 microRoentgens* per hour, with the highest readings being obtained in the drainage ditches along both sides of Brown Road. The average exposure rate within the fenced area of the site was 15 micro-Roentgens per hour. The average exposure rate in the 1.5 acre area in the western portion of the site was 113 microRoentgens per hour. The average exposure rate in the ditches along side Brown Road was 60 micro-Roentgens per hour. Exposure to this level for 2000 hours per year, a typical work year, would lead to an exposure of 120,000 microRoentgens. For comparison, a typical chest X-ray (according to Department of Health, Education, and Welfare data) might yield an exposure of 27,000 microRoentgens. Background levels in the St. Louis area averaged 8 microRoentgens per hour.

The National Council on Radiation Protection and Measurement (NCRP) has recommended a maximum annual whole-body exposure rate of 500,000 microRoentgens per year to an individual continually exposed in the general public. This value corresponds to 250 microRoentgens per hour for 2000 exposure hours (40 hours per week and 50 weeks per year) or to approximately 60 microRoentgens per hour for continuous exposure. The guideline of 250 microRoentgens per hour would be exceeded at five locations at the site if the area were frequently occupied.

At the present time, access to the Airport Storage site is restricted and controlled by the airport manager. The only persons who occupy the site are those who deliver and unload clean rocks and fill material. These individuals spend only one or two hours per month on the site.

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

This present pattern of low occupancy reduces gamma radiation exposures to values well below the guidelines.

Soil along the northern fence has been disturbed by burrowing animals and eroded by water drainage. Erosion of this contaminated soil has spread the contamination to the drainage ditches north and south of Brown Road. This contamination is the cause of the elevated surface beta-gamma dose rates and external gamma radiation exposures found in these ditches. Although access to these ditches is not controlled, there is no reason to believe that any person occupies these ditches for more than a few minutes each month.

Inhalation of Radionuclides

Radon-222, the daughter of radium-226, is an inert gas which may leave the soil and enter the atmosphere. Measurements of the concentration of radon at locations adjacent to the site ranged to 0.99 picocuries* per liter and averaged approximately 0.33 picocuries per liter. None of these readings exceed the guideline value of 3.0 picocuries per liter for exposure of the general public as set forth in 10 CFR 20.† At the present, no structures exist on the site. However, if buildings were to be constructed over contaminated soil, radon concentrations higher than those measured on site could exist in the buildings. Estimates indicate that the radon concentration in structures built over the most contaminated soil could exceed the guideline value.

As may be seen in Table V-2, the decay of radon-222 produces a series of short-lived daughters. The unit which has been developed to

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

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

measure the concentration of daughters is the working level.* It is estimated that present radon daughter concentrations in air on the site are much less than 0.001 working level. These measurements are well below the guideline value of 0.03 working level suggested in 10 CFR 20. However, it is estimated that this guideline value could be exceeded in structures built over the most contaminated soil. Consequently, careful consideration should be given to the location of any structure built on this site in the future.

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

Other Considerations of Exposure

The concentration of radionuclides in ground water samples taken at the site were all below the concentration guide for water (CG_w) set forth in 10 CFR 20. Additional samples were taken from water flowing in drainage ditches north and south of the site and from Coldwater Creek which receives all site drainage. The concentration of radionuclides in all samples was well below the concentration guide values.

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

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

Risk and Radiation Exposures

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

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

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

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

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

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

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

The annual death rate from all types of cancer among all population groups in St. Louis County (as of 1970) was 154 deaths per 100,000 population. At the same time, the death rates from all types of cancer for all population groups in the United States and in the state of Missouri were 151 and 146 per 100,000 population, respectively. A one-year exposure to penetrating gamma radiation of 500,000 microRoentgen might increase the risk of death due to all types of cancer by about one-tenth of a percent. Exposures in excess of these guideline values would be expected to result in proportionately higher increases in risk. Consequently, any action taken to reduce either the rate or the duration of radiation exposures would also reduce the risk attendant to that exposure.

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

Remedial Measures

The radiation exposures at the St. Louis Airport Storage site are attributable to the presence of uranium-238 and radium-226 deposits in soil at the site. This contamination leads to exposures due to external beta and gamma radiation and from the inhalation of radon which is produced by deposits of radium-226 in the soil. Each of these exposures would be eliminated by the removal of contaminated soil followed by backfill with uncontaminated soil. Due to the depth to which radium is deposited, it would be necessary to remove the top four feet of soil

over most of the site. In some areas, it would be necessary to excavate deeper to remove contaminated equipment buried on the site. Contamination in the ditches alongside Brown Road is generally only a few inches deep. Current exposures from the pathways discussed here could be reduced to below guideline values by placing additional fill dirt over the areas containing the uranium and radium bearing residues. Periodic surveillance of the area would be required to insure that the additional fill remained intact and that use of the site did not change. The Department of Energy is now actively evaluating these and other alternatives under a priority program designed to assure public protection.

SUMMARY

The St. Louis Airport Storage Site is contaminated with residues resulting from the previous use of this site to store radioactive residues containing naturally occurring uranium-238 and radium-226. This contamination is leading to exposures resulting from beta and gamma radiation and from the inhalation of radon and its short-lived daughters. Measurements made at the site indicate that, in several cases, such exposures exceed pertinent guidelines. In addition, construction of buildings on the site could produce exposures to radon and its daughters which greatly exceed guidelines. Consequently, some remedial measures are in order. The Department of Energy has developed a coordinated plan which addresses the specific problems at this landfill site and other formerly utilized MED/AEC sites. Currently, work is underway to implement the elements of this plan.