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Formerly Utilized MED/AEC Sites Remedial Action Program

Radiological Survey of the Middlesex Sampling Plant
Middlesex, New Jersey

November 1977

Final Report

Prepared for

U.S. Department of Energy
Division of Environmental Control Technology
Washington, D.C. 20545

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Under Contract Number W-7405-ENG-26

By

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

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PREFACE

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

These reports contain the results of surveys of the current radiological condition of these sites. Based upon the findings of the surveys, further evaluation will be made at those sites where radioactivity above natural background is identified to determine whether further measures should be undertaken to assure the protection of the public health and safety.

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, Tennessee:

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RADIOLOGICAL SURVEY OF THE MIDDLESEX SAMPLING PLANT
MIDDLESEX, NEW JERSEY*

ABSTRACT

The results of a radiological survey of the former Middlesex Sampling Plant, Middlesex, New Jersey, are presented in this report. The surveyed property served as a uranium ore sampling plant during the 1940's and early 1950's. It was released for unrestricted use in 1968 following a radiological survey by the Atomic Energy Commission and is now a reserve training center for the U. S. Marine Sixth Motor Transport Battalion. The present survey was undertaken to determine whether the existing radiological status of the property is consistent with current health guidelines and radiation protection practices. The radiological survey included measurement of residual alpha and beta-gamma contamination levels, radon and radon daughter concentrations in buildings, external gamma radiation levels on the site and on adjacent property, and radium concentrations in soil on the site and on adjacent property. Surface contamination levels exceeded U. S. Nuclear Regulatory Commission (NRC) guidelines and ^{222}Rn concentration levels exceeded the non-occupational maximum permissible concentration MPC_a of 3 pCi/liter in some structures. These results indicate the possible need for extensive radon and radon daughter measurements in structures both onsite and offsite over periods as suggested by the U.S. Surgeon General (as adopted in 10 CFR 712).

Radium concentrations onsite and offsite range as high as 551 pCi/g and 2400 pCi/g, respectively.

INTRODUCTION

At the request of the Energy Research and Development Administration, Oak Ridge Operations, a radiological survey was conducted in Middlesex, New Jersey, at the former Middlesex Sampling Plant, which served as a uranium ore sampling plant in the 1940's and early 1950's. The site is now occupied by the Sixth Motor Transport Battalion of the U. S. Marine Corps and serves as a reserve training center. It is adjacent to several Middlesex homes and business establishments and is drained by three drainage ditches which, in turn, flow into a main stream. (see Fig. 1)

This facility served as a storage depot and a sampling plant during the 1940's and early 1950's for Belgian Congo uranium ore, which usually contains equilibrium amounts of radium. The plant was decommissioned in the mid-1950's, and the sampling was shifted to other locations. Originally the plant was operated by the Department of the Army, but control was transferred to the Atomic Energy Commission (AEC) after the formation of the AEC in 1946. The AEC maintained control of this seven-acre site until 1968, when it was turned over to the General Services Administration and, subsequently, to the Department of the Navy.

The property was last surveyed in 1967 subsequent to decontamination and prior to release by the AEC. The decontamination consisted of removal of some of the contaminated soil and sandblasting and cleaning of the building surfaces. Due to the lack of documentation on the

radiological status of the property at the conclusion of the 1967 decontamination and the concern of ERDA to maintain radiation exposure to a level as low as reasonably achievable (ALARA), the site has been resurveyed to determine the magnitude of radiation levels due to residual contamination on the property and the extent of any offsite contamination.

A radiological survey was conducted by three health physicists from Oak Ridge National Laboratory (ORNL) during the period of March 29-April 16, 1976. The survey included the site proper, adjoining property belonging to individuals and the Borough of Middlesex, and the major drainage path from the site to a nearby brook. This survey consisted of the measurement of (1) alpha contamination levels and beta-gamma dose rates in buildings and throughout the site; (2) radon and radon daughter air concentrations in buildings; (3) external gamma radiation levels on the site and on nearby property; and (4) radium concentrations in soil on the site, on adjacent property, and in drainageways carrying runoff from the site.

The discovery, during this survey, of significant levels of contamination in the flood plain and drainage path to the south and west of the plant site predicated a supplemental survey. Additional measurements were made during the period May 10-21, 1976, to determine (1) radon and radon daughter concentrations in dwellings and business establishments on adjacent property; (2) external gamma radiation levels in dwellings and business establishments on adjacent property; (3) radium concentrations in soil on adjacent property, in the low-lying area to the south of the main site, and along the banks of a small creek which drains the area; and (4) external gamma radiation levels at one meter above the

surface for those areas where the concentration of radium in the soil was measured.

RADIOLOGICAL SURVEY TECHNIQUES

Measurement of Residual Alpha and Beta-Gamma Radiation Levels

The fixed contamination levels of floor, wall, and roof surfaces of the buildings were measured with gas-proportional alpha and Geiger-Muller beta-gamma survey meters. These survey meters are described in Appendix I. The direct readings were averaged over the area surveyed and are reported as the "general" contamination found in that area. The maximum readings in the specified area are also reported. Survey meters were also used to measure alpha and beta-gamma contamination at outdoor locations. Transferable contamination levels in the buildings were measured using standard smear techniques.* The smear counters are described in Appendix I.

Measurements of Radon and Radon Daughter Air Concentrations in Buildings

Measurements were made of radon and radon daughter concentrations in the buildings by both grab-sample and continuous-monitoring techniques. The radon daughter grab samples were analyzed using an alpha spectrometry technique refined by Kerr.¹

Additional radon and radon daughter measurements were made with the assistance of the Health and Safety Laboratory (HASL), ERDA. Radon grab samples were taken using evacuated glass flasks coated inside with a

* A standard smear is performed by wiping 100 cm² of a surface with filter paper on soft absorbent paper. Moderate pressure is applied by the tips of the first two fingers to the back of the filter paper.

uniform layer of zinc sulfide. Scintillations from this layer of zinc sulfide are measured with a photomultiplier tube and are used to give instantaneous radon levels.² Also, continuous measurements were made of radon and radon daughter levels in air using monitors^{3,4} from HASL. These were placed at three positions in buildings on the site.

Errors associated with all radon and radon daughter measurements are expected to be $\pm 20\%$. While the spectroscopy technique is expected to be the most accurate for a given measurement, the resulting working level (WL)^{*} values may not be used to predict average annual conditions because of the short-term, noncontinuous nature of the sampling. Consequently, the measurements from the continuous-monitoring techniques are more representative of long-term average concentrations than those from the grab-sample techniques. It should be noted, however, that even continuous sampling over a period of 2 to 3 weeks cannot be extrapolated to annual conditions.

In order to measure radon emanation from surfaces on the site and on adjacent property, a charcoal canister technique⁵ developed by HASL was used. The radon flux emanating from the surface gives a qualitative indication of the radium levels in the soil or material underlying the measurement point. Several variables, including porosity of the soil, moisture content, and ambient temperature affect the measured values. Therefore, this technique should be regarded as only an indication of the relative magnitude of the radium levels.

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

Measurement of External Gamma Radiation Levels

The external gamma radiation levels were measured with scintillation and Geiger-Muller type survey meters (described in Appendix I) and with thermoluminescent dosimeters (TLD's). The survey meter measurements are indicative of the instantaneous exposure rate at the point of measurement, while the TLD readings allow calculation of time-averaged exposure rates over a period of approximately six weeks. Radiation levels at the surface and at one meter above the surface were measured.

Errors of $\pm 30\%$ or more are typical for survey instrument readings. However, thermoluminescent dosimeters are, in general, accurate to $\pm 10\%$ for environmental dosimetry in the exposure range encountered in this survey.

Measurements of Radium Concentrations in Soil

The grid shown in Fig. 2 and Fig. 3 was used to locate positions at which soil core samples were taken to assess radium and uranium concentrations. Samples were taken by a split-spoon sampling technique. A motorized drilling rig with a three-inch sampler was used at some locations; the remaining samples were gathered with a manually-operated, portable, one-inch sampler. In both cases the sampling tube was driven into the ground to a known depth, removed, and disassembled to obtain the continuous core sample. The samples were packaged in plastic bags or bottles before being transported to Oak Ridge. Part of the samples of soil were processed by ORNL personnel using Bureau of Mines facilities in Salt Lake City, Utah and the remainder were processed by the Bendix Field Engineering Corporation in Grand Junction, Colorado. In both

cases, the samples were dried for 24 hr at 110°C, then pulverized to a particle size of -35 mesh (500 μ m). Upon return to Oak Ridge, aliquots from each sample were transferred to plastic petri dishes, weighed, and counted using a Ge(Li) detector. The spectra obtained were analyzed by computer techniques (described in Appendix II). Radium concentrations were determined for all the samples; in addition, ^{238}U , ^{230}Th , and ^{210}Pb concentrations were determined for selected samples.

ONSITE SURVEY RESULTS

The entire site was divided into subsections by a grid with 100 x 100 ft subsections (see Fig. 2). In addition to measurements at the grid points, several measurements were made in the buildings. For convenience of reporting, the wall surveys were divided into a lower portion (up to six feet) and an upper portion (above six feet). Throughout this report, all readings include background. Wherever appropriate, area background readings are given for comparison purposes. This survey was conducted in accordance with guidelines in use at ORNL⁶. As the resurvey program was expanded to include other sites, ERDA adopted a set of guidelines for the release of property for unrestricted use which was being used by the U.S. Nuclear Regulatory Commission (NRC)⁷.

Alpha and Beta Gamma Radiation

In guidelines⁷ provided by the NRC for the release of property for unrestricted use, strictest limits for surfaces contaminated with alpha emitters apply to ^{226}Ra , among other nuclides. The average* and maximum* limits for direct readings of alpha contamination on surfaces contaminated

* Measurements may not be averaged over more than one square meter. The₂ maximum contamination level applies to an area of not more than 100 cm².

with ^{226}Ra are 100 dpm/100 cm² and 300 dpm/100 cm² respectively; transferable alpha contamination should not exceed 20 dpm/100 cm². These limits are 50 times more restrictive than the limits for natural uranium and are consistent with proposed ANSI standards⁸ (see Appendix III). Since uranium ores were handled on the site, and since some of the environmental samples taken on the site showed the activity of ^{226}Ra to be as much or more than the activity of ^{238}U , it appears that the more restrictive limits for ^{226}Ra should be applied to this site.

The process building, administration building, thaw house, boiler shop, and garage each had areas in which fixed alpha contamination exceeded NRC limits for surfaces contaminated with ^{226}Ra . The process building showed far higher alpha contamination levels than the other on-site buildings. Measurements on the exterior surfaces of the process building revealed alpha contamination in spots up to 10⁵ dpm/100 cm² by direct reading, although most readings were in the range of 200 to 3000 dpm/100 cm² (Table 1). In the interior of the process building (Table 2), the window ledges of the upper level (second story) showed alpha contamination as high as 25 000 dpm/100 cm² by direct reading, and direct readings on the floor of the lower level were as high as 12 000 dpm/100 cm². The direct alpha contamination readings in the other buildings were generally below 5000 dpm/100 cm² (see Tables 3 and 4). Measurements of fixed alpha and beta-gamma contamination levels on the ground surface revealed direct alpha readings to 1272 dpm/100 cm² and beta-gamma readings at 1 cm to 418 $\mu\text{rad/hr}$ (see Fig. 4).

According to NRC guidelines,⁷ the average and maximum beta-gamma dose rates measured at 1 cm from a surface should not exceed 0.2 mrad/hr and 1.0 mrad/hr, respectively. It can be seen in Tables 1 and 2 that these limits are exceeded at several places on the interior and exterior surfaces of the process building.

The transferable contamination levels in the buildings were generally low, with only a few of the smears indicating transferable alpha contamination exceeding 30 dpm/100 cm². Transferable alpha contamination levels below 30 dpm/100 cm² were not recorded. Because NRC guidelines were applied after the survey was conducted direct alpha and beta-gamma readings were not averaged specifically for areas of 1 m² or less. The highest measurement for transferable alpha contamination was 375 dpm/100 cm². The locations of transferable contamination exceeding 30 dpm/100 cm² are shown in Fig. 5, and the measurements are given in Table 5. None of the smears from the process building and thaw house indicated beta-gamma contamination in excess of 200 dpm/100 cm². (The NRC limit for removable beta contamination is 1000 dpm/100 cm² for those beta emitters found on this site.) Smear samples taken in the boiler shop, the garage, the storage shed and the administration building showed less than 30 dpm/100 cm² alpha and 200 dpm/100 cm² beta contamination.

Radon and Radon Daughter Measurements in Onsite Structures

Radon and/or radon daughter concentrations in air were measured in the process building, boiler shop, garage, and administration building (see Figs. 5 and 6). Measurements of instantaneous radon daughter concentrations in air taken during the normal working day ranged from

0.003 WL to 0.10 WL, with the highest concentration being measured in the lower level of the process building (see Table 6). Continuous measurements taken on the lower level of the process building were as high as 0.15 WL (see Table 7); and these measurements were integrated over a six day period and hence include nighttime readings, which are typically higher than daytime readings. With the exception of one instantaneous level measured in the administration building, all radon daughter levels in onsite structures exceeded the average background level of 0.009 WL (see Table 8) in dwellings in the Middlesex area. Background radon measurements taken in various parts of the country are listed in Table 9.⁹

Indoor radon measurements were in the range of 2.4 to 29 pCi/liter, with the highest measurements being recorded on the lower level of the process building. The non-occupational maximum permissible concentration (MPC_a) for radon is 3.0 pCi/liter.¹⁰

The dose to individuals delivered by radon is small compared with the dose delivered by its daughter products (about 500 times less at equilibrium.¹¹ However, the measurement of radon concentrations in the buildings allows determination of the potential radon daughter levels assuming minimum ventilation. A concentration of 1 pCi/liter of radon in a room could produce a radon daughter concentration as high as 0.0085 WL.¹² Hence, with poor ventilation, the highest radon concentration found in the process building (29 pCi/liter) could produce a radon daughter concentration of 0.25 WL.

The situation at this site bears some resemblance to that encountered in Grand Junction, Colorado, where radium-bearing uranium mill tailings were used for private purposes, including construction of residences and commercial structures. At the request of the State of Colorado, the U. S. Surgeon General has developed a set of guidelines for use in considering the need for remedial action in such cases. These guidelines were adopted by ERDA as the basis for the Grand Junction Remedial Action Criteria, which has been codified as 10 CFR 712 (see ref. 13; also Appendix III). In considering the need for remedial action in structures where the radon daughter concentration exceeds background, it is recommended that indoor radon daughter concentrations be determined by "(1) averaging the results of six air samples each of at least 100 hours duration and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission." An average indoor radon daughter concentration of 0.01 WL above background for dwellings and schoolrooms, or of 0.03 WL or greater above background for other structures, will be considered by ERDA and regulatory authorities as an indication that remedial action may be necessary. The limited exploratory measurements made during this survey indicate the need for continued sampling in the process building over longer periods as recommended in 10 CFR 712, since radon daughter concentrations exceeding 0.03 WL above background were measured in that building. Also, as will be discussed later, measurements of external gamma radiation levels on the site indicate a possible need for continued radon daughter measurements in the other buildings onsite.

Radon Emanation Measurements

Radon emanations from soil surfaces on the site were measured at locations shown in Fig. 7. The results of these measurements are given in Tables 10 and 11. The average ^{222}Rn emanation rate for all outdoor locations on and immediately adjacent to the Sampling plant was 3.2 $\text{pCi/m}^2\text{sec}$. Background measurements taken at locations in the Middlesex vicinity, but remote to the Sampling plant, showed an average emanation rate of 0.45 $\text{pCi/m}^2\text{sec}$. The average world-wide background emanation rate is reported to be 0.43 $\text{pCi/m}^2\text{sec}$, with some background values within the United States reported as high as 1.4 $\text{pCi/m}^2\text{sec}$. (ref. 14). Since the contaminated area around the Sampling plant is small and the ^{222}Rn emanation is less than an order of magnitude greater than background, the incremental ^{222}Rn daughter exposures attributable to contamination at the Marine base will be negligibly small for the surrounding population.

External Gamma Radiation

Survey meter readings of external gamma radiation were taken at one meter above the surface at each of the points of the grid map, at several points on the periphery of the site, and at points on adjoining property. Measurements varied from 22 $\mu\text{R/hr}$ to 147 $\mu\text{R/hr}$, with the maximum exposure rate being found both near the fence and toward the center of the site. Readings are shown in Fig. 8. Background external gamma readings taken at one meter above the ground at points between 0.5 and 25 miles from the site were in the range of 5 to 10 $\mu\text{R/hr}$.

The locations of TLD measurements are given in Fig. 9, and the exposure rates determined from the TLD's are given in Table 12. The

exposure rate at TLD location 38 (342 $\mu\text{R/hr}$) far exceeds the measurements at the other 28 locations.

For locations where both TLD and survey meter measurements were taken, a comparison was made. The results of the comparison (see Table 13) show satisfactory agreement between the two techniques. Apparently the exposure rate does not fluctuate significantly over a period of several weeks.

According to the Surgeon General's guidelines any external gamma radiation measurement above 50 $\mu\text{R/hr}$ for dwellings and schools, or 150 $\mu\text{R/hr}$ for other structures is a basis for remedial action. However, any external gamma value more than 1 $\mu\text{R/hr}$ above background requires measurements to ascertain the indoor radon daughter concentrations. Since measurements indicated that background external gamma radiation levels in the Middlesex area are no higher than 10 $\mu\text{R/hr}$, the results shown in Table 14 indicate the need for further radon daughter measurements (as prescribed in 10 CFR 712) in all buildings on the site.

Radium Concentrations in the Soil

Soil samples were taken at the 46 locations indicated in Fig. 2. In addition, background measurements were taken offsite at location 47 on a vacant lot across Mountain Avenue from the Municipal Building and at location 48 at the corner of Lincoln and Mountain Avenues. Location 48 had the same type of soil which underlies the Marine base, with shale at varying depths, whereas location 47 was sandy and would be expected to have lower radium concentrations than location 48. The results,

which are given in Table 15, show far higher concentrations at many Marine base locations than at locations 47 and 48. Radium concentrations range as high as 577 pCi/g (at location 43 at a depth of 0.5 to 1.0 ft), compared with measurements of approximately 1.0 pCi/g at all depths of location 47 and measurements averaging 1.7 pCi/g at location 48.

OFFSITE RESULTS

The property to the south and west of the main site was surveyed and staked to clearly establish property lines. In addition, the distance along the main stream and three drainage ditches was marked at intervals of 100 ft, as shown in Fig. 3. The nomenclature used to designate the major drainageways is

MS = main stream

RR = main drain, following the course of proposed
Railroad Avenue

WS = side drain roughly paralleling the proposed
extension of Williams Street

DD = mosquito control drainage ditch dug in February
1976.

In order to specify location along a drainageway, the distance downstream from some convenient origin is used. For example, in Fig. 3, MS1 + 75 indicates the location on the main stream 175 ft downstream from the origin, which in this case is MS0 + 00 (the intersection of the main stream and the Railroad Avenue drainage ditch).

The main stream runs more than 2800 ft from the origin MS0 + 00 into Ambrose Brook, which is shown in Figs. 1 and 10. The various drainageways are shown in Figs. 11 through 16.

Several private properties were included in the survey (see Table 16 and Fig. 17). In the Borough of Middlesex, portions of Block 318 and Block 319 were surveyed. Block 319 is bounded by Wood Avenue, Mountain Avenue, William Street and the Marine base. Block 318 is bounded by the Lehigh Valley Railroad on the north; Mountain Avenue, Wood Avenue and the Marine base on the east; the Borough line on the south and Cedar Avenue on the west. Also, portions of several blocks in the Township of Piscataway were included in the survey. These are shown in Fig. 17. Radiation measurements were made on all the adjacent properties, and soil samples were obtained from the properties.

Radon and Radon Daughter Concentrations

Measurements were made in two private dwellings (locations F14 and F15, Table 7) and at two locations in a commercial establishment (locations F16 and F17, Table 7). The radon daughter concentrations in the dwellings did not exceed 0.004 WL, and the radon daughter concentration in the commercial establishment was found to be 0.014 WL. Hence, measured radon daughter concentrations were below the levels at which remedial action may be necessary, according to the Surgeon General's guidelines.¹³ However, the measurements were of an exploratory nature and were not taken over the periods of time specified by the Surgeon General's guidelines. Furthermore, the radon daughter concentration measured in the commercial structure is above the average background levels listed in Table 8 (even for background measurements taken in cellars).

External Gamma Radiation Levels

External gamma radiation levels were measured on all private properties adjacent to the Marine base. Although exposure rates were as high as 58 $\mu\text{R/hr}$ on occupied property, most measurements were near background levels. Gamma exposure rates and instruments used at each dwelling or business location are listed in Table 17. In some cases, external gamma levels were considerably higher than the upper background level of 10 $\mu\text{R/hr}$; this suggests the possible need for radon daughter measurements in some structures near the site, as prescribed in 10 CFR 712.

Along streams and drainage areas offsite, gamma radiation levels were as high as 235 $\mu\text{R/hr}$ * at three feet above the surface (see Tables 18 through 21 and Fig. 3). Highest levels were found along the main drainage ditch immediately south of the base. Along the main stream, gamma radiation levels decreased from 48 $\mu\text{R/hr}$ at the origin to less than 10 $\mu\text{R/hr}$ at points greater than 2000 ft downstream. Low levels of gamma radiation along the main stream, upstream from its intersection with the main drainage ditch, indicated there was no need for extensive measurements in that area.

Radium Concentrations in Soil

Soil samples were collected from the drainage area south of the main site and from private property adjacent to the main site. Radium concentrations measured in soil samples from adjacent properties (excluding the main drain) are given in Table 22 for sampling points shown in Figs. 3 and 18. Measurements from soil samples collected from the drainage area are given in Table 23.

* This corresponds to approximately 2 rem/year continuous exposure.

Highest concentrations of radium were found south of the site in and near the drainage area, where measurements ranged up to 2401 pCi/g. On the adjacent property east and north of the base, highest concentrations were found on the Middlesex Borough Block 318 Lots 11 and 12 (up to 63.5 pCi/g) and on the neighboring Lots 21 through 29 (up to 40.7 pCi/g). Property west of the base had generally lower concentrations of radium than properties to the east.

Radium concentrations from soil samples taken along the main stream are listed in Table 24. At the intersection of the main stream and the main drain, the concentration was found to be 317 pCi/g at 0 to 10 in. Most other measurements along the stream were considerably lower; however, at one point 1650 ft downstream, the radium concentration was 208 pCi/g at 0 to 10 in.

Samples were also collected along the banks of the main stream in an effort to determine the extent of contamination reaching out from the stream bed. The radium concentrations, which varied from less than 1.0 pCi/g up to 14.4 pCi/g, are listed in Table 25. The sample designation indicates the direction and the distance of the sampling point from the stream bed. For example, MS7R20 indicates a sample taken along the main stream (MS), 700 ft (7) downstream from the arbitrary origin (MS0+00 in Fig. 3), on the right bank (R), and 20 ft from the center of the stream bed (20). Only one sample was taken upstream from the "origin"; this sample was designated MS075L20 where the "075" was used to indicate 75 ft upstream.

Surface soil samples were also taken at the confluence of the main stream and Ambrose Brook (MM15), downstream along Ambrose Brook (MM16), and upstream along Ambrose Brook (MM17). (These locations are west of the area pictured in Figs. 3 and 18.) Radium concentrations at these locations were 3.0, 2.1, and 0.9 pCi/g, respectively.

Some offsite samples were analyzed for uranium (Table 26), and some were analyzed for ^{230}Th and ^{210}Pb (Table 27). The distribution of these radionuclides roughly parallels the distribution of ^{226}Ra .

The extent of offsite ^{226}Ra is shown in Fig. 19. Human exposure may be attributable to this contamination via habitation of structures built on the contaminated material (due to build-up of ^{222}Rn daughters within the structure) or by consumption of foodstuffs grown on the contaminated area.

The radon concentration C in the first story of a building which is built on contaminated soil can be estimated from the equation

$$C = \frac{J}{(\lambda_R + \lambda_V)} h ,$$

where

J is the emanation rate ($\text{pCi/m}^2\text{-sec}$),

λ_R is the radioactive decay constant for ^{222}Rn (sec^{-1}),

λ_V is the air exchange rate (sec^{-1}), and

h is the height of the ceiling (m).

It is assumed in the equation that the floor is not a barrier to radon. Hence, this is a "worst case" assumption, but is not unrealistic for

some floors. For floors which act as barriers, such as concrete floors, the value of J should be adjusted accordingly. For example, a 2-in. thick concrete slab would reduce the value of J by approximately a factor of ten¹⁵. If we assume that the emanation rate J is 3.2 pCi/m²sec (the average for all outdoor areas on and immediately adjacent to the base), that h = 3m, $\lambda_R = 2.1 \times 10^{-6} \text{ sec}^{-1}$ and that there is one air exchange per hour in the building, then

$$C = \frac{3.2 \text{ pCi/m}^2 \text{ sec}}{(2.1 \times 10^{-6} \text{ sec}^{-1} + 2.8 \times 10^{-4} \text{ sec}^{-1}) 3 \text{ m}}$$

$$\approx 3.8 \times 10^3 \text{ pCi/m}^3 \approx 4 \text{ pCi/liter.}$$

At the rate of one air exchange per hour, 1.0 pCi/liter of radon would produce a radon daughter concentration of approximately 0.005 WL at steady-state conditions. The maximum emanation rates measured were approximately an order of magnitude higher ($\sim 30 \text{ pCi/m}^2 \text{ sec}$) and would produce proportionately higher radon daughter concentrations in structures erected on these locations. If dwellings were to be constructed in the areas of highest radon emanation, radon daughter concentrations of 0.2 WL or greater could occur in these structures.

Tomatoes are grown in gardens on adjacent property. Since these are personal gardens, only a limited number of people would be exposed by consuming contaminated foodstuffs. Based upon the measured concen-

tration of radium in the soil, it is possible to estimate the uptake of radium and the resulting radiation dose in individuals consuming these tomatoes. The 50 year dose commitment (DC) from ingesting the tomatoes can be calculated using the equation

$$DC = A_i \times B_{iv} \times C \times D_{aipj}$$

where A is the soil concentration of radionuclide i, in pCi/g; B_{iv} is the concentration factor in the edible part of the crop, v; C is the weight of food consumed and D_{aipj} is the dose factor specific for age (a), radionuclide (i), pathway (p), and organ (j).

Appropriate factors for radium in tomatoes consumed by adults are

$$\begin{aligned} B_{iv} &= 3.1 \times 10^{-4}^{16} \\ D_{aipj} &= 0.302 \text{ for bone dose (mrem/pCi)}^{17} \\ &= 0.031 \text{ for total body dose (mrem/pCi)}^{17} \end{aligned}$$

Assuming that the average tomato weighs 150 g, the 50 year dose commitment per tomato is

$$\begin{aligned} DC_{\text{bone}} &= A \text{ pCi/g} \times 3.1 \times 10^{-4} \times 150 \text{ g} \times 0.3 \text{ mrem/pCi} \\ &= 1.4 \times 10^{-2} A \text{ mrem} \\ DC_{\text{whole body}} &= A \text{ pCi/g} \times 3.1 \times 10^{-4} \times 150 \text{ g} \times 0.03 \text{ mrem/pCi} \\ &= 1.4 \times 10^{-3} A \text{ mrem.} \end{aligned}$$

The highest radium concentration found on property used for gardening was 63.5 pCi/g.

SUMMARY

A comprehensive radiological survey of the former Middlesex Ore Sampling Plant and surrounding area has been completed. Radiation levels in excess of measured background levels were observed in numerous areas inside and outside of buildings on site and in some areas outside property boundaries. This facility was used to assay various uranium-bearing ores. It is known that large quantities of pitchblend were stored and sampled during the period this facility was in operation. It must be assumed that radioactive contamination on this property resulted from the ore handling activities.

The observed radionuclides in environmental samples were identified as uranium and its daughters, including radium. It was also observed that the degree of secular equilibrium in these samples ranged from about 25% to more than 100%. ^{226}Ra can occur in amounts greater than the parent ^{238}U due to selective leaching of the ^{238}U when subject to weathering. It is known that this facility was cleaned with water in 1967 prior to use by the present occupants. Because uranium is more soluble than radium and thorium, the residual radioactivity must be assumed to include ^{226}Ra as a significant fraction of the total. Because ^{226}Ra is considered to present a greater potential hazard than natural uranium, the standard for acceptable levels of residual radioactivity must be applied under the assumption that the controlling radionuclide is ^{226}Ra .

The process building, administration building, thaw house, boiler shop, and garage each had areas in which fixed alpha contamination levels exceeded the average and maximum NRC limits of 100 dpm/100 cm²

and 300 dpm/100 cm², respectively. The process building showed fixed alpha contamination levels as high as 10⁵ dpm/100 cm². Furthermore, some areas of the process building showed beta-gamma dose rates in excess of the average and maximum NRC limits of 0.2 mrad/hr and 1.0 mrad/hr, respectively. Transferable beta contamination levels were generally low in the buildings; however, transferable alpha contamination levels exceeded the NRC limit of 20 dpm/100 cm² at some points in the process building. It is possible that a few locations may have exceeded this limit but were overlooked due to the cutoff of 30 dpm/100 cm² which was used for the survey.

Radon levels in the process building exceeded the non-occupational MPC_a of 3 pCi/liter. Exploratory radon daughter measurements made in the process building indicated the need for continued sampling over longer periods as recommended in 10 CFR 712, since radon daughter concentrations exceeded 0.03 WL above background in that structure. Furthermore, the possible need for similar radon daughter measurements in the other onsite buildings is indicated by the fact that external gamma levels in those buildings exceeded background by at least 6 µR/hr. The average ²²²Rn emanation rate from the outdoor surfaces on and in the immediate vicinity of the site was approximately 7 to 8 times higher than background in that area. The soil onsite showed radium concentrations as high as 577 pCi/g.

Some radiation from the Sampling plant has been reaching adjacent property. External gamma radiation levels near offsite dwellings were as high as 58 µR/hr. The highest gamma radiation levels offsite (up to

235 $\mu\text{R/hr}$) were measured along the drainage ditches near the Marine base. Exploratory radon daughter measurements were above the background level in a commercial structure near the site. Furthermore, elevated gamma levels in some offsite structures indicate the possible need for extensive radon daughter measurements over periods as suggested by the Surgeon General (10 CFR 712). The soil in the vicinity of the Sampling plant showed elevated concentrations of radium, particularly in the drainage area to the south of the site; samples taken from that area showed concentrations as high as 2400 pCi/g.

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Table 1. Contamination survey of process building exterior

Location		Alpha (dpm/100 cm ²)	Beta-gamma ^a (mrad/hr)
North wall	Lower ^b	{ 500-1000 (gen'l) 1500-2000 (highest)	0.05-0.2 (gen'l)
	Upper ^c	1000-2500 (range)	
	Steps		0.25-0.30 (gen'l)
East wall (front)	Lower	{ 300-600 (gen'l) 3000 (highest)	0.1 (gen'l) 0.7 (highest)
	Upper	{ 200-500 (gen'l) 2500 (highest)	0.05-0.2 (gen'l) 0.4 (highest)
South wall	Lower	{ 300-1000 (gen'l) 100,000 (highest)	0.05-0.2 (gen'l)
	Upper	{ 500-1000 (gen'l to West) 100-300 (gen'l to East) 3000 (highest)	0.05-0.2 (gen'l)
West wall	Lower	{ 300-1000 (gen'l) 2000 (highest)	0.1-0.15 (gen'l) 1.25 (highest)
	Upper	{ 500-1000 (gen'l) 3000 (highest)	0.05-0.2 (gen'l) 2.9 (highest)
Roof		< 100 (gen'l)	0.05-0.2 (gen'l)
		4000 (highest)	0.25 (highest)

^aThe beta-gamma contamination is expressed in terms of dose rate at one cm above the surface. The G-M survey meter used for these measurements produced 1750 cpm per mrad/hr for surfaces contaminated with uranium at the site.

^bLower portion is up to 6 ft.

^cUpper portion is above 6 ft.

Table 2. Contamination survey of process building interior

Location	Alpha (dpm/100 cm ²)	Beta-gamma (mrad/hr)
Upper level		
Floor	< 100 (gen'l) 5000 (highest)	< 0.05 (gen'l) 0.9 (highest)
Walls	< 100 (gen'l) 300 (highest)	< 0.05 (gen'l) 0.9 (highest)
Window ledges	1000 (gen'l) 25000 (highest)	0.3-0.6 (gen'l) 4.3 (highest)
Lower level		
Floor	100-1000 (gen'l) 12000 (highest)	0.05-0.2 (gen'l) 0.75 (highest)
Walls	100-1000 (gen'l) 2000 (highest)	0.05-0.2 (gen'l) 0.3 (highest)
Window ledges (opened)	200-1000 (gen'l) 4000 (highest)	0.05-0.2 (gen'l) 0.3 (highest)

Table 3. Contamination survey of administration building

Location	Alpha (dpm/100 cm ²)	Beta-gamma (mrad/hr)
Interior walls	< 100 (gen'l) 1000 (highest)	< 0.5 (gen'l) 0.2 (highest)
Interior floors	< 100 (gen'l) 1000 (highest)	< 0.05 (gen'l) 0.2 (highest)
Exterior walls	< 100 (gen'l)	< 0.05 (gen'l)
Roof	400-600 (gen'l)	0.1 (gen'l)

Table 4. Contamination survey of thaw house, boiler shop, and garage

Location	Alpha (dpm/100 cm ²)	Beta-gamma (mrad/hr)
Thaw house		
Interior walls	300-600 (gen'l) 2000 (highest)	0.1-0.15 (gen'l)
Floor	0-200 (gen'l) 1200 (highest)	0.1-0.2 (gen'l) 0.9 (highest)
Boiler shop		
Interior walls	100-200 (gen'l) 1000 (highest)	
Floor	100-300 (gen'l)	
Exterior walls	1500 (gen'l) 5000 (highest)	0.2 (gen'l)
Roof	100 (gen'l)	0.05 (gen'l)
Garage		
Interior walls	100-200 (gen'l)	< 0.05 (gen'l)
Floor	100-200 (gen'l)	< 0.05 (gen'l)
Exterior walls	100-200 (gen'l)	< 0.05 (gen'l)
Interior beams	2000 (gen'l)	< 0.05 (gen'l)

Table 5. Smear sample data

Smear No. ^a	Alpha ^b (dpm/100 cm ²)	Smear No. ^a	Alpha ^b (dpm/100 cm ²)
18	39	1B	120
21	39	6B	258
29	36	11B	54
30	258	12B	33
32	33	16B	81
48	30	17B	90
61	30	18B	75
68	57	19B	33
73	41	21B	96
81	96	22B	375
2A	45	23B	207
4A	45	25B	45
60A ^c	372	29B	81
65A ^c	225	30B	90
83A	84	33B	33
96A	86		

^aSee Fig. 5.

^bSample data reported only for points >30 dpm/100 cm² alpha. No smear was found to give >200 dpm/100 cm² of transferable beta contamination.

^cSmear samples taken in the thaw house.

Table 6. Radon daughter concentrations using spot sample spectroscopy technique

Sample location number ^a	Description	Radionuclide	Concentration	
			pCi/liter	Working levels
1	Lower level process bldg. Shop	Ra-A	20.3	
		Ra-B	9.1	
		Ra-C	7.5	
		Total	37.0	0.10
2	Lower level process bldg. South end	Ra-A	17.9	
		Ra-B	10.1	
		Ra-C	10.3	
		Total	38.3	0.10
4	Upper level main bldg. North end hall	Ra-A	7.4	
		Ra-B	2.2	
		Ra-C	3.9	
		Total	13.5	0.03
6	Upper level process bldg.	Ra-A	8.4	
		Ra-B	4.1	
		Ra-C	3.7	
		Total	16.2	0.04
7	Upper level process bldg. Gymnasium	Ra-A	5.6	
		Ra-B	4.3	
		Ra-C	3.3	
		Total	13.2	0.04
8	Administration bldg.	Ra-A	1.8	
		Ra-B	0.1	
		Ra-C	0.1	
		Total	2.0	0.003

^aSee Fig. 6.

Table 7. Radon and radon daughter measurements

Location ^a	Radon measurements (pCi/liter)		Radon daughter measurements
	Flask	CHRIS	MOD (WL)
F1	23	29 ^b	0.15 ^b
	18		
	8.5	18.9 ^c	0.14 ^c
F2	31		
	4.4		
F3	7.0		
F4	12		
F5	16		
F6	4.4		
F7	13	12 ^b	0.090 ^b
F8	3.1		
F9	19		
F10	0.28		
F11	0.60		
F12	0.26	2.4 ^b	0.016 ^b
F13	0.02		
	0.25		
F14	0.4	0.5 ^c	0.0040 ^c
F15	0.2	0.5 ^c	0.0032 ^c
F16	0.5		0.014 ^c
F17	0.6		

^aSee Figs. 5 and 6.

^bMeasurement integrated over the period 4/9-4/15.

^cMeasurement integrated over the period 5/12-5/18.

Table 8. Background levels^a of ^{222}Rn and daughters in and around dwellings in Middlesex area

Measurement	Concentrations			Number of measurements
	Minimum	Maximum	Average	
^{222}Rn concentrations in cellars	0.72 pCi/liter	6.0 pCi/liter	2.65 pCi/liter	31
^{222}Rn daughter concentrations in cellars of dwellings	0.002 WL	0.040 WL	0.013 WL	56
^{222}Rn daughter concentrations in first floor of dwelling	0.002 WL	0.026 WL	0.006 WL	56
^{222}Rn daughter concentrations in dwellings (includes cellars, first floor, second floor, garage)	0.002 WL	0.040 WL	0.009 WL	112
^{222}Rn daughter concentrations outdoors	0.0015 WL	0.0026 WL	0.002 WL	5

^a Most measurements were taken within 15 miles, and all were taken within 50 miles of Middlesex, New Jersey. Individual measurements represent weekly average concentrations. The information was taken from a study by HASL (to be published).

Table 9. Background levels of ^{222}Rn concentration in dwellings^a

Location	Number of buildings investigated	Type of building and building material	^{222}Rn concentration outdoors (pCi/liter)		^{222}Rn concentration indoors (pCi/liter)	
			Range	Mean	Range	Mean
Boston area	7	One family houses:	0.01-0.15	0.05	0.005-0.23	0.07
		first floor (wood frame)			0.1-0.94	
	3	Basement (concrete)			0.01-0.19	0.09
		Apartments - brick			0.02-0.10	
Tennessee	4	Offices and laboratories			0.13-4.8 ^b	1.40
	15	Houses-most of them of concrete construction			0.03-3.6 ^b	1.26
Florida	16					

^aRef. 9.

^bConverted from working level units by assuming that ^{222}Rn and its daughters are in the equilibrium ratio 1:0.9:0.6:0.4.

Table 10. Measurement of radon emanation rate from surfaces onsite using charcoal canister technique

Location ^a	Radon emanation rate (aCi cm ⁻² s ⁻¹)	Surface	Location ^a	Radon emanation rate (aCi cm ⁻² s ⁻¹)	Surface
1	160	Soil	22	110	Paved
2	580	Paved	23	52	Hard soil
3	33	Paved	24	1000	Hard soil
4	11	Paved	25	5.3	Paved
5	59	Paved	26	24	Paved
6	270	Paved	27	3100	Hard soil
7	63	Paved	29	18	Paved
8	190	Paved	30	47	Paved
9	96	Paved	31	890	Gravel
10	620	Paved	32	63	Paved
11	160	Paved	33	11	Paved
12	160	Paved	34	25	Gravel
13	120	Paved	35	190	Hard soil
14	21	Paved	36	13	Paved
15	36	Paved	37	310	Grass
16	420	Paved	38	620	Grass
17	350	Paved	38	1200	Grass
18	170	Paved	38	450	Paved
19	81	Paved	39	770	Grass
20	13	Paved	39	1000	Grass
21	76	Paved	40	130	Paved

Table 10. (cont'd.) Measurement of radon emanation rate from surfaces onsite using charcoal canister technique

Location ^a	Radon emanation rate (aCi cm ⁻² s ⁻¹)	Surface	Location ^a	Radon emanation rate (aCi cm ⁻² s ⁻¹)	Surface
41	72	Paved	45	19	Concrete floor
42	110	Gravel	46	27	Concrete floor
43	690	Gravel	47	37	Concrete floor
44	63	Paved	48	1.2	Tile floor

^aSee Fig. 6; no data collected at location 28.

Table 11. Measurement of radon emanation rate offsite
using charcoal canisters

Location ^a	Radon emanation rate (aCi cm ⁻² sec ⁻¹)	Surface
77	240	Grass
78	540	Grass
78	650	Grass
79	700	Loose soil
80	53	Packed soil
81	98	Soil
82	36	Grass
83	190	Swampy
84	210	Loose soil
85 ^b	35	Soil
86 ^b	16	Gravel
87 ^b	43	Sandy soil
88 ^b	28	Soil
89 ^b	81	Grass
90 ^b	10	Soil
91 ^b	54	Grass
92 ^b	93	Soil

^aSee Fig. 7.

^bLocations remote to Middlesex Sampling Plant. Flux measurements may be interpreted as background for the Middlesex area.

Table 12. Onsite external gamma radiation measurements
using thermoluminescent dosimeters

TLD location ^a	Exposure Rate ($\mu\text{R/hr}$)	TLD location ^a	Exposure Rate ($\mu\text{R/hr}$)
1	28	26	24
2	21	27	49
3	20	28	34
4	23	29	22
6	97	30	29
7	144	31	20
13	22	32	19
19	80	33	15
20	33	34	14
21	44	35	17
22	34	36	27
23	28	37	60
24	63	38	342
25	142	39	49
		40	27

^aSee Fig. 8.

Table 13. Comparison of TLD and scintillation counter

TLD Location ^{a,b}	Reading ($\mu\text{R/hr}$)	
	TLD	Scintillation counter
1	28	33
3	20	22
4	23	24
13	22	47
19	80	74
22	34	31
25	142	147
27	49	46

^aThese are the only locations where both TLD and scintillation counter measurements were made.

^bSee Fig. 8.

Table 14. Gamma radiation levels in
buildings onsite

Building	Average exposure rate (μ R/hr)
Process	26 .
Thaw house	19
Boiler shop	24
Vehicle storage	27
Garage	17
Administration	16

Table 15. Radium concentrations in soil samples taken on the Marine base

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
1	M 1.1	0-0.5	2.1
	M 1.2	0.5-1	135
	M 1.3	1.0-2.0	7.6
	M 1.4	2.0-3.0	2.0
2	M 2.2	0.5-1.0	2.6
	M 2.3	1.0-2.0	1.7
	M 2.4	2.0-2.6	2.0
5	M 5.3		17
6	M 6.2	1.3-1.8	33
	M 6.3	1.8-2.6	1.7
8	M 8.3	1.5-2.5	3.8
9	M 9.3	1.0-2.0	106
	M 9.4	2.0-3.0	2.9
14	M 14.3	0.5-1	< 1
	M 14.4	1.0-2.0	< 1
	M 14.5	2.0-3.0	< 1
	M 14.6	3.0-3.5	2.4
15	M 15.3	1.0-1.5	0.9
	M 15.4	1.5-2.5	1.2
	M 15.5	2.5-3.5	1.1
16	M 16.2	0.5-1.0	2.3
	M 16.3	1.0-2.0	1.1
	M 16.4	2.0-2.5	1.3
17	M 17.3	0.5-1.0	20
	M 17.4	1.0-1.5	6.1
	M 17.5	1.5-2.5	0.87
23	M 23.1	0-0.5	9.2
	M 23.2	0.5-1.0	23
	M 23.3	1.0-2.0	28
	M 23.4	2.0-3.0	1.4
	M 23.5	3.0-4.0	1.4

Table 15. (cont'd.) Radium concentrations in soil samples taken on the Marine base

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
24	M 24.1	0-0.5	1.0
	M 24.2	0.5-1.0	360
	M 24.3	1.0-2.0	69
	M 24.4	2.0-3.0	8.8
25	M 25.3	0.5-1.0	2.0
	M 25.4	1.0-1.5	1.1
	M 25.5	1.5-2.0	1.6
26	M 26.3	0.5-1.0	5.3
	M 26.4	1.0-1.5	1.7
	M 26.5	1.5-2.5	1.4
27	M 27.2	0.5-1.0	33
	M 27.3	1.0-2.0	105
	M 27.4	2.0-3.0	3.2
	M 27.5	3.0-4.0	1.5
28	M 28.1	0-0.5	0.4
	M 28.2	0.5-1.0	126
	M 28.3	1.0-2.0	1.9
	M 28.5	3.0-3.8	1.4
31	M 31.1	0-0.5	68
	M 31.2	0.5-1.0	29
	M 31.3	1.0-2.0	1.2
	M 31.4	2.0-3.0	1.7
	M 31.5	3.0-3.5	1.0
32	M 32.2	1.0-1.5	1.2
	M 32.3	1.0-2.0	1.2
	M 32.4	2.0-2.5	1.2
33	M 33.2	1.0-2.0	1.8
	M 33.3	2.0-3.0	1.3
34	M 34.1	0-0.5	3.4
	M 34.2	0.5-1.0	38
	M 34.3	1.0-2.0	6.3
	M 34.4	2.0-3.0	1.5
	M 34.5	3.0-3.5	1.3

Table 15. (cont'd.) Radium concentrations in soil samples taken on the Marine base

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
36	M 36.2	0.5-1.5	4.2
	M 36.3	1.5-2.5	1.1
38	M 38.1	0.0-0.5	106
	M 38.2	0.5-1.0	111
	M 38.3	1.0-2.0	1.4
	M 38.4	2.0-3.0	2.4
	M 38.5	3.0-4.0	1.1
39	M 39.1	0.0-0.5	12
	M 39.2	0.5-1.0	5.0
	M 39.3	1.0-2.0	145
	M 39.4	2.0-3.0	2.5
	M 39.5	3.0-4.0	3.4
40	M 40.1	0.0-0.5	3.1
	M 40.2	0.5-1.0	2.1
	M 40.3	1.0-2.0	56
	M 40.4	2.0-3.0	1.5
	M 40.5	3.0-3.5	1.5
41	M 41.1	0.0-0.5	2.4
	M 41.2	0.5-1.0	1.6
	M 41.3	1.0-2.0	4.6
	M 41.4	2.0-3.0	2.2
	M 41.5	3.0-3.5	2.3
42	M 42.1	0.0-0.5	11.2
	M 42.2	0.5-1.0	1.2
	M 42.3	1.0-2.0	1.2
	M 42.4	2.0-3.0	1.1
	M 42.5	3.0-4.0	1.1
43	M 43.2	0-5.1.0	577
	M 43.4	1.5-2.5	0.8
44	M 44.2	0.5-1.0	144
	M 44.3	1.0-2.0	2.2
	M 44.4	2.0-3.0	22
	M 44.5	3.0-4.0	15
	M 44.6	4.0-4.8	57

Table 15. (cont'd.) Radium concentrations in soil samples taken on the Marine base

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
45	M 45.2	1.0-1.5	4.7
	M 45.3	1.5-2.0	1.6
	M 45.4	2.0-2.5	8.7
46	M 46.2	0.5-1.0	20
	M 46.3	1.0-2.0	1.0
	M 46.4	2.0-3.0	16
	M 46.5	3.0-4.0	1.3
	M 46.6	4.0-4.5	2.0
47	M 47.1	0.0-0.5	1.0
	M 47.2	0.5-1.0	1.1
	M 47.3	1.0-2.0	< 1.0
	M 47.4	2.0-3.0	< 1.0
	M 47.5	3.0-4.0	< 1.0
48	M 48.2	0.5-1.0	2.3
	M 48.3	1.0-2.0	1.4
	M 48.5	3.0-3.5	1.4

^aSee Fig. 2.

Table 16. Nearby property surveyed

<u>Block</u>	<u>Lot</u>	<u>Ownership</u>
<u>Piscataway Township</u>		
395	1-24	private
396	1-16	private
397	1-34	private
412	1-14	private
413	1	private
389	44-50	private
<u>Middlesex Borough</u>		
318	1-6	private
318	7-9	private
318	10	private
318	11-12	private
318	21-29	private
318	38A-41A, 48	private
318	44, 45A	Borough of Middlesex
318	43	private
318	50	private
319	24, 25	private
319	26-39, 39-44	Borough of Middlesex
319	47	Borough of Middlesex

Table 17. External gamma radiation levels on nearby occupied properties

Property identification ^a	Gamma exposure rate (μR/hr)
Residence (inside lots ^b 1-6	12 ^c
Rear lawn	25 ^d
Front lawn	27 ^c
Residence (inside) lots ^b 7-9	11 ^c
Rear lawn	33 ^d
Front lawn	25 ^c
Lot ^b 10 rear lawn	45 ^c
Lots ^b 11-12 rear lawn	58 ^c
Lots ^b 21-29	43 ^c
Residence (inside) lots ^e 44-50	9 ^c
Building (inside) lots ^b 38A-41A	33 ^c , 37 ^f
Rear of Lot ^b 48 near bldg. 7-9	11 ^d
Lot ^b 48 outside bldg. 7-9	14 ^d
Lot ^g 24-25	16 ^d
Lot ^b 43	67 ^c
Lot ^b 50	20 ^c

^a Lot numbers refer to lots listed in Tables 16 and 22 and shown in Fig. 17.

^b Middlesex Borough Block 318.

^c Measured with scintillation survey meter.

^d Measured with TLD's.

^e Piscataway Township Block 389.

^f Measured with "Phil" G-M Counter.

^g Middlesex Borough Block 319.

Table 18. Gamma radiation level at 3 ft above the surface
of the drainage area south of main site

Survey location ^a	Radiation level (μ R/hr)	Survey location ^a	Radiation level (μ R/hr)
A6	30	D6	48
A7	28	D7	76
A8	25	D8	39
A9	19	D9	25
A9.5	10	D9.5	17
A10	26	D10	15
B6	49	DF6	31
B7	32	DF7	26
B8	57	DF8	16
B8.5	26	DF8.5	13
B9	12	DF9	10
B9.5	10		
B10	14	DF10	10
C6	88	F6	26
C7	150	F7	14
C8	148	F8	12
C8.5	99	F8.5	11
C9	96	F9	10
C9.5	62		
C10	19	F10	9.5

^aSee Fig. 3.

Table 19. Gamma radiation level at the surface in the drainage area south of main site

Survey location ^a	Radiation level (μR/hr)	Survey location ^a	Radiation level (μR/hr)
A6	27	D6	96
A7	25	D7	106
A8	29	D8	38
A8.5	38	D8.5	42
A9	19	D9	19
A9.5	10	D9.5	15
A10	27	D10	23
B6	48	DF6	42
B7	35	DF7	17
B8	67	DF8	16
B8.5	29	DF8.5	12
B9	11	DF9	10
B9.5	11		
B10	19	DF10	10
C6	112	F6	29
C7	336	F7	13
C8	385	F8	12
C8.5	38	F8.5	12
C9	173	F9	11
C9.5	38		
C10	13	F10	10

^aSee Fig. 3.

Table 20. Gamma radiation level at 3 ft above the surface
along the main site

Survey location ^a	Radiation level (μ R/hr)	Survey location ^a	Radiation level (μ R/hr)
MS+00	48	MS15+00	25
MS1+00	32	MS16+00	19
MS2+00	29	MS17+00	10
MS4+00	15	MS18+00	23
MS5+00	22	MS19+00	12
MS6+00	13	MS20+00	10
MS7+00	31	MS21+00	10
MS8+00	30	MS22+00	10
MS9+00	19	MS23+00	8
MS10+00	14	MS24+00	8
MS11+00	23	MS25+00	10
MS12+00	23	MS26+00	9
MS13+00	14	MS27+00	10
MS14+00	36	MS28+00	8

^aSee Fig. 3.

Table 21. Gamma radiation level at 3 ft above the surface along drainage ditches

Survey location ^a	Radiation level (μ R/hr)
DD0+00	75
DD1+00	34
DD2+00	37
DD3+00	24
DD4+00	17
DD5+00	9.5
DD5+50	9.5
RR0+00	172
RR1+00	235
RR2+00	68
RR3+00	62
RR4+00	76
RR5+00	45
RR5+90	48
WS0+00	25
WS1+00	39
WS1+60	59

^aSee Fig. 3.

Table 22. Radium levels in soils on properties adjacent to Marine base

Property	Location ^a	Sample No.	Depth (ft)	²²⁶ Ra conc (pCi/g)
Lots 1-6 ^b	OSS1	OSS1	0-1.6	3.8
	OSS2	OSS2	0-0.5	13.8
	OSS107	OSS107.1	0-1.2	9.1
		OSS107.2	1.2-2.3	4.4
	MM25	MM25	0-1.5	11.6
Lots 7-9 ^b	OSS3	OSS3	0-1.5	9.8
	OSS4	OSS4	0-0.5	12.7
	OSS105	OSS105.1	0-1.3	8.0
		OSS105.2	1.3-2.3	2.1
	MM26	MM26	0-0.5	12.6
Lot 10 ^b	OSS5	OSS5	0-1.5	10.3
	OSS6	OSS6	0-0.5	16.5
Lots 11-12 ^b	OSS106	OSS106.1	0-0.8	63.5
		OSS106.2	0.8-2.0	9.9
	MM22	MM22	0-0.5	35.2
Lots 21-29 ^b	OSS7	OSS7	0-1.3	40.7
	OSS8	OSS8	0-0.5	16.9
	OSS9	OSS9	0-1.5	4.6
	OSS10	OSS10	0-1.3	3.5
	OSS104	OSS104.1	0-0.5	4.1
		OSS104.2	0.5-1.8	0.9
Lots 39-44 ^c	MM23	MM23	0-1.2	12.2
	MM24	MM24	0-1.2	6.7
Lots 24-25 ^c	OSS11	OSS11	0-1.0	1.5
Lots 26-29 ^c	MM27	MM27	0-1.2	1.9
Lot 47 ^c	MM14	MM14	0-1.3	7.9

Table 22. (cont'd.) Radium levels in soils on properties adjacent to Marine base

Property	Location ^a	Sample No.	Depth (ft)	²²⁶ Ra conc (pCi/g)
Lot 47 ^c (cont'd.)	D6	MM14	0-1.3	7.9
		D6.1	0-1.3	18
		D6.2	1.3-1.4	4
	D7	D7.1	0-1.0	34
		D7.3	2.0-2.7	8.4
	DF6	DF6.1	0-0.5	8.5
		DF6.2	0.5-1.0	1.5
		DF6.3	1.0-2.0	0.7
	DF7	DF7	0-1.3	2.4
	F6	F6.1	0-0.5	19
		F6.2	0.5-1.5	3.1
		F6.3	1.5-3.3	1.6
Lot 43 ^b	MM3	MM3	0-1.0	30.9
	MM6	MM6	0-1.0	408
	MM8	MM8	0-1.0	78.1
	A7 ^d	A7.1	0-1.0	27
		A7.2	1.0-2.1	2.4
	A8 ^d	A8.1	0-1.0	14
		A8.2	1.0-2.2	2.4
	B6	B6.1	0-1.0	11
		B6.2	1.0-2.0	16
	B7	B7.2	1.0-2.0	< 2
	B8	B8.1	0-1.0	98
		B8.2	1.0-2.2	4
	C6	C6.1	0-1.0	13
		C6.2	1.0-1.7	2.1

Table 22. (cont'd.) Radium levels in soils on properties adjacent to Marine base

Property	Location ^a	Sample No.	Depth (ft)	²²⁶ Ra conc (pCi/g)
Lot 43 ^b (cont'd.)	C7	C7.1	0-1.3	103
		C7.2	1.3-2.5	49
		C7.3	2.5-3.0	8
	C8	C8.1	0-1.0	57
		C8.3	2.0-2.3	9.9
	A6	A6.1	0-0.7	13
Lot 50 ^b		A6.2	0.7-2.2	1.9
	A7 ^d	A7.1	0-1.0	27
		A7.2	1.0-2.1	2.4
	A8 ^d	A8.1	0-1.0	14
		A8.2	2.0-2.2	2.4
	MS350R150		0-1.3	1.8
	MS7R20		0-1.0	5.3
	MS8R15		0-1.0	1.5
	MS8R125		0-1.0	1.3
	MS10R20		0-1.0	< 1.5
	MS12R20		0-1.3	3.1
	MS14R20		0-1.0	3.9
Lots 38A-41A, 48 ^b	OSS12	OSS12	0-1.0	3.3
	OSS13	OSS12	0-0.5	25.4
	OSS14	OSS14	0-0.5	5.5
	OSS100	OSS100.1	0-0.5	7.3
		OSS100.2	0.5-1.0	14.1
		OSS100.3	1.0-2.0	9.2
	OSS101	OSS101.1	1.0-2.0	2.8
		OSS101.2	2.0-3.0	2.1
		OSS101.3	3.0-3.5	1.1
	OSS102	OSS102.1	0-2.0	2.7
		OSS102.2	2.0-3.0	1.2
		OSS102.3	3.0-3.5	0.9

Table 22. (cont'd.) Radium levels in soils on properties adjacent to Marine base

Property	Location ^a	Sample No.	Depth (ft)	²²⁶ Ra conc (pCi/g)
Lots ^b 38A-41A, 48 ^b (cont'd.)	OSS103	OSS103.1	0-2.0	6.9
		OSS103.2	2.0-3.0	3.8
		OSS103.3	2.0 4.0	1.6

^a See Fig. 3.

^b Middlesex Borough Block 318.

^c Middlesex Borough Block 319.

^d Common to lot 43 and lot 50.

Table 23. Radium concentrations in soil samples taken in drainage area south of Marine base

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
A6	A 6.1	0-0.7	13
	A 6.2	0.7-2.2	1.9
A7	A 7.1	0-1.0	27
	A 7.2	1.0-2.1	2.4
A8	A 8.1	0-1.0	14
	A 8.2	1.0-2.2	2.4
A8.5	A 8.5.1	0-1.2	38
	A 8.5.2	1.2-2.3	5.3
A9	A 9.1	0-1.0	11
	A 9.2	1.0-2.3	2.0
A9.5	A 9.5.1	0-1.0	17
	A 9.5.2	1.0-2.3	0.5
A10	A 10.1	0-1.0	4.9
	A 10.2	1.0-2.8	2.2
B6	B 6.1	0-1.0	11
	B 6.2	1.0-2.0	16
B7	B 7.1	0-1.0	----
	B 7.2	1.0-2.0	< 2
B8	B 8.1	0-1.0	98
	B 8.2	1.0-2.2	4.0
B8.5	B 8.5	0-1.5	2.3
B9	B 9.1	0-1.0	1.3
	B 9.2	1.0-2.2	1.3
B9.5	B 9.5.1	0-1.0	1.7
	B 9.5.2	1.0-2.2	0.8

Table 23. (cont'd.) Radium concentrations in soil samples taken in drainage area south of Marine base

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
B10	B 10.1	0-1.0	5.5
	B 10.2	1.0-2.3	1.5
C6	C 6.1	0-1.0	13
	C 6.2	1.0-1.7	2.1
C7	C 7.1	0-1.3	103
	C 7.2	1.3-2.6	49
	C 7.3	2.6-3.0	8
	C 7A	0-1.3	26
C8	C 8.1	0-1.0	57
	C 8.2	1.0-2.0	----
	C 8.3	2.0-2.3	9.9
C8.5	C 8.5.1	0-1.0	8.8
	C 8.5.2	1.0-2.0	2.6
	C 8.5.3	2.0-2.3	1.0
C9	C 9.1	0-1.0	51
	C 9.2	1.0-2.0	51
	C 9.3	2.0-3.0	4.1
C9.5	C 9.5.1	0-1.0	3.5
	C 9.5.2	1.0-2.0	1.3
C10	C 10.1	0-0.5	2.8
	C 10.2	0.5-1.3	2.0
D6	D 6.1	0-1.0	18
	D 6.2	1.0-1.4	4.0
D7	D 7.1	0-1.0	34
	D 7.2	1.0-2.0	----
	D 7.3	2.0-2.7	8.4
D8	D 8.1	0-1.3	25
	D 8.2	1.0-2.5	7.1
D8.5	D 8.5	0-2.0	5.9

Table 23. (cont'd.) Radium concentrations in soil samples taken in drainage area south of Marine base

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
D10	D 10	0-1.8	7.2
DF6	DF 6.1	0-0.5	8.5
	DF 6.2	0.5-1.0	1.5
	DF 6.3	1.0-2.0	0.7
DF7	DF 7	0-1.3	2.4
DF8	DF 8	0-1.3	3.3
DF8.5	DF 8.5	0-1.3	2.2
DF9	DF 9	0-1.3	1.1
DF10	DF 10	0-1.3	1.7
F6	F 6.1	0-0.5	19
	F 6.2	0.5-1.5	3.1
	F 6.3	1.5-3.3	1.6
F7 ^b	F 7	0-1.3	0.8
F8	F 8	0-1.3	1.3
F8.5	F 8.5	0-1.3	1.5
F9	F 9	0-1.4	< 1
F10	F 10	0-1.4	1.2
MM1	MM1	0-0.5	796
MM7	MM7	0-0.5	13.9
MM13	MM13	0-0.5	728

Table 23. (cont'd.) Radium concentrations in soil samples taken in drainage area south of Marine base

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
RR0+00	RR0.1	0-0.5	462
	RR0.2	0.5-1.0	520
	RR0.3	1.0-1.5	170
RR1+00	RR1.1	0-0.5	2401
	RR1.2	0.5-1.0	173
RR2+00	RR2.1	0-0.5	118
	RR2.2	0.5-1.0	84
RR3+00	RR3.1	0-0.5	148
RR4+00	RR4.1	0-0.5	82
	RR4.2	0.5-1.0	52
RR5+00	RR5.1	0-0.7	110
	RR5.2	0.7-1.3	33
	RR5.3	1.3-2.0	
DD2+00	DD2L25	Surface	79
DD3+00	DD3L20	Surface	1.4
DD5+00	DD5L25	Surface	1.3
DD5+50	DD550L10	0-1.2	2.4
DD6+00	DD6R100	0-1.3	1.7
WS0+00	WS0	0-0.5	1.0
WS1+00	WS1.1	0-0.5	1.8
	WS1.2	6-1.0	2.0

^aSee Fig. 3.

^bCommon to lot 40 Piscataway Township Block 389.

Table 24. Radium concentrations in soil samples along main stream

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
MS0+00	MS0.1	0-0.8	317
	MS0.2	0.8-1.5	182
	MS0.3	1.5-2.2	11
	MS0.4	2.2-2.6	27
MS1+00	MS1.1	0-0.8	66
	MS1.2	0.8-1.7	11
MS2+00	MS2.1	0-0.8	50
	MS2.2	0.8-1.7	12
	MS2.3	1.7-2.3	1.7
MS3+00	MS3.1	0-0.8	11
	MS3.2	0.8-1.7	3.6
MS4+00	MS4.1	0-0.8	18
	MS4.2	0.8-1.5	28
	MS4.3	1.5-1.8	2.9
MS5+00	MS5.1	0-0.8	16
	MS5.2	0.8-1.7	11
MS7+00	MS7.1	0-0.8	22
	MS7.2	0.8-1.5	44
	MS7.3	1.5-2.3	3.3
MS8+75	MS875.1	0-0.8	29
	MS875.2	0.8-1.7	31
MS11+00	MS11.1	0-0.8	46
	MS11.2	0.8-1.7	49
	MS11.3	1.7-2.5	5.7
MS13+75	MS1375	1.0-2.0	2.1
MS16+50	MS1650.1	0-0.8	208
	MS1650.2	0.8-1.7	46
MS18+75	MS1875	1.0-2.5	1.4
MS21+00	MS21	0-0.5	2.8

Table 24. (cont'd.) Radium concentrations in soil samples along main stream

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
MM9	MM9	0-0.3	2
MM11	MM11	0-6.4	53.2
MM12	MM12	0-0.3	60.5
MM18	MM18	0-0.3	69.9
MM19	MM19	0-0.3	118
MM20	MM20	0-0.3	48.6
MM21	MM21	0-1.0	33.7

^aSec Fig. 3.

Table 25. Radium concentrations in soil samples taken on left and right banks of the main stream

Grid location ^a	Sample	Depth (ft)	²²⁶ Ra conc (pCi/g)
MS1+00	MS1R25.1	0-1.0	14.4
	MS1R25.2	1.0-1.7	1.3
MS2+00	MS2L15.1	0-0.5	1.8
	MS2L15.2	0.5-1.3	1.3
MS3+50	MS350R150	0-1.3	1.8
MS5+00	MS5L15	0-1.0	1.4
	MS5R20	0-1.0	1.7
	MS5R150	0-1.0	5.3
MS6+00	MS6L20	0-1.0	1.8
MS7+00	MS7R20	0-1.0	5.3
MS8+00	MS8R15	0-1.0	1.5
	MS8R125	0-1.0	1.3
MS9+00	MS9L15	0-1.0	1.5
MS10+00	MS10R20	0-1.0	< 1.5
MS11+00	MS11L15	0-1.0	2.5
MS12+00	MS12R20	0-1.3	3.1
MS14+00	MW14R20	0-1.0	3.9
MS15+00	MW15L20.1	0-1.0	8.3
	MS15L20.2	1.0-2.3	1.7
MS0-75	MS075L20	0-1.2	< 1.0

^a See Fig. 3.

Table 26. Uranium concentrations in selected offsite soil samples

Sample ^a	Location	Uranium conc (ppm U)
MUD	Main drain-origin	1960
MM1	Secondary drainage ditch	5280
MM2	Flood plain south of Marine base	26.5
MM5	Main drain-100 ft downstream	5200
MM8	Flood plain south of Marine base	83.6
MM11	Main stream-500 ft downstream	449
MM12	Main stream-300 ft downstream	568
MM13	Secondary drainage ditch	4018
MM15	Ambrose below confluence w/mainstream	16.6
MM18	Main stream-1900 ft downstream	436
MM19	Main stream-1375 ft downstream	594
MM20	Main stream-800 ft downstream	262
MM21	Main stream-800 ft downstream	222
MM22	Middlesex Borough Block 318 Lots 11-12	126
MM25	Marine property adjacent Block 318 Lots 1-6	38.6
MM27	Middlesex Borough property SE corner of Marine base	17.5
OSS2	Middlesex Borough Block 318 Lots 1-6	48.1
OSS8	Middlesex Borough Block 318 Lots 21-29	75.5
OSS11	Middlesex Borough Block 319 Lots 24-25	4.2

^aSee Fig. 3.

Table 27. Lead-210 and thorium-230 concentrations in selected offsite soil samples

Sample ^a	Soil concentration (pCi/g)	
	²¹⁰ Pb	²³⁰ Th
MUD	1045	1230
MM1	1117	1689
MM5	1045	1559
MM12	116	187
MM15	9.8	2.5
MM19	146	201
MM20	71.6	101
MM22	52.7	5.1

^aSee Fig. 3.

Fig. 1. Aerial view of the Middlesex Sampling Plant and surrounding area.

Fig. 2 Grid used for locating sampling and measurement points.

CIRCLED VALUES ARE ALPHA READINGS
(dpm/100 cm²)
OTHER VALUES ARE BETA-GAMMA READINGS
(μrad/hr)

SCALE 1" = 150'

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- A WAREHOUSE & PROCESS BLDG-RES.
- B THAW HOUSE
- C BOILER SHOP
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Fig. 4 Surface contamination levels on the site

Fig. 5. Location of smear survey points and radon and radon daughter sampling points in the process building.

Fig. 6 Location of radon and radon daughter sampling points on the site and on adjacent property.

Fig. 7 Location of radon emanation measurements.

Fig. 8 External gamma radiation levels
at one meter above the surface
in $\mu\text{R/hr}$.

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SCALE 1" = 120'

Fig. 9 Location of thermoluminescent dosimeter monitoring stations.

Fig. 10. Confluence of main stream and Ambrose Brook.

Fig. 11. Main drainage ditch looking north toward Marine base,

Fig. 12. Main drainage ditch looking south away from Marine base.

Fig. 13. Williams Street drainage ditch.

Fig. 14. Mosquito control drainage ditch looking west.

Fig. 15. Confluence of main drain with stream.

Fig. 16. Path of main stream along southern boundary of survey area.

Fig. 17. Location of offsite properties.

Fig. 18. Offsite soil sample locations.

Fig. 19. Extent of offsite ^{226}Ra contamination.

APPENDIX I

DESCRIPTION OF RADIATION SURVEY

METERS AND SMEAR COUNTERS

RADIATION SURVEY METERS

Alpha Survey Meters

Two types of alpha survey meters are used to measure alpha contamination on surfaces. One type of instrument uses an ZnS scintillator and the other uses an end window gas-flow proportional counter to detect the alpha radiation.

The alpha scintillation survey meter (see Fig. I-A) consists of a large area (100 cm^2) ZnS detector with a photomultiplier tube in the probe which is coupled to a portable scaler/ratemeter. The ZnS detector is covered with a 5-mil aluminized mylar sheet in order to make the instrument light-tight. The mylar, in turn, is covered with a grid to prevent puncturing the detector when surveying over rough surfaces. This instrument is capable of measuring alpha surface contamination levels of a few dpm/ 100 cm^2 but must be used in the scaler mode to do this. It is highly selective for densely ionizing radiation such as alpha particles; the instrument is relatively insensitive to beta and gamma radiation.

The gas-flow proportional counter uses propane gas as the detection medium. It can measure alpha contamination levels from a few hundred dpm/ 100 cm^2 to several hundred thousand dpm/ 100 cm^2 . The probe has a surface area of approximately 61 cm^2 and has a 2-5 mil aluminized mylar covering with a protective grid. Due to the protective grid, the active area of the probe is 50 cm^2 . It is relatively insensitive to other than alpha radiation. This instrument, shown in Fig. I-B, is manufactured by the Eberline Instrument Company as their model PAC-4G survey meter.

Both of these instruments are calibrated at ORNL using ^{239}Pu alpha sources. While each instrument is individually calibrated, the calibration factors are typically 5 to 6 dpm/cpm.

Beta Survey Meter

A portable Geiger-Muller (G-M) survey meter is the primary instrument for measuring beta-gamma contamination. 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-C.

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 method was compared with a Victoreen Model 440 ionization chamber (see Fig. I-D) 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 Meter

A portable survey meter using a NaI scintillation probe has been used to measure low-level gamma radiation exposure. The scintillation probe is a $3.2 \times 3.8 \text{ cm}$ NaI crystal mounted on a photomultiplier tube. This probe is coupled with a Victoreen Model Thyac III ratemeter (see Fig. I-E). This unit is capable of measuring radiation levels from a few $\mu\text{R/hr}$ to several hundred $\mu\text{R/hr}$. This instrument is calibrated at ORNL with a NBS standard ^{226}Ra source. Typical calibration factors are of the order of 300 cpm per $\mu\text{R/hr}$.

SMEAR COUNTERS

Alpha Smear Counter

This detector assembly used for the assay of alpha emitters on smear paper samples, consists of a light-tight sample holder, a ZnS phosphor and a photomultiplier tube. This detector assembly was used with electronic components housed in a portable NIM bin. The electronics package consisted of a preamplifier, an ORTEC 456 940 high voltage power supply, a Tennelec TC 211 linear amplifier and a Tennelec TC 545 A counter-timer (see Fig. I-F).

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

Beta Smear Counter

The beta smear counter consisted of a thin mica window ($\sim 2 \text{ mg/cm}^2$) G-M tube mounted on a sample holder and housed in a 23 x 35 cm lead shield. Located under the counter window is a slotted sample holder, accessible through a hinged door on the shield. An absorber can be interposed in the slot between the sample and the counter window to determine relative beta and gamma contributions to the observed sample counting rate. The electronics for this counter were housed in a portable NIM bin and consisted of a Tennelec TC 148 preamplifier, an ORTEC 456 high voltage power supply and a Tennelec TC 545 A counter-timer.

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

Fig. I-A. Alpha scintillation survey meter.

Fig. I-B. Portable gas-flow proportional counter.

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

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

Fig. I-E. Gamma scintillation survey meter.

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

APPENDIX II

DESCRIPTION OF Ge(Li) DETECTOR AND SOIL COUNTING PROCEDURES

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

Data is gathered by a 4096-channel analyzer and is entered directly into a computer program which uses an iterative least squares method to identify those radioisotopes found in the sample. The program relies on a look-up table of radioisotopes which contain approximately 700 isotopes and 2500 gamma rays and runs continuously on the IBM-360 system at ORNL. In particular, the program brackets the six principal gamma rays in the ^{226}Ra decay chain (295, 352, 609, 1120, 1765, and 2204 keV). Additionally, the program identifies the ^{137}Cs line at 661.64 keV, and the amount of ^{238}U is estimated from the ^{234}Th lines found.

Fig. II-A. Sample holder and Ge(Li) detector.

Fig. II-B. Ge(Li) detector shield and counting system.

APPENDIX III

PERTINENT RADIOLOGICAL REGULATIONS,
STANDARDS AND GUIDELINES

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

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

November 1976

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

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

5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table I. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:
 - a. Identify the premises.
 - b. Show that reasonable effort has been made to eliminate residual contamination.
 - c. Describe the scope of the survey and general procedures followed.
 - d. State the findings of the survey in units specified in the instruction.

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

TABLE I
ACCEPTABLE SURFACE CONTAMINATION LEVELS

NUCLIDES ^a	AVERAGE ^{b c f}	MAXIMUM ^{b d f}	REMOVABLE ^{b e f}
U-nat, U-235, U-238, and associated decay products	5,000 dpm α /100 cm ²	15,000 dpm α /100 cm ²	1,000 dpm α /100 cm ²
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm ²	300 dpm/100 cm ²	20 dpm/100 cm ²
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm ²	3,000 dpm/100 cm ²	200 dpm/100 cm ²
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except SR-90 and other noted above.	5,000 dpm $\beta\gamma$ /100 cm ²	15,000 dpm $\beta\gamma$ /100 cm ²	1,000 dpm $\beta\gamma$ /100 cm ²

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

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

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

TABLE I (cont'd.)

^dThe maximum contamination level applies to an area of not more than 100 cm²

^eThe amount of removable radioactive material per 100 cm² of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

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

Excerpts From
Proposed American National Standard
N328

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

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 1 or Table 2. (Table 2 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 1

SURFACE CONTAMINATION LIMITS

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

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

*See note following Table 2 on application of limits.

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

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

****Values presented here are obtained from 10 CFR Part 20. The most limiting of all given MPC values (e.g. soluble vs. insoluble) are to be used. In the event of the occurrence of mixture of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fractions must be less than 1.

TABLE 2

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.

<u>Nuclide</u>	Limit (Activity) <u>dpm/100 cm^2</u>	
	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^3 of surface shall be considered to be contaminated above the limit, L, applicable to 100 cm^2 if:

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