HEALTH CONSULTATION

U.S. Radium Corporation

Orange, Essex County, New Jersey
CERCLIS No. NJD980654172

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Prepared by:

New Jersey Department of Health and Senior Services
Consumer and Environmental Health Services

Under Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry

BACKGROUND AND STATEMENT OF ISSUES

Summary

The U. S. Radium Corporation site is a National Priorities List site located in Orange, New Jersey. During the period 1915 through 1926 carnotite ore was processed to yield radium which was used for medical purposes, as well as to manufacture luminous paint for instrument and watch dials. Radiologically contaminated soil and structural materials from ore tailings and process byproducts have been found on the factory site and on over 100 individual properties in the vicinity. The properties are considered to constitute a public health hazard due to the risk to human health which results from exposure to ionizing radiation which emanates from radiologically contaminated soil, structural materials, and from indoor radon gas. Public health hazards include: (1) external whole body exposure to ? radiation from contaminated soil and building materials in site buildings and residential properties; and (2) inhalation of radon gas which results from radioactive decay of radium in contaminated soil and structural materials at site buildings and residential properties.

Background

The U. S. Radium Corporation site (74^{E} 14' 44" West Longitude and 40^{E} 46' 53" North Latitude) is located in the City of Orange (Essex County), New Jersey approximately 12 miles west of New York City. It consists of: (1) the former plant site at High and Alden Streets (about 2 acres in area); (2) the so-called Vicinity Properties area, which encompasses about 300 residential and light industrial properties which are located within about 25 acres (9 city blocks) around the plant site; and (3) the so-called Satellite Properties, which include approximately 50 non-contiguous residential and commercial properties located in Orange and a few properties in the adjacent communities of East Orange and South Orange. The locations of the plant, the Vicinity Properties area, and the Satellite properties are shown in Figure 1. Figure 2 shows the extent of the Vicinity Property area, and Figure 3 shows the former plant site at High and Alden Streets.

From about 1915 through 1926 the U. S. Radium Corporation, until 1921 named the Radium Luminous Materials Corporation, extracted radium from carnotite ore [$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$] at the facility located at High and Alden Streets in Orange. Approximately 0.5 - 2 tons of carnotite ore were processed each day for the 11 years the plant operated. The carnotite ore, delivered by train from Paradox Valley, Colorado, contained about 2-4% uranium dioxide (UO_2). A ton of carnotite ore yielded about 5-7 milligrams of radium, a daughter of the radioactive decay of uranium. As a result, large amounts of radioactive "tailings" were discarded as waste material on the property of the facility and at various Satellite and Vicinity Properties. Due to the discovery of higher yield ore (pitchblende) from the Belgian Congo (now Zaire), the radium extraction and processing activities at U. S. Radium ceased in 1926.

The purified radium was primarily used for medical purposes. However, in addition, luminous paint which contained radium (used to paint dials on instruments and watches) was also manufactured on the property. The majority of the painting activities was apparently done at the main facility, but

dial painting was also done at several of the Satellite Properties as piece work by over 100 workers. Even though law suits alleging health risks associated with the dial painting were filed in the mid-1920's (several people apparently died from radium poisoning), the dial painting operations at the High and Alden Street facility continued until approximately 1940, when the company moved to New York City.

There have been numerous owners of the former plant property since the U. S. Radium operations ceased; however, none of the activities at these businesses involved radioactive materials. Since 1940, most of the original buildings have been torn down, but portions of some have been incorporated into newer buildings. Some of the new buildings continue to be occupied today. In 1979, the former U. S. Radium plant property was identified during an initial survey[1] of former uranium processing sites by the New Jersey Department of Environmental Protection (NJDEP). In 1981 an aerial survey[2] was conducted which identified the U. S. Radium site and several other former radium processing sites in New Jersey. The plant site was placed on the National Priorities List (NPL), i.e. Superfund, in September, 1983. A chronology of site-related events through the end of 1996 is given in Table 1.

Site Visit

The site of the former U.S. Radium plant was visited by representatives of the New Jersey Department of Health (NJDOH), the Agency for Toxic Substances and Disease Registry (ATSDR), and the USEPA Region 2 Remedial Project Manager on November 9, 1995. The former plant property was found to be partially surrounded by an 8 foot high chain-link fence. Buildings A through E (see Figure 3), which were built after U. S. Radium left the property, are accessible to workers and the public since they continue to be occupied. Specifically, Building A is currently an office for a coal company; Buildings B and C are a gas station and an automotive repair shop, respectively. Buildings D and E, the offices of a pesticide applicator and a small building currently used by a motorcycle club, respectively, are less frequently occupied. Buildings F and G, portions of which are original construction, are surrounded by the chain link fence and are unoccupied, having been vacated in the mid-1980s. The cement channel which contains Wigwam Brook also restricts access to the south side of the property. There was no evidence of trespassing. There is no evidence of chemical or biological hazard, nor are there significant physical hazards.

Statement of Issues

This Health Consultation has been requested by USEPA Region 2 in order to evaluate the public health implications of exposure to radionuclides present in the soil and building materials at the former U. S. Radium Corporation and associated Satellite and Vicinity properties. The primary documents which have been reviewed include two Remedial Investigation/Feasibility Studies.[3,4] However, since the original RI/FS on Vicinity and Satellite properties was published in 1993, a large number of additional properties have also been characterized. The majority of the site characterization data relate to soil and building materials which are radiologically contaminated with Ra-226 and other radionuclides of the U-238 decay series, shown in Table 2.

There have been two previous evaluations of the potential public health effects which may be associated with the U. S. Radium site. In 1989 a brief Preliminary Health Assessment[5] indicated that the properties should "be considered to be a public health concern, ranging from potential to imminent, depending on the individual area". It also indicated that "further environmental characterization and sampling of the site be designed to address environmental and human exposure pathways". At the time of the Preliminary Health Assessment, only Buildings A, B, and C were occupied; few of the associated properties had been investigated.

In 1993, a Site Review and Update (SRU)[6] of the U. S. Radium and associated properties recommended that all remaining Vicinity and Satellite Properties be screened for radiological contamination. As of 1996, about 40-45 properties within the area of the Vicinity Properties have not been surveyed for radiological contamination; access to some of the properties has been denied by the owner. Due to their proximity to known contaminated properties, some of these (as yet unsurveyed) properties may also be radiologically contaminated.

This Health Consultation, initiated in lieu of the Public Health Assessment recommended by the 1993 SRU, will review the existing data on radiologically contaminated soil, ? radiation measurements, and quantities of gaseous and particulate sources of a radiation at the former U. S. Radium site and its associated properties. These data will be evaluated in order to assess the public health implications related to exposure to ionizing radiation in excess of ambient background levels.

DISCUSSION

The Enclosure briefly describes the terminology and units of measurement associated with ionizing radiation.

Natural (Background) Radiation

Since ionizing radiation is naturally present nearly everywhere in the environment, radiological contamination must be evaluated by comparison with natural background radiation. The average person in the United States is annually exposed to approximately 360 millirem [3.6 mSv][1] of background radiation[7,8]. Background radiation was previously called natural radiation, but it has been redefined to include common manmade sources of radiation such as diagnostic X-rays, nuclear medicines, and consumer products. Approximately 82% of background radiation comes from naturally occurring sources, including radon, cosmic rays, and terrestrial and internal (i.e. within the body) sources. More than half of the average human exposure to background radiation is due to the radioactive decay of radon.

[1] The units of radiation are given throughout in common and, in brackets, System International (SI) units. Definitions for both sets of units are given in Table 2 of the Enclosure.

As shown in Table 3, background radiation includes approximately equal components of terrestrial radiation (i.e. ? rays from natural radionuclides in the soil) and cosmic rays. The 1981 aerial survey of the Orange/Montclair/West Orange/Glen Ridge vicinity[2] determined the background ? radiation level in the area to be about 8 µR/hr. Consequently, the average individual in the vicinity of U. S. Radium will receive an exposure of about 70 mrem [0.7 mSv]/yr from cosmic rays and terrestrial ? rays.

The background concentrations of U-238 and Ra-226 in the soil in the vicinity of the U.S. Radium site and associated properties are about 1.8 pCi/gram and 1 pCi/gram respectively. These may be compared with the concentrations of radionuclides determined to be present in contaminated areas.

About half of the exposure to internal radiation (radiation from a source within the body) is due to radioactive potassium (K-40), a naturally occurring (approximately 0.01% natural abundance) radionuclide with a half life ($T_{½}$) of 1.26×10^9 years which primarily emits ß radiation, but is also a source of ? radiation.

The manmade component of background radiation (approximately 18% of the total) includes medical exposures such as those from diagnostic X-rays, dental X-rays, mammograms, and consumer products. For comparison, the average chest X-ray[9] today exposes the patient to approximately 15 millirem [0.15 mSv] (down from about 75 millirem [0.75 mSv] in the 1930's). Similarly, the dose equivalent of dental X-rays is now about 250 millirem [2.5 mSv] (down from about 2 rem [20 mSv] in the 1930's). A screening mammogram also requires about 250 millirem [2.5 mSv], or about a tenth of the dose equivalent for one done 20 years ago.

Contaminants of Concern and Exposure Pathways at U. S. Radium

Radioactive material in the soil and building materials, specifically Ra-226 and other products of the U-238 decay series, is the primary contaminant of concern at the former U. S. Radium plant and associated properties. Potential routes of exposure include: (1) exposure to external sources of ? radiation in soil and structural materials; and (2) the inhalation of emitters of a radiation in contaminated air or suspended particles of contaminated dust. There appears to be little likelihood of contaminated surface or ground water (there are no known potable private wells) in the vicinity. Although analysis of the soil at the former U. S. Radium property for chemical contaminants has shown the presence of some heavy metals, and volatile and semi-volatile organic compounds, the concentrations of these species are typical of urban areas. Consequently, this evaluation of the contaminants of concern at U. S. Radium is limited to the radioactive elements in the U-238 decay series.

Potential Effects of Exposure to Gamma Radiation

Ionizing radiation is a known carcinogen. The effects of exposure to radiation can be both stochastic (random occurrence; without threshold) and non-stochastic (non-random occurrence; with

threshold). Cancer is a stochastic effect caused by exposure to radiation, meaning that the probability of cancer depends on the amount of exposure. It has been assumed that there is a linear relationship, without threshold, which relates exposed dose with the probability of stochastic health effects. However, at low dose, the linear relationship between dose and effect, as well as the lack of threshold, are difficult to verify, since there are correspondingly few effects. Conversely, the severity of other potential effects of exposure to radiation, such as cataracts or skin erythema, depend upon the amount of exposure. The reason for limiting exposure to radiation is to minimize stochastic effects, while preventing non-stochastic effects.

Public Health Implications Associated with Exposure to Ionizing Radiation

Limits on exposure to chemical contaminants are typically defined in order to reduce the risk of adverse health effects to an additional one per million exposed individuals over a lifetime, i.e. the 10^{-6} rule. While it has been argued that establishing the degree of acceptable risk at the 10^{-6} level is somewhat arbitrary, the 10^{-6} rule of thumb can not simply be applied to radiological contaminants in any case, since the risk due to exposure to ambient background radiation already exceeds one in a million. For example, according to the 1988 United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)[10] the risk of a cancer fatality associated with exposure to low levels of radiation is 0.7 to 3.5 health effects per 10,000 (i.e. 70 to 350 per million) per rad [cGy] of exposure. Similarly, BEIR-V[7] predicts a lifetime risk of a radiation-induced cancer fatality for the general population of about 520 per million per rem [10 mSv]. USEPA[11] has predicted the risk of radiogenic cancer fatality to be 509 per million per rad [cGy]. Therefore, the risk of cancer associated with the former U. S. Radium Corporation site which would be caused by exposure to 100 millirem [1 mSv] above background per year over a lifetime is about 50 additional radiation-induced cancer fatalities per million exposed individuals.

Regulatory Limits on Exposure to Ionizing Radiation

Regulatory limits on the maximum permissible dose from occupational exposure to gamma radiation have declined substantially over the years - from 0.1 rem [1 mSv]/day in 1934, to 0.3 rem [3 mSv]/week in 1950, to 0.1 rem [1 mSv]/week in 1956, to 5 rem [50 mSv]/year in about 1960, to "as low as is reasonably achievable (ALARA)" in 1977. In 1991, the Nuclear Regulatory Commission (NRC) established the total effective annual dose equivalent (which includes both internal and external exposures) to be 5 rem [50 mSv]/year for occupational exposure of adults. Similarly, in 1993 the US Department of Energy (DOE) established a limit on total effective dose equivalent of 5 rem [50 mSv]/year for occupational exposure of employees at DOE facilities.

For members of the general public, the regulatory limit on exposure to ionizing radiation is lower. In 1990 the International Commission on Radiological Protection (ICRP)[12] recommended that chronic exposure to members of the general public be limited to 100 millirem [1 mSv] per year above background. This exposure limit was adopted by the Nuclear Regulatory Commission[13] in 1991. Similarly, in 1993 the National Council on Radiation Protection and Measurement (NCRP)[14] recommended the same exposure limit. On March 23, 1993 the US Department of Energy[15]

proposed (although it has not yet been adopted) the establishment of similar standards, i.e. the ALARA policy and a limit on effective dose equivalent of 100 millirem [1 mSv] per year, for protection of the public and the environment against radiation.

Other criteria have also been applied to radiologically contaminated sites. For example, in 1983 the USEPA[16] adopted 20 µR/hr above background (continuous exposure at this dose rate would result in an exposure of 175 mrem [1.75 mSv]/year as the standard for allowable exposure by the public. This regulation also established that contaminated soil be remediated to 5 pCi/gram (top 15 cm) or 15 pCi/gram (depths greater than 15 cm). Also, the so-called Grand Junction Remedial Action Criteria[17] indicated that certain remedial actions be performed at uranium-contaminated sites at ? radiation dose rates of 50 and 100 µR/hr. However, neither of these regulations is strictly related to the health risk associated with exposure to ionizing radiation.

Exposure to External Gamma Radiation

If an individual were to be continuously exposed to 11.4 µR/hr above background, this exposure would result in a dose equivalent of 100 millirem [1 mSv] per year above background. However, since a person is unlikely to be continuously exposed to a constant source of radiation contamination throughout the year, certain assumptions must be made regarding occupancy times (i.e. exposure) in order to accurately equate effective exposure dose with exposure dose rate.

For example, the USEPA Exposure Factors Handbook[18] indicates that an average individual spends approximately 70% of the time at home (and therefore 30% away from home). While at home, the average individual will spend 92% of the time indoors (and the remaining 8% of the time outdoors). In effect, the average occupant of a radiologically contaminated residence would be exposed to contamination each day for 15.5 hours indoors (24 hours x 0.7 x 0.92), and 1.3 hours outdoors (24 hours x 0.7 x 0.08), for a total occupancy of 16.8 hours/day for 365 days/year, i.e. 6132 hours/year. Using this scenario, there would be no radiological exposure above background for the remaining 7.2 hours of each day that the individual is away from the contaminated residence. Of course, there can be great variability in residential occupancy times, since some individuals very seldom leave their homes, while others are frequently away from their homes due to employment and other activities. By comparison, the remedial investigation for U. S. Radium[3] assumed a residential exposure of 24 hours/day, 350 days/year, i.e. 8400 hours/year, consisting of 75% indoor occupancy and 25% outdoors.

Radiological contamination of open areas or non-residential structures poses different circumstances, since an individual who is exposed to radiation in these locations will undoubtedly have different indoor and/or outdoor exposure times than would be the case when the contamination is at a residence. As with residential contamination, there is likely to be both indoor and outdoor exposure in the case of non-residential contamination. For example, the remedial investigation for U. S. Radium[3] assumed indoor exposure at contaminated commercial businesses to be 8 hours/day, 5 days/week for 50 weeks/year, i.e. 2000 hours/year. Conversely, contaminated open areas will result in outdoor exposure only. For the case of U. S. Radium, the occupancy time for trespassers of open

areas was assumed[4] to be 10 hours/day for 30 days/year (i.e. 300 hours/year). Clearly, several scenarios must be considered to adequately characterize exposure to the radiological contamination at U. S. Radium.

Inhalation of Alpha-Emitting Radiological Contaminants

Radioactive materials which are gaseous and emit a particles could pose a significant health risk if they were to be inhaled. Radon, a radioactive gas, is of special concern since it has been estimated to cause the majority of background radiation exposure in the United States (see Table 3). The radon-222 progeny from the U-238 decay series (shown in Table 2) are species which are solid at ambient temperature. If radon-222 were to be inhaled, its progeny could stay in the lungs where they could further decay to emit more a particles and other forms of radiation.

The action level for exposure to a radiation, which has been established by USEPA[19] and adopted by NJDEP, is 4 pCi/liter for radon (gas) and 0.02 WL for radon progeny (particulates) in ambient air at equilibrium. [See Enclosure Table 1 for the definition of Working Level (WL).] The average indoor radon concentration in New Jersey has been determined to be 1.35 ± 3 pCi/liter (1 s)[20]; radon concentrations which exceed the action level are not uncommon.

Other criteria have been proposed to provide guidance for allowable amounts of particulates on surfaces, since re-suspension and subsequent inhalation of a emitting particulates could also result in radiological exposure of public health concern. For example, for particulate sources of a radiation such as radon progeny, the criterion for decontamination of a activity on surfaces has been proposed as 20 disintegrations per minute (dpm) per 100 cm^2 for removable particles; in addition, the maximum allowable surface a activity, removable or not, has been proposed as 300 dpm/100 cm^2.[15]

Ingestion of Radiologically Contaminated Soil at U. S. Radium

Ingestion of radiologically contaminated surface soil is a potential route of exposure at U.S. Radium and its associated properties. Soil which is contaminated with uranium and radium has been found at the High and Alden Streets site[4] and also at numerous Satellite and Vicinity properties.[3] Consequently, additional risk could result if one were to be exposed to ionizing radiation via ingestion of contaminated soil. For example, ingestion of soil contaminated with 100 pCi radium/gram by a 2.5 year old toddler could result in an absorbed dose of approximately 20 millirem [0.2 mSv]/year in addition to normal background. However, exposure of adults to ionzing radiation via soil ingestion would probably be less, since adults are not likely to ingest as much soil.

Radiological Contamination at U. S. Radium Properties

There have been numerous radiological surveys of the former U. S. Radium Corporation (High and Alden Streets) site, the Vicinity Properties area, and the Satellite Properties. The aerial survey[2] which was conducted in 1981 of approximately 12 square miles in the Orange/West Orange/Montclair/Glen Ridge area was able to identify general areas (including the U. S. Radium site

and surrounding area), but not individual properties, which exceeded the background level for ? radiation (approximately 8 µR/hour). Ground surveys of individual properties are discussed below.

High and Alden Streets Site

The initial ground radiological characterization of the former U.S. Radium property was conducted in 1979-1980 by NJDEP, which surveyed Buildings A through D, F, and G for ? radiation, radon, and radon progeny.[1] Soil samples were also taken in Buildings F and G in 1980. Additional surveys of parts of the High and Alden Streets site were conducted in 1983 (radon and radon progeny in Buildings F & G), and 1985 (gamma, radon, and radon progeny in Buildings A, F, and G). The results of these early surveys are summarized in Table 4.

In 1991-1992 a comprehensive survey of ? radiation, surface and subsurface soils, radon, and particulate a contamination was conducted as part of the Remedial Investigation for Operable Unit 2 (OU2),[4] which includes the High and Alden Streets site and 4 other commercial locations.

More recently, in 1994 approximately 31 boreholes were drilled at depths up to 15 feet below grade in order to fully characterize radiological contamination on the site property. Up to 3300 pCi Ra-226/gram of soil and 220 pCi U-238/gram of soil were found at various depths in these analyses. The results of the surface soil samples are given in Table 5.

Satellite Properties and Vicinity Properties Area

The extent of the Vicinity Properties area was defined by the 8.5 µR/hr contour as determined by an aerial radiological survey of the area.[2] As of 1993,[3] 124 Vicinity Properties, and 39 Satellite properties had been investigated for radiological contamination. However, since the Remedial Investigation for the Satellite and Vicinity Properties was published in 1993, approximately 200 additional properties have been surveyed, such that as of the end of 1996, over 300 individual properties had been surveyed for radiological contamination. To date, approximately 104 properties have been shown to have radiological contamination of soil, structural materials, and/or indoor air. [As of December 1996, approximately 40-45 Satellite and Vicinity Properties which are suspected of being contaminated remain to be surveyed.] Tables 6 and 7 present the external ? contamination, radium contamination in soil and structural materials, and indoor radon found at known contaminated Satellite and Vicinity Properties.

The proposed plan for the U. S. Radium site and associated properties consists of a five phase remediation. Residential properties will be remediated in phases I, II, and III; the U. S. Radium site and several commercial properties will be remediated in phase IV; if needed, remaining properties will be remediated in phase V. The remedial activities are expected to begin in 1997. Interim actions have been taken at a limited number of properties. Radon ventilation systems have been installed in several structures (including properties #1, 33, 94, 98, and 224 and Building D/E on the U. S. Radium site), and lead sheeting has been installed in one property (property #1) to limit ? exposure.

As previously discussed and shown in Table 2, the average individual in the United States is exposed to approximately 300 mrem [3 mSv]/year from natural sources of ionizing radiation, including approximately 200 mrem [2 mSv]/year due to a radiation from radon and its progeny, and approximately 100 mrem [1 mSv]/year due to ß and ? radiation from the sum of terrestrial, cosmic rays, and internal sources. Since the former U.S. Radium and its associated properties are contaminated by radionuclides from the U-238 series, particularly Ra-226 and Rn-222, and it has been shown that a significant number of properties exhibit elevated ? and/or a emanations, these properties should be remediated to reduce external ? radiation levels to a level such that total effective dose equivalent (chronic exposure scenario) would be less than 100 mrem [1 mSv]/year. This will require a determination of most likely occupancy scenarios for both residential and commercial properties. In addition, indoor concentrations of radon and progeny should be remediated to achieve concentrations of less than 4 pCi/liter and 0.02 WL, respectively. (Note: current USEPA policy is to design a remediation to achieve these guidelines for radon and progeny. Exposure of the public to ? radiation, however, is not expressly addressed by remedial design. Rather, remediation of contaminated soil and structural materials at U. S. Radium and associated properties is being designed to achieve a maximum of 5 pCi radium/gram in the contaminated material.)

As mentioned above, interim actions have been taken to reduce interior radon levels by enhanced ventilation at several residential properties. Lead sheet has also been installed to reduce ? exposure in one Satellite property. Buildings F and G on the U.S. Radium property were vacated to terminate exposure. Nevertheless, a number of properties remain to be remediated in order to reduce the level of radiological contamination to that which would limit exposure to 100 mrem [1 mSv]/year in excess of background.

Potentially Exposed Populations

Figure 4 indicates that approximately 50,000 individuals reside in about 20,000 housing units within one mile of the U.S. Radium site property. However, as shown in Figures 1 through 3, not all properties within a one mile radius of the site are contaminated. Furthermore, there are also several contaminated properties located more than one mile from the U. S. Radium site. The approximately 104 known Vicinity and Satellite properties have remained contaminated throughout the past 70 years. Although it is not possible to reconstruct actual exposure to individuals who occupied the properties associated with U. S. Radium during all these years, it may be estimated that several hundred individuals could have been exposed to ionizing radiation in excess of 100 mrem [1 mSv]/year. The initial ground survey[(1)] of the High and Alden Streets site estimated that, as of 1980, there had been exposure to approximately 360 workers at the site for a total of some 3500 person-years. The majority of these individual exposures is likely to have taken place in Building F, which continued to be actively used into the 1980's.

Health Outcome Data

An analysis of health outcome data related to radiologically contaminated locations in New Jersey, including the U. S. Radium site, will be conducted by the NJDHSS in 1997.

CONCLUSIONS

The data which are presented above summarize a large number of a and ? radiation survey measurements and soil samples which have been taken at the former U. S. Radium site property, and at several hundred locations in the so-called Vicinity and Satellite Properties. The measurements show that radiological contamination exists from carnotite ore tailings and other process by-products from the High and Alden Streets U. S. Radium factory site. Radiological contamination of these properties has existed for approximately 70 years.

The Preliminary Public Health Assessment [5] of the public health implications of the U. S. Radium and associated properties concluded that a number of these sites posed a "public health concern" based on the likelihood of external exposure to or inhalation/ingestion of radiological contamination in excess of 500 mrem [5 mSv]/year. In addition, a number of properties were also concluded to present a "limited health concern", due to the potential for exposure to greater than 100 mrem [1 mSv]/year. However, subsequent to the Preliminary Public Health Assessment, the recommended action level for exposure to ionizing radiation was reduced from 500 millirem [5 mSv]/year to 100 millirem [1 mSv]/year. As a result, chronic exposures (total effective dose equivalent) of greater than 100 millirem [1 mSv]/year are presently considered to constitute a public health hazard. Consequently, the site of the former U. S. Radium plant and numerous occupied Vicinity and Satellite Properties currently (and will continue to until appropriately remediated) constitute a public health hazard.

Based on the levels of a and ? radiation found at the U. S. Radium properties, the following conclusions may be drawn:

- radiological survey has characterized ? radiation levels which result from contaminated soils at the site of the former U. S. Radium factory and numerous associated Vicinity and Satellite Properties. Many of the Satellite and Vicinity Properties have been found to exceed the USEPA ? radiation action level of 20 µR/hour above background.

- survey of the U. S. Radium locations identified several structures which exceeded airborne a radiation (i.e. radon) action levels. Most of these locations appear to have been remediated to achieve the a radiation indoor action level of 4 pCi/liter in ambient air, but pending confirmation of interim remediation activities, radon concentrations in some structures may remain above the a radiation action level.

- substantial amounts of contaminated soil exist at the site of the former U. S. Radium factory. Contaminated soil also exists at numerous Vicinity and Satellite Properties. Remediation of these properties is expected to commence in 1997;

contaminated building materials exist at a number of Vicinity and Satellite properties.

While it is not possible to accurately reconstruct exposure doses for the variety of human exposure scenarios over this extended period of time, it is possible to conclude that as many as several hundred individuals (based on known contamination of about 104 properties with an expected average occupancy of about 2.5 individuals per property) may have been exposed to radiation in excess of 100 millirem [1 mSv] per year above background.

RECOMMENDATIONS

The Preliminary Public Health Assessment[5] and Site Review and Update[6] recommended that all remaining unsurveyed properties which are suspected of being contaminated be surveyed. This recommendation has been substantially achieved, although, as of the end of 1996, approximately 40-45 suspected contaminated properties have not yet been surveyed, in some cases because access to the properties has been denied by the owners. Efforts should be made to complete radiological survey of those properties which are suspected of radiological contamination.

Site Characterization Recommendations

! survey should be conducted to determine radioactive contamination of the indoor air, soil, and structural materials, and ambient ? radiation levels at the approximately 40-45 properties which have not yet been surveyed.

! properties where ambient outdoor ? radiation levels exceed twice background should have surface soils analyzed for radium contamination;

! properties where indoor contact ? radiation levels exceed twice background should have structural materials analyzed for radium contamination.

Recommendations to Limit Exposure

! ? radiation remedial action levels applied to the former U. S. Radium factory and associated properties should be evaluated to reflect the most likely occupancy scenarios for residential and commercial properties (note: the permissible ? dose rate should be limited to 20 µR/hour, i.e. about 11 µR/hour above background, for the continuous residential occupancy scenario);

! current ? radiation levels at contaminated properties should be reviewed to confirm that exposure does not exceed the levels determined above; if necessary, interim measures such as restricting occupancy times, or temporarily vacating structures, should be taken in order

to limit exposure to limit annual ? radiation exposure to 100 millirem [1 mSv]/year above background;

! occupied structures which have been identified as exceeding action levels for radon and progeny [4 pCi/liter and 0.02 WL, respectively] in the basement during winter months should be remediated on an interim basis pending final remediation actions.

Public Health Actions

The Public Health Activities Plan (PHAP) for U. S. Radium contains a description of the actions to be taken by ATSDR and/or NJDHSS at, or in the vicinity of, the U. S. Radium property subsequent to the completion of this Health Consultation. The purpose of the PHAP is to ensure that this Consultation not only identifies public health hazards, but provides a plan of action designed to mitigate and prevent adverse human health effects resulting from exposure to hazardous substances in the environment. Included is a commitment on the part of ATSDR and NJDHSS to monitor this plan to ensure that the plan is implemented. ATSDR will provide an annual follow-up to this PHAP, outlining the actions which have been completed, and those actions in progress. This report will be placed in repositories that contain copies of this Consultation, and it will be provided to persons who request it. The public health actions to be implemented by ATSDR/NJDHSS are as follows:

Actions Undertaken:

(1) The environmental sampling data and remedial activities which have been conducted have been evaluated within the context of human exposure pathways and other relevant public health factors.

(2) ATSDR/NJDHSS will continue to coordinate with USEPA regarding anticipated interim and final remedial actions, particularly regarding contaminated properties which are occupied.

Actions Planned:

(1) NJDHSS will provide a Physician Education Newsletter on health implications of exposure to ionizing radiation to medical care providers in the vicinity of U. S. Radium.

(2) A Community Education Factsheet will be prepared by NJDHSS and distributed to interested persons in the vicinity of U. S. Radium and associated properties.

(3) ATSDR and NJDHSS will coordinate as deemed necessary with the appropriate environmental (USEPA and NJDEP) and public health agencies (West Orange Health Department) to develop plans to implement the recommendations contained in this Consultation.

Certification

This Health Consultation for the U. S. Radium Site in Orange, New Jersey was prepared by the New Jersey Department of Health and Senior Services (NJDHSS) under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). It is in accordance with approved methodology and procedures existing at the time the Health Consultation was initiated.

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The Division of Health Assessment and Consultation, ATSDR, has reviewed this Health Consultation and concurs with its findings.

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REFERENCES

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Appendices

Enclosure

The Language and Units of Ionizing Radiation

The definitions of radioactivity[21] and some associated terms are given in Enclosure Table 1. As used in this document, "radiation" means ionizing radiation, i.e. particles and photons which are capable of ionizing matter. Ionizing radiation includes particulates [alpha (a) particles, beta (ß) particles, neutrons, and protons] and photons [gamma (?) rays, X-rays, and cosmic rays]. It does not include so-called non-ionizing radiation, such as microwaves, radiowaves, or infrared, visible, and ultraviolet light.

Ionizing radiation is generally quantified by its activity (measured in Becquerel or Curie) and/or its specific activity, as defined in Enclosure Table 2. A radioactive element (radionuclide) is also characterized by its half life ($T_{½}$). Other definitions in Table 2 include: absorbed dose (in units of Roentgen, rad, or Gray); dose equivalent (units of rem or Sievert); and dose rate (measured in µR/hr).

Some of the common mathematical conversion factors relating activity, dose, and dose equivalent are given in Table 2. Other useful mathematical relationships and conversions include:

(1) Specific Activity (Curies/gram) = N x 1.873 x $10^{-11}/T_{½}$, where N is the number of radioactive atoms per gram of material (Note: 1 picoCurie (pCi) = 10^{-12} Curie, and 1 microCurie (µCi) = 10^{-6} Curie); and

(2) Dose Equivalent (rem, Sievert) = dose (rad, Gray) x Q, where Q is the quality factor [Q = 1 for gamma, X-ray, and beta; Q = 10 for neutrons and protons; Q = 20 for alpha].

The relationships between dose and dose equivalent for gamma radiation are given by:

1 µR/hr (air) = 0.869 µrad/hr (air) = 0.96 µrad/hr (tissue) = 0.96 µrem/hr (tissue)

Therefore, the absorbed dose rate for ? radiation in µR/hr for air is taken to be equal to (within 4%) the dose equivalent rate in µrem/hour for tissue.

Non-volatile radionuclides, such as radon progeny, which decay by emission of a particles are characterized by Working Levels (WL). Gaseous species, such as Rn-222, are quantified in terms of pCi/liter of air.

Table 1. Common Definitions associated with Ionizing Radiation

Term	Definition
Radioactivity	a property of some nuclides of spontaneously emitting particles or gamma radiation, emitting X-radiation after orbital electron capture, or undergoing spontaneous fission
Activity	the mean number of decays per unit time of a radioactive nuclide
Specific activity	the activity per gram of compound, element, or nuclide
Half life	the time required for a radioactive substance to lose 50% of its activity by decay
Dose, whole body dose, absorbed dose	the mean energy imparted by ionizing radiation to an irradiated medium per unit mass
Effective dose, effective dose equivalent	the product of the absorbed dose in tissue, quality factor, and any other modifying factors at the location of interest
Working Level (WL)	any combination of radon daughters in 1 liter of air which will result in emission of 1.3 x 10^5 MeV of potential alpha energy
Working Level Month (WLM)	exposure resulting from inhalation of air with a concentration of 1 Working Level of radon daughters for 170 working hours

Table 2. The Units of Ionizing Radiation

Unit	Measures	Conversion factor
Becquerel (Bq)	activity	1 dis/s; 2.7×10^{-11} Ci
Curie (Ci)	activity	3.7×10^{10} dis/s
Roentgen (R)	absorbed dose	0.00869 J/kg (air) 0.0096 J/kg (tissue)
Gray (Gy)	absorbed dose	1 J/kg; 100 rad
Rad	absorbed dose	100 erg/g; 0.01 Gy
Sievert (Sv)	dose equivalent	100 rem
Rem	dose equivalent	0.01 Sievert

Tables

Table 1. Chronology of Events at U. S. Radium

Date	Activity
1915	Radium Luminous Materials Corporation begin processing of carnotite ore
1921	Renamed U. S. Radium Corporation
1926	Cease carnotite ore processing Renamed Safety Light Corporation
1940	Cease watch and instrument dial painting
1979-1980	NJDEP ground survey (High and Alden Sts.) 25 hr/wk limit on use of Bldgs F and G
1981	12 sq mi aerial survey of Orange, West Orange, Glen Ridge, Montclair
1983	NJDEP survey (9 Vicinity Properties) Site added to National Priorities List
1984	NJDEP survey (31 Vicinity Properties)
1985	USEPA survey (Bldgs A, F, and G)
1986	USEPA survey (6 Vicinity Properties)
1989	ATSDR Preliminary Public Health Assessment Fence installed around Bldgs F and G
1991	USEPA survey (High and Alden Sts) Public meeting and availability sessions Radon and gamma mitigation at 4 properties 3 monitoring wells installed near Bldg A
1992	USEPA Satellite/Vicinity Properties survey Ground/surface water sampling(4 wells) Public availability sessions
1993	Draft Final Remedial Investigation OU1 ATSDR Site Reviews and Update(SRU)
1994	Groundwater sampling (7 onsite; 4 offsite)
1995	Draft Final Remedial Investigation OU2 USEPA Survey Vicinity/Satellite properties Public meeting NJDOH site visit
1996	USEPA survey Vicinity Properties USEPA design of remedial activities

Table 2. U-238 Decay Series[21]

Principal Decay Chain	Subchain	Nuclide	Half life
U-238	U-238 + D	U-238 Th-234 Pa-234	4.47E9 yrs 2.24E1 days 1.17E0 min
	U-234	U-234	2.44E5 yrs
	Th-230	Th-230 (ionium)	7.7E4 yrs
	Ra-226 + D	Ra-226 Rn-222 (radon) Po-218 Pb-214 Bi-214 Po-214	1.6E3 yrs 3.8E0 days 3.0E0 min 2.68E1 min 1.99E1 min 1.64E-4 sec
	Pb-210 + D	Pb-210 Bi-210 Po-210	2.23E1 yrs 5.01E0 days 1.38E2 days
	Pb-206	Pb-206	stable

D = daughter nuclides
E = exponent of ten (10^E)

Table 3. Background Radiation in United States (mrem/yr)[8]

Source	Percentage	Dose Equivalent (mrem/yr)
Radon	55	198
Cosmic rays	8	29
Terrestrial	8	29
Internal	11	40
Medical	11	40
Nuclear medicine	4	14
Consumer products	3	11
Other	<1	4
Total	100	365

Table 4. Radiological Measurements at U.S. Radium High and Alden Street Property[4]

Location	Date	Gamma (µR/hr)	Radon (pCi/l)	Radon Progeny (WL)	Surface Alpha (dpm/100cm^2)
Building A	1980 1985 1991	**47.3-69.2** **54-287** --	2-4 **4.5** <0.2	**0.021-0.038** 0.019 --	-- -- <100
Building B	1980 1991	15.8-26.3 --	**2-14** **13.8**	-- --	-- <100
Building C	1980 1991	16.3-27.9 --	**4-17** **22.9, 29.4**	-- --	-- **470**(<5)
Building D	1980 1991	15.3-20.1 --	**19,-44** **22.9, 37.1**	**0.14-0.31** --	-- <100
Building E	1991	--	**23.8, 24.7**	--	160(<5)
Building F (1st Fl)	1980 1983,1985 1991	17.2-**194.9** **>630** --	**5-38** **8.8-98.4** **17.5, 20.4, 51.6**	0.017-**0.13** 0.002-**0.29** --	-- -- **39500(551)**
Building F (2nd Fl)	1980 1983,1985 1991	**46.3-93.1** **>500** --	2-**14** 2.2 --	0.006-**0.05** 0.003-**0.176** --	-- -- **23700(187)**
Building G	1980 1983,1985 1991	33.6-**162.3** 25-646 --	**13-70** **7.5-160** **74.8, 110.2**	**0.14-0.9** **0.5-2.48** --	-- -- **48200(879)**

BOLD - exceeds action level
-- Not measured
( ) Removable alpha

Table 5. "Surface Soil" Analyses at High and Alden Streets Property[4] - 1994

Location	U-238 (pCi/g)	Ra-226 (pCi/g)	Th-232 (pCi/g)
BH-1	--	3.6	1.2
BH-2	0.21	1.8	0.27
BH-3	**25**	**210**	0.094
BH-5	--	2.9	1.0
BH-6	--	**18**	1.5
BH-8	--	1.8	0.99
BH-9	0.20	2.1	0.23
BH-10	--	1.8	0.93
BH-11	--	2.0	0.93
BH-12	1.0	4.2	0.12
BH-13	--	**6.1**	0.43
BH-14	--	3.8	0.65
BH-15	--	2.8	0.81
BH-16*	**6.9**	**480**	0.37
BH-17	--	3.2	0.36
BH-18*	--	**370**	<2
BH-19*	**48**	**640**	0.34
BH-20*	**110**	**620**	0.15
BH-21**	**220**	**1500**	0.31
BH-22***	**140**	**510**	1.4
BH-23*	**16**	**880**	0.25
BH-24*	--	**15**	1.0
BH-25	**19**	**51**	0.25
BH-26	--	**34**	2.5

Location	U-238 (pCi/g)	Ra-226 (pCi/g)	Th-232 (pCi/g)
BH-27*	**35**	**96**	0.37
BH-28**	3.7	**410**	0.24
BH-29**	4.1	**39**	0.15
BH-30	**21**	**1800**	0.22
BH-31	**16**	**300**	0.26
Under Alden Street	**38**	**160, 260,1500**	0.29

BOLD exceeds 5 pCi/gram; * 0-12" ** 0-18" *** 0-24" depth

Table 6. Radiological Contamination at U. S. Radium Satellite Properties

Property	Date	Gamma (µR/hr)	Ra-226 (pCi/g)	Radon (pCi/l)	Radon Progeny (WL)	Surface Alpha (dpm/100 cm^2)
#80	1984	**46**	--	3.4	--	--
#30	1984	**70**	--	3.6	--	--
#1	91/95	**150/880**	1.5/(**79.3**)	**15.9/14.1(?)**	--	**700**
#43	1986 1991	**290** **2000**	-- --	**6.1** --	0.0094 --	-- **330**
#111	92/95	**40**	**5.0**/0.9	0.4	--	--
#116	92/95	23/7	1.7/**7.6**	1.5	--	--
#28	1984	**2000**	--	**6.9**	0.0159	--
#28	91/95	8/**110**	1.9/(**754**)	2.6	--	--
#82	1984	**110**	--	**4.0**	--	--
#27	1984	**50**	--	2.5	--	--
#161	1984	**30**	--	**4.5**	--	--
#38	92/95	**35**/10	1.4/**12.7**	0.7	--	--
#13	92/95	**30**/10	2.1/**23.4**	2.2	--	--
#152	1986 1991	**121** **600**	-- --	1.33 --	0.006 --	-- **300**
#150	92/95	**280/60**	4.4/**26.9**	2.8	0.018	<95
#151	92/95	**70/30**	2.0/**13.1**	1.8	--	--
#101	92/95	**140/150**	4.4/1.1	**6.2/5.1**	--	--
#155	92/95	**37**/8	3.2/1.9	1.0	--	--
#94	92/95	**120/130**	3.9/2.3	**9.4(1.5)**	--	**270**(<1.7)

Property	Date	Gamma (µR/hr)	Ra-226 (pCi/g)	Radon (pCi/l)	Radon Progeny (WL)	Surface Alpha (dpm/100 cm^2)
#98	92/95	**70/200**	1.8/(**81.4**)	**19.5/14.3**(3.4)	**0.07**	**950**(2.3)
#162	92/96	**170/50**	--	--	--	--
#129	92	**50/70**	**(46.8/21.4)**/ 1.7	1.0	--	--
#74	1991	**300**	**38.3**	--	--	--
#65	1984 1991	**178** **450**	-- **79**	**10.6** **4.1**	-- --	**22,700** **240,000(4 ,200)**
#87	1984 1991	**120** **1700**	-- **15.2**	-- 0.9	-- --	-- **3000(127)**

BOLD - exceeds remediation criteria
-- Not measured
( ) - Radon after remediation
( ) - Radium in building materials
( ) - Removable alpha surface swipe
Gamma - highest contact reading outdoors/indoors
Shaded - commercial property

Table 7. Radiological Contamination at U. S. Radium Vicinity Properties

Property	Date	Gamma (µR/hr)	Radium (pCi/g)	Radon (pCi/l)	Surface Alpha (dpm/100cm^2)
#19	92/95	7	--	**4.1**	--
#21	92/95	20	**14.1**	**6.0**	--
#71	92/95	14	**5.1**	2.8	--
#99	92/95	20/8	**9.0**/2.8	1.5	--
#51	92/95	**30**/13	2.7/4.9	0.6	--
#37	92/95	**30**/18	1.1	2.5	--
#54	92/95	25/11	1.2/2.9	3.0	--
#102	1984 92/95	**30** **250**/12	-- 1.5/**10.2**	1.1 0.5	--
#143	92/95	13	1.1	0.3	--
#62	95	--	3.0	--	--
#224	94/95	--/**270**	1.7/(**310/370**)	**20.6**(0.7)	--
#33	91/95	**60/400**	4.0/(**180/158/26)2**	**15.3**(0.6)	<1.3
#235	94/95	**40**/12	2.7/1.7/4.1	**6.5**owner	--
#115	92/95	**400**	**223/290/167/38.6**	--	--
#113	92/95	**30**/10	1.9/1.4	0.4	--
#128	94/95	23	1.4/2.5	0.8	--
#26	91/95	**44**/7	0.96/**14.2**/2.8	0.5	--
#86	91/95	24/9	1.3/**57.5**/3.1	0.5	--
#25	1984 91/95	25 **60**/11	-- **6.3**/4.1/**16.4**	1 0.9	--
#15	1984 91/95	**40** **40**/14	-- **12.1/(909**)	1.3 0.7	--
#35	91/95	**45**/8	2.0/**23.2**/3.9	1.0	--
#2	1984 91/95	**50** **160**/6	-- 4.1/(**32.4/198**)	2 2.6	--

Property	Date	Gamma (µR/hr)	Radium (pCi/g)	Radon (pCi/l)	Surface Alpha (dpm/100cm^2)
#112	1984 91/95	**50** **125**/7	-- 2.0/((**61.5/71.7**))	0.75 1.6	--
#50	91/95	8/**90**	2.4/**12.4**	0.3	--
#130	91/95	**170/30**	2.1/(**106**)	0.3	**28,000(55)**
#131	91/95	**150/100**	2.0/**20/(232**)	1.1	--
#8	1984 92/95	**50** **800**/9	-- **7.1/(750)/9.5**	1.3 1.2	<1.6
#132	92/95	27/9	2.5/**19.5**/4.5	0.8	--
#125	92/95	15/7	2.0/1.6/**5.9**	<0.2	--
#106	92/95	**150/30**	1.5/4.8/(**114**)	0.6	**71000**
#126	92/95	**620**/7	1.9/(**814**)	1.5	<95
#90	92/95	**50**/8	**(180/58.3)/5.9**	0.9	--
#76	92/95	17/8	1.8/2.7	1.2	--
#95	91/95	**33**/8	**8.9**	1.4	--
#110	92/95	15/8	--	1.1	--
#108	92/95	17/20	3.1/4.0	0.7	--
#100/57/61	92/95	**230**/7	1.7/(**146**)	1.3	--
#44	92/95	17/8	1.2/1.4	0.9	--
#124	92/95	**30/120**	3.6/8.8/**41.4**	2.0	<95
#22	92/95	**50/80**	2.6/(**57.8**)	1.5	<95
#93	91/95	**100**/11	**(161)/5.9/26.1**	3.3	--
#103	91/96	20/10	**5.3**/2.8/3.8	0.4	--
#104	91/96	**40/33**	**(57.1)**/3.2/1.3	0.5	--
#107	91/96	**600/45**	**(150/955**)	**4.3**	--
#73	96 1984	25/11 **30**	2.7/(**75.8)** **--**	2.0 1.9	--
#119	92	**47**/23	**35.4/(879**)	1.5	--
#137	92	20/8	2.7	<0.2	--
#163	92	**30/30**	--	1.4	--

Property	Date	Gamma (µR/hr)	Radium (pCi/g)	Radon (pCi/l)	Surface Alpha (dpm/100cm^2)
#169	92	**67**/**40**	--	0.7	--
#172	92/96	**30**/10	**8.2**/2	0.5	--
#173	94/96	7/**30**	2.7/**9.3**	0.7	--
#175	96	20/7	1.4	0.8	--
#176	95/96	**1000**/8	1.9	1.1	--
#179	96	9/9	**5.6**/**6.5**/4.4	0.3	--
#183	96	**130**	**5.9**/1.4	--	--
#185	95/96	26/7	**5.0**	0.6	--
#188	95/96	20/8	4.0/**18**	0.4	--
#198	95/96	**200**/9	1.8	1.2	--
#200	94/96	6/**70**	4.3/**(210)**	1.9	--
#203	94/96	27/10	1.2/**(13)**	0.5	--
#208	94/96	**270**/8	**7.1**	0.4	--
#213	94/96	**233**/7	2.9	0.8	--
@216	94/96	17/10	2.7	0.5	--
#219	94/96	**83**/9	1.9/**(670)**	0.7	--
#225	94/96	20/7	2.0	0.6	--
#226	95/96	23/8	2.5	0.8	--
#240	96	--	3.5/3.8	0.7	--
#243	94/96	**90**	1.6	0.4	--
#244	94/96	15	1.3	0.5	--
#252	94/96	15/9	--	0.9	--
#253	94	--	--	0.7	--
#254	94/96	23	--	0.8	--
#256	94/96	15	(4.0)	0.2	--

Property	Date	Gamma (µR/hr)	Radium (pCi/g)	Radon (pCi/l)	Surface Alpha (dpm/100cm^2)
#259	95/96	**60**	1.4	0.9	--
#269	94/96	**67**	**5.5**/3.9	0.7	--
#262	94/96	20/7	2.7	1.2	--
#271	95/96	**100**	**(35)**	1.0	--
#273	95/96	--	2.2	--	--
#283	95/96	**73**	2.6	0.7	--
#292	95/96 1984	9/**93** 25	2.7 --	1.0 1.1	--
#304	95/96	27/6	--	0.8	--
#307	95/96	**53**	2.0/**(350/980)**	0.9	--
#312	95/96	**1700/400**	2.2/**(42/19)**	0.5	--
#316	95	27	--	--	--
#317	95/96	**200**/23	1.2	<0.4	--
#318	95/96	**87**/9	1.0	0.7	--
#322	95/96	8/9	--	1.0	--
#359	96	--	3.3/**13**	1.8	--
#120	91/95	13/8	--	0.7	--
#42	1991	**40**	**159** 6.2(Th)	1.0	**2400(310)**

BOLD - exceeds remediation criteria
-- Not measured
( ) - Radon after remediation
( ) - Radium in building materials
( ) - Removable surface alpha swipe
Gamma - highest contact reading outdoors/indoors
Shaded - commercial property

Figure 1. U. S. Radium and Surrounding Area

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To receive a larger copy of this map, please call the Hazardous Site Health Evaluation Program at the New Jersey Department of Health and Senior Services, 609-984-2193.

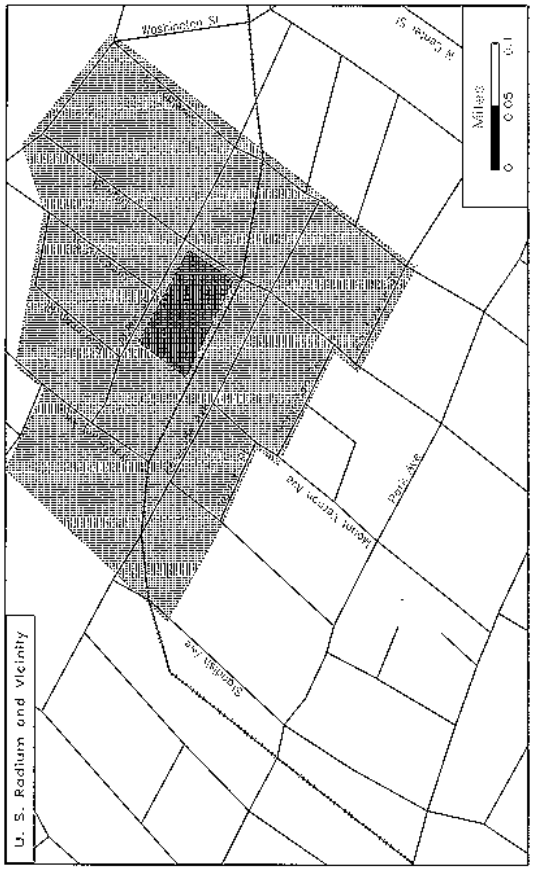

Figure 2. U. S. Radium and Vicinity Properties

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