U.S. RADIUM CORPORATION
422-432 Alden Street
Orange
Essex County
New Jersey

HAER No. NJ-121

HAER
NJ
7-ORA,
3-

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN BUILDINGS SURVEY
National Park Service
Northeast Region
Philadelphia Support Office
U.S. Custom House
200 Chestnut Street
Philadelphia, P.A. 19106

HAER
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HISTORIC AMERICAN ENGINEERING RECORD

U.S. RADIUM CORPORATION

HAER NO. NJ-121

Location: 422-432 Alden Street
Orange
Essex County, New Jersey

USGS Orange, New Jersey Quadrangle,
Universal Transverse Mercator Coordinates:
18.565059.4515451

Dates of Construction: 1917-1926

Engineer/Architect: Unknown

Present Use: Vacant

Present Owner: City of Orange, New Jersey

Significance: The U.S. Radium Corporation site, including the surviving structural components dating to the period 1917-1926, were associated with nationally significant developments in health and safety standards, the ability of woman reformers to secure protection for workers handling radioactive materials, and tools used to detect and measure radio-isotopes. Beginning in 1920, radium dial painters at the plant began reporting health problems later associated with radium exposure and many died over the next decade. There were no publicly recognized health or safety problems identified or standards established for handling radioactive materials at this time. The dead woman, and others who survived, became the first known victims of industrial radium poisoning. The survivors subsequent efforts to seek redress, in alliance with the Consumer's League, played a major role in the establishment of legislative protection for workers against industrial diseases. Equally important, scientific investigation of these dial painters, and of other victims of radium poisoning, led to the establishment of health standards used to protect workers in radioactive environments and to the emergence of human radiobiology as a field of study. These investigations had military as well as civilian implications. Even before official standards of workplace radiation exposure were established after World War II, data from dial painters' cases were a major source in the health and safety codes developed for the wartime Manhattan Project.

Project Information: The site is a Federal National Priorities List Superfund site (EPA ID # NJD980654172; USEPA 1992) and will undergo clean-up to remove radiological contamination. A previously conducted cultural resources investigation (Grossman and Associates 1997) determined that the site was significant and eligible for listing on the National Register of Historic Places. Two buildings on the site are associated with its period of significance (1917-1926) and will be demolished as part of contamination clean-up. To mitigate the adverse effect, the New Jersey State Historic Preservation Office stipulated documentation of the structures. Due to human health concerns arising from elevated levels of radiological contamination within the buildings, USEPA determined that restricted access to the buildings' interior areas was advisable and preferred. Therefore, only limited interior photographic documentation, in addition to exterior photographic documentation, was conducted to fulfill the New Jersey Historic Preservation Office's stipulation.
At the direction of the USEPA, the historical narrative for this documentation was redacted from the 1997 Grossman and Associates report.

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PART I - THE U.S. RADIUM CORPORATION FACILITY - SUMMARY DESCRIPTION OF THE SITE, ITS HISTORY, AND SIGNIFICANCE

This narrative history provides information on the occupation of the 2.2 acre U.S. Radium Corporation site, located in Orange, Essex County, New Jersey, between 1917 and 1926. The site is bounded on the east by High Street, on the north by Alden Street, on the south by Wigwam Brook which currently flows in a concrete channel, and on the west by private residences. Between 1917 and 1926 (referred to here as the U.S. Radium Period), the primary activity at the site by the U.S. Radium Corporation (known until 1921 as the Radium Luminous Materials Corporation) was the extraction and purification of radium from carnotite ore to produce luminous paints and other radium products for military, commercial, and medical purposes. During the plant's operation, radium was extracted from carnotite ore containing two to four percent uranium oxide. A large amount of process wastes and tailings containing radioactive elements were temporarily discarded on unused areas of the main facility, and much of it was ultimately disposed of off site. Some was used apparently to fill portions of the site, causing most of the radiological contamination on the property, and some buildings were constructed directly over the waste material. At the time of operation, the facility consisted of ten buildings. Only two of the original U.S. Radium buildings (the Paint Application Building - HAER NJ-121A, [422 Alden Street] and the Radium Crystallization Laboratory - HAER NJ-121B, [428 Alden Street]) remain as of May, 1999. They were used commercially until the early 1980's and are now vacant. Portions of the buildings are radiologically contaminated as a result of the U.S. Radium Period activities that occurred within them.

The significance of the U.S. Radium Corporation site derives from the events that occurred there between 1917 and 1926 and their subsequent consequences, particularly in regard to issues of worker health and safety. Although the two remaining original U.S. Radium Corporation buildings at the site have been impacted by later alterations and industrial uses, portions retain their U.S. Radium Period integrity and are contributing elements of the property's significance.

THE U.S. RADIUM CORPORATION FACILITY

The remaining two U. S. Radium Period buildings are plain, concrete-block structures with simple rectangular plans, low gable roofs, and tile-capped parapets. The two-story former paint application building fronts directly on Alden Street to the north, while the one-story former radium crystallization laboratory -- built only about three feet to the west -- is set back some 80 feet from the street. Both structures were built in 1917 in the northwest section of Orange, New Jersey, in a neighborhood of late 19th century worker housing, commercial buildings, and hat factories. Much of this neighborhood remains intact with many modifications, including the row of two-story homes on the north side of Alden Street opposite the property. The lot immediately west of the two facility buildings has been razed. To the east, on a lot formerly used for radium extraction and refining, are four small one-story concrete block buildings built since 1939 for a gas station, automobile body shop, and a number of small commercial operations. The rear of the facility property is defined by the former alignment of the Erie Railroad's Orange Branch -- from which tracks have been removed -- and channelized Wigwam Brook running between concrete walls. Both of the surviving U. S. Radium Corporation structures are substantially intact structurally and retain their original forms and locations, but they have been heavily altered by additions, removal of all original equipment and most original fixtures, removal of some original interior partitions and exterior walls, and replacement or blocking of windows, skylights, or doors.

Between 1926 and the late 1930's, U.S. Radium demolished most of its Orange facility, leaving the two surviving structures, a boiler house, and several small ancillary buildings. The boiler house and ancillary buildings were subsequently removed from the site.

NARRATIVE SUMMARY OF SITE SIGNIFICANCE

The surviving buildings of the U. S . Radium Corporation contain former work areas associated with nationally significant developments in health and safety standards, the ability of women reformers to secure protection for workers handling radioactive materials, and tools used to detect and measure radioisotopes. Despite their visually compromised condition, the simple forms of the paint application building and the crystallization laboratory retain original dimensions and construction materials. These structures convey the relatively spartan conditions in which radium bromide salts were crystallized for use with luminous paints which then were applied to watch or instrument dials. As many as 300 dial painters -- all women -- worked in the paint application building at one time, primarily on the second floor with its large window areas and now-filled skylights. The radium poisoning suffered by some of these women, and their attempts to seek redress in alliance with the Consumers' League, began chains of events pertaining to issues of worker health and safety which make the property historically significant today.

PART II - BACKGROUND INFORMATION

THE RADIUM INDUSTRY

Benchmarks in the Discovery of Radioactivity

The development and operation of the U.S. Radium plant in Orange, New Jersey between ca. 1915 and 1926 marks a key chapter in the development of the radium industry in the United States and in Europe. The plant's operation reflected contemporary developments in the identification, separation and isolation, and measurement of radioactive compounds both in the United States and Europe. An understanding of the major achievements of early researchers in the field of radium studies is pivotal in understanding the processes used at the U.S. Radium facility. Each production, calibration, and application procedure employed at the U.S. Radium plant derived from turn-of-the-century developments in the chemical techniques of radium isolation, refinement, extraction, and implementation. These techniques were used by the employees of U.S. Radium less than two decades after the 1896 discovery that barium and thorium salts, when chemically mixed with various elements, would emit invisible rays capable of fogging sealed photographic plates.

The discovery of radium salts and its potential for industrial application occurred within a short and apparently intense period of research and development lasting two decades. The energy-emitting properties of barium and thorium were first observed in 1896 by a French physicist, Dr. Henri Becquerel, and were identified and chemically isolated by Marie Curie beginning in 1898 (Rowland 1994:3). As early as 1904 commercial isolation, refinement, and manufacturing were underway at a French factory (Landa 1982). The first North American processing facilities were not commercially competitive with the French facilities until the period of 1914-1917. At plants in New Jersey, New York, and Philadelphia, the emergence of the American radium industry closely paralleled European scientific, political, and military developments.

Because of such parallels and the transfer of ideas and investments across the Atlantic, the origins of the U.S. Radium plant in Orange must first be discussed within the broader context of European science and technology. These initial techniques of separation, purification, and application of radium salts, which made the nocturnal observation of commercial and military instruments possible, formed the basis of the processes and techniques used in Europe and the United States. They are the same processes and techniques used in the operations of the U.S. Radium plant in New Jersey between 1917 and 1925. The original wet chemistry procedures used by the Curies to isolate and measure the relative intensities of the new family of radioactive elements and compounds were adopted with little variation by the first American producers of luminous dials.

Research and development in the radium industry may be divided into three periods. The first period, from 1896 to 1904, encompasses the initial discovery, separation, and industrial application of radium salts by the Europeans, to the apparent exclusion of significant American activity. Although several American mining firms were active in recovering radium-bearing ores during this period, predominantly for processing and refining abroad, limitations in the quality of North American ores precluded cost-effective exploitation of radium in America (Landa 1982).

During the second period in the commercial and technical history of the U.S. radium industry (1904 to 1914), North American companies and government agencies were actively engaged in the exploration and mining of radium-bearing ore deposits.

The third period was initiated in 1914, and was marked by a technological breakthrough under a major research and development program funded and coordinated by the United States government. A new processing technology was developed to bypass the chemical barrier which had limited the use of poorer-quality North American carnotite ores, making it possible to extract radium salts cost-effectively. The new ore purification method allowed United States companies and entrepreneurs to compete technologically and economically with Europeans producers, whose refinement capabilities with European and African pitchblende-based ores had dominated the field to that point (Landa 1982:187). As a result of the new purification method, the global economic networks of the emerging nuclear industry shifted to the United States, and the stage was set for the advent of the era of independent North American production without technical, scientific, or economic dependence on outside suppliers. An autonomous American industry of radium-producing and refining companies emerged, including the Radium Luminous Materials Corporation, which was incorporated in New York, New Jersey, and Delaware between 1915 and 1917 and was the parent company of the U.S. Radium Corporation. The U.S. Radium Corporation competed with several other firms, most of which were based in Pittsburgh, for the commercial luminous watch dial market and, more importantly, for government support in the development and manufacture of luminous dials and gun sights for nocturnal use by military ground troops and submarine and aircraft personnel (Landa 1981).

Initial Discovery and Separation of Radium

The techniques used by Mme. Curie to identify the existence of what subsequently was found to be a series of new elements, all sharing the capacity to emit charged particles without external stimulation from heat, light, or pressure, were employed, in refined form, in the later commercial exploitation of radioactivity throughout the period of domestic American radium production from 1914 to the mid-1920s. Three technical aspects of nuclear chemistry played central roles in the development of the early nuclear industry, both in the United States and Europe:

1) The development of the new science of wet chemistry for the separation and refinement of different natural and artificial compounds. The new technique consisted of chemical separation

through distillation, and the crystallization of dissolved compounds by means of heat and the use of differing concentrations of various acids. These techniques of molecular and nuclear chemistry were, in turn, based on the emerging understanding of the electrochemical characteristics of chemical compounds.

2) The initial development of instruments and techniques to detect and measure the presence of newly discovered radioactive compounds by the use of film fogging and charged electrostatic instruments, and the subsequent improvement of these instruments, rendering them useful for defining the absolute level or strength of the emissions of the discovered compounds. The measurements served as the basis for distinguishing among the compounds by making it possible to count the number of emissions from them within a given unit of time (the basis of the modern scintillation meter).

3) The ability to extract and refine the impure radioactive salt compounds cost-effectively into concentrations or grades of relatively pure compounds of commercially useable radioactive salts. A major aspect of this element in the development of the U.S. radium industry was the significant role played by the United States government in helping to develop extraction and refinement procedures appropriate for the North American ores. Until these techniques were developed by the U.S. Bureau of Mines, the domestic production of refined radium was impeded, thus effectively keeping the United States out of the race to dominate the international radium market prior to 1914 (Landa 1981, 1982).

Each of these major developments not only represents key aspects in the history of the radium industry, but also constitutes the framework for understanding the production stages used for the refinement of radium salts at the U.S. Radium Corporation in its commercial operations in New York and New Jersey. Accordingly, each of these major aspects of radium production is discussed below as a prelude to addressing the nature and purpose of the day-to-day operations at the U.S. Radium facility in Orange.

Insulation and Purification of Radium

The discovery of radium as a new element resulted from experiments with natural minerals that glowed or "luminesced" in the dark after being subjected to external energy. In 1896 Henri Becquerel, a French physicist, was conducting experiments with a broad series of phosphorescent and fluorescent substances which, as a group, shared the characteristic of emitting a glow after being energized by external sources of energy (i.e., exposure to light, heat, or pressure).

Becquerel was focusing on the fact that these naturally occurring compounds were emitting both visible light and other forms of energy. His observations were made after exposing his samples to sunlight and then measuring their effect on unexposed glass photographic plates contained within light-proof envelopes. In a series of related experiments, he repeatedly demonstrated that sunlight charged certain minerals, which then emitted energy by glowing, as well as fogging the encapsulated film through its light-tight wrappings (Grolier 1996b).

While undertaking these experiments with a range of compounds, Becquerel observed that mixtures of uranium salts had the capacity to fog film even without first being exposed to sunlight. This characteristic of uranium led the French physicist to conclude that he had discovered a new property of matter. This property was therefore initially known as Becquerel Radiation, and later as "radioactivity" (ANL n.d.j).

Within two years of Becquerel's observations, the source of these emanations had been identified. During the same two-year period, chemists made the observation that, in addition to their effects on unexposed film plates, these "new" compounds demonstrated two other properties, which would become pivotal to the emergence of the radiation industry in both Europe and America over the next decade. In addition to fogging film through the emission of energy, or "rays," these elements could also cause certain nonradioactive compounds to fluoresce without the action of sunlight, and without the presence of radioactive elements after initial exposure. Of the several compounds that demonstrated this characteristic, zinc sulfide showed the greatest capacity to glow after being irradiated. This effect of the "new" material on certain non-radioactive compounds became the basis for the development of a new generation of instruments to measure the absolute energy levels of radioactive elements. The higher the radiation levels, the higher the level of fluorescence. Radiation is invisible to the naked eye, but its effect on non-radioactive compounds provided the basis for measuring the differences among the chemically distinct radioactive elements being isolated by Mme. Curie and others and lead to the development of the instruments needed to measure the relative radioactivity of the study samples.

The new instruments were subsequently important to the development of the radium industry by providing a way of measuring ore quality, both at U.S. Radium and at other radium plants of the period. They also provided the basis for the development of the instruments later used at the U.S. Radium plant to measure the relative purity of the radium salts being refined, particularly within the small on-site laboratory fronting on Alden Street. The ability to measure levels of radioactivity by quantifying the number of "flashes" derived from the impact of radiation on wafers of zinc sulfide also provided the data that enabled Mme. Curie to establish relative radioactivity levels as distinguishing characteristics of different radioactive elements, once they had been chemically isolated (Grolier 1996b).

The discovery and isolation of radium and other radioactive elements was made by Marie and Pierre Curie between 1896 and 1898. Marie Curie had emigrated to France from Poland in 1867 and struggled in poverty as a teacher, governess, and student until she earned dual degrees in mathematics and chemistry in 1893 and 1894, respectively. She married Pierre, a physicist, in 1895 and gave birth to two daughters, in 1897 and 1904. Although Pierre Curie did not receive a formal degree until the year of his marriage, he had distinguished himself as an investigator of the properties of crystals. He discovered the phenomenon of piezoelectricity, the emission and absorption of energy as light or heat in crystals under pressure. This is the principle behind the common wick-free incandescent light sold today (Grolier 1996b; 1996c).

Until 1903, the Curies' innovative research took place under a severe shortage of funds. In that year, Marie and Pierre Curie and Henri Becquerel jointly won the Nobel Prize for their work on radioactivity. The Curies' first laboratory consisted of a simple shed in the courtyard of the School of Physics and Chemistry of the City of Paris (Landa 1982). They worked alone and secured their original supplies either as gifts from supportive colleagues and institutions or with their own funds. The initial samples of uranium-bearing pitchblende consisted of a small 100-gram sample, augmented by a gift of a 500-gram supply donated by the U.S. Geological Survey.

After an extensive search, Pierre Curie learned of vast waste dumps of a partially processed pitchblende which had accumulated as the by-products of the Austrian mines at St. Joachimsthal in Bohemia, which had been worked since the 15th century as a source of colored pigments and for uranium extraction in the 19th century. Through contacts with an Austrian colleague, Edward Suess of the University of Vienna, the Austrian government initially donated 100 kilograms to the Curies, ultimately permitting them to purchase for the cost of transport some 11 metric tons of mine waste (Landa 1982:183).

The laboratory procedures and technical inventions created to facilitate the Curies' research were inexpensive. The new procedures and developed instruments were simple and cost-effective, with the procedures easily replicable and the instruments easily replaceable. This pattern of shoe-string invention is illustrated by the design and construction of an instrument by Pierre Curie to make possible the quantified measurement of discrete radioactive emissions from uranium compounds, called the electrometer. This instrument provided the critical technological advance for the identification and measurement of the differing levels of radioactivity associated with the various grades and forms of radioactive compounds.

The Curies' early expertise in understanding and working with the physical and chemical properties of crystal structures facilitated their use of chemical methods to extract, isolate, and purify radium salts in 1898. Using these observations and laboratory methods, Mme. Curie succeeded in chemically separating the first of a number of radioactive salts through the application of procedures that dissolved various fractions of material and isolated them through precipitation. Because different salt compounds dissolve at different temperatures and at different levels of acidity, the repeated use of crushing, mixing with acids, boiling, and precipitating the resulting compounds into crystallized salts enabled chemists to gradually segment, isolate, and purify the salts of various radioactive compounds (Landa 1982).

For her doctoral thesis, Marie Curie chose to focus on the radiation emitted by certain compounds of pitchblende which had been discovered by Henri Becquerel. Pierre Curie, at that time a professor in the School of Physics and Chemistry of the City of Paris, had identified the source of Becquerel Radiation as a low-density salt compound associated with uranium (Kjaer n.d.a). Using the electrometer built by Pierre Curie to measure the radiation of different uranium compounds in absolute and finite units (light emissions/unit time), Mme. Curie documented that the level of radioactivity emitted from uranium ores was proportional to the uranium content, constant over time, and uninfluenced by external conditions. While testing a range of minerals for this effect, she also observed levels of radioactive emissions from compounds of thorium, indicating other elements had this characteristic (Grolier 1996a). Because she could quantify the differences in radiation levels between different compounds with the new electrometer, she discovered that samples of pitchblende ore, mined predominantly in Europe, and a North American ore known as carnotite, contained some four hundred percent more radioactivity than could be accounted for or be caused by their uranium content alone. This observation led to her revolutionary conclusion that the pitchblende and its American counterpart must therefore contain minute amounts of one or more new and previously unknown elements. She called the first of these elements polonium after her native land. Within the year she had separated a second distinct radioactive element or, more precisely, a salt compound of a second element, radium (Landa 1982:182-183).

The procedures Mme. Curie used to separate these compounds from uranium ore earned her the Nobel Prize, and were adopted by chemists working for commercial radium extraction companies throughout the first quarter of the 20th century (Landa 1982:183). Accordingly, her techniques and their application to the refinement of radium salts out of pitchblende and carnotite ores are relevant to understanding the production procedures used at the U.S. Radium facilities between 1915/1917 and 1925.

The chemical separation of radium from other compounds is based principally on the fact that radium salts have a chemical structure similar to barium salts. Both radium and barium form carbonates and sulfates that are insoluble in water, whereas compounds of chlorides and nitrates are soluble in water. These differences in solubility were used as the basis for extracting radium salts from naturally occurring ores (Landa 1982:180). Because of radium's chemical similarity to barium, any process capable of extracting or isolating barium also resulted in the precipitation of radium. Because both radium and barium drop out of solution in the presence of sulfates, it is desirable -- and in the 1920s was commercially essential -- that the primary ores used for radium extraction be free of sulfates that precipitate radium and barium salts before the latter two can be isolated from the ore. This requirement played an essential role in the development of the United States industry because the predominant North American uranium-bearing ore, carnotite, contains two to three percent gypsum (calcium sulfate). When this ore is dissolved in nitric acid it yields large quantities of soluble sulfates in amounts sufficient to precipitate all available radium and radium sulfate. This characteristic of the North American ores made them less useful than the pitchblende ores from European and European-controlled African sources until the development, through a massive United States government research effort, of chemical pretreatment procedures capable of neutralizing the sulfate problem (ANL n.d.o).

The extraction and purification of radium from both pitchblende and carnotite was undertaken in two stages: The first stage consisted of the use of precipitation to separate radium and barium salts from salts of unwanted non-radioactive minerals by treating the ores with boiling acid and water solutions, and subsequently cooling them. The second stage of the process consisted of the separation of the chemically similar radium and barium salts from each other though a process of "fractional crystallization," based on the fact that radium compounds are slightly less soluble than barium salts. Using this subtle chemical difference, first Mme. Curie, and later the chemists of the U.S. Radium Corporation, disassociated radium from barium by using successive saturated salt solutions of barium and radium chlorides which were allowed to evaporate to form crystalline precipitates. After many repetitions of this process, with a slight increase of ca. 50% in radium salt concentrations in each cycle, nearly pure residues of radium salts were obtained.

Mme. Curie's doctoral thesis, submitted to the Faculty of Science of the School of Physics and Chemistry in 1903, detailed the processes used to extract radium salts from the pitchblende tailings, acquired from the Austrian government. Her procedures were based on the fact that the discarded ore tailings had already been treated with (Landa 1982:184):

> ...sodium carbonate and sulfuric acid to extract the uranium, leaving the carbonate and sulfate salts of radium in insoluble residues .... The sulfates were transformed into carbonates by treating the residues with boiling sodium carbonate, and the carbonates were then transformed into soluble chlorides by treatment with hydrochloric acid. The solution was filtered to remove extraneous materials, then sulfuric acid was added, converting the radium into its sulfate form again, which precipitated .... [O]ne ton of ore yielded between 10 and 20 kilograms of crude sulfates of radium, barium and calcium, which were 30 to 60 times as radioactive as metallic uranium. The crude sulfates were purified by a similar series of steps designed largely to remove calcium. The yield was about eight kilograms of mixed barium and radium chlorides per ton of ore.

In general, the process of radium extraction and isolation implemented commercially at the U.S. Radium plant was similar to that originally used by the Curies. Large quantities of ore needed to be processed to acquire minute quantities of refined radium. Seven tons of pitchblende had to be processed to extract one gram of radium. By the 1920s, this laborious process of sequential crystallization had been improved, so that crystallization had become a continuous process in which solutions and crystals were constantly recombined, thus reducing the number of steps in the process. The principle of refinement remained the same.

Measurement and Detection

In addition to the development of cost-effective chemical procedures for the extraction and refinement of radioactive ores, the development of a secure basis for calibrating the strength and purity of the resulting precipitates constituted a second key element necessary for the development of commercially viable industries. Pierre Curie's device, the "electrometer" or electroscope, was the predecessor for all subsequent commercial and military-grade radiation instruments. Pierre Curie's electroscope made use of the capacity of radioactive materials to discharge static electricity. The instrument consisted of a glass jar with a strip of metal foil suspended in a "v" shape so that, when charged with static electricity, the panes of foil repelled each other. Alpha particles from a radium sample acted to dissipate the foil charge, causing the foil to drop to its original uncharged position. The relative radioactivity, or radium content, of the sample was measured by the amount of time it took the charged foil to discharge to its original state (Landa 1982:186).

By the 1920s this and similar types of instruments had been adopted by laboratories in Europe and the United States for the detection of radioactivity in water and ores, and for measurement of the quality of radioactive compounds being refined for both commercial and military purposes. At the time of the operation of the U.S. Radium Corporation in Orange (1917-1926), the electrometer or radioscope, as it was then called, was both sensitive and of simple design. The instrument consisted of a glass jar with a removable top which could accommodate either an inlet tube or detachable fluorescent screen. It operated by using a "film" plane or screen of phosphorescent zinc sulfide which, when struck by radioactive particles, produced flashes of light (referred to as scintillations). It is noteworthy that the instrument "invented" by Dr. Sochocky in 1917, the inventor of luminous paint and original chief chemist of the Radium Luminous Materials Corporation, was a copy of the early "foil" electrometer, which Pierre Curie manufactured prior to 1898 and apparently used until 1906, when Dr. Sochocky was in Paris studying with the Curies (Wall 1969:18-19; Sochocky 1921:25).

In a report in the archives of the Argonne National Laboratory, the design and workings of the Orange facility electrometer was described (ANL n.d.j):

> For testing water or other solutions of radio-activity, the jar should be half full of the liquid; for ores or any other solid material, place a few ounces of the finely crushed material in the jar and add water until the jar is about half full of the mixture. The jar is then corked and shaken vigorously for one minute. This operation releases a large percentage of the available emanation near the surface of the ore into the air space above the liquid. The cork is then removed, the screw cap which is provided with the lens and zinc sulfide screen, is quickly put in place on top of the jar. If the solution contained any radium or its emanations, brilliant flashes of light will be observed through the lens, which must be accurately focused on the phosphorescent screen.

> All operations must be conducted in a room comparatively dark, the darker the better, as it is absolutely necessary that the eye should be properly accustomed to the darkness before the lights can be seen. It is also necessary to keep all light away from the instrument for at least one-half hour before making the test, otherwise the screen phosphoresces so brightly that the separate flashes of light produced by the radium rays cannot be plainly observed.

The electroscope's design was the basis for the modern "scintillator," which operates on the same principle but use photo-multiplier tubes to record the light emissions from the radioactive bombardment of a phosphorescent plate. The use of this design provides a possible explanation of why U.S. Radium, both at the Orange plant and elsewhere, maintained its radioactivity measurement laboratory in a separate room or structure that could be maintained in isolation from the processing and paint application areas, free from worker traffic and ambient light. These requirements, especially the need to keep the instrument hidden from the energizing effect of sunlight, in all probability also held true for the effects of background radiation levels. Clearly, if the ambient or background levels of radioactivity were too high, the instrument would record both the background emissions and those of the samples being tested. If readings were consistently too high, the laboratory would have to be moved to a separate-off site location, away from contamination caused by proximity to the processing and production areas. It is probable that the numerous documented changes of location of the measurement facilities at the U.S. Radium plant -- first in an unheated metal shed at the rear of the plant for six months in 1917, then to a former residence (the late-nineteenth century Bulkley home) fronting on Alden Street from 1917 to 1925 (reportedly due to cold weather), then to an off-site facility next to the Edison Laboratories at 350 Main Street, and finally to New York City (after 1926) -- reflected the need for isolation not only from light, but also from ambient radiation (Eckert 1959a; Wall 1969).

Changing Ore Supplies in Europe and the U.S.

The history of the radium and uranium mining industry has been studied in depth by Edward Landa of the U.S. Geological Society from both an industrial and technological perspective (Landa 1981, 1982 and 1987). The subject is complex, with a large field of corporate entities and individual entrepreneurs involved in short-lived ventures both in the United States and in Europe from the
late 19th century onward, until the advent of modern techniques of isotope production (based on the use of linear accelerators to create artificial radioisotopes) made the mining of ores for radium obsolete. Several major developments in the discovery of higher-grade ores and refinements in the technology of uranium and radium extraction, along with the changing role of radium in commercial and military applications, provide a framework for understanding the advent, operation, and demise of the U. S. Radium Corporation facility at Orange.

In general, it can be stated that the history of the radium industry in the United States followed earlier developments in Europe, where mines yielding uranium had operated as sources of pigments since the 15th century. The beginning of commercial production and extraction in the United States was delayed not only by the competitive early mining tradition and availability of uranium in Europe, but also by the relative inferiority of 19th century American ores. One of the earliest sources of uranium in Europe came from the St. Joachimsthal mines in Bohemia, now part of the Czech Republic and, until the end of World War I, part of Austria. Originally mined for silver and then closed, the mines were reopened by the Austrian government for the extraction of uranium after the discovery of radioactivity (Landa 1982:183). From the spoils of this mine Mme. Curie acquired the primary supply of pitchblende, from which she isolated radium. This European source contained what amounted to approximately 1 gram of uranium per eight tons of pitchblende residue. Although minute in proportion to the amount of ore required, the St. Joachimsthal source was several times purer than contemporary North American ores known to contain uranium.

The primary North American uranium ore during this period, carnotite, was found in large outcrops in Colorado and Utah (Landa 1982). The initial discovery of uranium ore in the United States was made by a British metallurgist, Richard Pearce, who had been hired by a London firm to inspect gold mines in Gilpin County, Colorado in 1871, almost three decades before Mme. Curie's initial work (Landa 1987:5). While inspecting a mine that had been worked previously for gold in an area known as the Levenworth Gulch, Pearce came upon a spoils pile containing ..."a heavy black mineral which proved to be uraninite coated with a beautiful canary yellow material, uranium vitriol, a basic oxide of uranium" (Landa 1987:5). Upon his return to Great Britain, Pearce announced his discovery at a meeting of the Royal Geological Society (Pearce 1875). He described collecting a 220-lb sample, which he sold to a British company in London for $210. In 1872, Pearce returned to Colorado to operate, under lease, a smelter owned by the Rochdale Mining Company. He continued to collect material at the site of his original find, known as the Wood claim, managed to produce some three tons of sorted ore of approximately 60 percent uranium content, and shipped the product to London for a return of $7,500 (Landa 1987:5).

In contrast to the St. Joachimsthal-derived ratio of one gram of radium to eight tons of uranium spoils, the American carnotite deposits required the processing of three to five hundred tons of ore to extract the same one-gram quantity of radium salts, as well as 500 tons of chemicals and 1,000 tons of charcoal (Viol and Kammer 1918:382). By 1918, U.S. production approached 13.5 grams per year. The production of this relatively small amount of radium required the consumption of 6,700 tons of chemicals and 13,500 tons of charcoal. By the late 20th century, these materials, together with the processed ore, would become mountains of chemically laden radioactive spoils and leached ponds of caustic chemicals in the vicinity of commercial mining and extraction centers. By 1921, U.S. radium production had surpassed world radium production by a factor of three to one, with the total yield of radium for that year rising nationally to a reported 153.857 grams (Kjaer n.d.a). When multiplied against the stated ratios of chemicals and charcoal required to extract one gram of radium salts, the amount of resultant industrial waste and chemical by-products reached levels approaching 12 million tons of chemicals and nearly 154,000 tons of charcoal, numbers that translated into heavy industrial pollution and massive deforestation by the second decade of the 20th century in the U.S. alone.

Despite the number and extent of known American ore deposits, their significantly lower uranium content compared with Austrian pitchblende was the key factor that kept American mining operations at a disadvantage until 1913, when new developments in processing procedures made the low-grade American carnotite competitive with European ore. Before 1913, the inferior quality of American ore rendered the United States almost completely dependent on European facilities. Until 1912, nearly all of the carnotite mined in the United States was exported to foreign countries to be processed for radium and then reimported at costs of approximately $100,000 per gram of refined radium salts (ANL n.d.a; Landa 1982). The low levels of radium content in American ores were matched by a high concentration of sulfates which, as stated previously, interfered with the efficient refinement of radium salts. American production facilities were placed at a further disadvantage in 1913, when the government of Austria abruptly declared an embargo on the export of uranium ore and residue from its principal mines at St. Joachimsthal after the commercial and strategic value of radium to medicine and military use was realized (Landa 1982:184).

Perhaps out of parallel concern, or simply due to the economic advantage of being self-sufficient producers, many European countries established a wide range of mining operations and commercial and government production facilities during the first decade of the 20th century. France opened its first processing plant in 1904. Soon after, the Austrian government augmented its competitive status by opening its own plant for the extraction and refinement at the site of its primary mine holding at St. Joachimsthal. By 1910, that plant had produced 13 grams of radium, an amount that placed it at the top of the European market until external events changed the status quo, specifically the discovery of previously unknown ore deposits in Africa many times purer than the European sources. The British Radium Corporation opened a primary extraction facility to process native ores in Cornwall, which were then shipped to London for refinement into radium salt. Also by 1910, both Sweden and Russia had opened their own plants and refinement facilities (Landa 1982:186-187).

Against this broad network of early European production, the United States market was at the mercy of foreign imports until the United States government intervened to aid the fledgling U.S. radium industry. While the beginning of American self-sufficiency in production can be traced back to an early effort by Stephan T. Lockwood in 1906 to launch the first United States commercial radium facility in Gilpin, Colorado, the low grade of the ore and difficulties in obtaining adequate supplies of raw material for processing activities resulted in the closure of his Rare Metals Reduction Company only two years later in 1908 (Landa 1987). Commercially viable industrial production did not take place in the United States until 1913 with the opening of the Standard Chemical Company, which extracted radium from carnotite ore deposits in Colorado and Utah. By 1913, Standard Chemical was operating a competitive processing and refinement facility at its main plant in Caninsberg, Pennsylvania. By 1918, a total of six American radium extraction companies employing three hundred workers had produced a total of 13.5 grams of radium (ANL n.d.a; Landa 1987).

This belated surge in American production capacity came about as a direct result of the concerted and heavily financed U.S. government support of the development of cost-effective extraction procedures for low-grade carnotite ores, allowing the United States industry to become both economically competitive with and strategically independent of the European production and refinement monopoly. In a report produced sometime between 1924 and 1925, Swen Kjaer, an early government investigator of health problems at the U.S. Radium plant for the U.S. Department of Labor, stated (Kjaer n.d.a):

> Experiments conducted by the U.S. Bureau of Mines in 1913, under a cooperative agreement with another firm [no corporate reference were made in his manuscript], resulted in development of the most suitable extraction methods for American carnotite ores [Kjaer cited a 1915 publication for government scientists in Bulletin 104 of the Bureau of Mines, U.S. Department of Interior, entitled 'Extraction and Recovery of Radium, Uranium and Vanadium from Carnotite']...As a consequence, rapid advancement was made in the industry and the U.S. became the principal radium country in the world.

The first refined American radium salts were produced "by one of the largest firms," presumably Standard Chemical Company, by January 1914, within months of the government-sponsored breakthrough in cost-effective processing technology that employed an intermediate processing step of nitric acid treatments for the low-grade American ores (Viol 1914:25).

The near-demise of the North American radium industry, particularly the extraction of American radium ore, came about abruptly in 1922 with the exploitation of significantly higher-grade ores in the Katanga district of the Belgian Congo. Between 1913 and 1915, Belgian surveyors discovered a new source of pitchblende ores which far exceeded in quality both European and North American ores. The Belgian mining company, the Union Miniere du Haut Katanga, soon began commercial mining of large quantities of high-grade ore consisting of upwards of 50% pure uranium oxide, although large-scale exploitation did not occur until 1921. In contrast to the 300-400 tons of American carnotite ore necessary to extract 1 gram of radium salt, the Katanga ore yielded the same amount from only 10 tons of raw material (Landa 1982: 189).

This discovery had a devastating impact on the American radium extraction and processing industry. The American industry simply could not compete. By 1922, the Belgians had established a processing plant at Oolen, near Antwerp. The onset of production at this new facility in 1922 quickly resulted in the shutdown of all American-owned radium extraction plants in the United States except for the U.S. Radium Corporation, which continued to extract radium until 1926. All other American facilities either closed or converted solely to the extraction of vanadium. In addition to taking the United States producers of radium out of the world market, the availability of these new high-grade ore sources dropped the cost of radium from $100,000/gram to a fixed price of $40,000/gram. Although this event brought about the significant downsizing of United States production capabilities, United States involvement in radium production was maintained through financial and corporate links to Belgian companies. The Radium Chemical Company, a wholly owned subsidiary of the Standard Chemical Company, provided technical assistance to the new Belgian radium processing facility, and Standard Chemical became the sole agent for the sale of Belgian radium to United States companies (Landa 1982:189). This relationship continued until 1926. In 1927, the Belgians refused to renew their contract with the Standard Chemical Company as their sole-source American supplier. Standard Chemical was forced to liquidate within five years (Kjaer n.d.a). This brief chronology of events suggests why the U.S. Radium Company continued to extract radium salts from low-grade ores until 1926. As long as the Standard Chemical Company controlled access to the more cost-effective Belgian product, the U.S. Radium Company had no supply source unless they produced their own radium salts. Although it is unclear why U.S. Radium did not purchase radium directly from the Belgians via Standard Chemical, the reason may be financial, with prices reaching $100,000 per gram during this period, or an attempt to prevent reliance on a sole-source distributor. In 1926 the U.S. Radium company stopped the production of radium salts, closed its Orange plant, and moved its remaining operations to New York City.

The final chapter in the history of the U.S. Radium industry in the United States came about as a result of a second major discovery of high-grade ore, this time in Canada. As Landa observed, "the only radium processing company that could compete with the Belgian company was one that had access to another source of very rich ore" (Landa 1982:189). That opportunity was provided in 1931 with the realization that outcrops of pitchblende, originally discovered as a result of geological surveys in the vicinity of Great Bear Lake, Ontario, contained ore deposits containing uranium oxide with purity levels ranging between 30% and 60%, comparable to those of the Belgian-controlled deposits in Africa. An extraction plant was constructed by the Canadians in effort to compete, the U.S. Radium Corporation attempted to reenter the market in radium production through the formation of a wholly owned Canadian subsidiary, named Ratalin Kirk, 1932, with an initial production of 2 grams of radium salts per month, which reached nearly 4 grams per month by 1938. The availability of these new high-grade and high-yield North American sources undermined the monopoly of the Belgian producers, who then negotiated with the Canadians to divide the world market, with prices fixed at $40,000 per gram (Landa 1982:189).

With the onset of World War II, United States involvement with the Belgian monopoly emerged as a key geopolitical relationship. Although no references to original sources are available, the anonymous chronology (ANL n.d.k) provided by the Argonne National Laboratory lists the following information:

1940: With the outbreak of World War II, the Belgians secretly transfer available uranium supplies to the U.S. to prevent them from falling into German hands. Some 1,250 tons of high-grade pitchblende ore are shipped to Staten Island. The Belgians try for months to alert the U.S. government to its presence.

1941-1945: The U.S. will use more than 190 grams of radium for luminescent instruments during World War II. In contrast, less than 30 grams of radium were used worldwide for this purpose during WWI.

1942: The U.S. Radium Corporation expands its facilities and its technical and managerial personnel by 1,600%. At its peak, the company employs about 1,000 workers.
1942: E. Sengier of Union Miniere, with the help of J.A. Kelly Sr. of the Radium Chemical Company, sells the 1,250 tons of pitchblende ore stored at Staten Island to the Manhattan Project.

1944-1945: Radium Chemical Company supplies most of the radium required by the Manhattan Project. The radium is used as a neutron source for testing and operating atomic piles and for the trigger mechanism for the atomic bomb. J.A. Kelly Sr. received a U.S. government citation for his war efforts (ANL n.d.k).

The final demise of the U.S. radium industry did not come until Canadian production was halted in 1954 and the extraction plants in Belgium shut down in 1960 (Landa 1982:193). A note in an unsigned chronology, compiled in 1974, documents that as late as 1956, apparently in a last-ditch effort to compete, the U.S. Radium Corporation attempted to re-enter the market in radium production through the formation of a wholly owned Canadian subsidiary, named Ratalin Kirk, Ltd., based in Toronto, Canada. The investment was discontinued and sold two years later in 1958 (ANL n.d.k).

The death blow to the radium industry in general occurred as a result of technologies developed during World War II. The chemical processing of natural ores was gradually superseded by the "artificial" production of radionucleotides by nuclear reactors and particle accelerators. In nuclear medicine, radium was replaced by cobalt, cesium, and gold, among other elements. Also, radium and mesothorium were replaced by tritium and promethium 147 as the key elements in luminous dial manufacture (Landa 1982:193).

PART III - THE U.S. RADIUM CORPORATION AND ITS ORANGE, NEW JERSEY FACILITY

OPERATION AND PRODUCTION

U.S. Radium Corporate History

The company had its beginnings in 1913, when Doctor Sabin von Sochocky opened a small laboratory on 23rd Street in New York City, dedicated to the commercial application of his proprietary formulas for the manufacture of luminous paint. Dr. Sochocky had received financial backing from the Metals Thermite Company upon the development of a successful paint formula. In 1914, his company was formally incorporated (under the name of the Radium Luminous Materials Corporation) with an office at 535 Pearl Street, New York City. By July 1915, Sochocky's enterprise was financed by a $500,000 capital investment from the Metals Thermite Company, and was incorporated on July 12, 1915 as the Radium Luminous Materials Corporation (RLMC), with office headquarters now listed at 55 Liberty Street, New York City. Sochocky and Dr. George S. Willis were listed as co-founders of the firm, with Sochocky as president and Willis as vice president and treasurer (New Jersey State Office of the Attorney General 1915).

Between 1915 and 1973, the U.S. Radium Corporation underwent a number of corporate restructuring, name changes, and movements of company headquarters back and forth between New York and various cities in New Jersey, as well as to locations in several other states and two other countries. On July 27, 1917, the Radium Luminous Materials Corporation was incorporated under the laws of New Jersey, with its office headquarters officially listed at 15 Exchange Place, Jersey City (ANL n.d.b, n.d.f). On July 27, 1917, the company transferred its official company headquarters from New York to Delaware, and in October of the same year filed to have its corporate status removed from New Jersey. In August of 1921, the Radium Luminous Materials Corporation changed its title of incorporation in Delaware to the U.S. Radium Corporation, and the next week filed for a change of name in New Jersey as well, a legal move that coincided with the departure of Sochocky as president of the company, apparently to be replaced by a Mr. Roeder.

From its main office headquarters in Manhattan, the Radium Luminous Materials Corporation established a series of extraction and production plants in Newark, Jersey City, and Orange between 1915 and 1917. The first dial painting plant of the Radium Luminous Materials Corporation was opened on Third Street in Newark in January 1916. In 1917, the Radium Luminous Materials Corporation opened its main extraction plant at 166 Alden Street, Orange and moved the first dial painting operations to Alden Street. The Orange Tax Assessor's office recorded that the building was open for production as of October 1917. The actual date of opening is a matter of dispute in the record. A reference in Dr. Kjaer's original Department of Labor field notes and an unreferenced note mentioning the Consumers' League list the opening of the plant as June 1, 1917, with an attached note suggesting that both the date and the address referring to June 1 could represent errors on the part of the original recorders (Kjaer n.d.c). In either case, the Orange Tax Assessor's Office records clearly document that the plant was open for business as of October 1917.

The Radium Luminous Materials Corporation and its successor company, the U.S. Radium Corporation, maintained a diverse portfolio of mining, extraction, purification, and application facilities across the northeast and Colorado. A brief citation in the anonymous Argonne chronology (ANL n.d.k), and the address printed at the top of a 1919-1920 company letterhead (ANL n.d.n.), indicate that within a year and a half of opening its production facilities on Alden Street, the company also operated an extraction plant in Boonton, New Jersey, its treasurer being listed as Paul M. Lewis. No data are currently available to establish the functions and relative output of the Boonton plant. Information in a January 1974 letter from the Center for Human Radiobiology, Argonne National Laboratory, indicates that a number of companies based in Newark were allied with, or operated as subsidiaries of, the U.S. Radium Corporation, although the memo does not clarify their relationships to U.S. Radium further. The memo lists the Luminite Corporation at 24 Scott Street (1922); the Radium Aluminum Manufacturing Company at 263 New York Avenue, Newark (1925); the Radium Application Company at 44 Patterson Street, Newark (1925); and two watch companies, the Keystone Watch Company, listed as being at several Newark, Jersey City, and Riverside addresses (1911), and the Capital Crescent Watch Case Company on North 13th Street, Newark (1919; ANL n.d.c).

In Dr. Kjaer's original Department of Labor field notes, he recorded that the Radium Luminous Materials Corporation controlled holdings, presumably mines, in Paradox Valley, Colorado as of 1917. In addition, a 1960 memo by Lewis Barrer lists an unnamed subsidiary of the U.S. Radium Corporation, in Geneva, Switzerland, which was controlled by U.S. Radium through a 51% stake (Barrer 1960). This pattern of diversified production facilities in various locations continued into World War II. By 1944, the U.S. Radium Corporation maintained radium processing facilities in Bloomsburg, Pennsylvania, Bernardsville, New Jersey, Whippany, New Jersey, and North Hollywood, California (ANL n.d.j). Finally, in 1956, U.S. Radium attempted a short-lived Canadian venture called Ratalin Kirk, Ltd., located in Ontario, Canada, which shut down in 1958. Against this backdrop of diversified operations in New Jersey, New York, Delaware, Colorado, California, Switzerland, and Canada, the 11-year tenure of the company's operations at Alden Street represents an episode of corporate expansion and contraction, profit and dormancy, which coincides with the flux of military production during the First and Second World Wars.

After many transformations in name and corporate structure, the U.S. Radium Corporation ceased to exist in 1968 as a corporate entity processing radium. At that time, company officials transferred all processes and equipment to a "newly developed entity" called the

Nuclear Radiation Development Company, based in Grand Island, New York. No information is readily available concerning the functioning or products of this successor company, but a handwritten note at the bottom of a table of company holdings lists a final company of unknown affiliation called the U.S. Radium Medical Products Division which, as of 1973, produced flashers or radiation-alert badges used by X-ray technicians, and had corporate offices listed at 1425 37th Street, Brooklyn, New York.

Military Production and Contracts

United States government involvement in the radium industry did not end with research support to private industry in the development of new and more cost-effective ore extraction processes (Landa 1982). The documentary record has also provided evidence showing that during the period of peak operation between 1917 and 1921, which included American participation in World War I (1917-1918), the U.S. Radium Corporation was heavily involved in military contracts for instrument dials, gun sights, and Army-issue luminous field watches for American military personnel (Wall 1969). In addition to a number of secondary documents describing the military uses of luminous compounds, the employment levels at the factory for dial painters alone follow a bell curve that began, peaked, and ended with World War I. Postwar production saw worker levels drop from 300 dial painters in 1918 to a handful in 1921 (Grossman and Associates 1997:Figure 36).

In 1914 the first of several bills was introduced in Congress by then Secretary of Interior Lane to "...reserve radium bearing lands and provide purchase by government of ore." This action was not taken because of the outbreak of World War I. During the war, the United States placed an embargo on the export of radioactive ores (Eckert 1959a). Although much attention has been focused on the use of radium for commercial production of domestic watch dials and for medical purposes, the weight of the available evidence points to the military's critical appreciation of its strategic uses, both in Europe and the United States. That its medical benefits were appreciated at an early date is not in question. In 1913, the National Radium Institute was established as a cooperative effort with the United States Bureau of Mines to supply radium to several hospitals economically, including the General Memorial Hospital for the Treatment of Cancer and Allied Diseases in New York (Landa 1982:188). In France, the onset of the war prompted Mme. Curie to lend her expertise to the development and application of radioactive materials for the detection of wounds and broken bones (Grolier 1996a). By the onset of the war, scientists in the fields of both medicine and chemistry were writing articles highlighting the importance of radium as a strategic medical material. In a 1918 article entitled "The Application of Radium in Warfare" by two research chemists of the American Standard Chemical Company (Viol and Kammer 1918), reference was made to two earlier 1916 articles, one by a Frenchman and one by an American, which highlighted the importance of radium in military medicine (Cameron 1916:449-53). The subsequent American publication by the Standard Chemical Company research chemists did not equivocate: "Radium has found an important place in therapy and in this field it may be considered as a war material, since it is the most valuable agent known for the treatment of scars and keloids, resulting from wounds and burns..." (Viol and Kammer 1918).

Although the potential benefits of radium to medicine were recognized before the First World War, by the time of American involvement in that war (1917-1918), the focus had apparently shifted to the potential military applications of radium to aircraft, field gun sights, and submarine dials. The chemists of the Standard Chemical Company were explicit on this point (Viol and Kammer 1918):

> Use of radium which has a more direct application in warfare, and which now is becoming of almost as great importance as the medical use, is in the production of the so-called permanently luminous compounds. This luminous material finds a wide range of uses in all forms of dials and indicators that must be seen in darkness or semidarkness. One most important use is on the instruments of airplanes, for night flying. The intensity of the luminescence of this compound is such that the accommodation of the eyes is not impaired, as would be the case if a brilliant electric light were used, and so observations of the surroundings can be made more readily. With a luminous dialed instrument there is not the danger that a defective battery or generator or a broken wire would entail, the luminous dialed instruments being useful until the instrument itself is out of commission.

As Kjaer stressed, "the demand for self-luminous instrument dials and indicators, especially for submarines and airplanes during the war, stimulated the industry." He continued by pointing out that while commercial plants were established in the United States after 1913 for "the painting of the hands of watches and clocks, especially the cheaper grades....," from the onset of the United States radium industry in 1913 production was also geared to the manufacture of ".... dials and indicators, compass faces, gun sights and gauges...." (Kjaer n.d.b) .

The relative concentrations of radium additive (radium bromide) to the composition (zinc sulphide compound) of luminous paint varied considerably, depending on the end use of the products. The ratios in commercial applications ranged between the relatively low concentrations of 4.1 micrograms per gram of zinc sulphide for inexpensive watches to upwards of 100 micrograms per gram for the more expensive, smaller wristwatches. In contrast, the radium concentration was orders of magnitude higher for military instruments, especially for airplane dials. In 1917, the British Admiralty specified a concentration level of 215 micrograms per gram of luminous compound. Thus, while the proportion of civilian to military production output at the U.S. Radium plant in Orange, or at the other established commercial production centers in the United States, has not been established in the available archives, it is clear that the relative concentrations of radioactive materials used in military applications were much higher than in products produced for civilian consumption. Therefore, any future efforts to decipher the role of military versus civilian contract production must consider the relative concentrations of radioactive radium salts in the various categories of dial and instrument manufacturing, as well as units of production output.

Although it is clear that production for military contracts played a central role in the shifting growth and prosperity throughout this industry, and despite the extent of the unpublished primary file records at Argonne National Laboratory and other repositories, no records were found that would have permitted the quantification of production output for military purposes. However, two photocopied letters from U.S. Radium officials to various departments of the United States military suggest the need for further research in the military archives of both the Army and Navy which could contain key resources for a future investigation. One of the letters, dated 1915, was a letter of introduction on letterhead of the Radium Luminous Materials Corporation from Willis, a co-founder of the company, to the chief of the Bureau of Steam Engineering of the United States Navy. The text of this letter contains a reference to earlier conversations with Navy personnel, a description of the potential benefits of the products of the Radium Luminous Materials Corporation to the United States Navy, and an official request to be granted access to the Brooklyn Navy Yard to facilitate a demonstration of the benefits of their product. The letter states that (Willis 1915):

> ...radium paint has many advantages over the present system of electrically lighting many of your indicating devices.... it is particularly valuable when applied to indicators and dials which are necessary to see at night without the use of an electric light. If you would supply us with samples or specifications for the indicators used on the bridge of a ship for the control of the rudders and engine revolutions, we would gladly prepare these samples and submit them to you at the first possible moment.

The other document with explicit references to production for military purposes was a 1924 letter to the United States Navy Bureau of Ordnance from a Mr. William Day, "manager of the electrical and mechanical divisions," on U.S. Radium Corporation letterhead with the address of 30 Church Street, New York. This brief letter confirms that the U.S. Radium Corporation had previously been supplying its product, the "Undark Radium Luminous Compound," to a number of unnamed United States government departments, and that it was considered the "standard material for government use." Day described his product as having many uses "... in the way of locating things or places in the dark, either for the purpose of enabling one to go to them or keep away from them and for lighting dials of clocks, watches and other instruments or name plates, signs, aiming devices, etc." Day ended his letter to the Navy Bureau of Ordnance with an offer to supply "Undark," together with the personnel, materials, and equipment for its application, as well as training for military personnel in the application of the material (Day 1924).

Finally, a third document confirms that the U.S. Radium Corporation also was selling luminous radium material to the United States Army Air Corps as of September 1928. A memo identified during the survey of U.S. Radium business records, preserved on microfilm, referred to an Air Corps order (No. 29-959P), which had been filled to Army specifications (Spec. No. 3-99A, dated 4/21/28), consisting of 5-gm. vials of radium shipped to four unnamed destinations. The Army procurement office was listed as representing the Eastern District, with its address at 39 Whitehall Street, New York (ANL n.d.m). This memo, which post-dates the end of World War I, makes it clear that a contractual arrangement existed and, judging by the context and brevity of the order, that the relationship with the Army Air Corps was of long standing. In addition, this one order was both large and expensive. Although by 1938 world market forces had caused the cost of radium to drop to a relatively low negotiated level of ca. $40,000 per gram, radium had been selling at ca. $100,000 per gram during the preceding two decades (Landa 1982:188). At this rate, the single 5-gm. order from the local New York office of the Army Air Corps amounted to an expenditure of $500,000 in 1928 dollars.

Although none of the documents encountered provided detailed information on the production for the United States military, an anonymous chronology of industry-wide events, located in the archives of Argonne National Laboratory, points out that, for the period 1914-1918 (World War I), "radium dials are used extensively for aircraft and submarine instruments, and for watches. By the end of the war, one United States soldier in six wears a luminous watch" (ANL n.d.i). In an entry for 1918, the same chronology states concisely that "An estimated 95% of the radium produced in the United States (21.7 grams) is used to manufacture luminous paint for military purposes. The price of radium reaches $125,00 (and occasionally $135,000 or more) per gram, making it by far the most expensive substance on earth" (ANL n.d.h). Obviously, military production was significant to the economics of the industry.

Despite the lack of available primary archival materials concerning the absolute levels of production for military purposes at the U.S. Radium facility, two secondary lines of evidence exist. They are:

1. The changing numbers of dial painters during and between the First and Second World Wars.

2. Secondary references by corporate officers that production of luminous watch dials alone was not sufficient to maintain the fiscal health of the company.

The absolute numbers of employees for the U.S. Radium Company in New Jersey for the years 1917 to 1919 was not determined because of inconsistencies in surviving U.S. Radium archives. During this time, the U.S. Radium Corporation employed as many as two hundred women as dial painters; however, after 1920 the work "became sporadic" and many of the dial painters were laid off (New York City Department of Health 1928). Production levels and the numbers of employees dropped precipitously between the World Wars (1918-1939), but increased with the United States involvement in World War II (1941-1945; Landa 1982). This general pattern of flux can be attributed to changes in war-related production needs by the United States government. This pattern of change was verified in the course of an unpublished interview conducted in 1959 by James E. Eckert, then a graduate student at MIT working on his thesis titled "An Economic Study of the Radium Industry" (Eckert 1959a). Although the name of the company officer interviewed by Eckert was blacked out, the substance of the interview survived. The anonymous official described "the straits in which the company found itself during the 1920s and the meager Depression years," and explicitly referred to "... the business as a 'hand-to-mouth' operation from 1920 to 1939" (Eckert 1959b). Despite this characterization of the company's economic troubles during the years between World War I and World War II, the interviewed official told Eckert that between 1922 and 1929, the U.S. Radium Corporation sold 100,000 grams of luminous compound material per annum, clearly appreciable levels. However, this production output, presumably for predominantly civilian uses, was inadequate to maintain the Corporation's fiscal health at anything approaching that of the World War I phase of its history. Eckert's interview contains several other points of relevance to the issues of both fiscal health and military involvement of the company. Although Eckert was not clear on which war their discussion alluded to, his memo included the following (Eckert 1959b):

> The radium problem during the war was then discussed, and the part played by U.S. Radium in the defense picture. Approximately 500 grams of radium were used during the war by U.S. Radium, or about 10-12 grams/month. Their only competition at this time was Radium Chemical, and then, only in dial painting. Immediately following World War II (1946-1949), the backlog of dial painting for the clock and watch business kept U.S. Radium in business. During this time, they were developing diversified new products that used artificial isotopes and which today is the sustaining line of the company. They at present use 5 to 6 grams of radium per year, but this is very erratic. Most of that goes into the manufacture of neutron sources for oil well investigation.

Two points stand out from this citation: 1) after an implied focus on war-related production during the second World War, company output shifted back to the painting of clock and watch dials. 2) following World War II, the U.S. Radium Corporation branched out to a more diversified product line in the use of artificial isotopes for other applications, one of which was the manufacture of neutron sources for oil well investigation.

Although primary archival data in the form of contracts and lists of production output have not been found as part of documentation, additional lines of evidence from secondary sources combine to suggest strongly that the employees working at the plant during World War I were indeed well aware of the important role their activities played in the war effort. Perhaps one of the more explicit statements to that effect was made as an aside in Wall's 1969 article, in which she describes her experience as laboratory assistant to Dr. Sochocky at the U.S. Radium plant and as operator of the radioscope laboratory between 1917 and 1918. While describing the general operation of the plant in 1917, Wall observed that "... busy with war contracts, the radium extraction plant operated day and night" (Wall 1969:17). She also made a comment supporting the notion that the facility was applying its luminous paint to more than just watch and instrument dials: "... to the rear was a railroad siding where a constant stream of cars unloaded carnotite ore and, from various factories throughout the country, boxes of equipment to be touched up with luminous paint." In light of the explicit reference by the Standard Chemical Company chemists, Viol and Kammer, to the importance of luminous airplane instruments for night flying, and Dr. Kjaer's mention in a field report to the United States Department of Labor of "gun sights and gauges," it is likely that Wall's boxcar loads of equipment being brought to the plant for "touching up" consisted of military equipment (Viol and Kammer 1918:382-383; Kjaer n.d.a).

Although the records of military contracts appear to be limited to two letters from plant officials, the existence of these references to the production of war materials during World War I suggests the need for research into sources of military records which were not critical to the research goal of either MIT, Argonne National Laboratory, or other repositories of U.S. Radium data that focused predominantly on the workers and their job-related illnesses. The inconsistency between these allusions to military application of luminous paints and the almost total lack of primary military contractual documents suggests strongly that further documentary research in the National Archives and archives of the Bureaus of Ordnance of the Army and Navy for the period of World War I would yield important information on military uses of radium during that time.

Finally, although only tangentially relevant to the activities of luminous paint application at the Orange factory, a description exists of a little-discussed military role for radium as an exotic element, long before radioactivity became central to military applications at the end of World War II. In his article stressing the potential uses and benefits of radium in general, Dr. Sochocky refers to the military's need for radioactive material for the cost-effective production of explosives during World War I, 20 years before such materials were used in the development of nuclear weapons. This description is unique because no comparable allusion or characterization of the importance of radium to military efforts for the first quarter of the 20th century was encountered in other primary or secondary references reviewed for this study. In addition to the medical use of radium for the treatment of "some of the most troublesome diseases," Dr. Sochocky points to the potential benefits of this important new element to chemistry and, as a result, to the military production of explosives (Sochocky 1921:26):

> We can use the power of radium, without diminishing the total quantity of the radium itself, to produce nitrate and ammonia compounds from the air for explosives and fertilizer, twenty percent cheaper than we have ever been able to produce them by using saltpeter imported from Chile. Many millions of dollars worth of these nitrate and ammonia compounds are used in the U.S. each year.

The Technology of Luminous Paint Production

The technological and industrial foundation of the Radium Luminous Materials Corporation (RLMC) became a commercially viable investment area only after Marie Curie's 1903 discovery of radioactivity and the isolation of radium as a new ray- and energy-emitting element. However, the use of radioactive materials had its roots in attempts to exploit the luminescent properties of phosphorescent compounds as early as the third quarter of the 19th century. As described earlier, several phosphorescent substances were known to be capable of storing or absorbing energy, subsequently emitting a glow. In one of the early efforts to produce luminous paint, calcium sulphate was used and was patented in the 19th century under the name of Balmain's Luminous Paint.

The application of such compounds to watch and clock dials was tried as early as 1877, but abandoned in the 1890s because these compounds would only emit light after exposure to external light sources, and then only for a few hours. This condition rendered such technology of limited use for working at night or in unlit environments. After the discovery of radium, the key development in the commercial use of luminous compounds was based on the observation that "rays of radioactive substances were capable of exciting certain materials to the emission of visible light, even when not previously exposed to light" (Viol and Kammer 1918:383). Of the phosphorescent substances known in the 19th century, zinc sulphide was found to have the greatest luminescence when exposed to the rays of radium. Only later was it determined that this was caused by radioactive decomposition (Landa 1982). As described in 1918 by chemists at the Standard Chemical Company, "Phosphorescent zinc sulphide consists of a specially prepared crystalline form of zinc sulphide which, when mixed with an amount of radium, continues to emit a greenish yellow light, the intensity of the luminescence being dependent on the quality of the zinc sulphide and the proportion of radium used" (Viol and Kammer 1918:383).

The earliest development of a successful luminous paint compound in the United States is attributed to George F. Kunz of the Tiffany Company, for which he received his United States patent in 1903. He stated: "I applied radium mixtures to the first watch that ever had markers and hands coated with a radium compound, ... and have also been instrumental in drawing attention to many of those who have used this method." This claim by Kunz was raised in discussion and in response to a 1917 presentation before the American Electrochemical Society by Viol and Kammer. It was contradicted and debated by Dr. Viol in a written response to Kunz's complaints that he had been ignored in Viol and Kammer's treatment of the developmental history of luminous compounds. Viol wrote that they aware of Kunz's work, but that Kunz's patent had only been filed in 1903 and was not granted until May 1905. Viol ended with the following characterization of Kunz's work: "... Dr. Kunz has made no great efforts to follow up the development and improvement of radium luminous compounds, and his patents on luminous compositions have only served to impede in the United States an industry that has advanced far in European countries" (Viol and Kammer 1918:390).

Finally, Viol implied that Kunz might have plagiarized earlier work by Viol's colleague, Dr. Kammer, because Kunz had been present at a 1903 meeting of the American Electrochemical contained a mixture of zinc sulphide and radium six months before he filed his own patent. Although principles and the technological antecedents are debatable, both private industry and government agencies exerted extensive research efforts and expended large financial resources aimed at establishing cost-effective and efficient chemical compositions of sufficient luminosity and life span to be practicable for both commercial and military applications. Thus, from 1903 to the end of World War I, research and development efforts were focused on (Viol and Kammer 1918:383): 1) The production of a suitable luminous compound, the methods of applying this compound, and the methods used to check the luminosity of the compound before and after application, [which] have all presented problems of some difficulty; and 2) The culmination of the effort came in 1914, with Dr. Sochocky's successful development of the first commercially viable luminous paint.

U.S. Radium Operations at Orange

On the basis of experiments that he began in 1906, and with financial backing from the Metals Thermite Company, Dr. Sabin von Sochocky began commercial production of his proprietary formula for luminous paint in 1913 on a small scale at his own facility on 23rd Street, New York City, and then on a commercial scale in 1914 in facilities on Pearl Street. Large-scale production did not begin until the corporation opened its main processing facility in 1915 on Alden Street in Orange (ANL n.d.c).

Although the precise composition of Sochocky's original luminous paint mixture is unknown, the formula appears to have varied both in the types of materials used and their proportions. The basic structure of luminous paints consists of a fluorescing element (zinc sulphide), a bonding agent, a radioactive emitter, and various other chemical additives. A central theme present in both the primary archival record and subsequent published and unpublished histories of the industry is the changing role and proportion of the primary radioactive emitters. Before 1917, radium salts were used exclusively, but later radioactive mesothorium (Ra-228) became the primary energy emitter (Kjaer n.d.a). It is clear that mesothorium dominated the industry of luminous dial manufacture after 1917, whereas radium (Ra-226) was reserved for other, mainly medical, uses because of the relatively high cost of refinement (Kjaer n.d.a).

Mesothorium was discovered by the Curies shortly after they isolated radium, when they observed that compounds of thorium were also radioactive. Initially, they believed that mesothorium was a distinct new element, but later they recognized it as an isotope of radium (Landa 1982). Similar to radium in its characteristic of radiating energy, it differs in its rate and means of decay. Although recognized by European investigators early in the 20th century as a substitute for radium in luminous compounds, and despite efforts by scientists at the U.S. Bureau of Mines to introduce the "new" element between 1913 and 1916 as a substitute for radium, it was not adopted in the United States as a commercially viable substitute for radium until after 1917. The delay appears to have been partly the result of official secrecy maintained by European governments and private industry, and partly it was market-driven (Kjaer, n.d.b).

Just as the United States government had sponsored the development of effective radium extraction from the relatively impure and low-grade carnotite ores in 1913, it also managed and financed, in cooperation with the private sector, the subsequent research program to develop cost-effective methods of mesothorium production in the United States (Schlundt 1922:5). The primary distinction of mesothorium which affected its commercial, medical, and presumable military utility is that, when first isolated, mesothorium emits no alpha radiation. Alpha radiation is emitted by some mesothorium decay products, reaching their highest level of alpha emission 4.83 years after the mesothorium is chemically isolated (Kjaer n.d.a). Because luminous compounds require alpha radiation to excite the phosphorescent salts, mesothorium must be aged for at least a year before emitting sufficient alpha radiation to be of use in the manufacture of luminous compounds. However, because mesothorium emits beta and gamma radiation spontaneously, it could be used for "therapeutic" purposes within days of being prepared. Despite these differences in levels and types of radioactivity, as an isotope of radium it cannot be chemically separated from Ra-226; all thorium-derived extracts were observed to contain between 12% and 25% of radium. Although it is difficult to assign proper credit to particular corporations due to concerns with confidentiality, even as early as the 1920s it was observed that "one of the large firms" had obtained control of all mesothorium production in the United States following the development of effective purification procedures by the Bureau of Mines in 1918 (Landa 1982).

Following its commercial introduction in May 1919, when it was first used as a substitute for radium in luminous compounds, the production of mesothorium was limited by the availability of the thorium nitrate from which it was derived. Thorium nitrate was produced as a by-product of the manufacture of incandescent lantern mantles preceding the widespread use of electric light bulbs. After the introduction of electric light bulbs, the production of gas mantles decreased precipitously, and with it the commercial availability of mesothorium, until mesothorium ceased to be commercially viable by 1925 (Landa 1982).

In 1957, C.W. Wallhausen, then vice president of the U.S. Radium Corporation, wrote to Dr. Marinelli, Associate Director of the Radiological Physics Division at the Argonne National Laboratory: "I know that radium and mesothorium, as well as in some cases, radiothorium, were used in these paints, and the proportions were not by any means uniform from batch to batch, since it seemed to be standard practice to use whatever material was most readily available, and in many cases, used some unusual mixtures" (Wallhausen 1957). A related memo from Dr. Robley T. Evans (1966) of the Massachusetts Institute of Technology, based on a telephone conversation with Wallhausen, records that:

> Wallhausen says that he has no records of any sort left from the old days. They are all in the file he gave to Marinelli. He has nowhere to look for the composition of

paint sold to Waterbury Clock Company in 1926, 1927, and later. All of the people involved in the company at that time are either dead, in their late 70s, or out of their minds.... Barker would just mix whatever he had around the place and sell it, 50-50 or 10 percent Myth and 90 percent Ra, or whatever.

Industrial Processes and Layout of the Orange Facility

The eventual consolidation of ore extraction, radium refinement, pigment production, and paint application processes took place in stages at the plant beginning in 1917, following its initial operation as an ore processing facility. Immediately after the company's purchase of the property at High and Alden Streets in Orange, that facility was used exclusively for the extraction and processing of the raw carnotite ore, which was reduced through chemical precipitation and crystallization to form the pure radium salts that formed the active ingredient of Sochocky's paint mixture. It is not clear from the available record whether the pigments were prepared at the ore processing plant and taken in finished form to the Newark painting studio, or if they were first refined in Orange and then rendered into a pigment ready for painting at the Newark facility (Barrer 1960:3). What is clear from the surviving records and transcripts of former employees is that the increase in output, apparently due to World War I production demands, caused company officials to consolidate by moving the paint refinement application to the Orange ore extraction facilities in 1917.

The company implemented this consolidation of its operations through the purchase of a brick and concrete building from an unnamed chemical company on April 2, 1917 (Essex County 1917a), which was presumably the property of the Bulkley Iron Works which formerly occupied the site. The iron works had opened in 1889, and was one of many late 19th century industries in Orange. Located in a working-class neighborhood which developed on filled marshlands ca.1866-1890, the foundry site had the added advantage of the rail line immediately to the south, originally the Watchung Branch of the Montclair and Greenwood Lake Railroad completed in 1876. Although primarily a commuter line, this line accommodated ore shipments to the Radium Luminous Materials refining operation.

When the Radium Luminous Materials Corporation acquired the two-story building, which had been built in 1916, the sale excluded the front portion of Lot 21, which contained the house of Henry W. Bulkley, owner of the iron works. However, in the transfer, the RLMC did acquire a one-story cinder block structure located in the rear portion of Bulkley's residence, which was converted into the crystallization laboratory. Later in 1917, the RLMC acquired the front portion of Lot 21 containing Bulkley's residence, which they converted, as discussed below, into one of several on-site production and laboratory facilities (Essex County 1917b).

This patchwork of rapid acquisitions was accompanied by shifts in the location of different plant activities at the site over the first two years of its operations in Orange. These shifts were driven by other factors in addition to convenience, including: 1) The need to maintain the laboratory facilities away from the contaminated areas of the complex, which would impede the accurate measurement of radiation levels. 2) The need to provide the laboratory staff with warmer working conditions. 3) The need to maintain the radioscope and measuring activities separate and apart from Dr. Sochocky's quarters and from Dr. Sochocky himself who, from 1917 on, was recognized to be so heavily contaminated with radioactivity that his presence caused aberrant readings in the measurement of the levels of purity of the radium salts taken in the electroscope room. As of December 1917, the electroscope room, or radium measurement laboratory, was moved from an iron shed in the middle of the complex to the vacant former Bulkley residence (Wall 1969). Thus, by 1917, although subject to shifts in the location of the laboratory crystallization and radiation measurement work areas, the Orange facility was fully established as an integrated extraction, purification, and luminous paint operation in a number of buildings within one complex (Eng 1980a:6-9).

Although many of the original company records did not survive, interviews with several former employees (some of which were published), and testimony taken from others as depositions in the ensuing litigation, provide considerable detail about what activities took place at various locations in the plant (see below). A general outline of the functions of the rooms in each building was described by Eng in a study for the New Jersey Department of Environmental Protection (Eng 1980a). Other details, especially those concerning the manufacture and testing of the refined radium salts, were provided by Florence Wall, Sochocky's original laboratory assistant (Wall 1969:17-19). Other details on the processing of the ores, including the nature and amounts of chemicals used, were provided by unnamed informants who were interviewed in the 1970s by staff of the Argonne National Laboratories (see Siebert 1979; ANL n.d.d). Despite some serious gaps in coverage, these bits of surviving written and oral history make it possible to establish the functions of different parts of the radium plant and detail the processes occurring in those locations.

Eng's building-specific summary of functional areas, provided in the New Jersey Department of Environmental Protection report on contamination, appears to have been based directly on a September 21, 1979 interview transcribed by Patricia A. Siebert of the Argonne National Laboratory with an unnamed former worker involved with the ore extraction activities at the site between 1920 and 1925. Siebert's original transcription included a sketch map annotated in longhand, but lacks building numbers on the drawing. Both Eng's paper (1980b) for the 25th Annual Health Physics Conference held in Washington State in July 1980, and her formal Department of Environmental Protection report contain revised map interpretations consistent with Siebert's sketch and interview notes, which Eng received via personal communication with Siebert (see Grossman and Associates (1997).

Therefore, based on Eng's final 1980 reconstruction and the sketch and notes provided by Siebert, it is apparent that a total of eight separate and functionally specific buildings were in active use at the site between 1917 and 1925. Although Eng's report depicted nine numbered structures, the difference derives from her designation of Siebert's "Building One" as two buildings numbered One and Two, because Siebert describes her "Building One" as a complex of connected offices with functionally distinct structural subdivisions. The picture is further clouded by the fact that both Siebert and Eng provide text descriptions for only five of the structures.

An independent sketch map of the complex, also undated and unattributed, serves to corroborate both Siebert's and Eng's reconstructions. Although undated, the map was produced as an advertised announcement for the sale of the U.S. Radium Corporation, clearly dating to the period ca. 1926 (n.d.r). This date attribution is based on: 1) the fact that the U.S. Radium plant was originally put up for sale in 1926, and 2) the mid-1920s style of the automobiles photographed in association with the buildings on the masthead of the advertisement. The map provides what is apparently an accurately scaled outline sketch with only three of the buildings numbered, but with three additional outbuildings labeled as a store room, a boiler room, and a coal storage shed. The functions of the three numbered buildings are described in brief at the top of the map, and although general and not detailed, are consistent with Siebert's and Eng's reconstructions (Eng 1980b). The advertisement is also important because it is the only map that shows the layout and routing of the railroad spurs into the plant complex off of the Erie Railroad line which ran northwest and southeast at the rear, or southwestern, edge of the property.

Taken together, these five comparatively consistent sketch maps and interpretative reconstructions permit the assignment of function to each of the main buildings, and to most of the rooms within them. Because of the overlapping and often inconsistent numbering systems used by various authors, this study refers to Eng's building number designations and characterization of activities for the sake of consistency. These data are augmented in this report with descriptive details that appear on other depictions and in published accounts (Wall 1969).

On the basis of these combined sources, industrial operations at the plant can be divided into six major functional groups located in the complex of nine buildings: 1) stockpiling and storage; 2) ore reduction and refinement; 3) radioscope operations for ore and pigment quality control; 4) paint manufacture; 5) dial painting; and 6) shipping and offices.

At the initial stage of the process, the ore was shipped in 100-pound sacks to the Orange facility from its company mines in Paradox Valley, Colorado, and apparently also from other suppliers, 2,900 miles by rail (Eng 1980a:6-8). The ore was initially off-loaded and stored outside the long, rectangular stair case at the rear of the plant, which paralleled the rail spur leading into the facility. Although Eng showed this building as a single unit, the unidentified sketch recovered from the ANL archives depicts the storage unit in two sections, with the west end used for ore storage and the east end reserved for soda ash. A third major storage area for hydrochloric acid was maintained in the northwest corner of the property, northwest of the ore and ash sheds. This location was to the rear of the crystallization laboratory which, in turn, was located behind the former Bulkley residence fronting onto Alden Street.

Beyond this point, the structure and placement of the ore processing facilities is less well defined because Eng and others give different descriptions. Eng identifies a ore milling structure, which she labels Building No. 2, as part of a long, rectangular series of rooms attached to the west side of her Building No. 1 (see Eng 1980b).

Eng's 1980 reconstruction appears to be incorrect. Siebert had described this structure as a two-story wooden frame building with offices on both floors; located in its center section on the first floor was a steel tank used to "process radium." In the rear of the building was a single-story space used for the storage and refinement of uranium ores which were milled in the formerly separate ore-grinding structure (Eng 1980a; Siebert 1979). In the sketch derived from Siebert's 1979 interview with a former employee, the original ore-grinding facility was depicted as a separate three-story structure located northwest of Eng's Buildings Nos. 1 and 2. Siebert's notes describe the front part of this building as a single-story wooden frame structure in which the raw ore was ground and milled as the first step in the process . The building consisted of three floors which contained a series of acid vats or tanks used to break down the ground ore into the solid precipitates of radium, vanadium, and uranium (Siebert 1979). Siebert's memo distinguishes two stages to the reduction process. On the third floor the ground ore was initially processed with hydrochloric acid (HCL). Wall's 1969 account describes how ".. one ton of ore was mixed with 60 tons of water and six tons of hydrochloric acid" (Wall 1969:17). She further mentions that the mixture was then allowed to stand for one month before being processed further. Siebert's interview implies that there was an intervening step which Wall's account did not specify. After specifying the HCL tanks as being located on the third floor, Siebert' s interviewee stated that the "... second floor contained 3'-4' wooden tanks where the ore was processed further" (Siebert 1979).

Finally, Siebert records that the former employee specified that the first floor of the ore processing structure or "plant" was reserved for the separation and recovery of the three by-products of the second- and third-floor acidification steps. The vanadium was sent to steel industries and the uranium was disposed of as waste and, presumably, dumped in the rear of the facility, adjacent to the rail line. The radium compounds were then moved to Eng's Buildings One and Two at the corner of High and Alden Streets, to be further processed in the first-floor "steel Radium Tank" (Siebert 1979). Although no details of the functioning of the wooden tanks on the second floor are provided, Mme Curie's original unpatented descriptions of her acidification and precipitation procedures suggest that, following the treatment with boiling HCL on the third floor, the second floor was reserved for the addition of barium salts and sulfuric acid, which caused the radium to separate as a white cake of solid radium-barium sulfate (Eng 1980a:7). In addition to describing the presence of a steel "radium tank," Eng's account states that, once transferred to Building No.1 at the corner of Alden and High Streets, the radium-barium sulfate precipitate was

"... treated under pressure with soda ash solution, leaving a carbonate residue. The carbonate residue was packed in large steel drums and transferred...to Building 5...," which appears to have been building number 7 in this report (Eng 1980a:8).

All accounts and maps concur that the crystallization laboratory was a single-story cinder block structure which had been constructed immediately behind the former Bulkley house on Alden Street. However, it is not clear how and in what form the radium precipitates arrived from Building One (Siebert 1979; Eng 1980a). Eng's 1980 account describes the acid-reduced radium precipitate from Building One as a "cake" of radium-barium sulfate. Florence Wall, Dr. Sochocky's laboratory assistant, on the other hand, provides a different account of the form of this substance and the method of its transportation to the crystallization laboratory. Wall describes how, presumably after leaving Building One (Wall 1969:17):

> ...in the crystallization laboratory, large quantities of radium chloride solution from the plant progressed in stages from silica tubs, three feet in diameter and about a foot deep, into smaller evaporating dishes until, after conversion, the product appeared as a few crystals of radium bromide in a tiny dish, ½ inch in diameter. Once isolated with a yield of 5 to 7 mg. per ton of ore, the crystals were transferred to small glass tubes which were sealed and stored in a heavy lead container.

On the basis of a photograph of these storage units in Wall's 1969 article, it appears that the refined radium salts produced in the crystallization laboratory were stored in two sizes of containers. One size, apparently for bulk storage, was large and round, with a top and bottom section consisting of two concentric rings formed by thin, tube-like cylinders for holding the glass radium ampules, presumably with a thick outer layer of lead shielding. The photograph also shows the second type, a smaller storage unit consisting of a single tube holder. These units may have been used for transporting purified radium salts (Wall 1969:18).

The final stage of the production process was the manufacture of pigment. The luminous paint was mixed according to the formula developed by Dr. Sochocky in 1913. The first step consisted of the manufacture of luminous zinc sulfide by a single female employee who, during Wall's tenure, was known as Isabel, a commercial artist with familiarity with pigments. The zinc sulfide compound was formed by being baked in an oven, after which it emerged as a dry powder ready for the addition of radium to maintain the luminosity of the product. Wall specified that for each batch of zinc sulfide, radium and an unnamed adhesive were added exclusively by Dr. Sochocky, after which a second female employee weighed the paint into small glass bottles, where it was ready to be applied to instruments by the dial painters in the paint application building, Building No. 2 (Wall 1969).

A detailed account of the preparation and chemical composition of the specific paint mixtures prepared at the U.S. Radium plant was submitted as part of a legal deposition, but was not published because it was considered to be proprietary information. The deposition was given by an unnamed witness who was employed at the U.S. Radium Corporation as a chemist in charge of the manufacture of zinc sulfide, and also as a participant in the "rough crystallization" of radium. Although a pre-release agreement resulted in the blackout of names and addresses, thus limiting the possibility of attributing information to specific litigants, it is clear that the hands-on account of 1937 was provided by an individual who was intimately acquainted with the components and processes of paint manufacture. The chemist described the paint production process as follows (ANL n.d.b):

> I made the zinc sulfide which was the base of the paint and incorporated the radium into the paint, which makes the paint permanently phosphorescent or self luminous....The word 'phosphorescent' does not mean that the material contains phosphorus, for on the contrary, it does not. But that the zinc sulfide is of a special crystalline nature that has the property of responding to light rays or alpha rays from radioactive materials. ... However, that luminosity or phosphorescence was of short duration and for that reason we added the radium element in order to make the phosphorescence or luminosity relatively permanent....The process for preparing the zinc sulfide is rather complicated and involved; the end or final product, however, is in fact quite simple. It is nothing more than the crystalline zinc sulphide containing approximately the following: 1. One part cadmium sulphide to 825 parts zinc sulfide; 2. One part cupric sulfide to 7150 parts of zinc sulphide; and 3. One part of manganous sulphide to 23,000 parts of zinc sulphide.
>
> To this base there is added radium element in the form of soluble salt in varying amounts, depending upon the type of work the material is to be used for the element of radium varied from one part of radium element to 140,000 parts of the base -- zinc sulphide, to one part of radium element to 53,000 parts of the base. The radium element when added to the zinc sulphide (the base) is in an aqua solution. When that is added to the zinc sulfide which is in the form of a dry powder, it becomes like a paste. The radium element when mixed with the sulphide powder is soluble. In order to make certain that it will become insoluble and also that it will be equally distributed in the paste and also to prevent the radium element from being dissolved later when water is applied to it, I converted the radium into radium sulphate which is insoluble by adding amount of ammonium sulphate also in an aqua solution.

Chemical and Electroscopic Sample Analysis and Quality Control

Wall's recollections are important for the details she provides on the processes of ore extraction and purification at the facility. She was able to describe in detail the analytical and quality control procedures used to evaluate the composition of the ores that were being received from Colorado, and to provide specific details of the techniques used for the electroscopic evaluation of the refined radium salts derived from each batch of ore. Hired by Dr. Willis because she had studied radioactivity in college, her first U.S. Radium assignment in the summer of 1917 was the wet chemistry analysis of each car load of raw ore samples for their relative uranium and vanadium content. She specified that this was done through the chemical separation of uranium and vanadium oxides from the raw ore samples, a process that implies procedures of titration and precipitation (Wall 1969:17). No details were provided in her account on the locations where this work was performed.

Laboratory testing and quality control work were moved to new facilities on several occasions during the tenure of operations at the Orange plant. Wall recalls that the first electroscope laboratory, before December 1917, was housed in a "... dismal iron shed" which was uninsulated against the cold, and had a floor of thin planks covered with pieces of oil cloth." Her recollection was precise and bleak (Wall 1969:18):

> There were broad shelves along two walls. During the day, light came from two windows; at night from a single suspended bulb. The furniture consisted of a chair, laboratory stool, cabinet for supplies, a tall cylindrical stove, and several electroscopes of a model 'invented' by the doctor and his colleague, Dr. Willis.

This first laboratory was generally described as being situated in the center of the plant complex without providing precise details. This setting was short lived. Because of severe winter conditions in December 1917, the electroscope laboratory was moved to a new location in the former Bulkley house, a wooden frame building that had been acquired by the Radium Luminous Materials Corporation earlier the same year, possibly with the intent of converting it into more suitable quarters for the laboratory.

By the end of 1917, Wall was transferred to the new electroscope laboratory in the former Bulkley house, where she conducted evaluations of the relative levels of radioactivity of the refined radium salts from each lot of imported ore. She describes the purified radium salt samples arriving at her laboratory in tiny tubes, and subsequently being mixed with zinc sulfide and adhesives into luminous pigment. Her description provides otherwise unavailable specifics on the construction and workings of the electroscope initially used at the Orange plant beginning in 1917. As an aside, the problem of contamination of the testing facilities, one that must be overcome by nuclear scientists trying to measure very low levels of radioactivity to this decade (Rowland 1994), apparently precipitated at least one and possibly two other moves of the electroscope measurement facilities between 1917 and 1927. Two memos, found among the microfiche copies of the company business records, refer to the laboratory in 1923 as being "located about ¾ mile from the plant," and in May 1926 as "not working" and "moving out of our lab" (ANL n.d.g). Wall describes the electroscope process in detail and, incidentally, makes it clear that she followed safety procedures which were not equally mandated for the dial painters until a decade after Wall's employment at the Radium Luminous Materials Corporation. She also reveals that both she and others knew that Dr. Sochocky was heavily contaminated with radium and that the operation of the electroscope laboratory was adjusted procedurally to counteract potentially aberrant testing and contamination due to his presence when the tests were being performed (Wall 1969:18):

> Each tiny tube contained a sample from lot of ore and to be tested electroscopically and the result recorded. The doctor prepared all ... samples. Each was dissolved in water and sealed in a round flat-bottomed flask which had to stand exactly 24 hours to allow the heavy gas, then called merely radium emanation [now known as radon] to collect in the flask. After this time, the accumulated gas was quickly pumped into the chamber of the electroscope and left undisturbed for three hours. A reading was then taken with the time of discharge calculated to a fraction of a second on a stop watch...Each test, therefore, took 27 hours.

This description makes it clear that, at least in 1917, the Orange radium plant was using a simple, electrostatically based electroscope, as opposed to a more refined model with a fluorescent screen of the type used by the Curies in France. Wall describes how Sochocky, before he came to New York and set up his laboratory, knew five languages and had studied at various universities in western Europe after emigrating from the Ukraine, then part of the Austro-Hungarian Empire. Before emigrating to the United States in 1906, Sochocky had met the Curies in Paris, and "... learned all there was to know about radium at the time" (Wall 1969:19). What he knew was used at the U.S. Radium plant and appears to have included outdated electroscope technology. He had access to this technology early in his career at the Curie laboratory.

The Dial Painters' Activities

The dial painters of the U.S. Radium Corporation worked in a specific section of the plant, designated as Building No. 4 by Eng. The building has been well-documented by past authors (Eng 1980a; Kjaer n.d.a). In 1917, the dial painting operations were moved from the Newark paint application plant to the site of the ore processing and extraction facilities in Orange, where they were conducted on the second floor of Building No. 5 (Eng 1980b). Although considerable information on the actual application procedures is available, most vividly from the initial United States Department of Labor interviews by Kjaer, additional insights into the location and functional diversity of the dial painting facilities can be gleaned from the unpublished depositions and court testimony contained in several legal briefs and documents.

Although there are descriptions of how the dial painters worked at a series of long benches (estimates of the number varies with informant) in a well-lit room or loft situated on the second floor of Building No. 5, the court documents provide details making it clear that the dial painting work areas were divided into three separate rooms or task areas. Documents filed with the United States District Court, District of New Jersey on November 26, 1934 as part of the La

Porte vs. U.S. Radium Corporation litigation contain the testimony of two former female dial painters who described the layout of the dial painting work areas (ANL n.d.b):

> In 1917 when ... worked at Radium Luminous Material Corp., there were about 20 girls working in the 'Waterbury' room and 70-75 in the 'Yankee' room.' [Note: There was only one other room called the 'Midget' room and neither informant knew how many had worked there.] A second informant and former employee testified that she had worked in the `Yankee' room with 60-75 employees who 'pointed brushes with their lips.'

Given the information provided by Wall and others that some 200 women worked at dial painting during this period, the numbers given for the Yankee and Waterbury rooms, 70-75 and ca. 20, respectively, suggest by subtraction that the little-understood workings of the "Midget" room could have housed nearly 100 additional dial painters who were engaged in as yet unknown tasks. The evidence concerning the importance of military contracts and peak employment during World War I also suggests that the dial painters working in the Midget room were working on products for the war effort.

Despite the relative lack of official and corporate records (see ANL n.d.e), the best source of information for the present documentary study of the U.S. Radium plant and its operations is the detailed questionnaires completed by former employees for the Department of Labor investigator, Swen Kjaer. The completed questionnaires also provided detailed oral histories concerning the activities of the workers, the equipment and chemicals they used at the company, descriptions of their working environment, and some cogent characterizations of the company's policies and guidance concerning health and safety procedures, or the lack thereof. Although most of the interviewees repeated the same general descriptions of the plant and the activities performed there, some provide details that reflect the employee's specific job and level of experience. Kjaer recorded the following description of the activities of one 27-year old former dial painter (Kjaer, n.d.c:Appendix A, Case P):

> For dial painting the luminous material was furnished in small tubes, 1 or 2 grams in each, and one tube at a time. It was mixed by operator in a small crucible with the required adhesive by stirring, only small amounts mixed at a time. Part of mixture was ordinarily deposited on hands in mixing it. The wet composition was applied to figures on dials with a fine brush, which was rinsed in a glass of water from time to time when working with gum arabic adhesive on paper dials, and then pointed in mouth of operator. The water was used in beginning only, and was later taken away, as it was claimed the waste of material was too great. When metal dials were painted, a varnish adhesive was used and the mixture was thinned with turpentine, so brushes were not tipped in the mouths. She worked on both paper and metal dials, also painted pendants, which was done with a flat brush, that did not require pointing.

Mouth tipping was apparently only associated with paper dials, for which a water-soluble adhesive was used. Mouth tipping, or pointing of the brush, was not used by the girls as a technique to refine the application when they worked with metal dials, apparently in response to the recognized danger of using turpentine when working on metal dials. This distinction was highlighted by another 28-year old dial painter who worked at the plant from age 16 to 25, and for three of these nine years painted metal dials. "Metal dials," she reported, "... required varnish adhesive and turpentine thinner, so consequentially, brushes were not pointed in mouths" (Kjaer n.d.c:Appendix A, Case P).

In yet another interview with a 27-year-old female employee, who worked at the original dial painting facility at 3rd Street in Newark as well as at the new facility at Alden Street, until she left in 1922 due to chest pains, the medical investigator recorded the following (Kjaer n.d.c:):

> Luminous material was received in small containers, presumably 1 gram in each. For paper dials, a little at a time was mixed with a gum adhesive and applied to dials with a fine brush. The brush was tipped in the mouth every once in a while, to form a fine point, especially after brushes became old. The paint was mixed in a small crucible, ordinarily steadied by one hand while contents were stirred with a stick or rod in the other hand. Material was often splashed on hands during stirring. For metal dials the composition was mixed with a varnish or turpentine adhesive, and in this case on a slab instead of in a crucible. During painting of metal dials the brush was not tipped in the mouth, on account of the turpentine vehicle worked on both paper and metal dials.

This interview also provides details on production levels, reporting a monthly production of "5 or 6 trays per day, 46 dials per tray," which prorates to a minimum of 4,600 dials per worker per month, nearly 55,200 per year per dial painter.

A former dial painter (later a foreperson), employed at U.S. Radium between 1916 and 1925, provided information on other non-dial painting vectors of exposure. Before becoming a supervisor, this informant was engaged in "weighing and tubing of luminous composition, for distribution to dial painters," but states that when doing so she tied a handkerchief over the lower part of her face to avoid inhaling dust, which was very fine (200 mesh). She added later that this was done only after the danger was known. As part of the same interview, in response to the question "What special advice was given regarding dangers in use of radioactive material?" she responded, "None, until near end of 1924. Before that time dangerous practices were permitted" (Kjaer n.d.c).

PHYSICAL PLANT AND LAND USE HISTORY

Radium Extraction and Application Facilities (1915-1926)

The early industrial and corporate history of the U.S. Radium Corporation prior to ca. 1917 is vague, largely because most corporate records dating to that period have not survived. However, based on the available evidence, four phases of operation can be distinguished prior to 1926, when all plant operations in Orange ceased:

- About 1913 to about mid-1915 in Manhattan: Sabin Von Sochocky developed a luminous radium paint and began a small dial-painting operation. The operation attracted sufficient interest to secure backers who formed the Radium Luminous Materials Corporation (RLMC) in 1915.

- About mid-1915 to early 1916 in Manhattan and Orange: Dial painting continued in New York City, employing several dozen women. A partial radium extraction operation opened in Orange in the former Bulkley iron works, leased by RLMC.

- Early 1916 to mid-1917 in Newark and Orange: The leased extraction plant continued in operation in Orange, and a larger dial-painting facility, employing about 100 women, opened in leased quarters in Newark.

- Mid-1917 to late 1926 in Orange: RLMC purchased the Orange site and a Colorado ore source. RLMC also constructed additional extraction, laboratory, and paint application facilities and consolidated its extraction, dial painting, and paint shipment operations, employing as many as 300 workers.

RLMC business grew rapidly because of the demand for luminous watch and instrument dials during World War I (ANL n.d.h). Peak employment was reached in 1917, with nearly as many employees in 1918, as war contracts drove nearly round-the-clock work efforts. Within five years of the war's end, the Orange operation underwent a major contraction as a result of diminished post-war demand for luminous paint and the introduction of radium-bearing ores from the Belgian Congo, which eliminated most American radium extraction businesses. By 1921, the firm -- which that year became the U.S. Radium Corporation in a corporate restructuring -- had ceased in-house own dial painting and concentrated on selling its expertise to other companies (Clark n.d.:91-2, 1997:92; Tobias 1928). By the end of 1921 only about 24 women worked at the Orange site. The remaining paint sales allowed U.S. Radium to continue radium production on a reduced basis; by 1924, it was the only American firm mining ores and isolating radium for industrial use. U.S. Radium operations in Orange became increasingly untenable during the period of 1922-1925, as American radium manufacture disappeared and the health and safety issues, emerged and came under public and government scrutiny. The firm moved all of its operations to Manhattan in 1927 (Keeney 1915,1919; Moore 1920, 1922).

Although not well documented, the radium extraction activities that occurred in the project area are mentioned in several unpublished papers in the archives of the Argonne National Laboratory (ANL n.d.h; Gilante and Prusek 1960). It can be inferred that RLMC leased the Bulkley iron works in 1915 to refine radium, which had previously been separated elsewhere as radium-barium sulfate from uranium and vanadium in the crude ores. The firm did not purchase the 0.9-acre Orange site from the Bulkley family until April 1917, suggesting an earlier lease arrangement (Essex County 1917a). In that year the firm also purchased a Colorado ore source and presumably conducted preliminary ore processing. Until sometime in 1918, RLMC stored large quantities of ore in Denver, before apparently shipping much of it to Orange (Landa 1981, 1982). Descriptions of radium extraction processes at the Orange site ca. 1920-1924 clearly indicate that, after arriving by rail, previously sorted ore was ground, separated in a hydrochloric acid solution, and filtered into desired and undesired elements in a building located just west of the former iron works. In the roof-monitored brick structure of the former iron works, refinement of the radium-barium sulfate continued, producing a radium-barium carbonate residue which was crystallized into purified radium bromide salt elsewhere on-site, as noted below (Siebert 1979; Eng 1980a:).

The U.S. Radium facility was considerably expanded in 1917. Two of the new structures, the radium crystallization laboratory and the paint application building, still stand on the U.S. Radium property. A few additional details -- gleaned from insurance maps, brief accounts of plant activities ca. 1917-1925, and published accounts of radium industry processes -- provide information useful in understanding plant activities and the nature of any surviving plant remains. Two factors are particularly important when considered with the site's post-1926 history: 1) the speed with which most of the plant was erected to meet wartime contract demands, leading to strictly functional plant structures and often spartan working conditions; and 2) the variability in size, value, and portability of equipment in the plant structures.

Ore Analysis Building

Prior to radium extraction, plant chemists analyzed ore samples from each rail carload to determine quality. Results presumably allowed for adjustments in primary extraction procedures. Ore assessment included use of an electroscope developed by RLMC principals Sabin Von Sochocky and George Willis and, for about six months of 1917, took place in an unheated metal shed. Cartographic data indicate that the approximate location of the shed was "...in the center of a yard...isolated from other buildings..." (Wall 1969; ANL n.d.j). The shed apparently was subsequently converted into an old storage building. Extreme cold weather during the winter of 1917-18 led to the transfer of the analysis laboratory to a small portion of the former Bulkley home, acquired as part of the iron works in 1917. Increasing levels of background radiation, which skewed the ore analysis, led to a second relocation of the laboratory to a leased site on Main Street in Orange at an undetermined later date. The apparent ease with which these moves could be made reflects the portability of the laboratory equipment, all of which probably rested on table tops and required no special foundations (Parsons et al. 1915:87-106; Wall 1969).

Radium Extraction and Refining Building

The radium extraction process began in a frame building to which ore was brought from the ore storage shed in hand-pushed carts on narrow-gauge tracks. This building included an ore-grinding facility probably housed in the one-story portion of the structure located closest to Alden Street. The remainder of the frame extraction building consisted of three floors of tanks and filter presses used to separate the ground ore by a direct dissolution process employing hydrochloric acid. This process, one of several used in the early 20th-century American radium industry, is incompletely documented, but does not appear to match in all details the direct dissolution methods summarized by Landa (1981; cf. Seibert 1979 and Eng 1980a:7-8). RLMC personnel, including several men prominent in the radium industry, may have developed their own procedures or variation of methods used elsewhere. Although few details are available about the extraction plant or the refining plant installed in the former iron works, it is clear these structures housed relatively large pieces of equipment with sturdy metal bases and, perhaps, concrete footings (Landa 1982; Parsons et al. 1915).

Ore processing generated an undetermined amount of radioactive wastes, often disposed of in undocumented ways at the rear of the U.S. Radium plant (Eng 1980a:6-7).

Radium Crystallization Laboratory (see HAER No. NJ-121-B)

Surviving U.S. Radium Corporation records include a number of undated equipment lists and floor plan sketches (ANL n.d.g; n.d.q), both of which are relevant to this phase of plant operations. The laboratory in which purified radium bromide salts were refined and stored is one of two surviving U.S. Radium structures. Differences between the actual dimensions of this building and data on the floor plans suggest the drawings were alternative (unbuilt) versions of that structure. In addition to a masonry partition wall shown on insurance maps and partly visible today, there were probably a number of lighter-weight interior walls in the laboratory defining instrument, furnace, dark room, and other processing spaces. Virtually all of the equipment indicated on the available lists as having been used in the laboratory consisted of small table top items such as glass vials and tubing, and a few slightly larger items such as small generators, a 100-gallon still, and a small furnace. None of these items would appear to require heavy foundations or bases. One account of plant operations suggests the luminous paint was made in this building, which also included another, separate laboratory for von Sochocky, the chief plant chemist (Sanborn 1939; Wall 1969; ANL n.d.j).

Paint Application and Shipping Building (see HAER No. NJ-121-A)

Insurance maps, historic views, written accounts, and accounts obtained from informants on the dial painting operations indicate that watch dial or other instrument painting was done in a two-story structure. This structure, the second surviving U.S. Radium building, was divided by masonry partition walls into three major sections on each level. Accounts vary as to descriptions of the activities conducted in these six sections, and no drawings of interior arrangements have been found in the documentary sources reviewed. On the first floor, the north end apparently housed executive offices, the central section included a machine shop and an area used to make paint applicators (probably for sale off-site), and the rear or southern section was used for shipping and, presumably, receiving. Accounts agree that the central section of the second floor was a well-lit area used for dial painting. The north section of the second floor was used for office and/or dial painting space. The south section of this floor at one time contained a scale room and dark room, but may also have been used for painting during peak production periods. Dial painting areas had four parallel rows of work benches, aligned with the building's longer axis. Both floors included large wooden, double-hung, triple windows, and at least one section of the upper floor appears to have skylights in some historic views. With the exception of the building's heating unit, housed in a small one-story concrete block room at the rear of the structure, virtually all equipment used here was probably easily portable and required no substantial bases or foundations; any machine tools used were probably small general- purpose drills, lathes, or grinders (Sanborn 1939, Eng 1980a:8; ANL n.d.b).

Other Structures or Facilities

The boilers and stack associated with the boiler house were probably the only other non-portable features with substantial footings at the U.S. Radium facility. The narrow-gauge tracks used to transport ore on-site presumably had wooden ties and a very shallow bed of graded material. Other storage facilities, and the shop for pipe and carpentry work, would have had no special requirements other than flat, stable floors of wood or concrete.

Demolition, Leasing, and Sales (1926-1949)

The U.S. Radium Corporation began to consider leasing a part of the Orange plant as early as 1924, and evidently continued trying to lease some or all of the property for more than a decade after the firm reconsolidated all its operations in Manhattan in 1927. By the late 1930s, U.S. Radium demolished much of the plant, leaving the crystallization laboratory and paint application buildings, the boiler house, the acid storage building, and a small office associated with the refining plant. Some demolition evidently began earlier, before radium-related work ended late in 1926. The chronology and reasons for demolition are unclear based on information in the available sources, but probably reflect a combination of growing concern about legal liability, the health issue, and the limited reuse potential of the building for different commercial or industrial purposes. In 1936, U.S. Radium leased most or all of the property west of the existing service station to G.N. Coughlan Company, which installed a small brass foundry operation in the former radium crystallization laboratory. This lease probably established the western boundary of the present service station parcel, which first opened ca. 1939 under a U.S. Radium Corporation lease to the Shell Oil Company. The boiler house and refining plant office were probably demolished about this time. U.S. Radium sold the area west of the service station in two parcels on the same day in 1943 to Arpin Products, a plastics fabricator, and Albert Eckstein & Company. Arpin was using both parcels by 1951. One or both of these firms probably demolished the acid storage building and erected concrete block additions to the two surviving U.S. Radium buildings ca. 1944-1950. In 1949, U.S. Radium sold the service station and its parcel to Day Service Station (Sanborn 1939, 1951; Essex County 1936, 1939a, 1939b, 1941, 1943, 1949).

Later Site Uses (1949-1980)

Subsequent to 1943, the U.S. Radium site was divided into three parcels for which limited information is available (Sanborn 1951, 1977, 1987; Eng 1980a:2-5; Essex County n.d., 1945, 1951, 1952, 1959, 1964, 1974).

Service Station Parcel (Block 38, Lot 22)

Since 1949, this parcel has remained undivided through several owners. Two additional one-story concrete block structures were added after this date: 1) a ca. 1949-1950 building on Alden Street, constructed in two sections used by a series of largely undocumented small commercial operations or social clubs; and 2) a ca. 1977-1979 building behind the service station parcel, operated as an auto body repair shop. These structures, along with the service station and its underground gas tanks, were built over the former location of most of the extraction and refining buildings. Such construction may have removed or greatly disturbed any traces of earlier equipment footings or other remains.

Former Paint Application Building Parcel (Block 38, Lot 22A)

No documented construction has taken place on this parcel since ca. 1950. Later owners included a manufacturer of electric insulators, and a manufacturer of electronic components. The latter firm, T&E Industries, own the lot until relatively recently. T&E installed component-making machinery on the second floor of the enlarged structure and used the first floor for office space, component making, and assembly.

Former Crystallization Laboratory Parcel (Block 38, Lot 21)

Sometime between 1951 and 1977, one additional single-story concrete block section was added to the rear of this structure, which had been previously enlarged in the 1940s. A series of tenants, including a parcel and messenger service located there in 1979, used the structure, including the former laboratory area. The City of Orange took possession of this parcel and several others immediately to the west at some time not documented by the current research, planning to build a park. These plans were suspended when the site became a Superfund issue.

PART IV - SOCIAL IMPACTS AND THE U.S. RADIUM CORPORATION U.S. RADIUM AND WORKER HEALTH HISTORY

Worker Awareness and Scientific Documentation

The initial realization that radiation illness was striking U.S. Radium employees was slow in developing. Two tracks of inquiry must be addressed in order to gain an understanding of that development. These are: 1) when were the dial painters and their advocates first aware of the problem (the linkage between the work place and their medical conditions)?; and 2) when and how did the medical and scientific community come to understand the problem in clinical terms?

That radium is a dangerous substance and a cause of illness and death is now a given in the scientific and public sectors. However, the questions of when and how this realization became known to the outside world and who knew what when are of historical importance and require further study. These issues are addressed in the following sections dealing with the plight of the young women who worked at the U.S. Radium Corporation plant in the first quarter of the 20th century. The dial painters and other workers were aware of their deteriorating conditions at least as early as 1917. It took the medical profession until the mid-1920s to document that the incidence of acute dental disease, spontaneously broken bones, and "pernicious anemia" was linked to the handling of radium.

According to Dr. Robert E. Rowland, a leading radiation biologist and former Director of the Center for Human Radiobiology at Argonne National Laboratory, "Some of the early dial painters ingested very large quantities of radium, of the order of 5-10 mCi of 226Ra. The resulting body content, plus the external gamma rays in the area in which they worked, was probably sufficient to cause them to experience what is now termed the acute radiation syndrome" (Rowland 1994:98).

As defined by Compton's Encyclopedia (1996c), radiation sickness, or acute radiation syndrome, is described as:

> Sickness caused by exposure of a large part of the gastrointestinal tract or the bone marrow to intensive ionizing radiation; early symptoms include loss of appetite, nausea, and vomiting, followed by a symptom-free period; in the intestinal form, the main phase is characterized by abdominal pain, fever and diarrhea, which lead to dehydration, prostration, and a fetal shock like state; the main phase of the form associated with bone marrow exposure is marked by such symptoms as fever, weakness, loss of hair, infection and hemorrhage; when damage to the bone marrow is severe, death may result from infection and uncontrollable bleeding.

The illness is not subtle. The potentially damaging effects of radiation exposure through proximity and, in the case of the teenage and young married women who worked at the U.S. Radium Corporation, through direct ingestion or respiration, can have localized effects at the specific point of concentrated exposure as well as systemic effects on the hard and soft tissues of the body. The damaging effects of radiation exposure were well understood by both the Curies and their mentor, Dr. Henri Becquerel. As early as 1898, the Curies and Becquerel identified the occurrence of skin burns as being caused by the handling of unshielded vessels of radium (Landa 1982). Despite this early identification, the history of the radiation industry was marked by increasingly less credible claims to the contrary during the first quarter of the 20th century. According to one source, Marie Curie died of radiation-induced "leukemia" (in 1934), but this account may be subject to question (Keller 1969). Upon completion of a broad-based survey and measurement of former radium workers by an Argonne team, Dr. Rowland concluded that of all the identified cancer-related conditions, leukemia was the least common, only nine cases having been diagnosed out of a sample of 2,696 subjects (Rowland 1994:99; see also Rowland 1993).

In 1916, the British government officially announced that radium was hazardous and published warnings to that effect in England by 1921. The warnings were published seven years before any United States agency took official steps to protect American workers, and three to four years before American scientists published their "discoveries" of the link between radium, bone degeneration, anemia, and tumors, even though the Americans were probably equally informed (Clark 1993).

Dr. Sochocky, the co-founder of the Radium Luminous Materials Corporation, the precursor of the U.S. Radium Corporation, published a popular article entitled "You Can't Find the Keyhole?" in 1921, the year of his departure as President of the company, in which he highlighted the benefits of radium to industry and science as well as its potential dangers to human tissues. Sochocky wrote: "An ounce of [radium], if carried in the hip pocket in an ordinary glass tube, would kill a man in ten hours by destroying his tissues and his bones. If a man carried a gram of it for two days, the result would likewise be fatal. The careless handling of glass tubes containing only twenty-five milligrams of radium will cause deep wounds on the fingers of an operator." (Sochocky 1921:27)

Medical studies have often focused on the occurrence of radium-induced cancers in the exposed population. Cancers in U.S. Radium personnel definitely attributable to radium (the bone cancers and the "head cancers") thus far have been found only among dial painters who started work before 1926; after that, safety precautions seem to have been effective enough to prevent those kinds of cancers. According to Rowland (1994:101):

> In the study of radium exposed persons in the U.S., a total of 3,697 female dial

> bone sarcomas and 24 developed one of the carcinomas in the paranasal sinuses or mastoid air cells. Other malignancies perhaps induced by radium include breast cancer and multiple myeloma, but the excess incidence is small. Most of these latter cases worked for long periods, and were thus exposed to continual external radiation in addition to any internally deposited radium.

Early dial painters died not from cancer but from necrosis, infection, and anemia. According to Rowland, "we have only limited evidence of how many of these died and no figures as to how many suffered from such maladies and survived." Before 1929, the United States Department of Labor had identified 23 fatalities attributed to radium poisoning. At that time, cancer was not implicated. Cancer as a cause was first reported in 1929 in the deaths of two New Jersey dial painters (Martland and Humphries 1929). By 1931, 18 women in New Jersey were known to have died after working in radium dial-painting plants, 13 from various diseases that were not cancer, and 5 from cancer (Keller 1969). Illness rose steeply between 1922 and 1928, and deaths from recorded radiation exposure had reached 45 by 1959 (Grossman and Associates 1997:Figure 38). In addition, before or at the time of his on-site field investigations at the U.S. Radium plant, Dr. Kjaer summarized previously published reports and the results of interviews with other government officials in a field report to headquarters, which document that both illness and death from radium exposure were taken as given by some United States government scientists at least as early as 1921, and clearly by 1923. Kjaer reported the results of a visit to the United States Bureau of Standards which resulted in the following citation in his report (Kjaer n.d.b):

> ...radiations produce aplastic anemia, suppression of menstruation in female workers and cause sterility. Precautions were taken here, as in other establishments where considerable radium is handled, to protect workers against burns by use of forceps for handling the tubes and to protect them against radiation by use of lead screens, lead containers and distance from source of radiation. Blood counts of workers were taken periodically and any found affected were given vacations until recovered, or transferred to other work.

In the same memo, Kjaer referred to 1923 and 1924 articles in the industry-supported journal *Radium* from which he found multiple references to... "Radium solutions taken by mouth repeatedly will have a cumulative effect..." [and cause] "...infection and necrosis of the bone..."; and to five published or documented cases of death "...due to radiation or radium or X-rays..." as well as to ...carcinoma of the antrum..." (Kjaer n.d.b).

Although public awareness and initial official response to concerns for the health of the dial painters became a focused issue only after the Consumers' League of New Jersey had lobbied in the 1920s for state and federal agency recognition of radiation illness as an industry-related hazard, medical interest in radium absorption by humans was actively being pursued 10 to 15 years earlier. Early research into the issue of radium absorption and retention was published in the journal *Radium* which, until 1921, was privately funded by the Standard Chemical Company (Rowland 1994:4). One of the earliest publications relating to radium in humans was published in 1913 (Proescher 1913). In that work, F. Proescher reported on the results of experimental dosages of radium administered to humans to determine the curative potential of optimal dosages for a number of health conditions. Proescher had injected 34 people with radium, including 16 who suffered from arthritis. In his 1913 work and subsequent 1914 publications (see also Proescher 1914a, 1914b, 1914c), he reported that most received doses ranging between 70 and 350 microcuries, and that doses of 1,000 micro curies were tolerated. His conclusion estimated that the lethal dose for humans was around 60,000 microcuries, which is many orders of magnitude greater than what is now recognized as a safe level (ca. 50 micro curies - 1 microcurie = 1 microgram; see Rowland 1994:4).

Although interest in the potential medical uses of radium was shown by its producers at an early date, the first proponents of radium as a therapeutic agent came from the medical community. Several physicians experimented and published their findings between the second and third decade of the 20th century. One of the first was Dr. Everett Field, who worked for the Radium Chemical Company between 1915 and 1916. He reported on what he perceived to be the medical benefits and virtues of administered radium until the late 1920s, when the true dangers of radium were established by other physicians and researchers working primarily with former dial painters from the U.S. Radium Corporation. Field reported that he administered radium through intravenous injection to more than 6,000 people. Another contemporary medical practitioner in the Midwest reported that he had administered radium to hundreds of patients with doses of 100-300 pico curies. Years later, Argonne investigators had relocated 29 of his original patients, 5 of whom had developed forms of bone cancer commonly attributed to the intake of radium (Field 1926; Rowland 1994:7).

Aside from these early medical experiments by private physicians, the most common vector for radium ingestion among people other than radium workers came from the public's embrace of radium water as a cure-all for many ailments. This tonic, known as "Radithor," was sold by the case, and 30 bottles were a month's dosage. Each bottle contained 2 microcuries of radium in distilled water, suggesting an annual intake of 730 micrograms of radium per individual per year. The practice was widespread throughout the United States until 1932. In that year, Time Magazine published an account of the death of a prominent Pittsburgh businessman from radium poisoning following the consumption of 1,400 bottles of radium water over an approximately 4-year period (Rowland 1994:7). Evans estimated that a total of half a million bottles of Radithor, or radium water, were sold to the public (Evans 1933, 1937, 1966; Rowland 1994).

One important group of recipients of radium treatment was a part of medical experiments conducted in the 1920s which examined the use of radium for the treatment of acute mental disorders. As characterized by Dr. Rowland, "One study of the effects of intravenously administered radium had provided researchers with invaluable evidence regarding the retention of radium in the human body" (Rowland 1994:8). In a series of papers published between 1929 and 1933, Schlundt and colleagues described clinical results derived from the injection of radium into 32 mental patients at the Elgin State Hospital in Illinois. These 1929-1933 publications provided well-documented quantified data of "unique importance for the later determination of radium retention rates in humans" (Rowland 1994:9). This controlled test with human subjects emerged as one of the primary sources of data for establishing the rates and ratios of long-term human radium retention following initial ingestion, both orally and intravenously.

Because these experiments involved the administration of controlled amounts of radium over known periods of time, these cases, together with those of the dial painters at the U.S. Radium plant, emerged as key study groups for the definition of radiation safety levels in humans (Rowland n.d.; Grossman and Associates 1997:85). Although the number of individuals ultimately identified as having been exposed to, having ingested, or having received orally administered doses of radium rose to several thousand, the earliest analytical studies of human subjects were based on relatively few cases. Only several hundred cases existed during the period of scientific discovery and documentation of the correlation of radium ingestion with body cancers. At the end of investigations, the sample of measured radium workers engaged in dial painting had reached a total of 1,747 case studies out of a sample of 2,403 measured radium workers in all categories of work (Rowland 1994:Tables 1 and 4).

Medical and dental practitioners working in New Jersey were the first to realize that the claimed benefits of radium treatment were probably incorrect. This realization came as a result of the manifestation of medical and dental problems among a small group of female dial painters from the U.S. Radium plant in Orange. Beginning in 1917, the dial painters and their local dentists and doctors noticed that the women were experiencing redundant dental pathologies which appeared to be correlated in time and place with the period of their employment at the U.S. Radium plant. Only later did the scientific community, spearheaded by Harrison Martland, the Essex County Medical Examiner, and later joined by a number of scientists from other disciplines, voice their concerns and documented the connection (see Martland 1925, 1926). Although some recent scholars have questioned the motivation and level of empathy on the part of Dr. Martland toward his subjects (Clark 1993), Dr. Rowland has characterized his work as "truly remarkable." He states that Martland and his co-workers (Rowland 1994:26):

> ...thoroughly investigated the new phenomenon of radioactivity. They concerned themselves deeply with the symptoms in the individual cases and showed a good deal of compassion toward the victims of the industry. Martland and his colleagues bemoaned the

fact that the laws of New Jersey did not provide compensation for previously unknown forms of occupational diseases.

A quick succession of discoveries and published findings between 1923 and 1929 formed the basis for a new level of understanding concerning the dangers of radium (Rowland 1994).

Although the role played by Dr. Martland was "preeminent," the earliest published accounts of medical problems suffered by dial painters began with an article by a dentist, Dr. Theodore Blum. In 1924, Blum described the localized occurrence of "... an unusual mandibular osteomyelitis in a dial painter," a condition he called "radium jaw" (Blum 1924; Rowland 1994:23). An independently supported statistician from the staff of the Prudential Insurance Company, Dr. Frederick Hoffman, had been retained by the New Jersey Consumers' League to investigate the medical problems of the female dial painters at the Orange plant. In 1925, Dr. Hoffman published a formal report in which he documented the occurrence of incurable jaw infections and anemia among two dead and twelve living dial painters (Hoffman 1925; Rowland 1994).

Also in 1925, the initial publication by Dr. Martland and his colleagues appeared, marking the formal beginning of controlled scientific investigations of these issues. In the same year, Dr. Martland published his first paper, which reported the "detection of gamma rays from living dial painters and the exhalation of radon from their lungs" (Martland, Conlon, and Knef 1925; Rowland 1994:24). In 1929, Martland and Humphries published a paper which documented two cases of bone cancer in a sample of 15 former dial painters, all of whom had died of radium poisoning. The authors argued that the numbers were too high to be coincidental and attributed the cancers to the presence of radium in the bones of the deceased women (Martland and Humphries 1929). In 1931, Martland reported five deaths from bone cancer among a sample of 18 former dial painters at the U.S. Radium plant in Orange. Martland presented quantified data indicating that the bodies of the victims contained high levels of radium ranging between 243 and 400 micrograms. On the basis of these postmortem measurements, he argued that these data "proved" that radiation could cause cancer (Martland 1931; Rowland 1994:27).

Concurrent with these emerging scientific and medical studies pointing to a clear association between working with radium and a specific class of medical problems, the U.S. Radium Corporation began its own efforts to develop data that, its officials hoped, would shed a more favorable light on the occupation of luminous dial manufacture. The firm retained and funded a professor of Industrial Hygiene at Columbia University, Dr. F.B. Flinn, who sought to refute any causal link between radium and the workers' medical problems; in 1926, he published a paper that concluded that "no industrial hazard existed in the dial painting industry" (Flinn 1926). He maintained this position, which was favorable to the U.S. Radium Corporation's official position, until 1928, when overwhelming data to the contrary caused him to alter his conclusions.

The U.S. Radium Corporation also attempted to enlist the scientific support of several distinguished scientists from Harvard University, but with counterproductive results. Even before the publications by Dr. Hoffman and his colleagues, the U.S. Radium Corporation engaged Dr. W.B. Castle and Drs. Cecil and Katherine Drinker of the Department of Industrial Hygiene and Medicine to investigate the possible causal linkage between "radium jaw" and zinc poisoning, then thought by some to have been a contributing factor. The Harvard team was asked to delay the publication of its findings. The team members complied until goaded by representatives of the Consumers' League (Clark 1993; Rowland 1994). When their publication did appear (see Castle, Drinker, and Drinker 1925), their findings paralleled the findings of Dr. Hoffman and attributed the medical problems of dial painters to radium. It is also now apparent from unpublished letters and correspondence from the archives of the Argonne National Laboratory that the U.S. Radium Corporation may have done more than simply request a publication delay. These papers also appear to suggest that the U.S. Radium Corporation both misrepresented its findings to New Jersey officials and exerted considerable pressure on the Harvard investigators not to publish what they had found (see Grossman and Associates 1997:Appendix B).

Thus, before 1925 only a few medical investigators, dentists, and scientists appear to have adopted an advocacy position in support of the dial painters. The concerns of the employees were taken up by just a few health professionals, and access to the corridors of governmental power only became available as a result of the efforts of a small number of women health workers and female activists in the Consumers' League, who played an important role in persuading scientists and agency personnel to take action (Clark 1993).

The Role of the New Jersey Consumers' League

The New Jersey Consumers' League became involved with the plight of the dial painters for two reasons: 1) in response to the fact that the young female dial painters were not organized and thus were in no position to lobby for improved working conditions or better safety at the plant; and 2) in response to the perceived need for lobbying so that radiation illness would be recognized as a new occupational disease subject to compensation, with legislative safeguards to protect radium workers (Clark 1993). Although the history of the emergence of industrial health as a discipline and the development of safety standards have been addressed in depth by Dr. Clark (1993), the subject is outlined here because the New Jersey Consumers' League played a pivotal role in causing the scientific and medical communities to address the occupational origins of the dial painters' illnesses and in forcing federal and state agencies to initiate the requisite investigations and case studies.

The Consumers' League was "... a progressive reform organization of mostly middle and upper class women who sought to improve the lot of women and children workers through investigation, education, and legislation" (Clark 1993:86). Clark's in-depth historical reconstruction of the roles of the National and New Jersey Chapters of the Consumers' League traced their initial involvement to an interest on the part of Florence Kelley of the National Chapter and Alice Hamilton, a former settlement house worker and physician with an interest in industrial poisons, who shared a concern for worker safety (see Hamilton 1985). Both women engaged in inquiries into the emerging health problems of the dial painters of Orange, who had initially been perceived as suffering from phosphorus poisoning, or "phossy jaw," which had developed among workers in the match and fireworks industries.

In addition to the initiatives of these early industrial health reformers and the observations by local doctors and dentists who first recognized the link between the dial painters' medical conditions and their employment at the U.S. Radium plant (see above), a third important element in the history of health reform in the radium industry was provided by John Roach, Director of the Bureau of Sanitation and Hygiene in New Jersey's Department of Labor. In response to a letter of concern by Alice Hamilton of the Consumers' League, which highlighted the need to support unorganized workers through the League's efforts, Roach not only offered his support, but also brought to light a fact that became a central issue in the ensuing campaign to protect the dial painters. He brought to the attention of Hamilton and Katherine Wiley of the Consumers' League that although lead and phosphorus were listed as insurable causes of occupational disease, radium was not (Wiley 1923a, b, c). In this context, Roach made the "...relatively radical suggestion that New Jersey's compensation laws be expanded to cover all occupational diseases, a goal soon adopted by the Consumer's League" (Clark 1993:87).

The actions of this small number of state health workers and members of the Consumers' League in support of the workers at the U.S. Radium plant culminated in the recognition of radiation illness as an occupational disease subject to just compensation, and precipitated 70 years of in-depth scientific investigation aimed at assessing the nature and routes of radiation disease in the United States

The efforts on the part of the Consumers' League advocates to force state and federal agencies to take action were unsuccessful until 1924. When the official response came, it was inadvertently accelerated by the U.S. Radium Corporation itself. As detailed by Clark's historical reconstruction of the events, Hamilton of the Consumers' League wrote to Dr. Katherine Drinker of Harvard's Department of Industrial Hygiene, coinvestigator, with her husband, of the on-site study of the Orange plant funded by the U.S. Radium Corporation (see above), that "U.S. Radium...had forged a favorable report over the Drinkers' name" (Clark 1993:90-91). This revelation was met with indignation by the Harvard team members, which led them to publish their findings over the objections of U.S. Radium officials, a move that in turn precipitated a strong government reaction:

> In response to the discovery of U.S. Radium's duplicity, the New Jersey labor commissioner demanded compliance with the safety suggestions of the Harvard team ... subdued ... the U.S. Radium Corporation closed up shop in New Jersey ... to move across the Hudson River and to resume dial painting in New York City.

In addition, this revelation by the League precipitated a formal federal investigation of both the U.S. Radium plant in New Jersey and other luminous paint concerns throughout the United States. Between the end of 1924 and 1925, the United States Department of Labor began an in-depth investigation of the working conditions and health histories of the radium workers in Orange. This important investigation was spearheaded by Dr. S. Kjaer of the Bureau of Labor Statistics of the United States Department of Labor (see below). Its breadth of coverage and detailed forensic investigations of the vectors of exposure and radioactive "body load" of living and dead radium workers at the plant marked it as a watershed in United States scientific and regulatory investigation of radiation health hazards. Although later histories stressed the work of Hoffman, Drinker, Castle, and Martland, the forensic data collected by Dr. Kjaer and his colleagues of the United States Department of Labor must be viewed as of equal historical relevance to the emergence of subsequent avenues of research in American radiation health history.

The Consumers' League's contributions to bringing about general public awareness of the plight of the dial painters of Orange can be summarized on the basis of Clark's (1993) work, as follows:

- League reformers verified the dial painters' perceptions, systematized their data on the prevalence of disease, and uncovered a likely disease cause. They then organized support from medical researchers and government agencies.

- The League was responsible for finding lawyers for dial painters and pressured experts to testify on their behalf.

- The League lobbied for state and federal legislation making radium poisoning compensatable.

- The efforts by the dial painters and their private dentists to enlist official aid from municipal and state agencies were unsuccessful until women advocates of the New Jersey Chapter of the Consumers' League became involved in the cause in 1924.

- Only in response to the New Jersey Chapter's lobbying efforts did the United States Department of Labor initiate a formal, large-scale field investigation, which was conducted by Dr. Kjaer between 1924 and 1925 (see below).

- Federal action was initiated only after heavy pressure was organized by the League, resulting in the first federal health and safety guidelines for radiation exposure. Radiation illness was determined to be a compensatable industrial illness in New Jersey and New York.

Dr. Kjaer and the United States Department of Labor Investigations

As a result of the efforts of the Consumers' League, beginning in 1924 the United States Department of Labor employed a team of forensic investigators under the direction of Dr. Swen Kjaer of the Department's Bureau of Labor Statistics to locate and record detailed employment and health histories of former dial painters and other workers at the U.S. Radium facility and other comparable luminous paint concerns throughout the United States Kjaer's team ultimately documented 26 detailed case histories of current and former radium workers, both living and dead.

The original Department of Labor surveys document that most of the dial painters worked with radium during a 4-year period between 1916 and 1920. A New York City Department of Health (1928) memo reported a 1928 review of U.S. Radium employment, based on records and interviews with company officials. This memo listed 25 female dial painters in 1915, 100 in 1916, an average of 300 in 1917 (including "handlers in chemical plant"), fewer than 300 in 1918, down to 200 in 1919, 100 in 1920, 25 in 1921, 10 in 1922, and no more than 5 per year between 1923 and 1928 (New York City Department of Health 1928).

As documented by the original 1924-1925 case histories (see Grossman and Associates 1997: Appendix A), the investigators consistently found that, when undertaken at all, earlier medical evaluations had misdiagnosed symptoms of radiation illness as "anemia," arthritis, or dental decay. These early medical histories also repeatedly documented systemic bone and joint disorders, alone or in addition to bone and tissue decay (necrosis).

In addition to observations that the patients suffered from extreme deformities in body structure, including spontaneous fractures, shortening of limbs, and the inability to bend or stoop, the female dial painters were barren or prone to stillbirth. It is also recorded that physicians of the period routinely performed abortions on current and former U.S. Radium employees because they "would not permit development" of the fetus (Kjaer n.d.c). Despite these medical decisions, instead of diagnosing the cause of death of one patient in 1922 who suffered radium-induced poisoning, the death certificate attributed the cause of death to syphilis. This pattern of misdiagnosis, and of attributing radiation-induced death to other causes such as anemia and phosphorus poisoning, was not limited to a few individual cases, but appeared to reflect a broad-based pattern of practice by medical personnel engaged in the diagnosis and treatment of the U.S. Radium workers.

One of the earliest manifestations of medical problems on the part of the dial painters was described by local dentists who identified these manifestations as "dental necrosis" or "radium jaw," which they described as a condition characterized by dental pain, loose teeth, dental or alveolar lesions or ulcers, and the failure of the sockets of extracted teeth to heal. In addition, many patients complaining of illnesses characterized by pains, paralysis, deformities, or abnormal growths were diagnosed as suffering from a "rheumatoid" malady. When their maladies manifested themselves as chronic illness and fatigue, the diagnosis was recorded as "anemia," without attribution of cause (Kjaer n.d.c).

The symptoms of radium poisoning were not limited to the female dial painters or to the extractors of radium ore at the U.S. Radium facility. An unnamed person, described as a former Director, and later President of the General Radium Corporation with a medical degree (presumably Dr. Sochocky), who left the company in 1921 and died in 1928, underscores the fact that workers and employees died from vectors of exposure to radiation poisoning beyond that of the lip pointing practiced by the dial painters. This case history is pertinent because it corroborates that the senior employees of the plant were aware of potential health dangers at least as early as 1920, if not before the opening of the plant in 1917, and that these dangers were either ignored or downplayed at the time. The Department of Labor's medical report details the subject's exposure as follows (Kjaer n.d.c):

> ...exposed to heavy penetration from radium. During this time exposed to inhalation of dust in crystallization laboratories in 1919 to 1920, was exposed to heavy radiation in small room period [sic], large amounts of emation [sic] by inhalation and ingestion and highly concentrated dust from radium and mesothorium....
>
> ... [name deleted] was a physician, and knew he was handling dangerous material, but according to all reports ignored the dangers. He was fascinated by the qualities of radium and is reputed to have played with it taking the tubes of radium out of the safe and holding them in his bare hands, while watching the luminosity in the dark. He is also said to have immersed his arm up to the elbow in solutions of radium or mesothorium.

Kjaer's report shows that manifestations of radiation-related illness were becoming apparent by the beginning of the 1920s, and not half a decade or a decade later, as asserted by U.S. Radium officials. The review of the original 1928 U.S. Labor Department investigations by Dr. Kjaer also demonstrates that the peak period of worker exposure between ca. 1915-1921, the period of peak employment, was considerably shorter than later depositions by company representative and lawyers led the public and the courts to believe (ANL n.d.b).

The official investigations by the United States Department of Labor, based on interviews with surviving patients or, if the patients had died, with one or more of their attending physicians, indicate that official diagnoses of death or disease from radium poisoning, if they were made at all, were not made until after the death of the patient or until long after the patient's tenure as an employee at the U.S. Radium plant had ceased. In almost every recorded case the individuals, or their medical records, documented the onset of radiation-related medical problems early in their forensic history. For several, the onset of "radium jaw" (necrosis of the jaw) manifested by dental or alveolar pain, bleeding, and the failure to heal after tooth extraction, was unambiguously evident as early as 1918, as exemplified by the case of the female dial painter who worked at the plant for only 19 months between 1916 and 1917 (Kjaer n.d.c).

This pattern of attributing radiation-caused deaths and illness to "anemia, pneumonia, weakness, syphilis" and, finally, "phosphorus poisoning" was viewed with skepticism and criticism by Dr. Kjaer and other scientists. In one of the 26 medical histories taken by Dr. Kjaer in 1928, he wrote a succinct summation of the scientific and medical evidence related to the issue of phosphorus versus radium poisoning. In answer to question 20, requesting the subject's medical record concerning the current disease, he transcribed the following (Kjaer, n.d.c):

> Cheek started swelling in spring of 1922. Tooth was extracted by ____D.D.S., ____, Newark, N.J. Patient was discharged as cured, but trouble appeared again. Consulted _____, D.D.S. and exodontist, who performed several operations and removed part of lower jawbone, but were unable to check the necrosis. Deceased was admitted to Newark Homeopathic Hospital, Littleton Ave., where she was attended by ______M.D. _______ . Affliction was diagnosed as phosphorus poisoning (necrosis), and reported as such to _____, M.D., health officer for Newark, 94 William St., Newark, N.J. The question of phosphorus in luminous material was referred to _______, consulting chemist for N.J. Department of Labor, where the case had been reported by _______. He stated that luminous material did not, as far as he knew, contain any phosphorus, and according to his belief the condition of the jaw was caused by the influence of radium (Jan. 30, 1923). After analyzing a sample of the luminous compound stated, in letter of April 6, 1923, that no phosphorus had been found, and that he feels quite sure his opinion, as of Jan. 30, is correct.
>
> Death resulted on July 15, 1923. Death certificate, on file in Newark, N.J., signed by _____ stated "Cause, phosphorus poisoning of lower jaw (complete); contributory, lung abscess about 2 months; determined by, X-ray test, not decisive; contracted at, place of business."

The Deaprtment of Labor's (DOL) medical examinations of living patients and posthumous forensic reports provide information that the effects of radiation illness were not confined to jaw cancer from lip pointing by female dial painters. The DOL survey showed that the initial manifestations of multiple bodywide disorders were known by the investigators to extend beyond troubles with teeth and jaws well before the 1920s. In other words, the onset of symptoms could be shown to predate the official diagnosis by attending physicians by months or even several years. The evidence suggests that the former dial painters and factory workers showed effects not only in their mouth and blood, but throughout their bodies by the presence of tumors of the skeleton, disfigurement, skin lesions and acne-like outbreaks, limb shortening, and pulmonary failure, most of which resulted in death (see Grossman and Associates 1997:94 and Figure 38).

The DOL study also quantified data documenting levels of radium poisoning in the workers. In one particularly relevant case study, Dr. Kjaer reported systemwide radiation poisoning on the basis of controlled measurements of soft and hard body parts, which were collected during an autopsy of a 22-year old woman (Patient "X") who died in 1927. Her death certificate attributed the cause of death to "ulcerative stomatitis; contributory, syphilis; determined by Wasserman test." Her remains were exhumed by unnamed investigators shortly after her death "... for examination to determine cause of death" by a chemical pathologist ... who was affiliated with New York University, Bellevue and Allied Hospitals, and to the New York City Examiners Office, and by ...a professor of radio chemistry at Washington Square College [New York University]" (Kjaer, n.d.c:Case B).

The investigators measured the radiation levels of the femur, cranium, vertebrae, mandible, maxillary, liver, spleen, brain, and lung. Using an electroscope to measure radioactive emissions from the different body components, the scientists reported that for each body element tested, the alpha, beta, and gamma readings were higher by factors of 10 to 30 than the background radiation count. Where normal readings were logged for "normal human tissues" in the range of 10 radioactive divisions per periods of 2,800 to 3,000 seconds (ca. one count per five minutes), the samples from the ash of the burned organs of the exhumed dial painter flashed once every few seconds. All of the bones tested showed high radioactivity; likewise soft tissue organs including the liver, spleen, brain, and lungs showed elevated radioactivity ranging from 10 to 47 times the ambient levels of radioactivity. Normal levels of radium were defined as 0.0027 micrograms per gram of ash. The exhumed body parts of the dial painter contained 11.336 micrograms of radium per gram of bone ash, a level 11.98 times normal. The NYU pathologist concluded that the computation of measurable radium per gram of bone ash indicated that at the time of her death the former dial painter had the equivalent of 48.32 micrograms of radium in her system. Kjaer concluded his official DOL report on this radiological autopsy with a revision of the original cause of death from "ulcerative stomatitis and syphilis" to death from radiation poisoning, and with a strong statement concerning the levels of radioactivity in the subject's body.

In addition to documenting the level of contamination for a worker who was employed for the period of October 6, 1917 to September 12, 1922, the forensic analysis described above indicates that, given the range of soft and hard body tissues affected and the radiation levels recorded for each body element, radiation poisoning may have resulted from exposure to a wide range of sources. Lip pointing was not, apparently, the only avenue of radiation exposure in patient "X."

Dr. Kjaer apparently suspected other sources of radioactive exposure and poisoning, beyond the vector of lip pointing, as early as 1923. As reported by Dr. Rowland (1994:26), Kjaer had suggested for the first time in a unpublished memo dated July 21, 1923 that "... an intense flux of gamma rays in that plant might have been involved." He (Kjaer) went on to point out that "No notice appears to have been taken of this concept that an intense gamma-ray flux might have been present in the Orange, New Jersey, plant." Not only was Dr. Kjaer's early work ignored but, as indicated by hand-written notes in the margins of several of his papers, his field notes and the records of his interviews apparently did not finish passing through the official channels of the Department of Labor and the Argonne National Laboratory until 1959 (Kjaer 1959), when he appears to have forwarded personal copies of his documents to Argonne National Laboratory investigators (Grossman and Associates 1997:Appendix A). It is also unclear from the surviving record to what extent Dr. Martland and other early medical investigators working on the same problem were either aware of or had access to Dr. Kjaer's findings before their initial publication of the radium connection in 1925.

The findings of systemwide radioactivity, identified from the measurements of exhumed body organs and bone samples, were corroborated by the postmortem tests of a second former dial painter who had died in delirium on June 18, 1925, some two to three years after first becoming ill with body sores, oral bleeding, and crippling pain. The dead dial painter had worked at the plant from December 1917 to March 1925, until she was too debilitated by illness and pain to continue working. The study differed from the first case study in that body radioactivity of the patient was measured both while she was alive and after her death. Before her death, readings of her exhaled breath yielded levels of radioactivity three times those of normal background air samples (15.4 versus 5 counts per 30-second unit of measurement). The conclusions reached by Kjaer (n.d.c), based on his analysis of the woman's body after her death, was unambiguous:

> Tests showed that positive gamma radiation was present in the organs, and that alpha radiation was most marked from spleen, bone marrow, bone cortex and liver; also that there was practically no radioactivity in lungs, heart or kidneys. Dental films, strapped to one half of the femur, with small pieces of metal between the film surface and the bone, were removed and developed after six weeks. Exact shadow grams of the metal showed on the films. The same result was obtained on the inferior maxillae, which also showed definite exposure of films, with hazy shadow grams, after being strapped on for 60 hours.

> After considering all variations from pernicious anemia, hemolytic anemia, and aplastic anemia, this case was designated as rapid anemia of the pernicious type, due to radioactivity.
>
> Original death certificate, signed by H.S. Martland, M.D., states cause of death Acute anemia of pernicious type, probably secondary to exposure to radioactive substances; contributory Necrosis of the jaw, sepsis; contracted at Orange, N.J.; determined by Autopsy. Official death certificate is attached.

These early federal case studies also contained a number of references to women of child-bearing age, which in this case was most of the dial painters and workers at the U. S. Radium plant. Few if any were having children. Those that did conceive experienced still births or spontaneous abortions. Two of Dr. Kjaer's investigative case histories officially documented the problem in 1928. One of the women, a former dial painter, had a baby born dead in 1925. Soon after, in 1926, she was recorded as having experienced severe pain and crippling. The report also documents that a second baby was aborted on doctor's orders in May 1926 "... as physicians would not permit development." Two weeks later, the patient began to experience "severe pain" in the legs, and one leg began to shorten. The illness was diagnosed as "rheumatism" by an Orange doctor [name deleted] (Kjaer n.d.c: Appendix A).

Information collected from a second former dial painter who was still living in 1928 recorded that despite a history of jaw and tooth problems that failed to heal for three years, her main worry concerned her lack of children despite the fact that she had been married since 1920, or about eight years. The subject "... stated that she had been told very few of the girls who worked for U.S. Radium Co. any [sic] length of time had any children, a possible result of exposure" (Kjaer n.d.c).

Corporate Response

Kjaer's notes and report on his field investigations were either ignored or lost in the official and scientific record until Kjaer himself provided copies to Argonne National Laboratory in 1959. Furthermore, archival records provide evidence that the principals of the U.S. Radium Corporation (see Grossman and Associates 1997:97):

- May have actively sought to mislead the workers about the dangers of radium, perhaps as early as 1921, and at least by 1925.

- May have attempted to mislead state and federal investigators by undertaking to "clean" or cauterize the most contaminated localities of radium dust deposits within the plant before the initiation of official U.S. government and New Jersey State investigations in 1924.

- Sought to withhold from New Jersey Department of Health critical findings by Harvard investigators Castle and Drinker (see above).

- When it appeared that their efforts to mislead were about to be jeopardized by scientific publication, threatened the Harvard scientists with lawsuits if they did publish.

- Operated the U.S. Radium facility with a dual set of health and safety standards at least from 1917 on: one set of procedures, without protective measures to prevent radium contamination, for the dial painters, and another, with protective measures, for the chemists and scientists.

At the outset of his investigation for the Department of Labor, Dr. Kjaer reported that current and former staff at the U.S. Radium plant attempted to steer the investigation to the study of secondary, non-radioactive compounds as vectors of toxicity (Kjaer n.d.c). In addition to pointing to the use of solvents and acids at the plant, both the staff and several medical professionals attributed illness and death to "phosphorus poisoning." The issue of phosphorus poisoning of the workers remained a concern until federal investigators showed it to be invalid. The primary reason why the presumed phosphorus poisoning remained an issue for so long was apparently because the U.S. Radium Corporation kept the formula for its luminous compound a closely guarded secret. However, Bureau of Standards scientists also appear to have been well informed about the composition of luminous compounds at least as early as 1916 because of the use of these compounds for painting military as well as commercial dials. These and other scientists also knew well before 1923, and probably as early as World War I, that phosphorus was not used for the manufacture or application of luminous compounds (ANL n.d.j).

Correspondence by Harvard scientists who participated in the investigation of health problems among employees of the U.S. Radium plant in Orange, deposited in the files of Argonne National Laboratory, provides firsthand information on the efforts by company employees to reduce or eliminate radioactivity concentrations in the dial painting and extraction areas of the facility before official state investigators began their own study of the problem (see above). The allegations are contained in letters dating to 1925, 1928, and 1952 which include the correspondence of Dr. Cecil K. Drinker, M.D., Professor of Physiology, to Dr. Andrew F. McBride, the Commissioner of Labor of New Jersey dated June 30, 1925; and a 1952 letter from Phillip Drinker, Cecil Drinker's brother, to Dr. Alice Hamilton, one of the original Consumers' League activists in the case (Grossman and Associates 1997:Appendix B). The letters provide evidence that officers of the U.S. Radium Corporation first tried in 1924 to suppress the release of evidence by the scientists through the use of intimidation. When that failed, the company undertook to mislead the

Commissioner of Labor by deleting critical aspects of the scientists' findings from their report. The expurgated version of the report was submitted by Mr. Roeder of U.S. Radium to Commissioner McBride.

The 1952 letter by Phillip Drinker to Alice Hamilton is reproduced in full by Grossman and Associates 1997 as Appendix B. The critical passage of that letter documenting corporate tampering with the evidence during or before 1924 is quoted here. After digressing on the issue of exposure by lip pointing versus inhalation of radon gas as causes of radiation poisoning, Drinker continues:

> ... But what really bothers me is a fact that I know to be right and it never has appeared in print---Cecil told me (1924) when he and Castle were sure what had happened that he warned the Company they would have to clean up thoroughly and quickly and put in some good medical control -- or he would turn his data over to the State (New Jersey). They replied promptly that if he did they would raise heck and sue him for libel. He then asked a good corporation lawyer (another brother!) what he thought and the brother said to tell 'em to sue and be damned. Cecil called their bluff, on advice of counsel, and the company cleaned the place so that when Martland and others to follow went in they did not find luminous dust spread in minute amounts all over the place. Castle had found it and I helped him study it. The reason I have this down so pat is simple and wholly sentimental -- I was courting my wife at the time and was late to a very critical date because Castle and I got so intrigued looking at his dust particles. It was the kind of event that I don't forget and it brings back the whole chain of events. The lady in question has chided me on this from time to time -- and I've enjoyed the ribbing.

Pressure by the New Jersey Consumers' League helped to convince the Harvard scientists to publish their findings in 1925, (ANL n.d.l) precipitating the advent of federal health standards for radium workers (see above). The Harvard scientists are also on record over their displeasure concerning the heavy editorial license exercised by company officials over their work. In his letter to Commissioner McBride (ANL n.d.p), Cecil Drinker referred to the expurgated version of the Harvard group's report which the U.S. Radium Corporation submitted to the Commissioner.

Cecil Drinker's letter to the Commissioner criticized the draft report for failing to include "...later statements made by us bringing out the fact that there was a generalized overexposure to radium throughout the entire [U.S. Radium] plant." Cecil Drinker's letter states that "... some years ago..." the director of the British London Radium Institute, Professor Hottram, recognized the linkage between "pernicious anemia" and exposure to radium, and recommended as early as 1925 that "...workers exposed to radium should be able to carry photographic film for three weeks without any fogging." Following the submission of the Harvard scientists' (ANL n.d.l) first report to Mr. Roeder of the U.S. Radium Corporation to that effect, film was distributed around the plant and on workers' bodies as an experiment. All fogged rapidly before the end of three weeks. In his letter Dr. Drinker also points out that he had recommended to the U.S. Radium Corporation that a specialist in bone disease be assigned to monitor the workers before symptoms of necrosis were evident. He adds that "No attention was paid to this suggestion."

In his letter to the Commissioner, Dr. Drinker also states that despite the appearance of serious lesions on one employee's hands, who later died of "pernicious anemia," the worker "scoffed at the possibility of future damage." Drinker observes: "This attitude was characteristic of those in authority throughout the plant. There seemed to be an utter lack of realization of the dangers inherent in the material which was being manufactured. I remember that Mr. Roeder told me that no malignant growths ever developed on the basis of radium lesions, a statement so easy to disprove as to be ridiculous."

As a final evaluation, Dr. Drinker ended his critical letter to Commissioner McBride with the following: "I believe you are very right in your stringent attitude toward the Radium Corporation at the moment, since I do not think they are capable of appreciating any sort of advice or assistance other than that applied forcefully."

A detailed treatment of the litigation history of the U.S. Radium Corporation was not possible because the names and dates of the litigants and those giving testimony were deleted on the documents received from the Argonne National Laboratory archives. The available information, however, did provide some important insights into the nature and credibility of the positions taken by the U.S. Radium Corporation before the courts. A major focus of past litigation as well as of the investigations by federal and state agencies was on the question of who knew what and when relative to the potential dangers of working with radium as an illuminator for watches and other instruments, particularly during World War I. Numerous litigants brought suit on the premise that by 1917 the corporation was aware of the health hazards associated with radium processing, extraction, and application (ANL n.d.b).

Countering these suits by workers and other interest groups, both official and private, were legal arguments and testimony brought by the owners and operators of the U.S. Radium facility to the effect that the health problems associated with radium processing were not known until long after the plant had ceased to operate, and that therefore the owners/operators were not to blame for health problems that appeared to have resulted from workers' exposure to radium. Documents not previously cited by litigants on either side of the issue suggest that the officials and operators of the U. S. Radium plant were: 1) aware of the impact on individual health at an early date; 2) aware that the procedures followed by the dial painters may have had adverse health consequences for this group of employees; and 3) aware that these procedures were inconsistent with standard health and safety practices being followed by the chemists and trained laboratory scientists who were working together with the dial painters at the U.S. Radium plant in Orange.

Although subsequent public announcements and responses to litigation by officials of the U.S. Radium Corporation consistently argued that the workers did not become ill until long after their period of employment at the plant, the original forensic field records of the Department of Labor investigator, Dr. Kjaer, unambiguously document the fact that the dial painters were manifesting clear symptoms of radiation illness well before 1920, even though the symptoms were not properly diagnosed at their onset, often not until after the individual had died, due to the lack of medical monitoring by the company (ANL n.d.b; Kjaer n.d.c: see Grossman and Associates 1997: Appendix A). Although never published, the original Department of Labor case studies of former employees, both living and dead, conducted by Dr. Kjaer between 1924 and 1925, document that the workers were manifesting symptoms of radiation poisoning as early as 1917, while they were still working at the plant, contrary to the claims by the U. S. Radium Corporation.

In summary, ample documentary evidence exists showing that the U.S. Radium Corporation was fully aware of the dangers of human exposure to radium early in its existence and knowingly pursued a dual set of health and safety procedures for different categories of employees at the plant. The records show that the company followed recommended safety precautions in conformance with United States Government practices for its laboratory personnel but not for the dial painters. Before 1925, one of Dr. Kjaer's "investigative field reports" documented that scientists at the United States Bureau of Standards believed that "radiations produce aplastic anemia, suppression of menstruation in female workers and cause sterility" (Kjaer n.d.c.; see Grossman and Associates 1997:Appendix A). In recognition of these potential dangers, a number of precautions were instituted at the United States Bureau of Standards and other institutions to protect workers. These included the use of forceps, lead screens, lead containers, and the maintenance of distance between the workers and the source of radiation. The workers were medically monitored for changes in the blood and, if found to be anemic, given vacations or, because the effects were viewed by government scientists as cumulative, transferred to other work.

As further indication of the double standard for safety measures, practiced at the U.S. Radium Corporation, its co-founder, Dr. Sochocky, in all probability was aware of health effects from radium exposure as early as 1916, if not several years earlier. Sochocky amputated his own finger after suffering radium burns before Florence Wall arrived at the plant as his laboratory assistant in the summer of 1917 (Wall 1969). His professional awareness of these dangers at least as early as 1917 is also indicated by the fact that, from the outset of Wall's work as the operator of the radioscope laboratory for the evaluation of radium and ore quality at the Orange plant, the company scientists systematically used protective laboratory equipment and procedures, including storing the purified radium samples in thick lead-shielded containers. As Wall describes, "... I lumbered about in a lead-impregnated apron and always handled tubes of radium with ivory-tipped forceps. Anyway, I'm still here and many of my co-workers are not...." (Wall 1969:18). Thus, while as early as 1917 the radioscope operator and chemists at the plant followed similar procedures as those used at the Bureau of Standards, no such protective procedures were instituted for the dial painters (Wall 1969). Until 1920, the dial painters used their mouths to clean the brushes because the jars of water and associated cloths were removed to reduce the possibility of waste, and they were allowed to eat at their work stations without washing their hands (Kjaer n.d.c). All corporate efforts appeared to give priority to conserving the valuable luminous material, disregarding the workers' safety and health.

What stands out from the case histories and interviews with the affected dial painters and other workers is that when the workers themselves became alarmed, the company actively attempted to convince them that their work with radium was not the cause of their health problems. Specifically, on or about 1920 the instructor for the dial painters had returned to work with "eruptions on face, and the girls became frightened." In response, the company had "... [name withheld] ... come over from New York to convince the girls that it was not dangerous to handle it [radium]" (Kjaer, n.d.c.; see Grossman and Associates 1997:Appendix A, Case "S"). The U.S. Radium Corporation continued to contradict these findings, both in documents and verbally, until the practice of lip pointing was discontinued in 1926 (Rowland 1994). For nearly a decade after scientific evidence existed to the contrary, both in England and the United States, and long after standard health and safety procedures were practiced by government laboratories and hospitals as well as private corporate concerns involved with the processing and application of radium, the U.S. Radium Corporation denied these precautions to the dial painters at the Orange plant.

Chronology of Relevant Government and Research Actions

As indicated by the following chronology, the timing and sequence of events highlight the advent of awareness of illness, the diagnosis and identification of causality, the role of the New Jersey Consumers' League, and the timing of subsequent governmental response and reform (Eng 1980a; Kjaer n.d.a; Sochocky 1921; Clark 1993; Rowland 1994; Stewart 1929).

1903 - Dr. Becquerel and the Curies are awarded the Nobel Prize in physics for their work in radioactivity. In a 1903 interview, Pierre Curie describes the hazards of radium by stating that "he would not care to trust himself in a room with a kilo of pure radium, as it would doubtless destroy his eyesight and burn all the skin off his body, and probably kill him." He also indicates that in a recent experiment he found that a few milligrams of radium introduced beneath the skin near the vertebral column of a mouse produced death by paralysis within three hours.

1906 - Dr. Sochocky studies "all there is to know" about radiation under the Curies in Paris.

1917 - U.S. Radium consolidates ore processing and dial painting operations at Orange plant; 12-300 local women employed as dial painters during World War I.

1917 - Florence Wall assumes her position as Radioscope Laboratory Analyst for Dr. Sochocky. Utilizes radiation-blocking laboratory procedures for her own safety.

1918 - Wall leaves U. S. Radium.

1918 - Kjaer, United States Department of Labor forensic investigator, documents onset of dental and dermatological symptoms of dial painters' illnesses beginning 1918, 1-2 years after the start of major operations at Orange plant, 5 years before Drs. Drinker and Castle of Harvard Public Health School publish U.S. Radium Corporation-suppressed report documenting health abnormalities of workers.

1920 - Former dial painter reports being barren (Kjaer n.d.c).

1922 - First dial painter becomes ill and dies in 1923; jaw fell away from skull before death (Clark 1993); Suspected phosphorus poisoning reported to Newark Department of Public Health; triggers three New Jersey State investigations. A New Jersey Department of Labor inspection of site finds no violations.

1923 - Initial chemical evaluation of paint facility by New Jersey Department of Labor found no phosphorus, but linked skin and dental problems to radium. No official action (Clark 1993). Former forelady and instructor in lip pointing develops jaw and tooth problems (Clark 1993). Former instructor of dial painters files formal complaint with New Jersey Labor and Health Departments in Newark concerning several more cases of illness among former workers; L. Pound, health officer, confirmed evidence and filed report, no action taken (Clark 1993:80). K. Wiley of New Jersey Consumers' League corresponds with John Roach, Director of Bureau of Sanitation and Hygiene of New Jersey Department of Labor who becomes a supporter of the women and recommends state compensation laws be expanded to cover all occupational diseases; position adopted by Consumers' League advocates (Clark 1993:87).

1924 - January meeting in Dr. Barry's dentist office with dial painters to discuss link between illnesses and dial painting. L. Young of New Jersey Health Department again reports on 5 suspicious cases (3 dead, 2 sick) suggesting causality. Young becomes aware of 1922 study by United States Public Health Service of the Bureau of Standards of radium workers identifying cases of skin erosion and anemia, with "no serious defects" reported; recommends limiting worker exposure, vacations, and periodic blood examinations (Williams 1924; Clark 1993). In March U.S. Radium Corporation hires Harvard medical team headed by Drs. Cecil Drinker and Castle to investigate cause of illness at Orange plant; Drinker submits internal report on presence of radioactive dust throughout plant. Film fogging from radiation in evidence within 2-3 days and blood tests prove abnormal for 22 workers (Eng 1980a:10; ANL n.d.a); report suppressed; U.S. Radium officers argue that evidence is "tentative and circumstantial ... nothing harmful anywhere in works" (Clark 1993, note 25). "Forgery" of favorable report to New Jersey Commissioner over Drinker's name. Refusal to release report citing pending litigation (Clark 1993:90). In March of 1924 concerned dial painters hold second meeting with Dr. Barry and local dentists; Dr. Barry demands workers being treated resign their jobs at U.S. Radium (Clark 1993:85; ANL n.d.m). Frustrated by official inaction, L. Young and Erskine of New Jersey Health and Labor Departments set up "back channel" meeting with Florence Kelly, Executive Secretary of National Consumers' League, and with Katherine Schwab of Consumers' League of New Jersey, to enlist their aid in pressing for official action. Dental experts treated four former dial painters and knew of two others who were sick or dead; total of six between 1923 and 1924 documented with jawbone disfiguration, tooth problems, and/or death (Clark 1993:77; Eng 1980a, b). Wiley of Consumers' League contacts and interviews more dial painters and dentists who believed dental problems of workers due to "radio active teeth," convinced of causal link between radium and jaw necrosis (Clark 1993). Dr. T. Blum presents first scientific paper linking radium with jaw necrosis before American Dental Association in September, published September 1924 (Clark 1993:89). Wiley of Consumers' League and J. Roach of New Jersey Department of Labor make personal appeal to A. McBride, Commissioner of New Jersey Department of Labor to authorize request of U.S. Public Health Service for federal investigation; no action taken. Wiley lobbies United States Labor Department, Public Health Service for official investigations; no resultant action (Clark 1993:89). F. Hoffman, statistician of Prudential Life Insurance Company, retained by New Jersey Consumers' League, begins investigation of illness at Orange plant; documents 17 cases of illness and death and has results ready for publication in 1925. Wiley of New Jersey Consumers' League enlists aid of Dr. Hamilton of Harvard Department of Industrial Hygiene to help persuade Drinker to publish findings; uses Hamilton's impending publication indicating that Drinker's conclusions were misrepresented. This forces Drinker to publish so as to receive credit for "identifying" dangers of radium before Hoffman's findings go to press (Clark 1993:91).

1925 - U.S. Radium Corporation President writes to K. Wiley of Consumers' League stating that health problems due to outside causes "... not an occupational disease" (Clark 1993:89). Based on evidence of altered Drinker data, Wiley convinces United States Department of Labor to initiate first formal federal investigation; Dr. Kjaer, forensic field officer for Department of Labor, initiates field investigation of living and deceased dial painters (Grossman and Associates 1997: Appendix A). In April, Kjaer presents internal report concluding that radium was dangerous and correlating radium accumulation with worker bone necrosis; report not released to public (see

Grossman and Associates 1997:Appendix A for original field reports). Consumers' League helps arrange study by Dr. Harrison Martland, first Essex County (New Jersey) Medical Examiner which initially concludes "jaw rot" due directly to radium (later revised with position that radium first kills bone which then becomes diseased from dental caries). A second study establishes that spontaneous fracture occurs in long bones, vertebrae, and bones of feet weakened by radium. In October, Dr. Martland gives formal paper taking credit for discovering "a heretofore unrecognized form of occupational poisoning" and receives credit for "first positive proof" of radium poisoning and radioactivity in bones and soft tissues (Eng 1980a:10; Clark 1993:93; Martland, Conlon, and Knef 1925). These findings already suspected by workers and dentists as of 1922 and taken as given by Consumers' League at least by 1924.

1926 - Dr. Flinn, Professor of Pathology at Columbia University, with funding from the U.S. Radium Corporation, publishes first of three studies attributing dial painter illness as primarily due to bacterial infection; revised by 1928 to attribute radium as primary cause (Eng 1980a).

1927 - Attorney Barry of Newark, New Jersey filed suit against U.S. Radium on behalf of 5 ill workers; claimed $250,000 damages under New Jersey Workers' Compensation Law. Case referred to Court of Chancery because existing compensation laws did not cover radiation; U.S. Radium claims that the statute of limitations exonerated them of liability after two years; case settled out of court with each woman receiving $10,000 payment, stipend of $600/year, and coverage for medical expenses (Eng 1980a).

1928 - New Jersey Consumers' League lobbies and persuades Surgeon General to direct Public Health Service to hold formal conference and make recommendations regarding radium poisoning, to investigate conditions and codify best-known methods of protection (Eng 1980a). Public Health Service recommends rigid and continuous inspection of plants, hourly allocation of radium, use of hoods, medical monitoring (Eng 1980a:11).

1929 - State of New Jersey adds radium- and mesothorium-induced disease (necrosis) to list of compensatable diseases (Eng 1980a).

1930 - State of New York adds radium- and mesothorium-induced disease to compensation list (Eng 1980a).

1932 - American Medical Association removes radium from list of positive remedies for internal administration.

1934 - LaPorte vs. U.S. Radium Corporation litigation uses Flinn's data to argue against the U.S. Radium Corporation being liable for worker illnesses ANL n.d.b).

1934-38 - U.S. Department of Commerce issues series of federal guidelines for radium protection.

1942 - U.S. Radium Corporation expands its facilities and technical and managerial personnel by 1600%. At its peak, the company employs about 1,000 workers (ANL n.d.k).

1943 - U.S. Radium sells its Orange, New Jersey property despite its suspicions about the harmful effects of radium contamination at the facility (ANL n.d.k).

1947 - U.S. Radium Corporation in New York City ends hand-painting of radium dials and utilizes screening machines; one worker can now print 2,000 dials per day as compared to hand painting about 80 dials (ANL n.d.k).

1954 - U.S. Radium Corporation ends its dial-painting operations in New York and transfers its operations to facilities in Morristown, New Jersey and Bloomsburg, Pennsylvania (ANL n.d.k).

1957 - United States Atomic Energy Commission (AEC) initiates studies of living and deceased radium workers to determine safe levels of radium ingestion based on health histories of former radium workers; under AEC contract, New Jersey Department of Health locates 1,000 employees of radium industry and follows 160 cases for 10 years (Eng 1980a:12).

1970 - New ongoing studies by New Jersey Department of Health, MIT, New York University, and others consolidate files and studies under control of Argonne National Laboratory Center for Human Radiobiology, with focus on health effects of ingestion and exposure to radium.

1979 - New Jersey Bureau of Radiation Protection of the New Jersey Department of Environmental Protection (DEP) initiates a study (Eng 1980a) after United States EPA informs New Jersey that "the former radium processing plant in New Jersey might present a radiological problem" (Eng 1980a).

1980 - Eng DEP study documents radon levels at the U.S. Radium site of up to 50 microcuries per liter versus normal background 0.3 microcuries per liter. Near-surface soil samples document areas of "highly contaminated soil with 200-300 picocuries per gram and high nodes of up to 5000 pCi/g" (Eng 1980a).

Post-World War II Research

Rowland's 1994 synthesis of the history of U.S. Radium investigations highlights the range of institutional responses during the pre-World War II emergence of both scientific and governmental awareness concerning potential dangers of radiation exposure to human beings.

After the development of safety standards for human radiation exposure, questions were raised concerning the long-term health problems of individuals exposed to radiation, especially former dial painters. The official United States Government response was to initiate a series of research efforts throughout the country aimed at: 1) forensic investigation of both living and deceased radium workers; and 2) establishing accurate measures of human exposure and absorption. At the institutional level, efforts took place in two stages. First, a series of United States government grants was given to a number of regional medical and university facilities. After 1969, the government integrated these various studies fiscally and administratively within the Argonne National Laboratory under the aegis of the Center for Human Radiobiology (Rowland 1994:31-78).

Resulting institutional developments facilitated an understanding of the significance of U.S. Radium case histories. The emergence of controlled and quantified data from levels and vectors of radiation exposure and absorption, coupled with the definition of modern health standards, provided a contextual framework for the roles played by key investigators and scientists. These efforts were prompted by three issues facing the scientific community at the outset of the studies: 1) because health impacts appeared to occur in response to relatively low levels of radiation exposure, it was necessary to develop new techniques and instruments to provide accurate measurements of radioactive levels below those measurable using simple, crude indices such as relative film fogging or the intensity of "count-per-minute" recordings on a Geiger counter; 2) it was necessary to develop accurate ratios of ingestion versus absorption by establishing what fraction of ingested radioactive isotopic compounds stayed in the body and how much was excreted as by-products of human waste; and 3) given the fact that much of the early research was based on experiments with animals, to what degree did the levels of absorption and response correlate between the two mammal groups? Were equal amounts of exposure to radium of comparable impact on the two groups or, as the research ultimately demonstrated, did humans show adverse health effects at significantly different exposure levels than animals in general, and dogs in particular?

The subsequent 40-year program of laboratory-based investigations saw the emergence of a major concentration of research on the study of human subjects. On the basis of the health problems discovered among the workers at the U.S. Radium plant, a new program for the study of human case histories and their statistical evaluation was initiated primarily due to the efforts of Dr. Evans of the Massachusetts Institute of Technology (MIT). Dr. Evans argued that the analysis of data collected from human subjects on the results of their exposure to and absorption of radium and their associated medical symptoms should be the primary focus of research (Rowland 1994:30). As told by Evans, his premise was that "...the proper subject for the study of man is man" (Evans 1981). Dr. Evans and his colleagues at MIT demonstrated the limited utility of animal studies to the problem of human health (Evans, Harris, and Bunker 1944):

> Per unit body weight, 150 times as much radium was required to produce particular chronic symptoms in the rat as in man (or 250 times as much radium was required to produce the symptoms, expressed as the ratio of radium to calcium in the skeleton) ... and that ... even a few measurements on man must be regarded as overwhelmingly more important in determining the tolerance dosage for man than the most elaborate experiments on animals.

These early World War II-era clinical findings set the stage for spurring governmental decisions to fund human subject research in the field of nuclear and radiation health medicine (Rowland 1994: 30). In turn, this realization provided the historic framework for establishing the significance of the events and health problems affecting early dial painters at the U.S. Radium plant in Orange.

The medical insights on the effects of radioactivity described above, in combination with knowledge gained through the successful development of atomic weapons in the Manhattan Project at the end of World War II, serve to highlight the historic significance of the U.S. Radium dial painters in the development of national radiation health standards and methods of measurement in the United States As argued by Dr. Rowland: "The development of atomic energy implied that employees in the nuclear industries might risk incorporation of alpha-emitting radioelements in their bodies. Thus, the potential risks from the low levels of radium in the survivors of the early radium industry were of considerable interest" (Rowland 1994:30). The living and deceased dial painters at the U.S. Radium plant emerged as one of a small number of controlled human subset sample groups that provided forensic data used by scientific and health medicine professionals as primary evidence for establishing safe human health response thresholds to low-level radiation exposure. From the 1920s on the use of human subjects was important in the pursuit of radiation health studies. However, by 1993 the use of human subjects also led to the end of federal subsidies for radium-related health studies because of modern anxiety over the use of human beings in such research (Rowland 1994).

Although most institutional research after 1946 was funded by the Atomic Energy Commission (AEC), Evans' early work on human exposure to radium was supported by the predecessor of the AEC, the Office of Naval Research, which requested that he continue his human subject research (Evans 1981; Rowland 1994:31). Within a decade, Dr. Evans, together with his colleague Dr. Aub and other team members, published their first study of human dose-response, based on the evaluation of 30 patients who had been exposed to internally deposited radium for many years (Aub et al. 1952). Evans' MIT research program followed several primary courses of inquiry, with a focus on the investigation of the chemical and physical properties of radium, mesothorium, and their daughter by-products. This established that total radioactivity levels in human subjects were a function of the material's age (Rowland 1994).

In addition to work in basic quantitative radiation chemistry, Dr. Evans and his team concentrated on the development and implementation of refined measurement procedures and the accumulation of human case studies. Individuals who had ingested or been exposed to radionucleotides over long periods of time, either as experimental subjects, self-induced recipients of radium water for medical reasons, or as former employees in the early radium industry, were all of interest. During this period, the MIT team switched from the relatively crude measurement capabilities of early Geiger counters to the "newly developed thallium-activated sodium iodide, NaI(Ti), crystal for the detection of gamma rays" (Rowland 1994:31).

Work on humans began with the study of former employees of the Westbury Clock Company in Waterbury, Connecticut, the New England Watcb Company, and the Standard Chemical Company in Pittsburgh. After the termination of the New Jersey Radium Research Project in 1967, accumulated case studies of former U.S. Radium dial painters were added to the sample base of the MIT archive of human subjects (Rowland 1994:51).

Evans' role in the history of radiation biology went far beyond the ground-breaking research in human safety levels. Due to his recommendations, the United States government accepted the importance of studying human subjects which led to the establishment of the Center for Human Radiobiology at Argonne National Laboratory. In a formal paper presented in 1967, and in a position paper entitled "Comments on a National Center of Human Radiobiology" submitted to the AEC later that year, Dr. Evans presented the government with arguments that formed the basis for contemporary radiation health policy and funding. In 1968, the AEC formed a subcommittee to evaluate Dr. Evans' general proposals for future research in radiation health studies and his specific recommendation that a National Center of Human Radiobiology be established to centralize and continue the investigation of human health responses and safety levels for radiation exposure. Out of this effort, the Argonne National Laboratory was funded to continue and expand Dr. Evans' research (Rowland 1994:34). Now centralized, the Center of Human Radiobiology was established in September 1969 with a focus of buman subjects (Rowland 1994). These institutional developments establish the importance of the dial painters of Orange to research efforts. The research led to a new priority placed on incorporating past studies, including those of the radium workers, into a nationwide data bank which became the basis for refining exposure levels. Tbe new center, a result of this research, functioned as a centralized repository consolidating all past research data from different institutional research programs. The Argonne National Laboratory continued early postwar research on human responses to levels of radiation exposure on a much broader scale than had been previously possible.

The 1967 formation of a centralized researcb program at the Argonne National Laboratory built on the earlier research of Evans at MIT and on other programs funded by the AEC at the end of World War II. In fact, one of the primary goals of the new Argonne program was a broad-based effort to identify potential human subjects who had been exposed to radiation in the early radium industry, both before and after the practice of lip-pointing was regulated out of the work place in 1946. The first of these human subject studies involved efforts to remove radium from the body of a former radium employee who had worked with it for a period of 35 years (Rowland 1994).

The decade of the 1950s was an important turning point in the history of human radiobiology for other reasons. Not only did scientists begin a multidisciplinary effort to identify former radium workers across the country, but the recognition of the need to measure and quantify low levels of exposure led to critical new developments in detection instrumentation and electronics. In 1950, the Argonne team began a formal investigation of 32 mental patients who had been given unknown amounts of radium chloride by injection at the Elgin State Hospital in 1931. This human subject study set the stage for a series of long-term investigations which stimulated the search for new cases of radium exposure. In the end, this program elevated the U.S. Radium dial painters into an important sample group for comparative studies (Looney 1955; Rowland 1994).

In his earlier work at MIT, Evans had used a Geiger counter placed directly behind the subject. In the 1950s, L.D. Marinelli, then the Associate Director of the Radiological Physics Division at Argonne, proposed that this traditional, but relatively unsensitive technique be replaced with instrumentation based on the use of the newly developed Nal(Ti) crystal which produced light flashes "...proportional to the gamma energy lost within the crystal" (Rowland 1994:43). In other words, light flashes were produced within the crystal proportional to the gamma ray energy lost within the crystal. This allowed identification of the source of the gamma rays, whether it be background levels or from the decay of radium daughter products. At that time, however, the electronic instrumentation to measure these light emissions was not available, and first had to be built by Argonne personnel. In the early 1950s, an Argonne team was assigned the task of building light detection equipment and associated multichannel analyzers to record and measure the light emissions from the Nal(Ti) crystal. Over the same period, the crystal had been refined and larger crystals produced (increasing from 1.2 inches diameter in 1952 to 8 inches in 1956) which would be sufficient for measurement of subtle light emissions due to gamma radiation (Rowland 1994:43). Only after these technological hurdles had been passed was it possible for the scientific community to make accurate measurements of the relatively low-level radiation being studied in human subjects. After these techniques were available, it was finally possible to begin setting accurate absorption and health and safety levels.

In conjunction with these developments at the Argonne National Laboratory, additional investigations were aimed at establishing the amount of radium retained in the human body after ingestion. Argonne researchers used the sample of mental patients from the Elgin State Hospital as a core sample group that was of pivotal importance and had been studied and reported on by Schlundt, Nerancy, and Morris in 1933. The Argonne researchers determined that the injections given to the patients contained 10 microcuries of radium. On the basis of these known samples, other Argonne researchers developed the formula for characterizing radium retention in the body over time (Norris et al. 1955; Rowland 1994:47). This early quantitative research facilitated the later determination of human retention levels of radium and other related radionucleotides. As a result, between 1960 and 1969 investigators worked on a series of experiments which culminated in the determination that the "... absorption of radium from dial paint was on the order of 20%" (Dudley 1960; Maletskos, Keane, Telles, and Evans 1966; Rowland 1994:32). These findings underscored the critical need to expand studies with additional controlled data from human subjects.

Concerted efforts to identify and evaluate former radium workers and dial painters were initiated in 1957. The AEC funded the New Jersey Radium Research Project, under the aegis of New Jersey's Department of Health, whose purpose was to identify and locate former dial painters, reconstruct their work, and accumulate medical and dental histories in the metropolitan areas of New Jersey, New York, and Philadelphia (Rowland 1994:51). Because the Department of Health lacked appropriate facilities, the actual investigations were subcontracted to other institutions. The investigations included whole-body studies at New York University Medical Center, the Department of Physics at MIT under Dr. Evans, and Argonne National Laboratory (Rowland 1994:54):

When the project started, the names of two individuals thought to be living in the area were provided by the U.S. Radium Corporation. A list containing 83 of the corporation's employees [out of a sample of over 200] dated to 1921, was obtained from the files that had been transferred by the corporation to the radium program at Argonne ... By the end of the program in 1967, 978 names were in the files ... of these 328 were alive, and 269 were dead ... of the 978, 520 had been employed as dial painters, 80 as laboratory workers. Out of this large sample, members of the multidisciplinary team were able to interview a total of 161 cooperative former radium workers (Rowland 1994:53). Parallel efforts to expand the sample of former radium workers were initiated independently in 1957 by an investigator named Miller at the Argonne National Laboratory. The efforts resulted in measurements of 92 human subjects for body burdens as well as X-rays. On the basis of these data, Miller "...observed that the individuals who started work after 1925 had low radium body burdens, and his search efforts concentrated on women who had worked as dial painters before 1925" (Rowland 1994:54). This focus continued, unchanged, until 1969 when Dr. Rowland, co-director of the Center of Human Radiobiology, shifted the coverage to encompass all employees of the dial industry, suggesting all were equally important to the program's research goals. By the end of the program in 1990, 2,403 former radium workers were measured, of whom 96 were diagnosed as having developed some form of radium-induced cancer, either carcinomas or sarcomas (Rowland 1994:68, Table 4).

SOCIAL HISTORY

The readily available data on the social impacts caused by the operation of the U.S. Radium plant are limited and conclusions drawn from them are primarily inferential. In addition to the physical health impacts on the dial painters and other workers at the plant, the facility's operation appears to have had identifiable economic, social, and perhaps psychological impacts on many individuals in the surrounding Orange community.

Although Orange had been maintained by a thriving hat industry in the last quarter of the 19th century, by 1910 the working-class piece workers who lived in the vicinity of the plant had fallen on hard times (Picillo 1980:17). Two late 19th century economic downturns in the hat industry had left many of the workers unemployed or in insecure temporary jobs. A "terminal strike" by hatters between 1909 and 1911 left the local economy floundering for much of the next decade.

With American involvement in World War I, many of the male work force were drafted. Because of the resulting scarcity of male workers, the newly opened radium plant on High and Alden Streets hired out of necessity many of the young women of the community (Wall 1969). Fortunately for the U.S. Radium Corporation, many of the young working women had previous experience in the use of finely pointed brushes, gained while painting designs on porcelain vessels for a ceramics business formerly located in the area (Bensman 1977). Experienced ceramic design painters could easily transfer their talents to the painting of instrument dials. Thus, the U.S. Radium plant not only had access to existing industrial buildings (the former Bulkley Iron Works), trans-national railroads, and electric and water utilities, but also a local pool of unemployed, trained female workers.

Local Economic Impacts

The economic impact of the opening of the U.S. Radium plant on the local working population was significant. Throughout the last quarter of the 19th century, annual income of the hatters was no more than $500 per year (Bensman 1977; Picillo 1980:17). In comparison, the lucrative nature of dial painting is illustrated by figures cited by the Production Manager of the U.S. Radium Corporation in a letter dated October 18, 1920 to a female job applicant. The manager writes: "...operators on piece work are making as high as $36.00 per week..." (ANL n.d.n). When multiplied by 52 weeks, this rate translates into an annual income of around $1,872 dollars, more than three times that made by the male heads of families who worked in the hat industry. It was from those families that many of the dial painters, primarily female, came. Assuming a figure of 300 dial painters per year employed at the U.S. Radium plant during the period 1917-1921, the income infusion into the local community for that period was significant, reaching approximately $561,000 per year (300 people x $1,872.00).

When evaluated in terms of family units, the effect of this increased income is even more marked. In 1920, the population of Orange was 33,268, up from 21,000 at the turn of the century (Williams 1937:29). Assuming a nuclear family size of four to five individuals, the census data suggest that a total of approximately 7,500 families resided in the town, of which 200-300 families had a member who was a dial painter. The cash infusion, therefore, represents a threefold increase in income for approximately one out of every 25 to 30 households.

Public Health and Social Impacts

In 1979, the first official governmental investigation of the U.S. Radium site was conducted after that agency was notified by the USEPA that the facility "might represent a radiological problem" (Eng 1980a:10). The study reported on the results of field tests that showed elevated radiation levels in collected air and soil samples. It concluded (Eng 1980a:64):

> The radiological measurements indicate the site is contaminated and that there is a slight risk which can be attributed to long term exposure. The retrospective evaluation of past exposure (1935-1979) indicates that no large scale public health problem has occurred and that the small number of people involved, less than 3,500 person years, would make a clinical epidemiological study inconclusive.

In contrast to these conclusions, however, the plant does appear to have had physical health and psychological impacts on the post-World War I Orange community. The Grossman and Associates (1997:117) study of the U.S. Radium facility suggested that the health impacts on the surrounding community may have been greater than initially understood for several sampling-related reasons:

- The use of the term "large scale" is ambiguous and undefined relative to community and regional population levels.
- The time frame used (1935-1979) for the evaluation of past exposure post-dates the four-year period (1917-1921) of greater exposure for the approximately 300 dial painters and the surrounding community.
- There is no evidence that the local community beyond the area immediately adjacent to the plant was studied; nor was any effort made to identify, sample, or test the houses of workers.

The post-1935 sample used for the NJDEP study, which post-dates the period of peak radium production at the plant, may not be relevant for assessing potential health impacts on plant workers employed between 1917-1921, the period of peak radium production, or their families.

Published accounts make it clear that at least some members of the community were concerned about the foul odors, soiled laundry, and possible effects of the U.S. Radium plant operation on the health of local school children as early as the start of the 1920s. During that period, the town proposed a plan to build a school in the vicinity of the U.S. Radium plant, but subsequently withdrew it because of the perceived unhealthy conditions around the facility (Kisslinger n.d.). In addition to being aware of air pollution, many in the community of Orange were also aware, by the middle of the 1920s, that a noticeable number of women dial painters had died or were sick with anemia, severe and unhealing dental and jaw infections, maternity problems, and other illnesses not diagnosed (Clark 1993; Keller 1969). By 1925, seven former dial painters who had lived in the community had died, by 1933 twenty-two painters had died, and by 1949, a total of 44 individuals who had previously worked at the plant were dead (Keller 1969). By the 1940s some 40 families totaling 160 to 200 individuals had suffered the loss of an immediate relative. When compared with the approximately 8,200 families in a population of 37,000 living in Orange in 1940, the social impact of radium-related deaths is striking, affecting approximately one out of every 205 families. This ratio constitutes approximately one half of one percent of the families living in Orange in 1940. The 40 families mentioned above represent a statistically large and significant percentage of the estimated total number of families who had had a member working at the plant between 1917 and 1926. These figures do not take into account the number of individuals who became ill as a result of their employment at the U.S. Radium plant but did not die, nor the impact that those illnesses had on their families. In comparison, data from the U.S. Bureau of the Census (1995) show that in 1994 approximately 0.08 percent of the families then comprising the U.S. population were affected by the death of a family member from AIDS.

Other lines of documentary evidence suggest that secondary health impacts on the workers and their immediate families were extensive, and certainly evident, by the early to mid-1920s. As part of his field studies (1924-1925), Dr. Swen Kjaer submitted detailed questionnaires to a sample of the Orange community; the replies document a sense of concern and perception of loss by local citizens prior to 1924. As documented in the case studies reproduced by Grossman and Associates (1997:Appendix A) of this report, in addition to describing the pain, deformities, loss of stamina, and/or death experienced by former employees, family members expressed concern over loss of sexual and emotional companionship, abnormal births, and other disorders (Kjaer n.d.b, n.d.c; see Grossman and Associates 1997:Appendix A). Kjaer's records and notes were used as evidence by former dial painters and their relatives who sought redress for their suffering in subsequent litigations. One case in particular stands out for its implications about the scope of health impacts. The case, documented by Dr. Kjaer in 1925, involved a former dial painter's sister who had reportedly died from radiation exposure but had never worked at the U.S. Radium plant. The source of contamination appears to have been her sister, the dial painter, with whom she shared a bed (Kjaer n.d.a; see Grossman and Associates 1997:Appendix A).

The existence of secondary health effects on family members of radium workers due to emotional stress is also indicated by court documents relating to a law suit filed by the husband of a former dial painter in November of 1929 (Keller 1969:17). The husband claimed damages from the U.S. Radium Corporation due to loss of companionship and sexual liaison because his wife was permanently disabled from radium-induced illness.

Media and Public Awareness

Contemporary newspaper coverage played an important role in raising community awareness and concern beginning with the announcement by the New York Times in May of 1925, and later by the local press (Keller 1969), of the deaths of five women workers from the U.S. Radium plant and the fact that ten other former dial painters were sick with similar illnesses. Despite short-term effects of this news, there was apparently only limited coverage of events concerning the U.S. Radium facility during the remainder of the 1920s (see Grossman and Associates 1997). Only after the announcement by the Atomic Energy Commission and associated organizations of a concerted program to study former dial painters did newspaper coverage increase.

Possible Regional Impacts of the U.S. Radium Operation

There are indications that the radioactive slag by-products from the U.S. Radium facility were used to fill three locations in the nearby communities of West Orange, Glen Ridge, and Montclair, N.J. (see Grossman and Associates 1991). The three areas together comprise approximately 210 acres of radiologically contaminated fill, 5 to 15 feet thick.

Accounts indicate that the U.S. Radium facility was processing a half ton of ore per day (Wall 1969; Siebert 1979). Assuming a six-day work week, this amounts to 156 tons of processed ore and spoils produced each year. Assuming that this rate of production was constant from the facility's opening in 1917 to its closing in 1926, an accumulation of approximately 1,700 tons of radioactive spoils, predominantly in the form of uranium slag, would have been generated and would have required disposal. Given the relatively small area of undeveloped land at the U.S. Radium plant which could be used for storage, so large an amount of radioactive waste would have had to have been disposed of off-site, possibly at the Montclair, West Orange, and Glen Ridge radioactive landfill sites. There is no other known source of production of this large volume of radioactive ore spoils in the region at the time.

PART V - HISTORICAL SIGNIFICANCE OF THE U.S. RADIUM SITE

HISTORICAL SIGNIFICANCE OF EVENTS THAT OCCURRED AT THE U.S. RADIUM SITE BETWEEN 1917 AND 1926 - SUMMARY

The historical significance of the U.S. Radium site is due to the events that occurred at the facility between 1917 and 1926, and their subsequent consequences. These can be divided into three categories:

- **Health and Safety Standards/Worker Protection.**

The dial painters' discovery of their radium poisoning, and the efforts of researchers like Robley Evans, Harrison Martland, and Swen Kjaer to understand the sickness, led to the emergence of public, governmental, and scientific awareness of the dangers of radiation to public health. This awareness, fostered by the advocacy of the Consumers' League, led to the subsequent development of national health standards and guidelines for workers in the radiation industry. Since 1949, investigation of the medical history of the former dial painters by agencies of the U.S. government involved with the development of safety standards for radiation exposure has continued, indicating the importance of the original data set. For the U.S. Radium dial painters, this awareness of the hazards of radiation was instrumental in the implementation of health protection practices for workers handling radioactive industrial materials in the radium industry and, subsequently, other radiation-related industries. The formulated federal health and safety standards and protective guidelines, in association with contemporary New Jersey State and New York State guidelines and statutes, represents the first large-scale involvement of government in issues of worker protection. The efforts of researchers like Evans and Martland also led to the creation of institutions to study the effects of human exposure to radioactivity and to the invention of instruments still used to detect and measure radioisotopes.

Clark (1997) has produced a detailed study addressing the role of radium dial painters in industrial health reform between 1910 and 1935.

- **World War I Military Applications.**

The documentary record provides insights into the military application of radium and related products beginning with World War I. A major portion of U.S. Radium production was apparently associated with military contracts involving the application of luminous compounds to gun sights, naval and air instrument dials, and government issue watches for soldiers. The company also considered, and possibly conducted research on, the use of radium in the production of nitrate-based explosives. Military applications apparently constituted most of the firm's business, at least through the end of World War I, and possibly thereafter. The importance of military applications for U.S. Radium Corporation business contrasts with the assumed notion that the firm was primarily dedicated to the production of watches with luminous dials for the public and private sectors of the economy.

These aspects of U.S. Radium site's significance are addressed in more detail below:

Recognition of Radiation Illness as a Significant Public Health Hazard

The onset of adequate health and safety standards in the radium industry in the U.S. lagged behind comparable developments in Europe by nearly a decade. Government health and safety recommendations in this country were developed only after pressure from advocacy groups and the growing public awareness of the medical plight of many of the former dial painters forced state and federal agencies to act, resulting in the official Department of Labor investigations between 1925 and 1928. Delay in government action was also apparently caused by the U.S. Radium Corporation's efforts to impede investigators through: 1) the loss or destruction of records; 2) tampering with on-site evidence; 3) attempts to intimidate the initial medical investigators; and 4) misrepresenting the findings of the initial investigators to state and federal agencies between 1924 and 1925.

The efforts by the staff of the Consumers' League, beginning in 1922, with help from a limited number of allies in the dental and medical professions, on behalf of the dial painters resulted in the establishment by the Department of Labor in 1928 of the first health and safety standards for radiation workers. The formulation of these standards along with the application of New Jersey State workers compensation laws to ill former dial painters led directly to the increase in national awareness of the hazards of the radiation industry. This prompted still greater federal efforts to protect workers in the radium industry in the 1920s and 1930s.

The public health risks of the contamination that occurred at the U.S. Radium site continue to the present. Because the well-defined time frames of dial painter exposure to radioactivity were seen by the scientific community as reconstructible, and thus a controllable variable, the U.S. Radium worker case studies continue today as an important data set for modern nuclear medicine and health investigations currently being conducted under the organizational umbrella of the Nuclear Regulatory Commission and its designated lead agency, Argonne National Laboratory. From 1949 to the decade of the 1980s, all research on former U.S. Radium employees was consolidated at Argonne National Laboratory. Research included the acquisition and evaluation of all existing worker records and case studies. These documentary and forensic data bases are the principal source of information on radiation illness for the period prior to World War II and continue to provide information for evaluating the long-term health effects of radiation exposure. The dial painter sample population, many individuals of which are still living or have died only recently, is the oldest study group available for scientists concerned with these issues.

Relevance to World War I Military Production

Although it has been assumed that the U.S. Radium Corporation was principally involved in the production of luminous watch dials for the public and private sectors, the results of the study by Grossman and Associates (1997) suggest that, at least for the period of World War I, the plant's production was directed primarily towards military applications. In addition to watch dials for soldiers, production activities included the painting of airplane and ship instrument dials, gun sights, and other categories of unidentified military equipment and machinery that was regularly shipped by the government to the factory for luminous paint application (Wall 1969).

This investigation has also indicated the potential importance of radium compounds in the production of explosives during World War I. According to Sochocky (1921), the original founder and lead scientist at the U.S. Radium Corporation, the use of radium in nitrate-based explosives permitted a 20-30 percent reduction in the cost of production compared with traditional techniques of explosives manufacture.

Prior to American involvement in World War I, and after its conclusion, the numbers of dial painters employed at the plant did not exceed a dozen, apparently adequate to meet peace time commercial needs. However, during the war years, the time of peak plant employment, the number of dial painters fluctuated between 200 and 300. These numbers indicate that approximately 95 percent of the peak work force was involved directly or indirectly with the production of luminous dials for war-related activities.

Within this context, the activities of the U.S. Radium Corporation are significant for understanding the importance of radium and non-nuclear radioactivity to the waging of World War I, long before the development of bombs based on nuclear fission during the Second World War.

Significance of Surviving U.S. Radium Corporation Buildings

The architectural assessment of the surviving U.S. Radium facility buildings by Grossman and Associates (1997) indicated that only two of the standing structures - the two-story former dial painters' building and portions of the cinder block Radium Crystallization Laboratory - contain structural elements contemporaneous with the U.S. Radium Period of operations at the site.

Although the structures have been impacted by later alterations and industrial uses, limited portions retain their U.S. Radium Period integrity. They are contributing elements of the property's significance which derives from the events that occurred there between 1917 and 1926, and their subsequent consequences (see above).

Among recognized structural and architectural forms of early 20th century industrial plants (see the 1999 recordations HAER No. NJ-121A and HAER NJ-121B), these buildings are somewhat unusual in their resolute absence of style and, especially in the paint application building, a structural system usually seen in inexpensive, auxiliary one-story buildings. The use of concrete block could reflect a wartime shortage of steel, because more steel was usually used in reinforced-concrete structures. It is possible that the Radium Luminous Materials Corporation decided to expand so much and so fast in response to wartime contracts that the most quickly-built design was chosen. Brick bearing walls would have served as well structurally, but would have taken more time to erect.

PART VI - SOURCES OF INFORMATION

ORIGINAL DRAWINGS

United States Radium Corporation operations are poorly documented in available drawings. The only drawings contemporary with plant operations indicated are a few sketches of one or more equipment arrangements in an unidentified structure which is probably the crystallization laboratory (ANL n.d.q:Microfilm 7). It is not known which, if any of these arrangements were actually installed. The most detailed plan of spatial and functional plant arrangements appears in a sketch plan with notes created during a 1979 interview with an unidentified facility superintendent who worked during the early 1920's (Siebert 1979).

Another contemporary drawing of the Orange plant is a site plan prepared for inclusion in the 1926 "Factory For Sale" notice of the U.S. Radium Corporation (ANL n.d.r).

HISTORIC VIEWS

A small number of photographs taken during or shortly after U.S. Radium Corporation operations at the Orange, New Jersey facility survive in archives of the Argonne National Laboratory, six of which were xerographically reproduced for inclusion in this work. Available finding aids for this archive do not specifically locate these views, which were obtained by Grossman and Associates 1997 during an earlier phase of this documentation. Another historic view of the front of the plant was included as part of the 1926 "Factory For Sale" notice of the U.S. Radium Corporation (ANL n.d.r).

For further information on historic views of the U.S. Radium site, as well as on other site related data, contact Dr. Carol Giometti, BioSciences Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439, Telephone #: (630) 252-2000.

INTERVIEWS

Dr. Joel Grossman of Grossman and Associates (121 Essex Street, New York, New York 10002), Principal investigator for the 1997 study from which this Historical Narrative is drawn, interviewed by telephone and correspondence Dr. R.E. Rowland, Environmental Research Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439, Telephone #: (630) 252-2000. Dr. Rowland, former director of the Center for Human Radiobiology at Argonne National Laboratory, is an expert on the effects or radium in humans and on the history of radium studies in the United States. Dr. Joel Grossman interviewed and, for a time, worked with Dr. Claudia Clark on his 1997 study. Dr. Clark is an assistant professor at Central Michigan University. She completed her dissertation on the U.S. Radium Corporation (at

Rutgers University) and is an expert on the industrial processes that were conducted there and on the health history of its workers.

Dr. Joel Grossman interviewed Mr. Edward Lander of the United States Geological Survey, Reston, Virginia. Mr. Lander is an expert on radium industry processes.

Dr. Claudia Clark (see Clark 1993, 1997) interviewed Dr. William Castle (Harvard Researcher investigating health conditions at the U.S. Radium plant - see Castle, Drinker, and Drinker 1925) and Florence Wall (Laboratory Assistant, U.S. Radium Corporation, Orange Facility), and others.

Patricia A. Siebert of Argonne National Laboratory conducted interviews with individuals who worked at the U.S. Radium Corporation, Orange plant during the period 1920-1925 (see Siebert 1979). Information from that interview was included in the 1997 Grossman and Associates report.

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Dr. Claudia Clark's 1997 work on the radium dial painters was published after the Grossman and Associates (9197) study was completed. Clark's work is an exhaustive study on the history of radium dial painters in New Jersey, Illinois and elsewhere and their role in industrial heath reform. It also contains a comprehensive bibliography on radium/dial painter related issues and locational information for relevant primary sources. Another excellent bibliography is included in Rowland (1994).

Additional documentary data identified but not included in the Grossman and Associates (1997) report are housed at the following repostories:

Center for Human Radiobiology, Argonne National Laboratory, Argonne, Illinois (contact: Christopher A. Reilly, Director, Environmental Research Division) -
Robley Evans Papers; Commissioner Harris (New York City Health Department) Correspondence Files; Swen Kjaer (Department of Labor investigator) Papers; Medical Files; New Jersey Department of Public Health Files on Everett Field; Radium Archives, U.S. Radium Corporation Records.

Harvard Medical School, Harvard University, Boston, Ma. -
Francis A. Countway Library of Medicine
Reference Desk, Historical Section (contact: Mr. Dick Wolf)
Archives of the Francis A. Countway Library of Medicine
Industrial Hygiene Department Records
Physiology Department Records
Frederick Shattuck Papers.

University of Medicine and Dentistry of New Jersey, Newark, New Jersey -
Special Collections and Archives, University Libraries (contact: Ms. Barbara Irwin and Ms. Lois Densky-Wolff); Harrison Martland Papers.

Newark Public Library, Newark, New Jersey - Radiation and Radium Clipping File
New Jersey Historical Society, Newark, New Jersey - Women's Club of Orange Records.

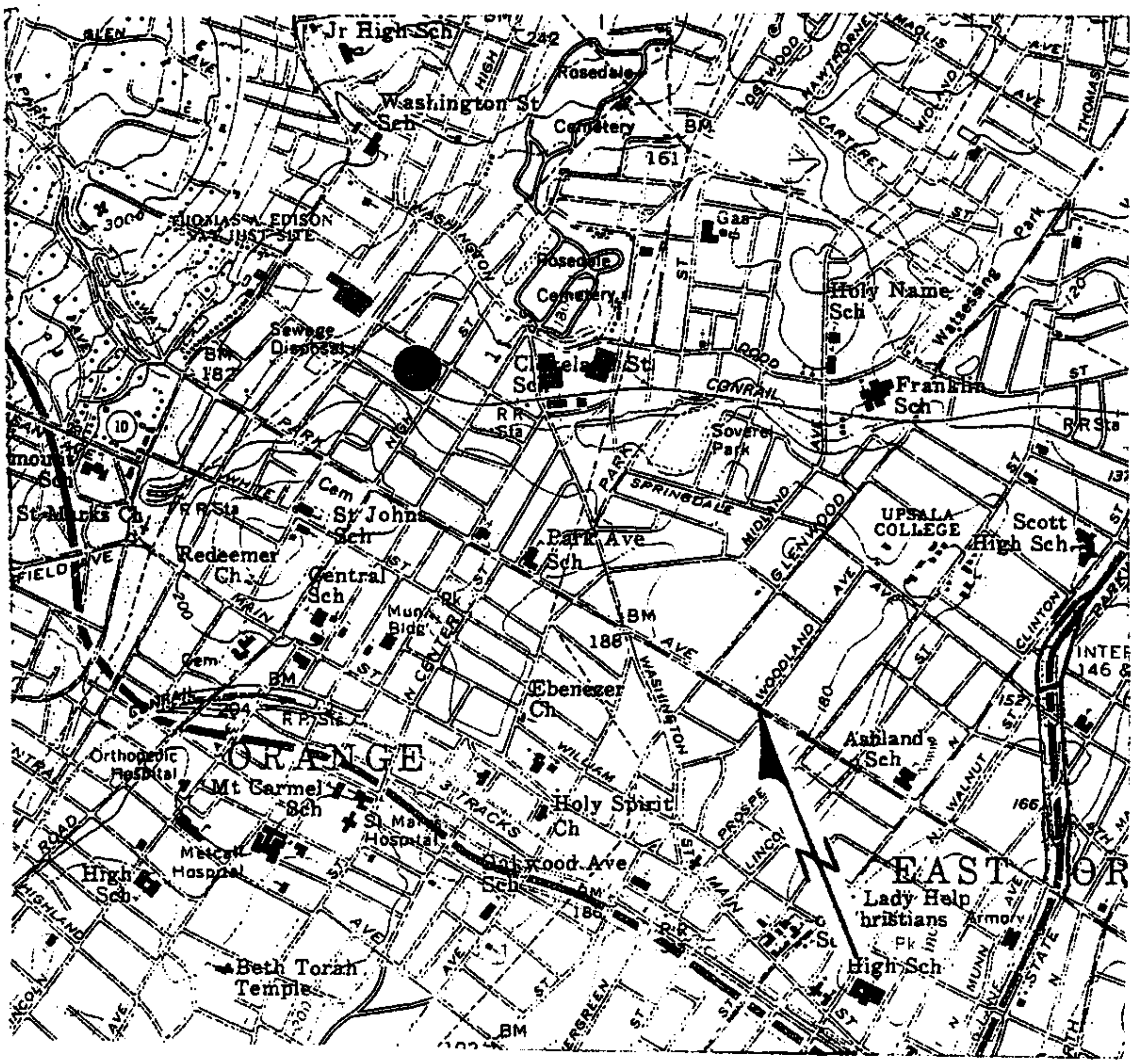
Rutgers University Libraries, New Brunswick, New Jersey -
Special Collections and University Archives
Consumers' League of New Jersey Papers, League of Womaen Voters of New Jersey Papers.

School of Public Health, University of Illinois at Chicago, Chicago, Illinois (contact: Dr. Russell Mulner).

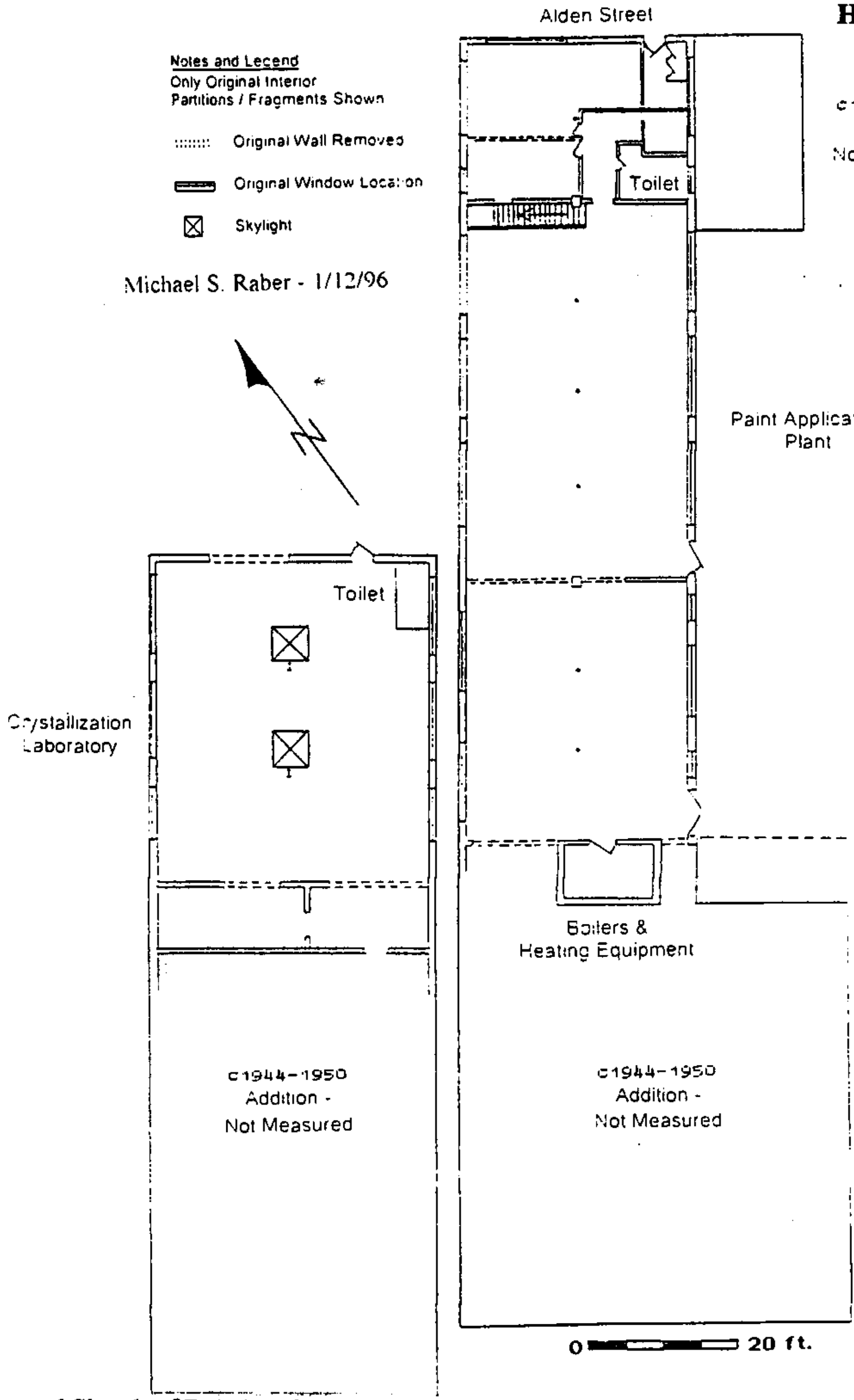
Other repositories of U.S. Radium related data identified by Clark (1997) but not reviewed for the 1997 Grossman and Associates study:

Schlesinger Library, Harvard University, Cambridge, Ma. -
Alice Hamilton Papers; Hamilton Family Papers.

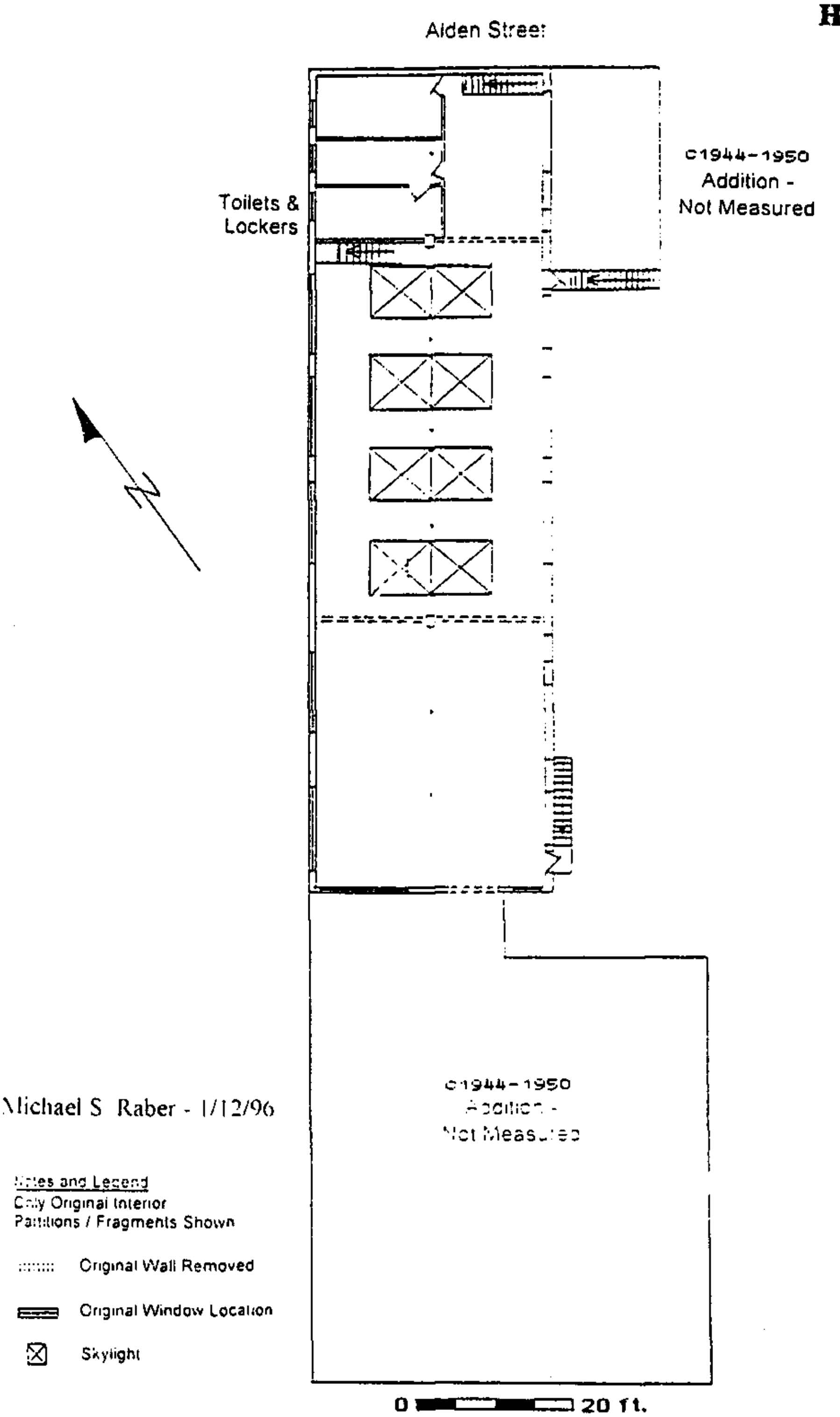
The New York Public Library, New York, New York -
Astor, Lenox, and Tilden Foundations, Rare Books and Manuscripts Division
Florence Kelley Papers.



U.S. Radium Corporation Site
Base Map Source: United States Geological Survey 1981
Scale of Original: 1:24,000



Measured Sketch of Existing Conditions on the Ground Floors of the Former Paint Application Building and Radium Crystallization Laboratory



Measured Sketch of Existing Conditions on the Second Floor of the Former Paint Application Building