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THE RADIUM INDUSTRY IN THE UNITED STATES

> Practically all of the carnotite ore mined in the world in 1912 was shipped abroad and . . . this country was furnishing annually nearly three times as much radium from its Colorado carnotite deposits as all the rest of the world put together. It was further pointed out that this material has been bought by European buyers at a price entirely incommensurate with its radium value and that efforts should be made to keep at home both the radium itself and the profits of its manufacture.
>
> **—Charles L. Parsons, 1913**

IN 1921 THE *NEW YORK TIMES* PUBLISHED A PAGE-LONG ARTICLE ON "The Story of Radium" explaining "how America took the lead" in radium mining. The article's leading figure was Pittsburgh entrepreneur Joseph Flannery, who, a decade earlier, via his company Standard Chemical, had spearheaded a shift within the United States from mining vanadium to mining radium, applying all "his time and talents to its production."[1] He was not alone. Joined by his brother James Flannery, he had established the Flannery Bolt Company in 1904. A couple of years later, the two wealthy brothers founded the American Vanadium Company, signing lucrative contracts with the Ford Motor Company. James was the president of two Pittsburgh banks, and the brothers were well connected in business and political circles.[2] At the time, carnotite ore was mined for uranium and vanadium, which was mostly used in the steel and glass industries. But carnotite also became a source of radium, and the Flannerys pounced on this new challenging mining business.[3]

While the Flannerys were trying to set up the radium industry in the United States, Marie Curie and her colleagues in Paris were pioneering the use of radium in cancer therapy, pushing its value upward and driving a worldwide search for radium. In Europe, large uranium mining areas, including at St. Joachimsthal in Bohemia, switched operations to focus on the extraction of radium-containing ores. The Austrian government took steps in 1912 to establish a monopoly over radium supplies. It was then that large US companies took note.[4] To these companies, already active in mining vanadium, uranium, and copper in the southwestern Colorado Plateau and Utah, the emerging commercial opportunities in the new element were already apparent.

Radium rapidly became the new century's most promising material: great expectations and hopes surrounded its use as an unlimited energy source and as a powerful medical therapy, not least for the treatment of cancer—about which concerns were growing.[5] The Standard Chemical Company, founded by Flannery in 1911, rose quickly to the dominant position within the US radium industry. This company is the focus of this chapter, through which I explore the unique commercial exploitation of radium in the United States in the early twentieth century. Having secured a monopoly in radium mining, Standard Chemical then entered the medical radium market. This was crucial for its development and paved the way for the company's expansion into the radium painted watch industry in the mid-1910s.

In these early days, the company's major business and branding strategy was to transform the conversation about radium into a serious and earnest scientific and medical narrative, while downplaying earlier popular notions of radium as a "magical" element. Familiarizing the American public with radium meant developing a novel scientific discourse about its benefits in medicine and its large-scale commodification.

In sharp contrast to Europe, where radium production and use were bound by state monopoly so as to reserve its supplies for research laboratories and physicians, US private corporations, with Standard Chemical in the lead, tightened their grip on radium. From mining to the market for medical and radium-based commodities, they fended off attempts by the US government to follow the European model.[6] Eventually, Standard Chemical established a monopoly over it, keeping medical radium at the top of the company's agenda. Indeed, in the United States, companies fought fierce battles for dominance in the radium business, having commercialization developing hand-in-hand with commodification. As a result, the process of bringing new radium products into the market, transformed radium into probably the most familiar commodity of the interwar period.

By the 1920s, 80 percent of the world's radium came from the United States, which meant that it was now the world's leading radium producer and ahead of its European counterparts.[7] This was all the more remarkable given the technical challenges of extracting radium from US carnotite deposits, whose yield was typically much less than in Europe. For example, 500 to 600 tons of Colorado ore produced only 1 gram of radium; in Europe the same amount of radium could be obtained from just 5 to 6 tons of ore. An additional challenge was transportation. The Paradox Valley on the Colorado Plateau, which contained the largest deposits of carnotite, was 65 miles away from any railroad and in an extremely mountainous terrain. Yet, to the advantage of the United States, the process of extracting radium from carnotite ore, which involved complex chemical processes, had not been patented by Europeans.[8]

Still, transferring existing laboratory processes to large-scale production entailed daunting efforts. Most US radium companies, including Standard Chemical, whose radium operations ran from mining to market were in urgent need of experienced chemists and physicists. So they turned to major European universities and laboratories for help, only to find out that the few experts working in European mines were unwilling to relocate to Colorado's far-flung wilderness. Despite the challenges, Standard Chemical rose to commercial success, becoming the major actor in an economically important sector of the US economy. It furthermore wielded political influence, for instance, in congressional hearings and shaped public attitudes toward health and everyday life.[9] The political intrigues and early science policy debates of the 1910s became the basis for an extensive monopolized industrial development of radium research and commodification.

In dealing with the unprecedented challenges of mining and refining radium, US companies such as Standard Chemical took scientific research far beyond the academic laboratories that were historically the main centers of experimental research. Those holding rights (or "mining claims") to mine radium-containing carnotite ores had no other option but to set up laboratories in remote locations. They also had to offer the sort of salaries that would entice radioactivity experts to these locations.[10]

This kind of on-site or in-house research, which became a hallmark of American radium companies, was not new. Rather, in-house research by large corporations had emerged early in the twentieth century as a key competitive strategy against rival firms. Several companies, notably within the pharmaceutical, electrical, and petroleum industries, had been quick to establish research laboratories, including the explosives manufacturer DuPont and Thomas Edison's Menlo Park, regarded as the first industrial research laboratory. Indeed, Edison and DuPont broke new ground in using research and development to pursue corporate objectives.[11] With teams of first-rate physicists, chemists, and engineers and very well-equipped laboratories envied by academic scientists, these industries were among the most successful commercial enterprises in the United States. World War I provided a powerful spur for industrial research and contributed further to the gradual realization by business leaders that science and scientists were valuable assets. In-house laboratories became an integral part of commercial strategy, as did innovative schemes such as fellowships and consultancies designed to build links with universities and attract scientists into industry.

The US radium industry followed in this tradition. Yet the firms that dominated mining and radium extraction throughout the 1910s—Standard Chemical Company, the Radium Company of America, and the American Rare Metals Company—have largely evaded the historical record. There has been surprisingly little research on the emergence and the development of the radium industry in the United States. Furthermore, the striking contrast with its European counterpart remains poorly understood.[12] This is all the more remarkable since the US radium business affords rich opportunities for examining the development of in-house and laboratory-based research in an industry that was shaped by commercial interests and goals. The Standard Chemical Company in particular had vast financial resources. This allowed it to invest in infrastructure such as railroad lines, factories, and settlements for its workers in previously isolated and inaccessible areas. Flannery was determined to turn his comprehensive vision of a radium business that could expand from mining carnotite ore to marketing radium products into a reality. To do so Flannery not only amassed immense economic power but sought to ensure political influence on a state level and to shape public opinion through innovative mass media campaigns in newsreels and newspaper advertisements.[13]

At the same time, the success of the radium industry posed a distinct set of problems to physicians and academic scientists. They worried about the supply of radium and losing access to it for research and medical purposes, not least in cancer therapy. These concerns fueled their efforts to establish a federal radium monopoly and state-controlled radium production. To this end, they also sought to enlist the support of major hospitals, to lobby politicians and key state administrators, and also to engage with the public on this issue through press conferences on the medical potential of radium, particularly in cancer treatment.

This set the scene for a battle over the supply and governance of radium in the United States, a battle won in large part by radium concerns, notably Standard Chemical, the country's largest radium company. But while the radium industry expanded, and more radium products filled the market, little attention was paid to the dangers of radiation exposure, which were increasingly coming to light in this period.[14] Radiation "protection" was not a priority in the radium workplace, be it the mines in Colorado or the urban laboratories and factories of radium companies such as Standard Chemical in Pittsburgh. It seemed that business priorities and goals trumped concerns about the dangers of radiation, which had long remained unproven and contested in a country in which business operated largely free of health and safety regulations.[15]

Mining in Paradox Valley, Colorado Plateau

The first systematic attempt to extract radium in the United States was made by the American Rare Metals Company and its subsidiary, the Rare Metals Reduction Company. In 1900 the company director, Stephen Lockwood, an attorney from New York, brought back samples of carnotite ore from Richardson, Utah. Two years later he published the first radiographic plate from this American ore in the *Engineering and Mining Journal*. As a result, the company set up an experimental plant in Lackawanna, New York, in 1903. But there was also a need for scientific expertise, and to this end Lockwood contacted Alexander Hamilton Phillips, a mineralogist at Princeton University, and George Pegram, a physicist at Columbia University. He also started corresponding with Pierre Curie, asking him to disclose details of his radium extraction process.

In the meantime, Lockwood asked Bertram Boltwood, a chemist who offered consultancy services from his private chemical laboratory, to analyze carnotite samples and measure their radioactivity. But carnotite proved disappointing as a source of radium: the huge costs of extracting radium through fractional crystallization left little margin for profit.[16] So the Rare Metals Company gradually ceased operations, and Lockwood donated portions of his radium-barium sulfate concentrates to Columbia University and the Smithsonian.[17]

Large-scale carnotite ore mining in the United States began only in 1911, when Joseph Flannery incorporated Standard Chemical under the laws of the State of Delaware. Flannery was also involved in vanadium mining and produced vanadium alloy steel. As vanadium's main producer in the United States, he persuaded General Goethals, in charge of building the Panama Canal, to use his product for the canal's lock gates. Impressed by the qualities of this metal, Henry Ford used it to build motorcars. After World War I, Flannery acquired major shares in the General Vanadium Company and controlled large deposits of vanadium ore in Peru.[18] But radium mining was just one part of the Flannery business enterprise.

At the time American carnotite ore was mined mainly in open pits. Though extensive, the deposits were patchy, near the surface, and accessible to open-pit mining, which involved removing large quantities of overburden and waste rock. Standard Chemical was the first to drill for deeper deposits in Paradox Valley, where Flannery had his radium claims.[19] Acquiring radium was a complicated, painstaking, and very expensive process. Underground mining, for instance, involved building access tunnels and shafts that raised the price of the final product. The ore mined by Standard Chemical was hand-sorted, placed in sacks, then hauled down the hillside trails by mules. Two short documentary films about Standard Chemical operations, produced in 1913 for promotional reasons, show miners shoveling up the ore, scraping the radium-bearing sediment from metal sieves, and packing the ore into sacks with bare hands. When full, these sacks were then picked up by trucks or wagons and hauled ten to forty miles to the company's concentration mill near the San Miguel River.[20] The river was diverted to provide adequate water supplies for the operations, and major building work was carried out to service the mining operation, including the construction of a two-story boarding house that provided accommodation for the thirty men who worked in the mill, and occasionally their families.

The mill was designed to extract uranium from the ore. The extraction area was usually located near the mines to reduce transport distance, but processing was difficult and costly because all the new sites on the Colorado Plateau were far from the railway. At the mill, the ore was crushed and leached with sulfuric acid, a process that extracted not only uranium from the ore but also vanadium, iron, and lead. The uranium was then extracted from the leaching solution. The end product of the work in the mill, known as "yellowcake," was again hand-sorted, weighed, and packed in canvas sacks. The yellowcake was then hauled by wagon—and later by truck—to Placerville, sixty-five miles away on an old stagecoach road. There it was reloaded on narrow gauge trains bound for Salida, Colorado. From that point, the sacks were sent by standard railroad to the company's reduction

FIGURE 1.1. Loading a carload of carnotite ore for shipment from Placerville, Colorado, to Standard Chemical's reduction mill in Canonsburg, Pennsylvania. The picture appears in a photographic album relating to the operations of Standard Chemical and probably dates from 1915 to 1920. Courtesy of Paul Frame, Health Physics Historical Instrumentation Collection, Oak Ridge Associated Universities.

mill in Canonsburg, Pennsylvania, where the next step in radium refinement took place.

The cost of mining, sorting, and packing in Paradox Valley varied from twenty-eight to forty dollars per ton. Hauling charges to Placerville were between $18 and $20, but there were additional expenses for mules that transported the sacks from the mines to points accessible by wagons. The approximate cost for the entire trip from the mines to Canonsburg was $70 per ton, a considerable amount at the time. Standard Chemical was spending $30,000 per month on transportation costs when all the remaining companies in the area were spending a combined $3,000 per month.[21]

The company's investments on radium mining were obviously astronomical. But transportation was just one cost among many: the production of each gram of radium required 500 tons of ore, 500 tons of chemicals used in the different stages of the refinement process, power from 1,000 tons of coal, and 10,000 tons of purified water. Radium was an expensive business: companies had to commit to huge financial investments before seeing any revenue. Given Flannery's extended vanadium business, he had in place much of the infrastructure and definitely the capital to invest. The Pittsburgh operations began in Canonsburg, south of the city, where approximately 150 people worked long hours and under hazardous conditions to produce a mix—or salt—of barium and radium chloride: the radium component was only a tiny fraction of this salt.

By 1914 Standard Chemical's investment amounted to $135,000, almost equal to $3.5 million today, including the purchase of the mines, the construction of mining camps and the entire mill infrastructure, road improvement, and wages.[22] The company was not yet making money from its investment: radium products were not yet on the market. In fact, the market didn't even exist yet. But Flannery was an entrepreneur with an eye for profit and was already conceiving ways to earn a handsome return on the company's huge investment. His vision centered on making Standard Chemical the "first mover"—in Alfred Chandler's terms—in the radium economy: investment in large-scale economies had to be accompanied by the development of managerial capabilities and proprietary knowledge.[23]

The company remained focused on its radium refinement operations. The specific extraction method used by Standard Chemical was a well-guarded secret. The chemicals, used in large amounts in this process, were highly corrosive and dangerous to handle: damage to equipment at the mill was routine, leading to substantial costs in repairs and spare parts. Radium refinement was time consuming, laborious, and hazardous. But the work was unregulated, as was the entire industry, and health protection virtually nonexistent.[24]

Of the chemists engaged by Flannery to devise the basic process for extracting radium, the most prominent was Bertram Boltwood, who, along with chemist Joseph Hyde Pratt, ran a consulting firm of mining engineers and chemists in New Haven. In 1910 Boltwood joined the faculty of Yale University as professor of radiochemistry. He had already worked with Ernest Rutherford in Manchester, England, for a year. In 1911, when Flannery proposed he become a consultant for Standard Chemical, Boltwood agreed and fully supported the company's vision. In one of his letters, he expressed confidence "that the separation of radium salts from low-grade carnotite ore is commercially practical and should be very remunerative."[25] Boltwood was paid $2,500 per year for his scientific and technical services. These included monthly visits to Pittsburgh and, throughout 1911, an active role in the development of the company's research laboratories in Canonsburg and Pittsburgh, recommending personnel and advising on the process of refining radium from carnotite ore.

George Lees from Standard Chemical, who handled most of the correspondence with Boltwood, accepted his suggestion that the company hire one of his students at Yale, Rowland Bosworth. Eager to set up the laboratory in Canonsburg and start production, Lees then sent a detailed description of the laboratory equipment on June 20, 1911. The technology was impressive for its time and included a gas engine, a rock crusher, and a grinding mill large enough to handle ten tons of ore per day situated in a large building that also housed two "state of the art" laboratories. Lees had received recommendations from Boltwood as to what was needed and was keen to follow his advice. Radium refinement on this scale was new, and tensions were sometimes apparent. For example, the company's chemists were bitterly divided as to whether the wash water could be discarded or not.

It is clear that Boltwood was a key source of advice and reassurance to Lees on technical and operational issues when these arose in setting up the refinement process, and they corresponded regularly.[26] Indeed, Boltwood wielded powerful influence over technical aspects of Standard Chemical's radium production. On June 21 he telegraphed Lees: "Advise delay erecting roasting furnace until further notice."[27] Lees and his colleagues at Standard Chemical were ready to put up a basin and a heating furnace with a sand bath for concentration of the liquids in large acid-proof stoneware vessels, and he needed to know whether they should proceed to the roasting process. Meanwhile, Boltwood was experimenting at his private laboratory in New Haven with a simpler method with the help of his student Bosworth, who was on Standard Chemical's payroll. Clearly, a new partnership was being forged within the radium industry between academics and their research labs on the one hand and commercial companies on the other.

Soon Boltwood informed Lees that he was "more certain than ever that a considerable, more efficient and simpler process of extraction can be worked out." He "strongly advised" them to hold off on the construction work in Canonsburg until further notice.[28] With Flannery's blessing, Lees followed Boltwood's advice and suspended work at the furnaces, even as several carloads of ore awaited. On June 29 Boltwood sent an extended outline of the new method, including the cost of the chemicals required for each step, noting also that "there is a large margin of profit," music to the ears of Lees and Flannery.[29] Working at and across the academic-business divide was a learning process for all parties, and clearly Boltwood was mindful of reactions to the costs of setting up this highly technical and groundbreaking enterprise.

During this intense collaboration Lees regularly reminded Boltwood of the very different cultures in industry and the academy, impressing on him the need for their work to remain confidential and seeking assurances about Boltwood's allegiance to the company. Lees was either clumsy or impatient—or perhaps both—and had still much to learn about working with university professors. Certainly, Lees appears to have crossed a line when he wrote to Boltwood suggesting that he share his insights into commercially sensitive aspects of work being carried out by his European colleagues.[30] Though willing to advise on scientific matters, pumping Boltwood for information from his European colleagues was a step too far—as was the use of Boltwood's name in promoting Standard Chemical and marketing its nonmedical products the earliest of which were radium fertilizers. Certainly, this kind of behavior so annoyed Boltwood that he abruptly ended his professional relationship with Standard Chemical at the end of 1911.

This was a short-lived and somewhat fraught association. Lees was disappointed and sought to downplay the difficulties, emphasizing that "we hoped and still hope to make our relations mutually agreeable and satisfactory and we would like to feel that you will continue to be associated with us."[31] Working across the boundary between his academic and industrial work was not completely new to Boltwood—nor was it for most of Standard Chemical's academic consultants, especially those who worked for the development of radium fertilizers. But relationships at this boundary had to be handled with care. The Boltwood–Standard Chemical case illustrates the importance of academic-industry cooperation in the radium business and that both sides stood to gain from this association. However, unlike their colleagues in Europe, scientists working in American universities exerted far less influence in the country's radium industry.[32]

The Vanadium Building

From the point of view of organization, Standard Chemical operated like any other large chemical company in the country. The infrastructure of the company's mining activities and the large number of specialized chemists in its radium refinement process were neither surprising nor novelties in themselves. What was astonishing, however, was the extent and intensity of the company's in-house research at its laboratories in Pittsburgh. It was

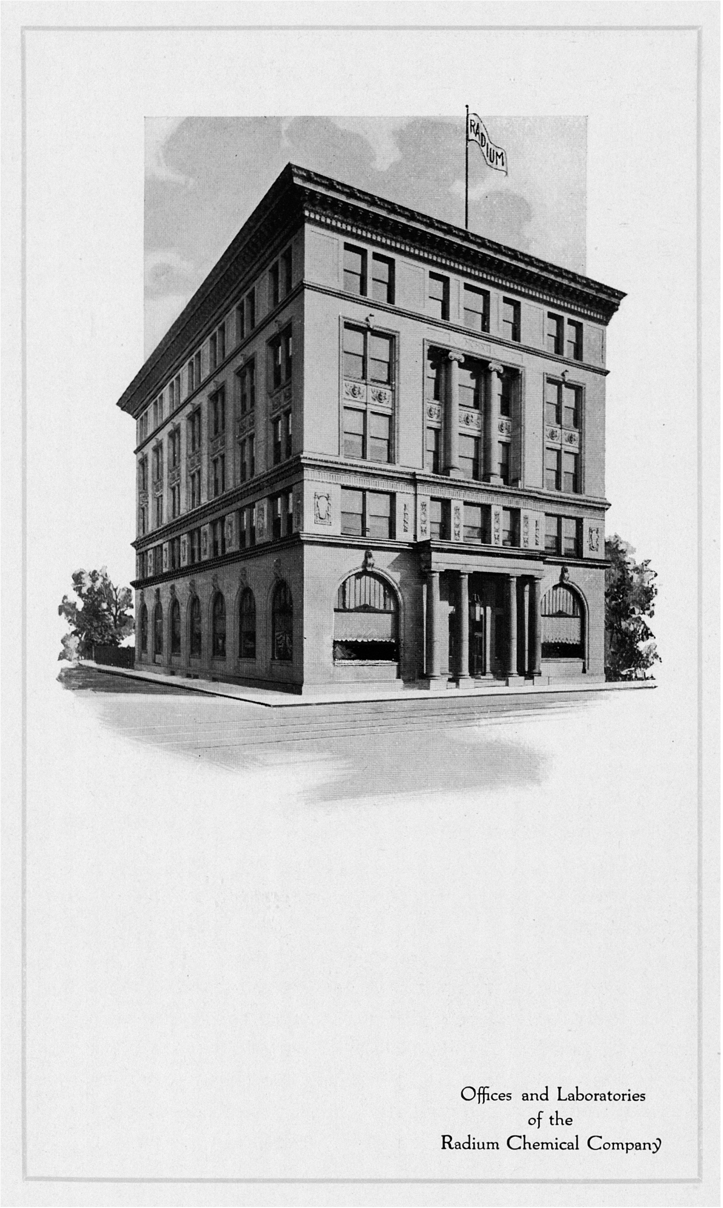

FIGURE 1.2. The Vanadium Building on the corner of Meyran and Forbes Avenues in Oakland, downtown Pittsburgh. The picture of the building appeared on the back cover of a number of *Radium* issues and advertising pamphlets of the Radium Chemical Company. From the collection of the Historical Medical Library of the College of Physicians of Philadelphia.

here that the final product of the radium refinement process—a mix of barium-radium crystals—derived from preliminary large-scale crystallizations at Canonsburg became subject to wide-ranging, meticulous analytical investigation. This reflected Joseph Flannery's deep commitment to making the Standard Chemical laboratory in Pittsburgh a place for the generation of knowledge on the chemical and medical properties of radium.

Beyond being important contributions to science, this work was central to Flannery's commercial vision and became the basis for the array of radium-based products by Standard Chemical that dominated the US market for years. These included medical pharmaceuticals primarily for the treatment of cancer, radium fertilizers, and radium paint.

In the world of big business, presentation could carry the day. Perceptions of success were closely bound up with the company image. An ambitious science- and technology-based company needed headquarters that exuded success, influence, even glamour. In early 1910, Joseph Flannery commissioned Frederick John Osterling, a celebrated Pittsburgh architect, to design a grand and imposing building for a prestigious downtown address that would become Standard Chemical's headquarters.

The Vanadium Building, named after Flannery's original vanadium business, opened its doors in 1911. The building housed the headquarters of all the companies owned by the Flannery brothers. James Flannery, president of the Oakland Bank and the Oakland Savings Trust Company, established in 1901 and 1906, respectively, joined the venture and took charge of the company's finances drawing on his banking experience. He also ran the family's American Vanadium Company.

The opulent lobby of the Radium Company, Standard Chemical's marketing subsidiary, and Joseph Flannery's office resonated with wealth and commercial success. State-of-the-art laboratories ensured the efficient production of radium. According to the *Pittsburgh Post-Gazette*, "The Standard Chemical Company has equipped one of Pittsburgh's newest and most modern buildings with every facility, every comfort and every sort of analytical and metallurgical device that will serve to demonstrate the value of radium."[33]

Demonstrating the medical and commercial value of radium through a burgeoning portfolio of products became the company's raison d'être and defined its business strategy. In designing the Vanadium Building, Osterling took into consideration the company's unique radium refinement and manufacturing processes. Indeed, the final stage of radium's refining process to the point of radium salts was taking place, ironically, at a centrally located building in downtown Pittsburgh. The manufacturing of radium-based commercial products also took place in the absence of any concerns about radiation protection. But, in addition, Osterling paid attention to the commercial ambitions of its owners. Most importantly, he sought to capture the Zeitgeist surrounding the perception of radium as the new century's most promising material. The building was a statement that Standard Chemical was going to be in the vanguard of fulfilling this promise.

Staff from Canonsburg regularly traveled by train from Washington County, Pennsylvania, to Pittsburgh, and then transferred to an Oakland-bound tramcar. These messengers carried radium salts in glass bottles with cork stoppers carefully placed in galvanized steel cans. "Now hold your hat!" exclaimed the late 1960s Arthur Miller, a chemist who worked for Standard Chemical. "Tommie and his helper, with a can in each hand brought them [dried radium-barium chloride salts] to the Pittsburgh lab on the trolley! Probably a couple hundred mg radium."[34] The radium salts were the "raw material" for radium-based products manufactured at Standard Chemical's Pittsburgh laboratories. It remains an open question if it was a case of shocking indifference or naïve ignorance that, by one estimate, these messengers received an annual dose of 1 sievert when the annual total effective dose equivalent for the whole body is 0.05 sievert.[35] In Pittsburgh, the radium salts were stored in the company's chemistry laboratory, known as the Radium Research Laboratory.

Standard Chemical was keen to emphasize the innovative and scientific nature of its work. Fifteen chemists, all men, worked under Austrian Otto Brill at the company's chemistry laboratory in the Vanadium Building in Pittsburgh. Brill, a chemist, had experience in radium extraction and refinement from his work at the St. Joachimsthal mines in Bohemia, and in academic research in William Ramsay's laboratory in England. Radium research was an international enterprise, and researchers in this field were often transnational actors: European academic laboratories and US radium companies were nodes within the same network that was forming around this naturally occurring radioactive element in the early twentieth century. Those within this network moved across national borders and different research settings bringing their laboratory experience with them: research and laboratory cultures varied between sites and countries. It is perhaps unsurprising that encounters at these cultural intersections were not always smooth. Brill was seen by his American colleagues as difficult to work with, though he was perhaps struggling to adapt to the business culture within Standard Chemical. Indeed, Brill returned to Vienna in 1915 to head the company's new offices there.[36]

FIGURE 1.3. The Radium Research Laboratory at the Vanadium Building. Courtesy of Paul Frame, Health Physics Historical Instrumentation Collection, Oak Ridge Associated Universities.

After Brill's departure, the role of director of the Radium Research Laboratory went to physicist Charles Viol. Educated and trained at the University of Chicago, Viol had a ruthless business instinct and made maximizing profits and sales an absolute priority. Viol's colleagues included Glenn Donald Kammer and Henry Titus Koenig: in 1912 Kammer had just received his bachelor of science in chemical engineering, and Koenig had a degree in chemistry. Both were University of Pittsburgh graduates, and each had their own ideas about the extraction of radium from low-yield radium carnotite ore. For all three young, eager, and entrepreneurial scientists, the Standard Chemical was the gateway to an exciting career in a new and rapidly expanding scientific industry. Wholly in tune with Joseph Flannery's vision and ethos, Charles Viol moved quickly up the Standard Chemical echelon and soon became an influential figure within the American radium business.

Viol, Kammer, and Koenig were closely involved in developing and overseeing the final, delicate, and crucial stage of radium refinement:

fractional crystallization, a process carried out in small, open porcelain pans in the company's Radium Research Laboratory in Pittsburgh. Working without any form of protection, staff stood above the porcelain bowls carefully monitoring the crystallization process but also routinely inhaling radioactive steam and acid fumes. The end product, ready five weeks later, was a tiny pinch of nearly pure radium bromide. When freshly evaporated, radium bromide (chemically, radium in the form of a salt) resembled powdered sugar, which, in the dark, glowed blue. Placed in sealed bottles or tubes, radium bromide turned brownish, gradually losing the bluish phosphorescent glow. All the final-stage steps, such as fractional crystallization, handling and transferring the radium salt, bottling and storing it, were carried out in the labs in the Vanadium Building in Pittsburgh without measures to minimize or protect against radiation exposure.[37]

Radium salts were stored on the first floor of the Vanadium Building in a steel vault. This was a measure taken for security reasons: between $120,000 and $160,000 per gram, radium was expensive. Yet by far the most hazardous task at the Standard Chemical laboratories was the tubing process, which involved filling glass tubes, needles, and later capsules with radium salts. Radium tubes and needles were different types of radium applicators, by then routinely used to apply radium to patients, mainly the cancer patient.[38] Malignant disease was the major medical market for radium. The therapeutic principle of radium was ablation, which meant that essentially the radioactive energy of radium was used to destroy, or burn, the malignant lesion.

Flannery's initial motive for entering the medical radium business was a personal one: to supply radium for treating his sister, diagnosed with cancer in 1909. In an effort to find a cure, and in the absence of radium authorities in the United States, he took her to Europe, where he realized radium was a scarce and extremely valuable material. It was far from a familiar commodity but more an exotic remedy, a scientific object highly regulated by European research institutions. Upon returning home, he embarked on the project of developing a radium extraction method for large-scale industrial production and on setting up his new radium corporation.

Extremely common among the Standard Chemical workforce were radium burn injuries, the most obvious sign of radiation damage.[39] As Viol later explained, "At the outset little information was available as to methods of handling the material and with a realization of the great value of the material being handled and with no exact idea of the dangers involved, it was the custom at first to handle the tubes with the bare hands. This was

TABLE 1.1. Radium production at the Standard Chemical Company, 1913–1918

YEAR	AMOUNT OF RADIUM (GRAMS)
1913	2.1
1914	9.6
1915	1.7
1916	5.0
1917	7.0
1918	13.6
TOTAL	**39.0**

Source: Charles Viol, "Radium Production," *Science* 49, no. 1262 (1919): 227–28.

soon found to be disastrous, resulting in the production of typical radium burns on the end of thumbs and forefingers."[40] All five employees routinely handling radium tubes and needles, including Viol, suffered extensive radium burns to the thumb and fingers of both hands. Others suffered burns too in the course of transporting radium, within and beyond the Standard Chemical laboratory system.

In 1914 Standard Chemical introduced the use of forceps to avoid direct contact with radium, but it would be another seven years or so before the company introduced lead shielding to protect the torso. In the years before World War I, radiation risk remained poorly understood and, in the case of X-rays, contested: arguments that exposure to ionizing radiation is a serious health risk intensified, but the evidence remained unclear. There was neither a complete picture of radiation risks nor a sense of the long-term effects of radiation exposure. Worker health and safety had not yet gained political traction. Neither radium miners nor radium workers were unionized. Thus the radium business remained unregulated. Certainly, at Standard Chemical, the safety of employees was not a primary concern.[41]

"Radium for Our Own People"

Standard Chemical produced its first batch of radium salts in 1913, a true feat given the demanding procedures. From that point onward the company's output increased steadily during the war. But almost as soon as radium production was underway, Standard Chemical was confronted by a sudden and serious threat to its business. In 1913 there was an attempt to impose a federal monopoly over radium, an initiative headed by an alliance between flag-waving nationalist politicians and physicians anxious about national supplies of this promising means to treat malignant disease. The medical uses of radium and hopes that it could treat and perhaps even cure cancer, a disease of great concern in medical circles but also the public, fueled uneasiness about the adequacy of national supplies and the cost of importing radium from Europe.[42]

On October 31, 1913, Charles Parsons, chemist and chief of the Division of Mineral Technology of the US Bureau of Mines, addressed the annual convention of the American Mining Congress in Philadelphia. His theme was “Our Radium Resources.” Parsons was not interested in the “wonders of radium,” an adage already made trendy by popular and scientific magazines. Instead, he wanted to present an overview of the commercial situation regarding radium and the country’s natural resources, mostly the ores in Colorado and Utah, to an elite audience of the US mining industry’s most senior and influential engineers and executives. As executive secretary of the American Chemical Society and a high-ranking government employee, Parsons was worried about the unmonitored development of the radium industry and the implications for research and medicine, given that, medically, radium was highly valuable. His chief message to his audience was the need “to keep at home both the radium itself and the profits of its manufacture.” A powerful figure within the US Bureau of Mines, Parsons hoped to pave the way for the newly created National Radium Institute, through which the government sought to monopolize radium.

Parsons took charge of the bureau’s radium investigation in 1913. Private companies like Standard Chemical, had already invested major funds in the infrastructure necessary to set up a US radium industry. A great deal was already at stake when the question suddenly arose as to who should control US radium resources and have the final say on the uses and allocation of the country’s finite supply. The fierce battle to shape and control the contours of the US radium market pitched private mining and chemical interests, including Standard Chemical, against the US government. Speaking to the American Mining Congress on Halloween 1913, Parsons noted that in 1912 three-quarters of radium salts produced in the world had come from America’s ores. He also made sure to note that most of this had been exported to and refined in European laboratories, only to make its way back into the United States in the form of expensive devices such as applicators intended for medical use, especially on cancer patients. In Parsons’s view, this was outrageous: the American people were losing out on what was an American resource. His solution was to end the export of US radium ores, emphasizing instead "what it [radium] can accomplish for the public knowledge and the public weal."[43]

Two months later, on December 30, Franklin Lane, a Democrat and commissioner of the Interstate Commerce Commission, upped the ante. He sent a letter to Illinois representative, fellow Democrat, and chairman of the Committee on Mines and Mining Martin Foster, outlining a plan to protect the nation's radium deposits from private interests. He urged Foster to enact legislation that would empower President Woodrow Wilson to transfer all rights and ownership of radium-bearing ores located on public land to the US government. According to a report on the country's mineral resources in 1913, which supported both Parsons's and Lane's claims, the estimated value of recoverable radium, when extracted from uranium and vanadium ores in Colorado and Utah, amounted to $1,020,000, or slightly more than $24,000,000 today. The value of imported radium salts, however, exceeded $17,000 in 1911 and increased to $18,285 in 1912.[44]

Agents from several other nations had already arrived in the United States to seek supplies for shipment abroad. The International Vanadium Company of Liverpool in England formed an American subsidiary in 1909, the General Vanadium Company, and began mining a year later. With a second subsidiary, the Radium Extraction Company, the International Vanadium Company was considered the largest exporter of carnotite ore from both Colorado and Utah. Eager to expand their export business beyond the United States, International Vanadium began construction of a new radium plant in Liverpool in 1913. Several other independent operators mined and shipped carnotite from Colorado, mainly to Hamburg, Germany, including prominent figures such as Thomas Curran, William Cummings, O. Barlow Willmarth, and David Taylor.[45]

But as it turned out, 1913 was Lane's year. In January he was elected chairman of the Interstate Commerce Commission, and a month later he was nominated secretary of the interior. Lane worried that increasing interest in using radium for cancer treatments would allow some of the carnotite ores to fall into the hands of speculators, or agents acting on behalf of foreign interests. In his view, the United States had failed to secure this invaluable material "for our own people," while its physicians and hospitals continued to depend on European laboratories for radium supplies.[46]

Frank Hess, an economic geologist working for the US Geological Survey, provided a detailed report of the country's ore deposits and their worth. Based on the estimations of Ernest Rutherford and the Bureau of

Mines, he calculated that the 2,269 short tons of dry carnotite-bearing ore produced that year would yield 8.5 grams of recoverable metallic radium, equivalent to 15.9 grams of (hydrous) radium bromide. Most importantly, according to Hess, a large portion of that hydrous radium bromide, 8.9 grams, had already been sold to a "French firm for experimental treatment" or had been shipped to Europe with a price tag of $120,000 per gram. During 1913 only two US companies had developed the expertise to isolate radium salts: the Standard Chemical Company and the Radium Company of America at Sellersville, Pennsylvania, with ores from Utah. It was clear that the lack of local infrastructure for radium's refinement at this time meant shipping all ore mined in the United States to Europe.[47]

Nonetheless shipping ore overseas was far from straightforward. First, deposit exploitation was extremely wasteful. Some four tons of low-grade ore were dumped or mixed with mine waste for every ton of shippable ore. Although the carnotite deposits from Colorado and Utah were at this time among the most extensive deposits of radium ore in the world, foreign manufacturers already owned claims in the area, the most prominent of whom was Marie Curie. Indeed, Curie was at this time the chief holder of radium in Europe and was said to hold 2.6 to 3 grams in 1914. When Austria declared an embargo on exporting ores in 1912, she purchased ore from Portugal and Colorado.[48]

Lane was not alone in arguing that radium ore and the profits from radium-based products ought to be kept at home. Thomas Walsh, a Democratic senator from Montana, echoed Lane's views, arguing that as long as radium resources remained in private ownership, there was a risk that the radium supply itself would fall "into the hands of a few persons, to whom the hospitals of this country must pay exorbitant profits."[49] The lobby seeking a state monopoly over radium production wanted to ensure that radium would remain available to the medical profession. In his report to the US Committee on Mines and Mining in 1914, Martin Foster even argued that "the people of this country must buy back from foreign countries at speculative and exorbitant prices the very radium which was their own."[50] Their worries were not unfounded.

In 1913 Lane hatched his plan for the government to sequestrate land containing radium ores, extract ores in these locations, and also construct an ore reduction plant under the control of the Bureau of Mines. Control over US radium deposits and the supply of radium was the all-important issue for both Lane and the bureau. It is possible that this was all a preliminary test for the Bureau of Mines. Established by the Organic Act of

1910 in response to a wave of catastrophic mine disasters, the bureau was conceived as a national focal point for innovative science and technology in the minerals field. It was intended as a robust governmental agency that would reassure the public on governance of the country's mining industry.

In taking a stand against mining companies with interests in radium, especially at a time when radium was becoming a much-sought medically valuable asset, Lane needed strong allies. The bill he crafted was carefully tailored to align with a recent attempt made by prominent physician Howard Atwood Kelly and James Douglas, owner of the richest copper mine in the world, to establish a National Radium Institute in the United States modeled on its English counterpart and geared to controlling radium-containing American ores for the benefit of humanity. [51]

The National Radium Institute

"Whether radium is or is not a cure for cancer, the motive of the two philanthropists commands profound respect."[52] This is how on October 25, 1913, the *Boston Daily Globe* reported on efforts by Howard Kelly, a leading gynecological surgeon at Johns Hopkins Hospital and Medical School, and James Douglas, a leading expert in copper mining, to establish a National Radium Institute (NRI). Douglas's interest in medical radium was animated by the death of his daughter in 1910 from breast cancer. Having made a fortune from his copper business, he offered $100,000 to the Memorial Hospital in New York on condition that they hire his physician, James Erwin, become a specialist hospital in cancer therapy, and use primarily radium for cancer treatments.[53] These two "generous donors" had agreed to provide $150,000 earmarked for this project, creating thereby a major new institutional player in the American radium landscape.

In addition to an illustrious medical career developing new surgical methods and diagnostic techniques, Kelly was among the first in the United States to recognize the therapeutic potential of radium. An article documenting the American development of radium therapy in *Radiology* in 1933, portrayed Kelly as the "Father of Radium Therapy." As early as 1904 Kelly had bought a small tube of radium in Paris and soon after returning to the United States began using it to treat external lesions. By 1907 he owned twelve thousand dollars' worth of radium, and in 1911 he was among the first to use radium to treat cervical cancer at Johns Hopkins.[54] The Austrian monopoly on the extraction and sales of radium and the high price of imported European radium products in the United States instilled in Kelly the belief that the development of a domestic infrastructure for this valuable element was an absolute priority.

His difficulties in purchasing radium sparked concerns in America about an alleged European radium trust—European mining companies that were attempting to gain control of American radium lands.[55] Kelly's argument lent credence to Parsons's plans for a national agency to extract, control, and allocate radium. To Kelly and Douglas, it became a "patriotic duty" to develop the country's radium industry and ensure enough of the material for medical use in cancer therapy. It was radium's use in the treatment of cancer that galvanized Flannery and his creation of Standard Chemical.

Moves to establish the NRI coincided with Kelly's involvement in the treatment of Congressman Robert Bremner for cancer. Around the end of 1913, Kelly performed a complex operation on Bremner at his private clinic in Baltimore. The operation was widely covered in the national press, and congressional officials followed the case closely. Bremner's illness cast the value of radium in cancer therapy into sharp relief, and for a short time the entire "American radium situation" seemed to be bound up with the outcome of Bremner's treatment. If he recovered, it would be considered a landmark scientific success, bolstering the value of radium in cancer therapy and further cementing Kelly's reputation and standing in government circles.

On Christmas Day 1913, Kelly inserted eleven tubes of radium salts worth one hundred thousand dollars into Bremner's shoulder. It was the first time that such a large amount of radium had been used in a single operation: Bremner's illness was among the most advanced Kelly had encountered. The tumor was enormous and extended over his left shoulder, reaching almost across his heart. The *New York Times* reported that it was "one of the most malignant recently brought to the attention of medical scientists."[56] For Kelly, it was obvious what needed to be done. "The great need now is for an institute to test all possibilities of radium in the treatment of a great variety of disease, especially of cancer," he stated on December 28.[57] Unfortunately, Bremner died on February 5, 1914.

Devoting himself to the establishment of such a national radium institution under the direction of scientific authorities, Kelly argued that if the US government followed Austria's example by "rescuing" the carnotite fields from private exploitation, the resulting radium would be enough to meet the nation's needs. Clearly, Kelly's ideas drew on the model of European radium institutes where radium acquisition, supply, and uses were in the hands of scientists. In his 1914 report, Foster noted that "a very different condition exists" in Europe. The NRI would accordingly be modeled on the London Radium Institute, established in 1911 with government subsidies.[58]

In Europe, governments, municipalities, or other public entities were centrally involved in the purchase of large quantities of radium and mesothorium in cancer treatment. The transfer of the European model to the United States required federal support and swift action by the Bureau of Mines. Indeed, on October 23, 1913, Parsons referred to the creation of the NRI before the American Mining Congress in Philadelphia. It was another three months before Lane made public the full text of the agreement for the creation of the NRI. The project included prominent roles for Kelly and Douglas: the former was appointed president, the later director. Douglas's nephew Archibald Douglas became NRI treasurer and secretary.[59]

Among the first actions of Kelly and Douglas at the NRI was to purchase twenty-seven mining claims in Paradox Valley, Colorado, for $150,000, sixteen of which contained carnotite. The claims belonged to the Crucible Steel Mining and Milling Company, which agreed to have these claims worked for three years on a 15 percent royalty basis and to receive the remaining uranium and vanadium ore after radium was extracted. The bureau agreed to shoulder the entire cost of the extraction and refinement of radium. It made available its facilities and expertise to the new NRI, provided for the scientific and technological study of methods for mining and concentrating radium ores, supplied the necessary chemists and technicians, and built a radium-recovery plant in Denver, Colorado. In short, the bureau sought—via the NRI—to introduce a commitment to research and link industrial development to the state.

Richard Moore, chief chemist of the Bureau of Mines, was assigned head of the Denver laboratory. He was among those trained in the laboratories of leading physicists across the Atlantic, such as that of William Ramsay in England. At the bureau's laboratory, Moore developed his own technique for radium extraction. According to his estimates, the carnotite fields in the United States were not expected to produce more than one hundred grams of radium, which fell short for cancer treatment. As Moore observed, this amount, "although large scientifically, would be small in proportion to the probable demands."[60]

According to the signed agreement between, on the one hand, Kelly and Douglas and, on the other, the US government, the first seven grams of radium bromide salts were to be used exclusively for cancer treatments. These were to be divided up between Kelly's private clinic in Baltimore and the Memorial Hospital in New York represented by Douglas. Any radium produced beyond the first seven grams was to be handed to the bureau for experimental purposes.[61]

The government and the press attached great patriotic importance to the agreement, and just before the end of the year, Congressman Foster introduced a bill to the House Committee on Mines and Mining that would establish a federal monopoly of public lands containing carnotite ore. Yet, when Lane presented the NRI agreement to the House Public Lands Committee of Congress, radium companies were furious and moved to oppose the proposal.

This moment revealed the differences between the United States, with its embrace of corporate values and power, and Europe, where national radium institutes thrived.[62] In the United States the mining and refinement of radium ores, that is, radium production, began in corporations. In the course of building the technical capacity and infrastructure for this massive, challenging, and expensive project, these corporations drew academics from the universities into the radium business. They were vehemently opposed to government intervention, or what they saw as interference in the radium business in which they had invested heavily, and which, until now, they had controlled.

The Lane initiative and the NRI triggered an intense and acrimonious debate between the leading companies in the US radium business and the federal government, with serious implications for both the Bureau of Mines and the NRI. Throughout this process, the lines between scientific knowledge and policy were constantly redrawn and contested by state officials, physicians specializing in radium therapy, and radium entrepreneurs shaping regulatory decisions about radium and its uses for years to come.[63]

Federal vs. Industrial Radium Monopoly

On January 14, 1914, the Committee on Mines and Mining began public hearings on Lane's pending bill. The committee gave those directly affected by the bill six days to appear and testify. The three leading cancer surgeons in the country were Kelly, Curtis Burnam, who worked closely with Kelly at his private hospital in Baltimore, where both specialized in cervical carcinoma, and Robert Abbe from New York, who was one of the first to introduce radiation to cancer treatment. They appeared first with casts and photographs of cancer patients before and after treatment. For

Congressman Foster, these images were "in themselves more than sufficient argument for the proposed legislation."[64] The respectful physician Abbe argued that "if [radium] is not conserved, it will be sold everywhere by the makers who have the ware to sell, and it will be bought up by doctors all over the country, who simply want to have a little as a toy, who do not know how to use it. . . . It will open up a fool's paradise."[65] Harvey Gaylord, director of the New York State Institute for the Study of Malignant Disease in Buffalo, a sought-after speaker on issues related to cancer, was called to appear. He argued forcefully that US hospitals were in need of the precious material (radium) to treat the most malignant of diseases. His claims were backed up by Frederick L. Hoffman, a well-known statistician, who claimed that seventy-five thousand people died annually from cancer in the United States alone.

Joseph Flannery, representing the Standard Chemical Company, and O. Barlow Willmarth, president of the Colorado Carnotite Company, vehemently opposed the bill. Of the 450 claims (to mining radium-bearing ores) considered to be of reasonably good quality at that time in Colorado and Utah, Standard Chemical controlled approximately 170. Fifty-eight belonged to General Vanadium, 25 to the Radium Company of America, 25 to Willmarth, and the National Radium Institute had rights to just 16. The NRI was indeed in a weak position relative to the radium companies and unable to compete with private business.[66]

In contrast to Flannery and Willmarth, the president of the Radium Company of America, Angus Cameron, maintained a low profile during the hearings. He hastened to reassure the government that his company posed no threat and that there was no real need for Lane's bill. "Buyers from abroad come to us," explained Cameron, "eager to contract for our entire production for a year or more ahead. We have refused to entertain their proposals. It is our policy to furnish radium to medical practitioners in our own country."[67]

Willmarth's company had begun work in Colorado in 1912. The Austrian chemist Siegfried Kohn was hired to head its technical department and oversee radium extraction—as was the case at Standard Chemical, the Radium Company of America also hired European expertise as it set about its radium operations. Willmarth, like Flannery, vehemently opposed the bill. Speaking before the committee on January 24, he questioned Kelly's position and accused him of having ulterior motives. But the committee perceived this to be unwarranted and the chairman, Martin Foster, rushed to defend Kelly. Willmarth was perhaps already a waning force in the radium business: his company was weakly placed in terms of mining claims, and two years later he sold his mining operations to Standard Chemical.[68]

Clearly, the company with most to lose was Standard Chemical: although it had been in existence for only three years, it was already a radium empire and the country's largest producer of radium. On January 11, 1914, Flannery arrived in Washington—every inch the confident, successful entrepreneur—to protest the Lane proposal and persuade Congress to reject it. Before Congress, Flannery protested persistent attempts by members of the committee to portray his company as having a radium monopoly based on the extent of Standard Chemical's carnotite ore claims in Colorado. Like Angus Cameron, he sought to allay concerns about the radium supply, arguing, "Let the situation alone and the country will get enough radium."[69] He went one step further by offering to disclose Standard Chemical's secret process for extracting radium from carnotite ore on the condition that the government use it for humane and philanthropic purposes.

But the next day, Flannery was forced to admit that his company had just closed a deal for five additional land claims in Colorado, a move that brought charges that he was instructing his staff to buy all the radium claims they could "lay their hands on." Flannery shifted the focus to Kelly and, echoing Willmarth, accused Kelly of trying to gain control over radium for his own benefit. He was both more strategic and more effective than Willmarth. His line of defense was that both the Bureau of Mines and the National Radium Institute were producing radium for just one private hospital—Kelly's—and for his personal benefit. As the controversy flared, Flannery began trading insults with Kelly in Congress and through the press. When on February 5, 1914, Congressman Bremner died, Flannery went so far as to hold the physician responsible for his patient's death. In a further blow to Kelly, another famous patient of his, actress Jacques Bradley Swift, had also died a few days earlier. This made the front page of the *Washington Post* and gave Flannery an opportunity to emphasize another of Kelly's failures.[70] Flannery was actually capitalizing on the medical controversy after Bremner's death over the use of radium in cancer treatments.[71]

Amid the intensity and bitterness of the committee hearings, and the enormity of what was at stake—control over what was now a mainstay of cancer therapy—additional hearings before the Senate were arranged and began on February 10, 1914. In an attempt to rehabilitate his reputation as a ruthless businessman who had attacked Kelly, a leading cancer surgeon, Flannery changed tack. He testified that a philanthropist and close friend of his was willing to provide $15 million to build and equip twenty radium hospitals in as many cities for cancer treatment. Standard Chemical would supply each hospital with five grams of radium. Although Flannery declined to reveal the philanthropist's identity, he leaked John Rockefeller's name to the press.[72]

While Flannery was trying to forestall government intervention in radium mining and, by extension, state interference in his business, the Bureau of Mines was by now actively producing radium. As part of its deal with the NRI in early 1914, the bureau designed a plant to accommodate part of the radium extraction process in south Denver and rapidly ramped up the project. The first building was completed in March, and experimental work began immediately. A second structure was erected around the same time to house radium refining. By June 1914 the first two steps of the process were perfected and in use.

Though full-scale production was under way, the bureau's scientists still had to deal with the problem of refining radium. By late 1914 they devised a novel method based on Curie's principles. Satisfied with the progress made during that year, Kelly and Douglas decided to finance the construction of a boiler and compressor plant in order to double production. In February 1915 the technologically advanced plant was ready to process 3.5 tons of ore per day.[73]

On November 22, 1915, Lane broke news of a major development at the NRI that would "benefit humanity": five grams of radium had been extracted from American ores at the Denver experimental laboratory. As previously agreed, half of it was delivered as radium bromide to Kelly's clinic in Baltimore and the other half to the Memorial Hospital in New York, which Douglas sponsored. Lane proudly asserted that this radium was produced for less than one-third of the present selling price and that this new and cheaper method of extraction was patented for the "benefit of the people."[74]

Lane's announcement reignited the dispute between the NRI and the radium companies, especially Standard Chemical. Everett Field, a physician and Standard Chemical sales representative, vehemently challenged the government's claims that its production methods reduced the price of radium from $120,000 per gram to just $37,000 per gram, when it was actually Kelly alone who received preferential treatment when it came to getting radium.[75]

Despite attempts by Lane and his supporters to establish a state monopoly over radium, his legislation failed to pass Congress. By the end of March 1914, the government realized that the plan for federal control of radium-bearing ores was doomed. The Utah senator, George Sutherland, questioned the effectiveness of what came to be known as the 1914 Appropriation Radium Bill, defending the private sector. The great advocates of the bill, leading physicians in the treatment of cancer, argued that even if the bill passed without amendment, action would come too late to enable the government's experts to carry out their original plan. In the sixty-three days since Lane's bill went to Congress, all mining claims on the Colorado Plateau had been taken up by prospectors. Certainly, Flannery had been trying to purchase as many claims as possible for Standard Chemical, making it the biggest frontrunner and winner of the battle for control over radium in America. In effect, its dominance of the radium industry amounted to something close to a monopoly.

In 1917 the US government left the radium business. Even the NRI's Denver plant was sold to Standard Chemical. As the *New York Times* put it: "Federal Control of Radium Doomed."[76] Untrammeled by state interference, oversight or regulation, Standard Chemical went from strength to strength and by the early 1920s had developed into a complex and multisector radium corporation with a global reach.

Conclusion

Standard Chemical, the commercial company that dominated radium mining by excluding the state from its regulation, was the main force behind radium's transformation from a scientific object into a commodity in the United States. The company's economic interests determined how scientific facts were presented; medical findings were contested depending on whether they fit corporate development plans. In these early days cancer treatment became the major market driving the company's development. From huge investments in mining and refinement infrastructures, moving pictures, and silent newsreels to aggressive testimonies in congressional hearings, Standard Chemical legitimized and imposed its presence in the national radium market. The first steps of the process of making radium familiar to the US public were taken within congressional courtrooms and cinemas.

The finances behind radium mining and refinement were gargantuan: radium production required a vast infrastructure, resources such as labor, expertise, and technology, and major investment. The radium yield, especially from carnotite ore, was very low: radium was therefore scarce. It was much sought because of its healing promise, not least as a new approach to treating cancer at a time when this disease was given new prominence and caused great concern. The fact that radium was expensive, rare, and highly valuable profoundly shaped its history, which was marked by fierce competition and included attempts by several national governments to secure a monopoly over its supply and use.

The history of radium differed markedly within each national setting: in the early twentieth century, its development in Austria, for example, followed a very different pattern to that in the United States. In 1911, following long negotiations, the Austrian government bought the only two radium mines in St. Joachimsthal from private individuals. In so doing, Austria brought to an end a long-standing rivalry with German and French institutions vying for control over these radium resources. This development attracted international attention, including some criticism: as the *U.S. Daily Consular and Trade Reports* put it, this now gave the Austrian government "a monopoly on the radium output of the world."[77]

The picture looked very different in the United States, where private business interests were and remained central. In 1913 an attempt by the US Congress to secure a federal monopoly over the carnotite ores in Colorado and Utah ended in failure. Powerful companies moved in to protect their commercial interests: the huge financial investment they had made, and were continuing to make, in developing the radium business. Standard Chemical operated at every point of the supply chain of this business, from mining to refinement to developing and marketing innovative products that came to define the radium market. As soon as the joint effort by the National Radium Institute and the Bureau of Mines to establish a monopoly over radium collapsed, Standard Chemical increased its claims in the Colorado area and monopolized radium mining and production moving rapidly into the medical radium market.

In 1915 Flannery clearly argued that "it is now conceded that radium has a definite place in therapy. It has been used very successfully in the treatment of certain forms of cancer and in the treatment of a great many non-malignant skin growths, and lately radium is even finding a considerable use in internal medicine."[78] Senior academic scientists such as Otto Brill and Bertram Boltwood were important in this strategy. Flannery's business acumen, and his ruthless pursuit of his vision for Standard Chemical, allowed the company to expand immensely.

Throughout this period, however, clouds kept gathering. They would eventually cast a huge shadow over the radium business, as suspicions mounted in some quarters that exposure to ionizing radiation emitted by X-ray machines and by radium might pose a serious health risk. Prior to World War I, these dangers remained uncertain and were even contested. This allowed Standard Chemical and its competitors in the radium business in the United States to overlook this problem. As the evidence grew steadily stronger, mainly from the wartime use of X-rays on the battlefield, radiation dangers came to adversely impact the radium market, and a regulatory framework was put in place. But the dangers were still not in the foreground, and the radium business, from mining to marketing radium, remained unregulated. The radium market, with Standard Chemical in the vanguard, forged ahead unchecked toward new horizons of profit.