Part I The problem

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The awakening

I can't think about that right now . . . I'll think about that tomorrow.

Scarlett O'Hara, *Gone with the Wind* [1]

In January 1949, the Atomic Energy Commission (AEC) held a seminar on radioactive waste. In his opening remarks, AEC Chairman David Lilienthal cast the problem of waste disposal as part of "learning to live with radiation." According to Lilienthal, this learning curve was the same as how we humans learn to live with anything else unfamiliar. The Chairman of the AEC acknowledged that radioactive wastes could become "a subject of emotion and hysteria and fear . . . [but] we do not believe those fears are justified provided technology applies itself to eliminating the troubles." The previous year, Robert Oppenheimer, Chairman of the AEC's General Advisory Committee, had dismissed the waste problem as "unimportant." [2–3]

In spite of these pronouncements, dealing with radioactive waste gained greater urgency upon passage of the Atomic Energy Act of 1954, making possible the widespread use of nuclear energy for civilian purposes. As such, the nuclear industry would now be close to major cities and towns. And dilution was not the solution. Given the anticipated size of the US nuclear industry by the year 2000, it would require a volume equal to about five percent of the world's oceans to dilute the dangerous waste to recommended safe levels. This exceeded the volume of freshwater stored worldwide in lakes, rivers, groundwater, glaciers, and polar ice caps. [4]

In February 1955, the AEC signed a contract with the National Academy of Sciences (NAS) to establish a committee of leading scientists to study the problem of geological disposal of radioactive waste. Five months earlier, Eisenhower had waved his magic wand to start groundbreaking for the Nation's first commercial nuclear power plant. Arthur E. Gorman, a champion within the AEC for dealing responsibly with the waste, spoke to the newly formed committee. The remote locations of the agency's atomic weapons plants had made it possible, he said, "to sweep the problem under the rug, [but now] we must face up to the fact that we are confronted by a real problem." Finding satisfactory methods for radioactive waste disposal had to be accomplished if the nuclear industry was to reach its full potential. [5]

Chartered by Congress during the Civil War, the NAS serves as the federal government's premier scientific advisor. The NAS Committee included several distinguished scientists. Hydrogeologist, C.V. Theis, had developed a mathematical equation for predicting the response of groundwater levels to pumping. Published in 1935, the *Theis equation* revolutionized the science of groundwater hydrology. Another member, John C. Frye, is credited with creating the field of environmental geology. And then there were Harry H. Hess, chair of the committee, and M. King Hubbert. Hess and Hubbert were widely respected in the scientific community, but were quite different personalities.

Harry Hammond Hess, head of the geology department at Princeton University, was a giant in the world of marine geology. While serving in the US Navy during World War II, Hess managed to map the Pacific Ocean floor while cruising from one battle to the next. His understanding of the seafloor later played a pivotal role in a revolution in geologic understanding of the Earth. [6]

For centuries, mapmakers had observed the parallelism of the opposing coasts of the Atlantic Ocean, suggesting that the continents had drifted apart. How this might have happened remained a mystery. Hess proposed that the seafloor is created as magma rises up from the Earth's interior along mid-oceanic ridges. The new seafloor spreads outward and eventually sinks into deep oceanic trenches in a conveyor-belt motion. The continents are carried along as part of large, rigid plates. As evidence for seafloor spreading gained credibility, this hypothesis became accepted as the theory of plate tectonics.

Hess also played a prominent role in designing the Nation's space program. In 1962, he was appointed by President John F. Kennedy to the prestigious position of Chairman of the Space Science Board of the National Academy of Sciences. Hess suffered a fatal heart attack while chairing a meeting of the Board in 1969. In spite of his considerable fame, Hess is remembered as a humble man who was sought after throughout his life for his fairness and open-minded nature.

Figure 1.1 Harry Hess commanding the *USS Cape Johnson* in 1945. On this troop transport ship, Hess mapped the Pacific Ocean floor with sonar during World War II. Photograph courtesy Department of Geosciences, Princeton University.

M. King Hubbert, the other key member of the NAS Committee, was a widely regarded geoscientist who worked for Shell Oil. King, as he was known, came from a family with a tradition of unusual names. King's great grandfather named many of his 15 children after his heroes. There was David Crockett Hubbert, Benjamin Franklin Hubbert, and Andrew Jackson Hubbert. Educated in a one-room schoolhouse in the hill country of Texas, King Hubbert managed to work his way to the University of Chicago. There he became the first graduate with a triple major in physics, mathematics, and geology. He refused to pick just one. King wanted an *education*, not a *major*. [7]

Figure 1.2 M. King Hubbert (on the left) setting up a resistivity instrument for a geophysical survey in Franklin Co., Alabama, September 22, 1934. Photograph by E.F. Burchard; courtesy US Geological Survey.

M. King Hubbert could be abrasive and was often a lightning rod for controversy. He was on the NAS Committee because of his intellectual depth and breadth in the earth sciences. Among his contributions, Hubbert's theoretical work laid the foundation for the study of regional groundwater flow systems. Although he made landmark contributions to earth science, King Hubbert would become most identified with the concept of *peak oil*.

In 1956, as the NAS Committee continued to deliberate on nuclear waste, Hubbert was invited to give a keynote address on the world energy situation at a meeting of the American Petroleum Institute. The public relations representative of Shell Oil pleaded with Hubbert to tone down the "sensational parts" of his speech. Not one to heed such advice, Hubbert informed the oil men in attendance that oil production in the lower 48 States would peak between the late 1960s and the early 1970s. Production would then decline sharply on the downward side of the classic bell-shaped curve. As the reserves of oil and other fossil fuels diminished, Hubbert predicted that they would be replaced by nuclear energy, "an energy supply adequate for our needs for at least the next few centuries." [8]

Hubbert's conclusions about peak oil were widely criticized. Following his pronouncement, Morgan Davis, president of Humble Oil (the largest domestic oil producer at the time), had King Hubbert followed from meeting to meeting to refute his arguments. There were also limits to his methodology. Hubbert focused on "easy oil" that was recoverable by the methods practised at the time. He also did not directly consider the effects of price on supply and demand. Nonetheless, Hubbert's prediction of peak oil in the lower 48 was realized in 1970, about the same time that the Arab oil embargo temporarily brought the Western world close to a stand-still. In essence, Hubbert predicted an oil crisis some 20 years before it actually occurred.

The first meeting of the NAS Committee was held in April 1955 at the Johns Hopkins University. The university was a logical choice. Abel Wolman, chairman and founder of the Sanitary Engineering Department at Johns Hopkins, was a pioneer in public health and an outspoken, though constructive, critic of the AEC's waste practices. Once, while dining at the home of Robert Oppenheimer, Wolman told his distinguished host: "[I have] tremendous respect for your field of activity and your views," *but*, he added, "When you enter my field . . . your ideas as to how we manage this 'unimportant' problem are characterized by a total ignorance of the nature of disposal." Wolman later recalled that, despite the strong differences of opinion, they "parted friends." In 1950, Abel Wolman and Arthur Gorman called it "highly questionable" whether the important task of dealing with radioactive waste should be left entirely to the AEC – a premonition that became increasingly hard to refute. [3, 9]

One problem faced by the NAS Committee was that outside the hallowed halls of the AEC, and apart from a few individuals like Abel Wolman, little was known about the problems associated with nuclear waste. The only member of the Committee who had any direct knowledge of the AEC facilities was C.V. Theis, from coordinating work between the US Geological Survey and the AEC. Most of the information on the Nation's nuclear waste legacy was classified.

The meeting at Johns Hopkins was followed by a conference at Princeton University. Two years later, in 1957, the NAS Committee summed up their findings in a report. Like many to follow, the Committee viewed nuclear waste disposal as essentially a technical problem. Three key conclusions stood out that would significantly influence events over the next couple of decades [5]:

(1) Wastes may be disposed of safely at many sites in the United States, but conversely, there are many large areas in which it is unlikely that disposal sites can be found.
(2) Disposal in cavities mined in salt beds and salt domes is suggested as the possibility which promises the most immediate solution to the problem.
(3) Disposal could be greatly simplified if the waste could be made into a solid form, relatively insoluble in character.

The first conclusion, though reasonable in the light of knowledge at the time, contributed to a false sense of confidence about the ease of finding a suitable site. The second conclusion – burying the waste in salt beds – became the cornerstone of waste disposal policy for the next 20 years. The third conclusion – converting radioactive waste into solid form to reduce its mobility – has stood the test of time and has become the focus of considerable worldwide research and development (R&D). The report also represents the beginning of the international consensus to pursue on-land, subsurface disposal of high-level radioactive wastes.

The NAS Committee was very forthright about the limitations of their knowledge. They were the first to admit that certain assumptions needed to be verified. For example, would the extreme heat from the radioactive material reduce the ability of salt to contain it? The Committee also warned, "The hazard related to radioactive waste is so great that *no element of doubt* [emphasis added] should be allowed to exist regarding safety." Over time, it has become clear that such absolute assurances are not possible. [5]

To put the Committee's report into context, in 1957 the first practical computer models of hydrologic systems were a decade away and very few studies had been undertaken of subsurface chemical processes – both critical areas for nuclear waste management. The Committee also assumed that the waste would be reprocessed and would require isolation for only 600 years or less. The idea that tens of thousands to hundreds of thousands of years of safe containment might be required was simply not on the radar screen. In the same way that plate tectonics required revision of many principles of geologic processes, the Committee's conclusions needed re-evaluation as new insights were gained. It would be decades before this reality sunk in.

The Committee report appeared to have little effect on the AEC. While the Academy scientists suggested searching for a repository site among the best possible geologic locations, the AEC, with an eye to cost and convenience, had other ideas. They favored establishment of repositories at existing atomic weapons facilities where virtually all of the wastes were located at the time. "They pressured us right from the start that they wanted a disposal site at each of these plants," recalled M. King Hubbert. "They never let up on this." [10]

The NAS Committee became increasingly frustrated by the AEC's lack of responsiveness to their recommendations. In 1960, Harry Hess wrote a letter to AEC Chairman, John A. McCone. As spokesman for the Committee, Hess recommended that urgent action be taken to establish facilities at suitable geologic sites, instead of taking the path of convenience. Hess also urged that approved plans for safe disposal of radioactive wastes be a prerequisite before any new nuclear power plants could be built. The AEC responded that the Committee's proposals were costly and unnecessary. Having "practically no further duties except for trivialities," fumed Hubbert, the NAS Committee might as well have been disbanded. [10–11]

AEC Chairman McCone, a California industrialist, had a history of steadfast support for established AEC positions. He also had a will to match that of Hubbert. A few years earlier, during the 1956 presidential election, ten California Institute of Technology (Caltech) scientists concerned about radioactive fallout had issued a statement supporting Adlai Stevenson's proposal to ban atmospheric nuclear weapons tests. McCone, a member of the Caltech board of trustees and campaigner for Eisenhower, accused the scientists of being taken in by Soviet propaganda. According to the scientists, he tried to get them fired. When they weren't fired, McCone resigned from the board. Two years later, Eisenhower appointed him Chairman of the AEC. [12]

In 1963, when M. King Hubbert became chairman of the earth sciences division of the Academy's National Research Council, he promptly confronted the AEC. "I told them I didn't propose to keep any committee standing around twiddling its thumbs . . . they should either discharge it or give it something worthwhile to do." The AEC reluctantly agreed to let the Committee review their R&D program on waste disposal for nuclear power. For perhaps the first time, the AEC conducted a fieldtrip for an outside group. The NAS Committee visited Hanford and other weapons sites, as well as two salt mines near Lyons, Kansas where preliminary experiments on waste disposal were taking place. After being briefed on research involving waste solidification in glass and ceramics, the Committee reported that it was "favorably impressed with the whole solidification program." However, they were definitely not impressed with the waste disposal practices at the weapons sites, and said so in a draft report to the AEC. [10, 13]

A tug of war ensued. The AEC argued that the NAS scientists had overstepped the scope of their study and pressured the Committee to delete their criticisms. The Committee refused to delete anything. As responsible citizens, they felt a duty to raise these concerns. When the NAS Committee submitted their final report to the AEC in May 1966, they again stated their conviction that "none of the major sites at which radioactive wastes are being stored or disposed of is geologically suited for safe disposal of any manner of radioactive waste other than very dilute, very low-level liquids." The Committee acknowledged one possible exception – some intermediate waste might be safely disposed by mixing with grout and injecting it into fractured shale at Oak Ridge. [10, 13]

The AEC fought back. First, they prepared a 15-page response to the NAS report, taking the position that the scientists had been misguided in their major conclusions. Second, they suppressed the report, arguing that it had already been made available to pertinent personnel. Finally, the Commission disbanded the NAS Committee and replaced it with a new group that had "a broader spectrum of scientific discipline." [10, 14]

With this accomplished, the Atomic Energy Commission turned its attention to salt deposits as the preferred medium for disposal. Within a few years, the next phase of confrontation would begin.

THE SALT OF THE EARTH

Salt beds are formed by the evaporation of inland seas or enclosed coastal bays. Under the right conditions salt can really pile up, eventually forming beds hundreds, even thousands, of feet thick under vast areas. For a number of reasons, salt beds are a good choice for disposing of radioactive waste. Given that salt dissolves easily in water, thick salt deposits mean that groundwater has been absent for the many millions of years required to form them. The physical and mechanical properties of salt are also favorable. Salt is approximately equal to concrete in its ability to shield harmful radiation. And because of its plastic nature, particularly at depth, fractures tend to seal up. Salt also conducts heat better than other types of rocks, alleviating localized over-heating. Finally, salt deposits usually occur in areas of low seismic activity.

Yet, there are drawbacks. When water does appear, it forms highly corrosive saline brines – bad news for the waste containers. Brine also tends to migrate toward heat sources such as hot waste.