EXPERIENCE WITH DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE: BUILDING CONFIDENCE FOR AND AGAINST THE REGULATIONS

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ABSTRACT

Following the controversy regarding the potential use of the Ward Valley site in California as a low level radioactive waste facility, an Advisory Group and a Scientific Panel were formed to recommend alternatives to the Governor. During the course of the Group's and Panel's deliberations, the arguments for and against near surface burial and waste classification were crystallized. In this paper we discuss the bases upon which the arguments were formed and what we can learn from them.

Keywords: low-level radioactive waste, disposal, regulations, public perceptions

1- INTRODUCTION

Several countries, including the United States, have selected disposal in a near-surface facility as the ultimate management strategy for low-level radioactive wastes (LLRW). The U.S. Nuclear Regulatory Commission (NRC) has defined disposal as "the isolation of radioactive wastes from the biosphere inhabited by [humans] and containing [their] food chains by emplacement in a land disposal facility" [1]. In principle, depositing the wastes and closing the facility should be the only active measures required to ensure long-term safety.

Efforts within the United States to develop new LLRW disposal facilities have encountered effective opposition and the parties involved have become increasingly polarized. Most recently, the President of the University of California formed an ad hoc Advisory Group and a Scientific Panel on LLRW to suggest both workable and scientifically sound alternatives for California's low-level radioactive waste disposal [2]. The group and panel included both proponents and opponents of near-surface disposal for LLRW. The issues raised by both are relevant to a broader range of issues in waste management and environmental management.

In this paper we critically examine questions about the protectiveness of the regulation that governs the disposal of LLRW in the United States as they arose in the California experience and in the context of the debate over what can be learned from the past performance of disposal facilities. We also examine related questions regarding the bases and possible impacts of classification schemes for LLRW.

2 - LLRW IN CALIFORNIA

The state of California generates commercial low-level radioactive waste in its nuclear power plants, military bases, biotechnology companies, hospitals, and universities. The Low-level Radioactive Waste Policy Act (LLWPA) [3], passed by the federal government in 1980, gave the states responsibility for managing commercial low-level radioactive waste (LLRW). California has no disposal facilities for low-level radioactive waste. Shortly after the federal government enacted the LLWPA, California joined with Arizona, North Dakota, and South Dakota to form the Southwestern Compact. The compact designates California as the first host for a LLRW disposal facility to serve the member states.

Through a screening process during the 1980s, a site — Ward Valley, which sits on federal land in San Bernardino County — was selected as the location for the compact's regional disposal facility. The selection triggered years of litigation, culminating in a March 1999 federal district court decision in which the court ruled that the U.S. Department of Interior was not required to transfer federal land in Ward Valley to the state [4]. The Department of Interior informed California that it would no longer process the transfer.

On June 2, 1999, the Governor of California, Gray Davis, announced that the state would not appeal the district court decision. Governor Davis asked the president of the University of California, Richard Atkinson, to form and chair an advisory group charged with proposing ways to find workable alternatives for California's low-level radioactive waste disposal. The Governor asked for "pragmatic policy alternatives to Ward Valley for disposal of California's low-level radioactive waste that are environmentally and economically viable" [2]. The charge also emphasized that consultation was to take place with organizations and interested parties experienced and knowledgeable about these issues. Atkinson, in consultation with the Governor's office, appointed a committee of 19 California citizens. The appointees included heads of relevant state agencies, representatives from affected industries, representatives from environmental public interest groups, politicians from the vicinity of Ward Valley, representatives from academia, and three other prominent citizens.

To support the activities of the Advisory Group, a Scientific Panel was formed. The first author of this paper, William Kastenberg, chaired the Scientific Panel. The Scientific Panel began as a group of thirteen scientists, engineers, physicians, and social scientists with relevant expertise. Following complaints by Advisory Group members opposed to disposal of LLRW in California, two more members, a physician and a scientist selected from a proposed list, were added halfway through the Panel's activities. The Panel was assisted by pro bono consultants with relevant expertise and by the second author of this paper, Micah Lowenthal, who served as technical staff for the project.

3 – POINTS OF CONTENTION IN CALIFORNIA'S LLRW PROJECT

From the outset of the activities of the Scientific Panel, self-described opponents of near-surface disposal of LLRW argued that the practice is dangerous and irresponsible. In support of this position, they stated that every LLRW disposal facility in the United States has leaked, as have sites in the United Kingdom and in France. Leaking facilities, they said, include those in desert locations such as Nevada and the Negev desert. This was cited as evidence that the concept of permanent disposal, whereby little or no active management is required after closure of the facility, is unrealistic. They pointed to the costs of remediation or managing sites that have leaked, to the nearly interminable responsibility of managing those sites, and to the potential threats to people and the environment. They concluded that the history of land disposal of LLRW and of chemically hazardous waste demonstrates that near-surface disposal is not a reliable management option.

The central criticisms of the regulation, 10 CFR 61, concern the duration of the hazards posed by LLRW. Waste classes established in the regulation designate which wastes are legally suitable for disposal in a near-surface facility. Opponents of near-surface disposal argued that the waste classes are too broadly defined, allowing radionuclides with long half-lives in LLRW. For some, the long half-lives combined with what they deemed a certainty that near-surface disposal facilities will fail demonstrate that the regulation is not protective of human and environmental health. Others were more circumspect, stating that it would be arrogant to think that we can design facilities that guarantee isolation of LLRW from the biosphere over thousands (some said tens of thousands) of years when no facility has operated for even a few decades without leaking. From this perspective, greater humility is required regarding our engineering capabilities and the Precautionary Principle[a] should be applied to management of LLRW. Alternative waste classes based on the half-life or so-called "hazardous life" of the radionuclides and management schemes that require indefinite, active, aboveground maintenance and surveillance were proposed. One of these is examined in a later section of this paper.

Proponents of near-surface disposal argued that it is the safest and most responsible management option. They disputed the use of the term "leak" to describe migration of radionuclides from some of the trenches where the waste was disposed; some preferred a definition of leakage that is linked to the regulatory limits on migration from the disposal facility. While proponents agreed that there were problems at facilities licensed before the current regulation was promulgated, in 1982, they claimed that even with the terribly flawed practices and facilities of earlier days, the migration of radioactive material was detected, remediation efforts were made, and no health effects resulted. Proponents held that some of the closed facilities were inherently flawed and could not be built today and that contamination at other sites now is due entirely to improper disposal of wastes during the 1960s and 1970s. Lessons learned from past failures and other experience, proponents said, led to the 1982 regulation, better practices, and much better performance. Some went on to argue that the character of LLRW is such that even if it did leak from a properly designed and operated facility, the likelihood of a significant impact on human health is negligible.

Proponents of near-surface disposal preferred not to change the existing waste classification scheme, arguing that the existing classes are based on concentration limits derived from calculations of radiological hazards and that the proposed alternatives are unrelated to risk. Finally, some claimed that indefinite active maintenance and monitoring would result in greater risks and substantially higher financial costs.

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[a] The Wingspread Statement of the Precautionary Principle (1998) is "Where an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically." Other versions state that the harm must be serious or irreversible to require precautionary measures.

4 – REGULATIONS CONCERNING DISPOSAL OF LLRW

The NRC promulgated 10 CFR 61 "Licensing Requirements for Land Disposal of Radioactive Waste" in 1982. The regulation concerns civilian radioactive waste that is neither high-level radioactive waste (HLW), nor by-product material (i.e., tailings). The regulation establishes four classes of LLRW, requirements for management of each class of LLRW, dose limits for members of the public and for future inadvertent intruders, restrictions on waste forms, and criteria regarding siting of new disposal facilities. The dose limits for future inadvertent intruders restrict the concentration of medium-lived and long-lived radionuclides in the waste. The dose limits to the general public are assumed to be driven by groundwater transport and therefore restrict the overall inventory of radioactive materials that can be disposed of at the site.

The four NRC LLRW classes—Class A, B, C, and "greater than class C"—are defined by concentration limits for certain radionuclides in the waste. The concentration limits are lowest for Class A waste, and highest for Class C LLRW. NRC deems Class A, B and C waste suitable for near-surface disposal but requires greater confinement disposal for greater than class C waste. The concentration limits are derived from calculations of doses to a person (an intruder) constructing a home or growing food on a LLRW near-surface-disposal site 100-500 years after closure of the site. Different disposal requirements apply to the different classes of LLRW such as grouting, deeper burial and/or high-integrity containers for Class C waste. The intruder scenario begins with these disposal requirements and includes assumptions about the behavior of both the intruder and the waste in the disposal facility. For example, the special requirements for class C waste are assumed to make the waste distinguishable from the surrounding soil for 500 years after disposal and it is further assumed that an intruder would cease his excavation if he found distinguishable waste containers.

The regulation states that doses to a member of the public resulting from releases from LLRW disposal facility must not exceed 25 millirems per year and that efforts should be made to maintain releases of radioactivity as low as is reasonably achievable (ALARA) below the dose limits. Based on a performance assessment for the disposal site, the NRC regulations provide that the regulator shall limit the total amount of LLRW that can be disposed of in the facility and may further restrict the wastes deemed acceptable for disposal at that site.

5 – EXPERIENCE WITH COMMERCIAL LLRW DISPOSAL IN THE UNITED STATES

As noted above, experience with LLRW disposal was a point of debate within the Scientific Panel. Seven commercial LLRW disposal facilities have operated in the United States: Beatty in Nevada (1962-1992), Maxey Flats in Kentucky (1963-1977), West Valley in New York (1963-1975), Sheffield in Illinois (1966-1978), Barnwell in South Carolina (1971-), Richland in Washington (1965-), and Envirocare in Utah (early 1970s for by-product material, expanded to include class A LLRW in 1990s). The experience accumulated in operating, monitoring, and in some cases remediating these sites is relevant to the current discussion because both opponents and proponents of near-surface disposal refer to this history to support their positions.

Some of the LLRW disposal sites are collocated with disposal facilities for chemically hazardous waste (Sheffield, Beatty and Envirocare), but it should be noted that prior to promulgation of 10 CFR 61 all of them, except Envirocare of Utah, accepted waste that would now be considered hazardous under the Resource Conservation and Recovery Act of 1976 (RCRA). In 10 CFR 61, NRC established joint regulation with EPA for mixed waste (waste that is both radioactive and chemically hazardous), which required disposal facilities to be separately licensed by EPA for disposal of mixed waste.

Unless otherwise noted, the descriptions of LLRW disposal sites and their histories are taken from Reference [3]. The description of the Beatty facility draws on more references due to disagreements over what has gone on there and what is happening even now. Several of the facilities were operated by Nuclear Engineering Company, Inc. (NECo) and its successor, U.S. Ecology. We will refer to the operator only as U.S. Ecology.

Sheffield - U.S. Ecology operated the LLRW disposal site in Sheffield, Illinois accepting 88,000 cubic meters of waste containing something over 2,250 TBq which were disposed of in 21 earthen trenches between 1966 and 1978. Estimates attribute approximately 33 percent of this radioactivity to cobalt-60, 25 percent to cesium-137, 10 percent to tritium, 8 percent to plutonium-239, and 6 percent to strontium-90. Most of the waste was packaged in steel or fiberboard containers.

Tritium was first discovered in groundwater beneath the Sheffield LLRW facility in 1976, when the U.S. Geological Survey (USGS) began a study of the site. Five years later tritium was discovered in groundwater offsite and soon it was observed in Trout Lake. Covers were installed on the trenches, but water continued to infiltrate. A low-permeability cap was installed in 1989. The increasing concentrations of tritium at monitoring wells began to drop after 1990. Measured concentrations of tritium in a nearby strip-mine lake have never exceeded 0.3 percent of the discharge limit of 3000nCi/L, mostly because of the substantial dilution afforded by the lake. The lake and the area overlying the flow path of the groundwater from the LLRW facility to the lake have been added to the buffer or exclusion zone, which originally just included the LLRW site. Tritium in water beyond this exclusion zone has never been measured to be above background. The operator of the facility has paid out $4.4 million for future maintenance and possible remedial actions at the site by the state, which took over responsibility for managing the site in 1988.

Maxey Flats - The Maxey Flats LLRW disposal site is located in Fleming County in Northeastern Kentucky. Between 1963 and 1978, U.S. Ecology leased the site and disposed of approximately 140,000 cubic meters of waste. Problems began early on and worsened during further operations and during some of the remediation efforts. Regulators cited the operator for allowing too much water in the disposal trenches, burying unauthorized material and disposal of liquid wastes [4]. The facility was shut down in 1977. The site was placed on the National Priorities List for cleanup under CERCLA (Superfund) in 1986.

Several factors are blamed for the problems that arose at Maxey Flats, some operational and some intrinsic to the site. Operationally, waste in the trenches sat or lay randomly in the trench with void spaces both within and between waste packages. While layers of dirt were routinely laid on top of the waste to provide shielding for workers, no effort was made to cover the trench to keep out rainfall or surface runoff until the trench had been filled to within 1 meter of the original ground level, at which point a cover was emplaced. The period from excavation to covering of the trench was typically one to one and one half years, during which water accumulated in the trenches due to natural features of the site.

The impermeable soils in which the trenches were cut trapped water resulting in what is termed a "bathtub effect," whereby the trenches would fill until they overflowed. Drainage of this water by natural means was slow enough that the trenches would never fully drain and the time the water was in contact with the waste was substantial. Fractures in the rock provided nearly all of the drainage, which meant that the accumulated water was removed slowly but traveled quickly through the subsurface fracture network. The water degraded packages and the waste itself, leaching out radionuclides. The process was accelerated by solvents such as toluene that were in the waste packages. These degraded packages and the soil compacted over time to fill the void spaces resulting in subsidence of the cover, causing it to crack and allow more infiltration. The problems were observed and the operator began pumping water from the trenches for treatment in an evaporator or to be solidified.

Tritium, cobalt-60, strontium-89, strontium-90, cesium-134, cesium-137, plutonium-238, and plutonium-239 were detected offsite in 1974. Three years later, radioactivity was detected in groundwater 90 meters from the source trench. Investigations following this discovery led to closure of the site at the end of 1977. Monitoring wells were place at regular intervals around nearly the entire fence line of the restricted area of the disposal site. Tritium was detected in nearly all of the monitoring wells. The average concentration during 1989 for the most contaminated well was 360 MBq/L (compared to the regulatory limit of 0.11 MBq/L). Plastic covers were emplaced, reducing infiltration to an extent such that the state ceased operating the evaporator. Natural dilution prevents exposures to the general public from exceeding regulatory limits.

Beatty - The State of Nevada leased land to California Nuclear, Inc. (and later US Ecology) to operate the first commercial LLRW disposal facility in the United States. The site, which lies in the Amargosa Desert, 17.7 km from town of Beatty near the border with California and Death Valley National Park, received 139,500 cubic meters of LLRW containing 26,500 TBq of radioactivity during its operation between 1962 and 1992. Approximately half of the 0.34 square kilometer site is a chemical hazardous waste disposal facility that began operations in 1970 and continues to this day.

Beatty fits what regulators might consider the ideal profile for a near-surface waste disposal facility: It is an arid site with average annual precipitation of 11.4 cm and a maximum recorded rate of less than twice that value, in 1982. The average depth to water in the soil is 85-110 meters. No surface water persists within 16 km of the site. There is episodic flow in the Amargosa River, the dry bed of which runs 3 km from the site.

Early analysis of the site suggested that the low annual precipitation and high evaporative capabilities in the area would prevent percolation of water to even a meter of depth below the surface. More careful analysis shows that deeper percolation can occur because of the episodic nature of the precipitation and the fact that most precipitation occurs when evaporation occurs least, in winter [5].

Beatty has exhibited elevated levels of radioactivity in soil samples near the disposal facility and monitoring wells have detected pulses of radioactivity in the ground water in certain years. A large pulse in the gross alpha activity (26.3 Bq/L) in 1982 coincides closely with spikes in the gross beta activities (12.6 and 34.4 pCi/L) and tritium concentrations (888 and 1,813 pCi/L) in 1982 and 1983. One down gradient well reported a maximum of 15,710 Bq/L of tritium in 1982. The alpha and beta activity are predominately due to potassium-40 and the decay products of natural uranium and natural thorium [3]. The US Geological Survey (USGS) operates a field laboratory adjacent to the Beatty site. The USGS has mapped out the concentration of tritium in water vapor at a depth of 1.5 meters. The highest measured tritium concentration was 4,369 Bq/L [6]. One test hole was dug to monitor tritium at greater depths and shows tritium in concentrations up to 209 Bq/L all the way down to the full depth of 108.8 meters [7]. Samplings of water in the water table show no elevation in tritium concentrations. Concentrations of tritium in the vapor are rising and there is not a clear indication what the maximum value will be, when it will be reached, or how long it will last.

At least 2,800 cubic meters of liquid wastes were disposed directly into trenches at Beatty and liquids have migrated from the chemical hazardous waste trenches at the site, as well. There is disagreement as to whether this direct disposal of liquid waste sufficiently explains the migration.

Experience with the Beatty site is in some ways the most relevant to potential sites in California because of the proximity and similarity in geology, hydrology and climate. The experience at Beatty is also controversial in part because water transport through the unsaturated zone is not as well understood as other types of water flow. The evidence of lateral movement of tritium in vapor hundreds of meters from disposal trenches is puzzling. Wilshire and Friedman [8] contend that fast paths—most likely a combination of fractures and favorable litho-faces—are the only possible explanation for discovery of tritium in soil vapor samples at significant depth and distance from the trenches. But the unconsolidated alluvial sand, clay and gravel occupying the first 30 meters below the surface would not be likely to have fractures. Andraski et al. [5] hold that there is slow net movement of water upward as vapor from the water table to 12 meters depth, the limit of infiltration from the surface. Transport of tritium and carbon-14 may be occurring by diffusion in the vapor phase, which would have less alarming implications for other, more hazardous radionuclides, such as strontium-90, cesium-137, and isotopes of the actinide elements.

One clear conclusion to be drawn from the data and the debate over Beatty is that our understanding of contaminant transport in the unsaturated zone is still evolving year to year. Claims by anyone that they have a definitive explanation of the behavior of contaminants in these environments do not appear to be justified.

West Valley - Nuclear Fuel Services, Inc. constructed and operated the Western New York Nuclear Fuel Service Center, a reprocessing facility for spent nuclear fuel, 20 miles south of Buffalo, New York near West Valley. Two low-level waste disposal facilities were constructed on the site: One was licensed by the State of New York and operated from 1963 to 1975, accepting 66,500 cubic meters of waste containing 27,260 TBq of radioactivity from commercial sources across the state. The other facility was licensed by the US NRC and was used for disposal of non-high-level wastes from the reprocessing plant between 1966 and 1986. The two sites are adjacent to each other.

Radioactivity was detected in creek water above background concentrations just over 6 months after the Fuel Service Center began operations, and three years after the state-licensed disposal facility started accepting waste. Regulatory limits were not exceeded, but gross beta concentrations on the order of 10-25 Bq/L were found. Deer with access to the site and fish in the creek water were contaminated with a variety of radionuclides, particularly in strontium-90 in the fish. Although estimated potential doses to the public were well below regulatory limits, operators of the LLRW disposal site stopped discharging water from the holding lagoons into Erdmann Brook in 1972 after it was determined that this was contributing to contamination of the nearby creek water. Subsequently the water was treated as liquid waste.

Groundwater has also been affected. Tritium has been detected in groundwater near trenches at concentrations of 740 Bq/L. Water continued to collect in trenches and there was evidence of hydraulic connection between some trenches. A slurry wall approximately 9 meters deep was installed alongside one of the trenches and new covers were emplaced on nearly all of the trenches in 1992. Releases of radioactive material from the state-licensed disposal facility have been small compared to those from the reprocessing facility, making it more difficult to isolate the effects offsite of the disposal facility. Active maintenance is still required to remove water from the trenches.

Barnwell - One of the three commercial LLRW disposal facilities still operating in the United States is the Chem-Nuclear facility 8 km from Barnwell, South Carolina, about 0.3 km from the U.S. Department of Energy's Savannah River Site, and adjacent to the Allied General Nuclear Services Barnwell Fuel Facility, a commercial spent fuel reprocessing plant that was never operated. Since the disposal facility began operation in 1971, about 785,000 cubic meters of waste containing around 370,000 TBq of radioactivity have been disposed at the site [9]. The water table can be found at an average depth of 12 meters, but is as high as 9 meters below the surface in some areas. The area sees average annual precipitation of 108 cm.

Tritium was detected in a monitoring well at the site in 1978. In 1991, it was found that the tritium had migrated farther than expected, prompting Chem-Nuclear to emplace a multilayer, impermeable cover over a 5 hectare area. Two more covers were installed in the following years, covering nearly all of the trenches constructed before 1983. Groundwater sampling stations on and around the Barnwell site in 1992 observed average tritium concentrations between around 33 Bq/L and 66 Bq/L. In 1993, the plume was roughly 230 meters wide and 940 meters long and sat almost entirely within the site boundaries. While most of the plume had concentrations lower than 370 Bq/L, about 1 percent of the plume has concentrations greater than 37,000 Bq/L. Still, the Barnwell facility has never been shut down for regulatory violations and operates to this day.

Richland - The Richland LLRW disposal facility sits amidst retired reactors, reprocessing facilities, and waste storage and disposal facilities in the middle of the U.S. Department of Energy's Hanford Reservation, about 37 km northwest of Richland, Washington. The State of Washington leases the site from the Department of Energy and the operator (first California Nuclear, Inc and then U.S. Ecology) leases it from the state. Approximately 383,000 cubic meters containing 143,000 TBq of radioactivity have been disposed of at the site since it began operations in 1965 [3][9]. The facility currently accepts waste only from the Northwest Compact and the Rocky Mountain Compact. Moreover, the site is arid or semiarid with 16 cm of average annual precipitation, nearly half of which occurs between November and February. The water table lies at a depth of 97 meters below the LLRW facility and generally flows toward the Columbia River, around 13 km away.

Elevated concentrations of gross alpha, gross beta, and tritium radioactivity have been detected in groundwater downstream from the disposal facility, but at Richland it is difficult to establish the source of the contamination. The Richland facility sits in the middle of the Hanford Reservation and DOE facilities surrounding the commercial LLRW disposal site are acknowledged sources of contamination with tritium concentrations more than a factor of fifteen higher than at the LLRW facility in the early 1990s (91 Bq/L versus 1632 Bq/L). While Reference [3] states that environmental monitoring demonstrates that disposal operations have not resulted in any measurable increases in the environmental concentration of radioactivity near the LLRW facility, Wilshire and Friedman [8] dispute that claim. Based on the direction of groundwater at the sampling locations, Wilshire and Friedman conclude that contamination at the LLRW monitoring points are not from other sources and point out that migration elsewhere Hanford has occurred significantly faster than predicted.

Envirocare - In the 1970s, Envirocare of Utah established a waste disposal site in Tooele County, Utah, to dispose of by-product materials located nearby. In the 1990s, Envirocare of Utah received a license to dispose of most Class A LLRW in engineered trenches. The company currently has an application under review by the State of Utah to accept Class B and C waste. We are not aware of any claims that migration of radionuclides has taken place at Envirocare.

6 – ARGUMENTS AGAINST THE CURRENT REGULATION

Critics of the current regulation say that LLRW poses a threat of significant and long-term damage to human and ecological health, and that this threat requires a precautionary approach. A precautionary approach, they say, is one that assumes failures of both engineered and natural barriers, because history has demonstrated that they might occur. Further, it was argued, they are certain to occur during the time frames over which some LLRW remains radioactive, which are long compared to human history. Opponents of near-surface disposal were reluctant to suggest what quantities or concentrations of LLRW might leak into the environment without significant damage to human and ecological health. The so-called San Bernardino Proposal [2] did suggest an exemption for quantities of radioactive material that are one tenth of the quantity that requires labeling as radioactive under current materials-licensing regulations. In this proposal, LLRW classes would be based on the half-life or half-lives of the radioactive constituents of the waste, and on nothing else. Actively monitored and maintained storage would be required for the waste's "hazardous life." The San Bernardino Proposal defines hazardous life as 20 half-lives of the longest-lived constituent of the waste plus 20 half-lives of any radioactive daughter products. This corresponds to a reduction in radionuclide concentration by a factor of over one million. Waste would be separated into two classes: waste with a hazardous life of 100 years or less, and all other wastes. Management until acceptable release could be contemplated for the shorter-lived waste. The longer-lived wastes require a solution that has not yet been identified.

7 – ARGUMENTS FOR THE CURRENT REGULATION

Proponents of near-surface disposal note that in the late 1970s and early 1980s the NRC evaluated accumulated experience with near-surface disposal design and practices (see, e.g., Reference [10]) to find what lessons could be learned from past failures and successes. Problems were identified in site selection [11][12], waste forms [10], facility design [13], and trench-cover design [14], as well as operations. 10 CFR 61 is a result of that effort. Proponents of near-surface disposal point out that no human-health effects resulted from LLRW disposal despite direct disposal of liquids, mixed wastes and unstable waste forms, despite poor site selection, poor facility design and shoddy cover construction, and despite actual migration from some disposal trenches. This is because the migration of radioactive material is relatively easily detected and remediation efforts have prevented more extensive migration and mitigated contamination. Proponents preferred not to change the existing waste classification scheme, arguing that the existing classes are based on concentration limits derived from calculations of radiological hazards and that the proposed alternatives are unrelated to risk. They also argue that indefinite active maintenance and monitoring would result in substantially higher financial costs.

8 - DISCUSSION

We find that there is evidence and enough uncertainty to support opposing conclusions about the protectiveness of facilities that meet the regulations. The case for protectiveness uses multiple layers of analysis, each reinforcing the improbability of a significant release, to build confidence that a facility will not cause unacceptable harm to the public and the environment. But natural and engineered systems have interacted neither as they were intended to do, nor as they were predicted to do. As experience with observing contaminants in groundwater and the unsaturated zone has increased, and as understanding of transport mechanisms has improved, natural barriers to migration have been shown to be penetrable in much shorter times than previously thought. Reference [15] (see sidebar 2.6) provides a graphic illustration of the evolution of estimated travel times for contaminants in arid environments, revealing a decrease by orders of magnitude over the last three or four decades. Appendix G of Reference [16] points out that different models that follow the same guidelines for assessing risk can yield results that differ by three or four orders of magnitude when applied to the same task. Unsaturated-zone transport is a particular problem. For engineered barriers—such as waste forms, containers, and structures—to be effective, people must carry out construction and operations well and with the proper materials. Ensuring high-quality performance by institutions charged with carrying out these activities is challenging. All of these factors tend to mitigate confidence in the arguments for the protectiveness of the regulation.

The case against the regulation, too, requires multiple layers of analysis, each emphasizing under-predictions of release, harm, and probabilities in the regulatory analysis. But making an argument that the regulation is not protective requires that we discount progress that has been made in constructing, maintaining, monitoring, and understanding these systems. It is difficult to argue that the changes made to the regulations are not improvements. Experience has demonstrated that conforming to the new regulations decreases or eliminates substantial migration at the operating sites, at least in the near term. Because of the character of the waste itself and the situation it is placed in, several elements of the barrier system must, in general, fail for the regulation to prove non-protective.

These circumstances raise issues and questions that pertain broadly to waste management and environmental management. How should past problems or failures influence current decisions? To what extent can credit be taken for learning from those problems or failures? If potential hazards are pushed into the indefinite future, has the system done a service by providing protection for some time, or has the system done a disservice by disconnecting the feedback mechanism that lets us know the consequences of our actions?

The potential capacity for the regulation to be protective may be less important than our confidence that it is protective. Predictability of the behavior of the disposal system is valued in the regulation. Gillham and Cherry [17] argued in 1982 that some media might be more desirable than others for disposal facilities based on their predictability, and not just their potential for confining or isolating wastes.

Regarding the bases and possible impacts of classification schemes, we find that each approach is appropriate only in the context of a particular kind of management (i.e., near-surface disposal, assured isolation, etc.), neglects potentially important information, and creates practical problems from an implementation perspective. The current US NRC classes come from hazard calculations based entirely on scenarios that may or may not be realized at particular sites in the future. As a result, they might be conservative or non-conservative. The proposed alternative described above incorporates risk considerations only if you think that the waste will be volatilized and inhaled directly. This could result in a great deal of effort being expended on managing wastes that are less hazardous most materials commonly encountered in everyday life, and no progress being made on managing the more hazardous radioactive wastes. Challenging as it may be, a coherent and consistent waste classification scheme is, nonetheless, essential to appropriate management of radioactive waste.

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