DOE/NV/10576--T6

U.S. Department of Energy

Office of Environment, Safety and Health

Critical Comments on the U.S. Environmental Protection Agency Standards 40 CFR 191

by

Chris G. Pflum
Science Applications International Corp.

Richard A. Van Konynenburg
Lawrence Livermore National Laboratory

Paul Krishna
TRW, Environmental Safety Systems, Inc.

January 14, 1993

Acknowledgements

The authors thank Raymond Pelletier and Edward Regnier of the Department of Energy and Michael Voegele of Science Applications International Corporation for their helpful comments. We also thank Paula Austin, Andrea Jennetta, James Rogers and Steven Woolfolk, all of Science Applications International Corporation for their valuable contributions to this report.

Chris G. Pflum
Task Manager

Contents

Figures

Tables

I. Introduction

This paper is about the U.S. Environmental Protection Agency (EPA) *"Environmental Standards for the Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes,"* 40 CFR 191. These standards regulate the disposal of radioactive wastes in geologic repositories. Currently, two repository sites are under investigation: the Waste Isolation Pilot Plant (WIPP) site, located near Carlsbad, New Mexico, may become the repository for defense-generated transuranic waste (TRU); and the Yucca Mountain site, located near Las Vegas, Nevada, may become the repository for spent reactor fuel and a small amount of reprocessing waste (hereinafter called high-level radioactive waste or HLW). The paper was written for readers who have an interest in 40 CFR 191 but do not have the time or inclination to ponder the technical details.

Since their inception in 1982, the standards have been criticized by, among others, the Nuclear Waste Technical Review Board, the Edison Electric Institute, the Nuclear Regulatory Commission, the Advisory Committee on Nuclear Waste, the National Academy of Sciences, the national laboratories and the U.S. Department of Energy (DOE). Despite repeated appeals, the EPA still maintains that a geologic repository can be proven to cause no more than 1,000 fatalities to 10 billion people in 10,000 years. No industry on earth aspires to such a lofty goal; nor is such a goal even measurable.

This paper continues the criticism but from a slightly different perspective. To reach a more general audience, our style, tone and analogies differ from what one may find in a purely technical document. We concentrate almost entirely on the containment requirements at 40 CFR 191.13. These requirements limit the probabilities with which a repository's release can exceed a certain number of curies. This paper refers to the containment requirements in a less precise but simpler way; we call them "release limits," "standards" or "rule." Finally, we examine the financial losses should the Yucca Mountain or WIPP sites fail to comply with the standards. Past reviews alluded to these losses but did not fully examine them.

We had just finished a preliminary draft of this paper when Congress passed the Energy Policy Act of 1992 (P.L. 102-486).[1] It directs the EPA to "prescribe the maximum annual effective dose equivalent to individual members of the public from releases to the accessible

[1]This legislation applies only to the Yucca Mountain site.

environment from radioactive materials stored or disposed of in the repository [at Yucca Mountain] " (Section 801(a)(1)). The law also directs the EPA to consult the National Academy of Sciences on, among other topics, whether institutional controls would prevent humans from breaching the repository's engineered and natural barriers.

While encouraging, the law does not specify dose limits. The law promises an objective debate over the feasibility of trying to predict whether humans may disturb a repository. At the same time the law introduces a new debate over the feasibility of institutional controls that would prevent disturbances. Given these uncertain outcomes, we felt compelled to complete this paper. Perhaps our arguments will convince those who will review the EPA's rulemaking that the standards should be less stringent and that it would be far more difficult to predict human activities than to prevent them.

II. The History of 40 CFR 191

The EPA's Mandate to Establish Generally Applicable Environmental Standards

The safe and permanent disposal of spent fuel has been a matter of concern ever since a nuclear reactor in Shippingport, Pennsylvania, began producing the first commercial electricity in 1957. Early expectations were that all spent fuel would be chemically reprocessed to recover usable uranium and plutonium, with the other radioactive byproducts being separated and disposed of as high-level waste (HLW). These expectations were not realized, and it now appears that all of the spent fuel, now considered HLW, will be disposed of directly without reprocessing.

Disposal concepts such as deep geologic disposal, disposal beneath the seabed, disposal in outer space, chemical resynthesis, rock melting, transmutation, and ice-sheet disposal were evaluated by the government during the course of its analyses (see Final Environmental Impact Statement--the Management of Commercially Generated Nuclear Waste, DOE/EIS-0046F). As the boundaries of knowledge expanded, an increasing confidence in geologic disposal developed. Today, the majority of informed technical opinion holds that disposal in deep geologic repositories is the preferred method of permanent isolation.

Likewise, for four decades TRU waste has been accumulating from this nation's defense activities such as nuclear weapons production and the operation of nuclear-powered naval vessels. In 1975 the Atomic Energy Commission (now the DOE) authorized a detailed evaluation of the area occupied today by the WIPP site. This site was identified earlier by Sandia National Laboratories as the most promising to fulfill the requirements for a geologic repository in bedded salt. By Public Law 96-164, Congress authorized the WIPP in 1979 as "...a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States."

Created in 1970, the EPA was given broad responsibility to protect human health and the environment. One mandate was to establish "generally applicable environmental standards for the protection of the general environment from radioactive material...[where]...standards mean limits on radiation exposures or levels, or concentrations or quantities of radioactive material, in the general environment outside the boundaries of locations under the control of persons possessing or using radioactive material." (Plan, 1970). It was not until the late 1970's that sufficient funds were allocated to allow significant progress to be made on the development and regulation of a comprehensive management system for radioactive wastes (including high-level waste, defense transuranic waste, low level waste, and uranium mill tailings).

The First Attempt to Develop Disposal Standards

In 1978, following a series of public workshops to formulate "generally applicable criteria," the EPA proposed "Radiation Protection Guidance" for the disposal of all types of radioactive waste (43 FR 53262). This guidance was withdrawn in 1982 because the public convinced the EPA that "the characteristics of different kinds of radioactive waste are not sufficiently similar for generally applicable criteria to be appropriate." (EPA, 1982). The EPA then set out to develop separate standards for the disposal of high-level and transuranic waste, low-level waste, and uranium mill tailings. The Nuclear Waste Policy Act of 1982 (NWPA) further clarified the EPA's directive to develop standards for the high-level waste program.

The EPA's 1982 Proposed Disposal Standards

The EPA proposed disposal standards in December 1982 (EPA, 1982a). Subpart B of the standards included numerical containment requirements (release limits, which are the subject of this paper) and qualitative requirements to ensure that the containment requirements would be met. The release limits were based on the EPA's prediction of what could be achieved by a well-sited and designed repository containing the radioactive inventory from 100,000 metric tons of spent uranium fuel. The EPA asserted that this repository would cause no more than 1,000 fatalities world-wide ("health effects") in the next 10,000 years. The EPA conceded that this health risk is extremely small; it is supposedly no greater than the risks from an equivalent amount of unmined uranium ore. (Indeed, actual uranium ore bodies exceed this level of risk; see Williams, 1980). But because the EPA thought that the objective could be easily attained by the available technology and would require little additional expense, it felt no need to address whether the standards were too stringent, or the costs to achieve the standards were warranted.

The rule states that population-based release limits are to be applied to "all significant processes and events," such as human intrusion, that could result in radioactivity release. Recognizing that moderate releases of radioactivity could result from likely events, the rule states that the cumulative releases for 10,000 years shall have less than one chance in 10 of exceeding the quantities given in the regulation. Releases that could result from unlikely events shall have less than one chance in 1,000 of exceeding ten times the quantities given the regulation.

Summary of Major Comments on the 1982 Proposed Standards

The scientific community sharply criticized the proposed standards. The EPA had based its standards on what it thought technology could achieve rather than what is needed to adequately protect the public. When the proposed rule was published, the EPA encouraged public comments on the technical aspects rather than on the fundamental risk-management decisions. Despite this request, many government bodies, industry organizations, and individual experts raised fundamental issues that went beyond the rule's technical aspects. These same issues have been raised over and over again in succeeding years -- on the 1985 final standards and again on three official and one unofficial drafts of new standards.

The fundamental issues raised in the 1982 and subsequent comments went to the heart of the technical achievability approach. Commenters argued that the risk levels inherent in the containment requirements were unnecessarily far more stringent than other regulations, and compliance with these requirements would be extremely difficult to demonstrate, particularly in a licensing proceeding. It is worth noting that, at that time, site-specific studies were at an early stage and could not be used to test the proposed standards. Without real sites, the commenters did not emphatically challenge the EPA, but did so later, when experience with attempting to apply the standards to real repository sites revealed the fallacy of the EPA's approach.

Some of the fundamental issues raised on the 1982 proposed standards included the following:

- The containment requirements (curie release limits) are unnecessarily conservative, and reflect a numerical risk unusually low compared to other risks considered acceptable to society. (DOE, 1983a); (SAB, 1984); (EEI, 1983a and 1983b).

- The probabilistic nature of the standards (i.e., predicting sequences of unlikely events far off into the future) requires a degree of precision which is not likely to be achievable and will be both unworkable and unnecessary; there will be substantial uncertainties in the projections. (NRC, 1983); (DOE, 1983a and 1983b); (SAB, 1984); (EEI, 1983b).

- The EPA assessed the implementation and, hence, the achievability of the standard by analyzing hypothetical repositories located in simple, perfectly understood geological environments. For a real repository, geological complexity and imperfect information are major barriers to licensing; the EPA's analysis did not consider these problems (ibid.).

- The standards impose requirements that provide no corresponding health benefit for such costly implementation; significant shortcomings in the EPA's economic analysis supporting the proposed standards resulted in the costs being underestimated. (DOE, 1983a); (SAB, 1984).

Summary of Major Comments on the 1985 Final Standards

The standards were issued as a final rule by the EPA on September 19, 1985 (EPA, 1985c). The most important change in the final rule was the addition of limits on doses to individuals and contamination of ground water. These limits applied only for a period of 1,000 years, and they applied only to undisturbed conditions. (As in the draft rule, probabilistic calculations are required only for the containment requirement.) In issuing its final standards, the EPA responded to comments on specific technical issues, but did not fully respond to the fundamental issues. The EPA characterized these as issues "associated with policy and risk management."

By 1985, the Waste Isolation Pilot Plant (WIPP) was nearly constructed, but its performance assessments had not progressed to a level that would expose the implementation problems of the standards. Yucca Mountain had not yet been selected for site characterization. Although the EPA attempted to model a generic repository in different geologic media, there was not enough information about specific sites to fully evaluate the standards.

Prior to this time, the Nuclear Regulatory Commission (NRC) had begun developing its regulations, 10 CFR 60, which, by law, must be compatible with the EPA standards. While the NRC staff had again expressed in public forums concerns about the EPA's lack of technical justification for the conservative models and assumptions, they still did not emphatically argue for a different approach. The NRC staff stated in memoranda to the Commission, in direct contradiction to the views from the NRC advisory body -- the Advisory Committee on Reactor Safety (ACRS) -- that the standards are reasonable and achievable and that the risks are comparable to other nuclear standards (NRC, 1985a and 1985b). The ACRS (comprising nationally and academically prominent scientists) attempted to convince the Commission otherwise. In two memoranda to the Commission, the ACRS continued to argue that the standards were unduly restrictive; the predictive nature made them difficult to satisfy with any certainty; and the corresponding dose limits that the EPA added to the standard were not health-risk based (ACRS 1985a, and 1985b). Members of the ACRS, which included a former member of the EPA's Science Advisory Board, Dr. David Okrent, expressed grave concerns about the ability to implement such a standard and the excessive costs that would be incurred, without a corresponding benefit to public health and safety. Dr. Okrent's continued criticism of the standards (Okrent, 1992a, 1992b, 1992c and 1992d) raised concerns that are similar to those in this paper.

Summary of Major Comments on the Working Drafts of New Standards to be Repromulgated

Shortly after the EPA issued its final standards, a number of states and environmental groups sued the EPA because the ground-water protection requirements did not have the same numerical dose limits as the EPA's clean water regulations and because the EPA did not explain why this protection should last only 1,000 years. The First District Court of Appeals (court) agreed and remanded the standards in 1987. Since the court's remand, the EPA has released four drafts of proposed standards.

After the 1987 remand of the standard's Subpart B, the technical community again questioned the EPA's risk-management decisions. Comments on the four drafts continued to criticize the EPA's approach and bases for the standards. With actual experience in conducting performance assessments for two real sites, it became increasingly clear to both the DOE and the NRC, as well as others (e.g., the National Academy of Sciences, the Advisory Committee on Nuclear Waste, the Nuclear Waste Technical Review Board, and the national laboratories) that the standards were impractical.

Comments on the four drafts continued to raise the same fundamental issues as before, but with greater fervor. The issues include:

- Excessive stringency of release limits (e.g., for carbon-14);
- The infeasibility of making quantitative predictions over long periods of time (e.g., for human intrusion);
- Continued application of simple, overly conservative models and assumptions by the EPA;
- Risk limits far below those of other risks accepted by society;
- Excessive costs without discernable benefit to public health and safety;
- Inconsistent approach with recommendations from the International Commission on Radiological Protection and the National Research Council of the National Academy of Sciences.

While the occasion of the 1987 remand gave the EPA an explicit opportunity to address concerns and change the standards, the four drafts did not give evidence that serious consideration had been give to the intrinsically problematic nature of a risk management approach based on technical achievability. Instead, in the face of consistent criticism on each of the key issues discussed above, the EPA proposed "technical bandaids" that made cosmetic changes to the standard, but did not address any of the key issues. In fact, draft #4 is more stringent than the original rule. According to this draft, releases and exposures from an undisturbed repository would have to be predicted for up to 100,000 years. The higher uncertainties of such long-term predictions would further frustrate the regulatory proceedings. To date, the EPA has not shown how these added requirements would improve safety.

III. Health-Risk versus Technology-Based Regulations

A fundamental decision about any environmental regulation is how stringent it needs to be. To make this decision, the regulator generally considers three factors: risk, technology and economics.

Health-risk-based regulations are set at levels considered adequate to protect human health and the environment. However, when asked to orient the HLW standards more towards a health-risk-based approach (DOE, 1992), the EPA responded, "...we have not seen a convincing basis for a change in the fundamental approach of the rule which is technological achievability." (EPA, 1992a).

Technology-based regulations impose limits that correspond to the use of specific technologies. Technology-based regulations can either be based on current technology, or be **technology-forcing regulations**, which require industry to develop new technology to meet them. For example, regulations that administer the Clean Water Act impose three types of technology:

1. Best Practical Technology (BPT) is the average of the best existing performance by well-operated plants;

2. Best Available Technology (BAT) is the very best control and treatment measures that have been or are capable of being economically achieved; and

3. Best Conventional Technology (BCT) controls conventional pollutants such as suspended solids and fecal coliform bacteria.

Regulations that administer the Clean Air Act impose two types of technology:

1. Best Available Control Technology (BACT) is the maximum degree of emission reduction that is achievable on a case-by-case basis taking into account cost and other factors; and

2. Maximum Available Control Technology (MACT) is the maximum degree of reduction of hazardous air pollutants that is achievable taking into account cost and other factors.

The release limits of the HLW standards are based on technological achievability, which does not fit into any of the above categories.

Economic-based regulations are set at the level where the incremental value of additional protection is balanced against the incremental cost. Such regulations must still adequately protect the health and safety of the public. Because the EPA thought that its HLW standards could be easily achieved, regulatory costs were dismissed.

According to the Safe Drinking Water Act (Section 1412(b)(4)-(7)) and the Occupational Safety and Health Act (Section 6(b)), a regulation begins as risk-based, and then becomes a less stringent technology-based regulation if compliance with the risk-based regulation would be impossible or impractical. Risk-based levels (Maximum Containment Level Goals and National Institute of Occupational Safety and Health Recommendations) are first developed as goals. Later, enforceable regulations (Maximum Containment Levels and Occupational Safety and Health Administration Standards), which are technology-based and may be less stringent than the risk-based levels, are developed.[1]

As Chapter II has described, the HLW standards were based on what EPA thought technology could achieve.[2] Unlike technology-based regulations, these standards use technical feasibility not to delineate a necessary compromise between risk and economics, but to set standards that are *more stringent* than what risk-based standards would be.

The EPA claimed, but never confirmed, that the HLW standards were attainable with current technology. No repository actually existed at the time the standards were developed, so the EPA was obliged to devise hypothetical repositories to support development of the standards. Five repositories were modeled theoretically, assuming geologic structures and hydrologic flow systems conceptually much simpler than those found in actual sites (Smith et al., 1982). The results of this effort were taken to be a representation of what could be achieved by "well sited, well designed geologic repositories." It is not surprising that such an approach does not accurately represent the performance of repositories in actual geologic sites. Real sites are much more complex than these simplified conjectures.

---

[1]The Clean Water Act and Clean Air Act originally had similar structures. As a result of numerous court cases and congressional amendments, limits imposed under these laws are now based on complicated mixtures of risk, current technology, economics and technology-forcing.

[2]Supplementary information suggested that the rule was also based on the risk from the amount of uranium ore that would have been mined to create 100,000 metric tons of spent fuel. However, EPA representatives have subsequently acknowledged that the actual basis for the standards was a "generic assessment of the protection provided by well sited, well designed geologic repositories" (Galpin et al., 1992).

The land disposal regulations that administer the Resource Conservation and Recovery Act (RCRA) are much like the standards, i.e., they are technology-based regulations that are more stringent than safety goals. But in this case, the stringent regulations accomplish exactly what Congress wants: "reliance on land disposal should be minimized or eliminated, and land disposal, particularly landfills and surface impoundments, should be the least favored for managing hazardous wastes" (RCRA, Section 1002(b)(7)). The stringent HLW standards, however, discourage a Congressional initiative "to provide for the development of repositories for the disposal of high-level radioactive wastes" (Nuclear Waste Policy Act, Section 1). Furthermore, these standards are even more stringent than regulations that, by law, must *"minimize"* or *"eliminate"* a technology.

IV. Regulatory Excess

Unnecessary Conservatism

Using hypothetical repositories, the EPA determined what it thought a repository could achieve: limit the number of health effects to fewer than 1,000 for the entire world population (assumed to grow to 10 billion people) over a 10,000-year period per 100,000 metric tons of spent fuel. No one disputes that materials as toxic and long-lived as high-level waste must be managed so as to protect the health of our fellow human beings throughout the world and in future generations. But to extend quantitative regulatory limits to the entire world population over such a long span of time is impractical and unprecedented. Protection of the world population is more properly the domain of treaties and international conventions than of EPA regulations. It is unnecessary for the U.S. to establish stringent limits for repository releases of carbon-14 when the health risk is so insignificant. Moreover, other countries are reprocessing spent fuel and venting much larger amounts of carbon-14 directly to the atmosphere. This numerical limit is therefore faulty, both in its quantitative basis and in its scope, given the real world situation.

Another important point is that the EPA took no account of either the benefits of the nuclear-produced electricity that results in the production of the waste or the additional risks associated with the production of electricity by burning coal. While the standards are set at a level that limits the increase in death rate to less than one in one billion over the observed death rate from all causes, it is unquestionably true that the elevated standards of living and medical care that come from availability of electric power reduce the death rate by a much larger amount than one in a billion, completely canceling the hypothetical increase. These excessively stringent standards may also discourage the construction of new nuclear power plants. Some state laws and public opinion have tied the licensing of new nuclear power plants to the availability of waste disposal facilities. Less reliance on nuclear power means more reliance on coal, and coal-fired power plants release about four times as much radioactivity plus the hydrocarbons that nuclear power plants do not release.

Even if the EPA is disposed to ignore the benefits of nuclear power and chooses to compare the standards to the calculated risks from unmined uranium ore bodies, one still finds that the 1985 standards were excessively conservative. In the EPA's analysis of three actual ore bodies (as distinguished from their hypothetical "model" ore body) the calculated risks came out a factor of 30 to 300 larger than the quantitative level the EPA used for the repository standards (Williams, 1980, as updated in EPA, 1985b). In other words, even natural deposits of uranium ore would violate the standards by a significant margin, if judged on the basis of equal uranium tonnage.

The difficulties do not stop here. Besides basing the standards on imaginary repositories, the EPA disregarded the possibility that there is a threshold below which exposures to radiation are not harmful. According to BEIR V "epidemiologic data cannot rigorously exclude the existence of a threshold in the millisievert [hundreds of millirems] range. Thus, the possibility that there may be no risks from exposure comparable to external background radiation cannot be ruled out" (BEIR V, 1990).

The EPA then chose to apply its stringent, no-threshold standards using a Linear Model. This model predicts radiation effects (i.e., radiation risk) that are directly proportional to the dose received. Although the Linear Model is routinely used in the regulation of radiation, it disregards considerable evidence that cells can repair the damage from low dose rates Again, according to BEIR V, "In general, the effectiveness of a given dose tends to decrease with decreasing dose rate" (ibid.). Nevertheless, regulators prefer to err on the side of safety; so they continue to use the Linear Model in setting regulations. But none, to our knowledge, even bother with individual doses that are in the range of microrems.

There is another hypothesis, called the Linear Quadratic Model, that predicts less damage to living organisms at low dose rates (Sinclair, 1980). At low dose rates, incremental[1] radiation risk predicted by the Linear Model is more than three times that predicted by the Linear Quadratic Model (Beebe, 1981). The National Council on Radiation Protection (NCRP) states that the actual risk could be smaller by a factor of two to ten than the risk predicted by the Linear Model (NCRP 64, 1980). At extremely low dose rates, we expect (but cannot empirically verify) that the incremental radiation risk predicted by the Linear Model would be more than ten times that predicted by the Linear Quadratic Model. It is entirely possible that the number of health effects from a repository's releases would actually be zero. Both of these models are portrayed schematically in Figure IV-1.

---

[1]The dose rate from a repository would be added to the background dose rate as an incremental risk.

Relationship of Risk versus Dose

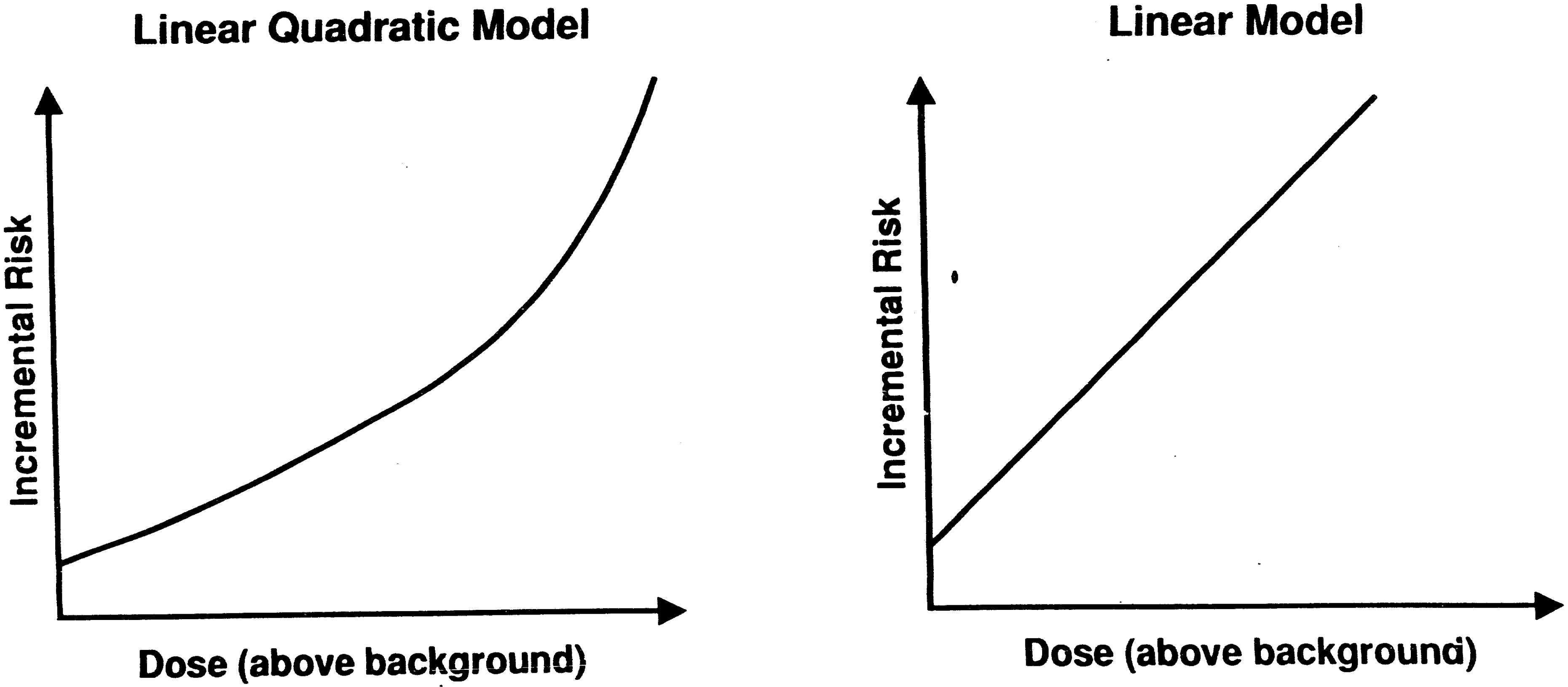


Figure IV-1

LINECDR 125/11 10 92

Overly Stringent Standards

No regulation in the world compares in scope or stringency to the EPA standards (IEAL, 1987). Moreover, no other regulation attempts to protect so many people, so rigorously, for such a long period of time. Other environmental regulations that deal with world-wide changes have been undertaken when the world environment is perceptibly threatened. Some of these regulations and policies, for example, are phasing out the use of chlorinated fluorocarbons that threaten the ozone layer, are taking action against global warming and have stopped atmospheric nuclear testing. Imperceptible changes in world-wide background levels of natural environmental constituents, such as releases of carbon-14 from an HLW repository, have never triggered regulation.

The standards require 99.9% confidence that radioactive releases to 10 billion people will stay within prescribed concentrations for 10,000 years. Other regulations, which are not so ambitious, protect individuals, or sometimes local populations. The period of protection varies from regulation to regulation (Table IV-1), but only the HLW standards, and to a much lesser extent the deep-well injection regulations (40 CFR 148), presume that 10,000 years of protection can be proven.

The deep-well injection regulations allow a waiver of the "land ban" forbidding deep-well injection of untreated hazardous wastes if an applicant can show that there will be "no migration" of the hazardous wastes for 10,000 years (40 CFR 148). This strict requirement was imposed because Congress ordered that land disposal be "minimized or eliminated." (In contrast, Congress encourages deep geological disposal of HLW.) Nonetheless, EPA has made it relatively easy to obtain the waivers. Waiver applicants can rely on existing data and have rarely drilled new boreholes for data collection. They do not have to speculate about future events or unknown physical processes; only anticipated conditions are predicted, and only processes listed in the regulations are analyzed. Faults and earthquakes are the only disruptive events considered; risks of human intrusion are ignored. Applicants can assume that any penetration of the confining beds above the injection zone will, if sealed to current industry standards, remain impermeable for 10,000 years. Thus, the waiver process is incomparably less stringent than the HLW standards, in spite of the apparent similarity to the 10,000-year containment requirements. Indeed, nearly 20 waivers have been granted to date, with an average cost to the applicant of $350,000 to prepare the application.

Table IV-1

Periods of Protection Provided by Disposal Regulations [1]

Regulation	Subject	Period of Protection After Closure
40 CFR 241.209-3 (b) & (c)	Disposal of solid waste	1 year
40 CFR 264.117, 265.117, 267.23 (b), 267.33 (b), 267.44	Disposal, treatment, storage and monitoring of hazardous waste	30 years
10 CFR 61.52 (a) (3)	Disposal of "Class C" (low-level) radioactive waste	500 years
40 CFR 192.32 (b) (1) (i) & (ii)	Disposal of uranium by-product material	1,000 years
40 CFR 191.13 (a)	Disposal of high-level and transuranic radioactive waste	10,000 years
40 CFR 148.20 (a)(I)(i)	Disposal of hazardous wastes by underground injection	10,000 years

1. Except for the NRC regulation, 10 CFR 61, all regulations are issued by EPA

RADPFLM12 125/1 14 93

To further compare the standards to other regulations, we must scale population risk to lifetime individual risk, assuming a linear relationship between the two. As did the EPA, we will assume a linear dose response with no threshold for purposes of this scaling. (As noted previously, a linear-quadratic response might be more appropriate.)

Risk (sometimes called mortality rate) means the probability that a population or individual will suffer a fatality within one year or within a lifetime (70 years). According to the standards, a repository can cause no more than 1,000 (10^3) fatalities to 10 billion (10^{10}) people in 10 thousand (10^4) years. Dividing 10^3 fatalities by 10^{10} people and then by 10^4 years we get a world-average risk to an individual of 10^{-11}/year (equivalent to 2.5 x 10^{-5} mrem/year)[2]. If we assume that this individual lives for 70 years, his lifetime individual risk would average 7 x 10^{-10} (equivalent to 1.8 x 10^{-3} mrem).

Although simple and straight-forward, averaging is not the only means to convert the standards' collective risk to individual risk. The equations that EPA used to formulate the standards assumed that a repository would release radionuclides into a generic or "world average" river and from there reach 10 billion people through a succession of some 30 "world-average" pathways. Instead of simply dividing the collective risk by 10 billion people and 10,000 years, one could reconstruct the EPA's formulas and assumptions to focus the risk on one person rather than 10 billion. Calculated in this manner, the risk to some individuals may be higher than the average (10^{-11}/year): the value upon which we and others have based our stringency arguments (e.g., ACNW, 1992, ACNW, 1990, ACRS, 1985a, NRC, 1991, NWTRB, 1991, NWTRB, 1990, ORNL, 1992 and SAB, 1984).

Table IV-2 compares the risk allowed by the standards to risks that society often ignores. We make this comparison only to give the reader a sense of how stringent the standards are. For example, the table shows that one would be killed by a bee sting or struck by lightning before one would be harmed by a repository. While instructive, this Table clearly cannot provide a basis for HLW regulations.

---

[2] $\text{mrem} = \dfrac{\text{risk}}{4\text{x}10^{-7}}$

Table IV-3 compares the world-average risk allowed by the standards to the more local risks allowed by other EPA regulations.. If distributed over large populations, these local risks would be smaller. For example, the clean air regulation (40 CFR 61) allows a maximum risk of 7×10^{-4} which is one million times less stringent than the standards. According to the EPA this maximum risk would, in practice, limit the risks to large populations to less than 10^{-6} which is still ten thousand times less stringent than the standards. Recognizing this discrepancy between world-average risks and local risks, we can still conservatively say that the standards are far more stringent than other regulations.

Table IV-4 is more of an "apples to apples" type comparison. It compares average radiation exposures from different sources throughout the world. For example, all of the world's coal-fired power plants expose the average person to 0.020 mrem/year while nuclear power plants expose the average person to 0.005 mrem/year. To be fair, we assume 10 geologic repositories; one in each of the following countries: Belgium, Germany, Canada, France, Japan, Sweden, Switzerland, the United Kingdom, Russia and the United States (IEAL, 1987). We also assume that each repository complies with the standards, although none probably would (Pflum, 1988). The table indicates that if the standards were relaxed by a factor of 10, the average exposure from ten repositories would still be comparable to or below exposures from other radiation sources.

From all these perspectives, the EPA standards are seen to be overly conservative. In addition, it is unprecedented to attempt to regulate the effects of such immeasurably small individual radiation doses over the entire world population for such a long period of time. It is unrealistic to believe that we are capable of accounting for such small, far-flung effects in the distant future. This is not a valid basis for establishing standards for real-world repositories.

A COMPARISON OF REPOSITORY HAZARDS TO OTHER HAZARDS

Table IV-2

Hazard	Annual mortality rate	
Repository	1×10^{-11}	1 in 100 billion
Bee sting[1]	2×10^{-7}	1 in 5.5 million
Being struck by lightning[1]	5×10^{-7}	1 in 2 million
Flying[1]	1.2×10^{-6}	1 in 833,000
Walking[1]	1.85×10^{-5}	1 in 54,000
Cycling[1]	3.85×10^{-5}	1 in 26,000
Driving a car[1]	1.75×10^{-4}	1 in 5,700
Riding a moped[1]	2×10^{-4}	1 in 5,000
Riding a motorcycle[1]	1×10^{-3}	1 in 1,000
Smoking cigarettes (1pack/day)[1]	5×10^{-3}	1 in 200

1. Source: DNEPP, 1988

RADPFLM4 125 1 14 93

Table IV-3

A COMPARISON OF THE RISKS ALLOWED BY DIFFERENT EPA REGULATIONS

Regulation	Law	Example Contaminents	Lifetime Risk
40 CFR 191[1]	AEA	High-level and Transuranic Radioactive Wastes	7×10^{-10}
40 CFR 61[2]	CAA	Radioactive Emissions to air	7×10^{-4}
40 CFR 761[2]	TSCA	Poly-chlorinated biphenyls (PCB)	1×10^{-6}
40 CFR 141[2]	SDWA	Benzene	8×10^{-6}
		Tetrachloroethylene (TCE) & Lead	1×10^{-6}
		PCB	1×10^{-5}
		Vinyl chloride[3]	1.1×10^{-4}
40 CFR 261[2]	RCRA	Benzene, TCE, vinyl chloride	1×10^{-6}

Acronyms:

AEA - Atomic Energy Act
TSCA - Toxic Substances Control Act
SDWA - Safe Drinking Water Act
RCRA - Resource Conservation and Recovery Act
CAA - Clean Air Act

1. Considers 10 billion people
2. Considers local populations
3. The risk of cancer from drinking vinyl chloride at the level permitted under the Safe Drinking Water Act (the MCL) is 1.1×10^{-4}. This is seen by multiplying the MCL of 2 *mg/* by the slope factor of 5.4×10^{-5} cancers/(*mg/*) approved by EPA [Health effects assssment summary tables, USEPA Report OERR 9200.6-303(91-1), January 1991].

HADPFLM9 125/1 14 93

WORLD-AVERAGE EXPOSURES TO RADIATION

Source	Dose[1] (mrem/year)
Natural Background (includes radon)	240.
Radon	110.
Diagnostic Medical Treatment	100.
Industrial Activities[2]	5.00
Power Plants	
Coal	0.020
Nuclear	0.005
Oil	0.001
Repositories [3]	.00025

1. Effective dose equivalent for an individual
2. Includes ore mining and processing (e.g., zinc, copper, lead, phosphate, coal, and uranium)
3. Assumes 10 repositories

Source: UNSCEA, 1988

Table IV.4

Repository Risk to Local Populations

According to the standards, a repository can expose individuals to very little radiation, about 0.025 microrems/year (see previous section). This exposure is 40 thousand times lower than what many countries, such as Canada, consider "below regulatory concern" (1 mrem/year or 1,000 microrems/year). Women who wear heels are exposed to about 0.3 microrems/year more cosmic radiation than women who wear flats (Park, 1992). Yet the Surgeon General has not classified high-heeled shoes as carcinogens. By the same token, the EPA should not assert that the repository's 0.025 microrems/year will take 1,000 lives.

The 1,000 health effects is the product of an individual dose (2×10^{-5} millirems/year) times the population size (10^{10} people) times the number of years (10^{4}) times a conversion factor (5×10^{-7} health effects per millirem). As one can see, the huge population (10^{10} people) inflates the number of health effects.

It would be more reasonable to examine the impacts to local populations living within 50 miles of a repository. Using a hypothetical source term that just meets the standards' release limits, health effects due to human intrusion were calculated for local populations near Yucca Mountain (12,000 people) and WIPP (96,000 people) (Woolfolk, 1992). Over a period of 10,000 years less than one health effect can be attributed to either repository even if each of the local populations grew 600 fold (Table IV-5). For comparison, 20% of all the deaths in the U.S. are attributed to cancer.

IMPACT OF HUMAN INTRUSION
ESTIMATED NUMBER OF CANCER DEATHS
(for population within 50-mile radius of the site)

Source of Radiation	Years after emplacement	Population Dose[a] (person-rem)	Number of Cancer Deaths
Yucca Mtn.	1,000	3.14	1.3×10^{-3}
Yucca Mtn.	10,000	3.95	1.6×10^{-3}
Background			44[b]
WIPP	1,000	8.58×10^{-4}	3.4×10^{-7}
WIPP	10,000	4.81×10^{-5}	1.9×10^{-8}
Background			340[b]

(for the maximumally exposed individual)

Source of Radiation	Years after emplacement	Individual dose[a] (rem)	Number of Cancer Deaths
Yucca Mtn.	1,000	3.14×10^{-2}	1.3×10^{-5}
Yucca Mtn.	10,000	5.17×10^{-2}	2.1×10^{-5}
WIPP	1,000	5.7×10^{-5}	2.3×10^{-8}
WIPP	10,000	3.7×10^{-5}	1.5×10^{-8}

[a]Based on 70 year cumulative effective dose equivalence (EPA/540/1-89/002)
Health effects per person - rem = 4×10^{-4}

[b]Deaths caused by background radiation

RADPFLM11 125/1 14 93

Table IV-5

Repository Risk to Individuals

Earlier we scaled the EPA's population risk to lifetime individual risk assuming a linear relationship between the two. If a repository can cause no more than 1,000 (10^3) fatalities to 10 billion (10^{10}) people in 10 thousand (10^4) years, then the world-average risk to an individual would be 10^{-11}/year, and the lifetime individual risk would be 7 x 10^{-10}.

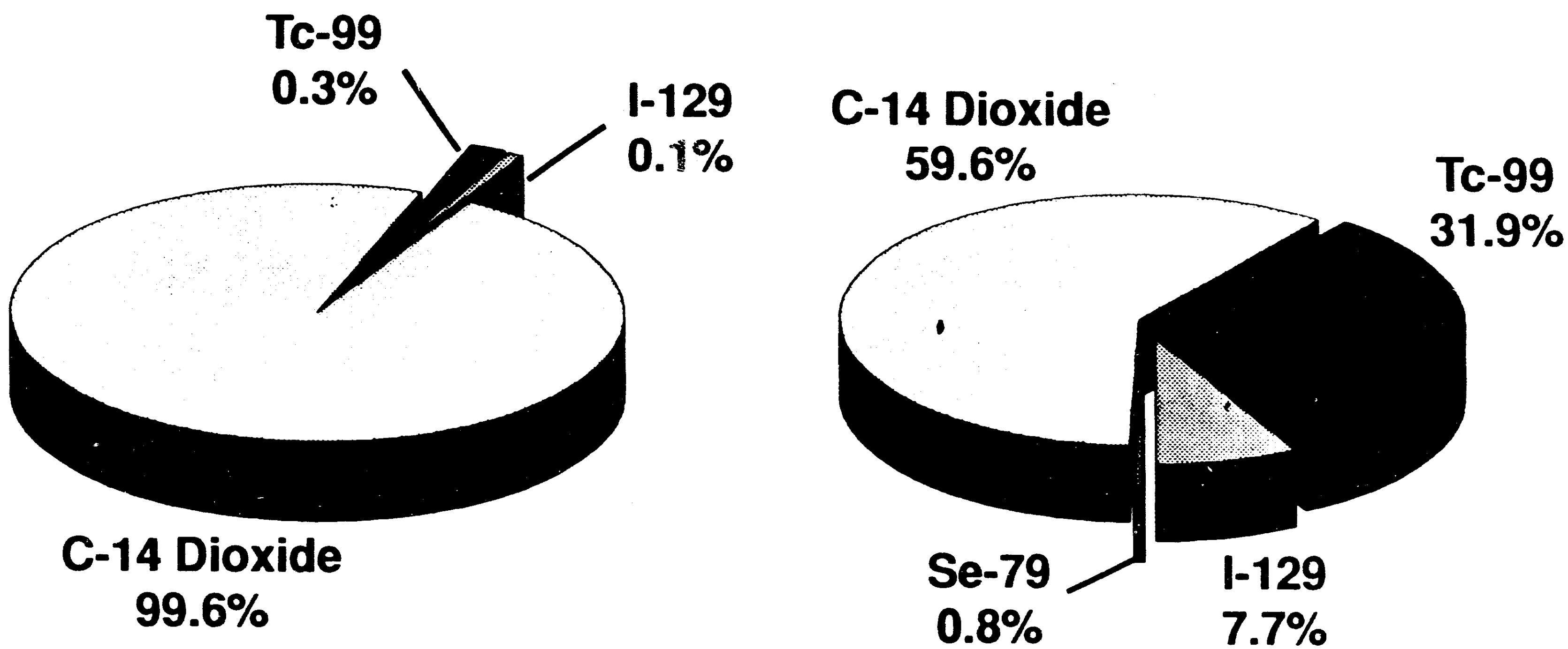
According to a draft subcommittee report from the EPA's Science Advisory Board, an unsaturated HLW repository could pose lifetime individual risks of 3 x 10^{-9}, about four times as much as the standards allow (SAB, 1992). This risk corresponds to an average individual lifetime dose of about 0.01 mrem (ibid.). By comparison the National Council on Radiation Protection and Measurements recommends no more than 100 mrem (NCRP 91, 1987) from all man-made sources of radiation, excluding natural and medical sources which expose an average U.S. resident to 360 mrem per year (BEIR V, 1990).

The above risk (3 x 10^{-9}) and dose (0.01 mrem) figures assume that half the repository's inventory of carbon-14 is released as carbon-14 dioxide over 10,000 years. Other radionuclides were not considered. However, both matrix flow and fracture flow models (Barnard et al., 1992) indicate that releases of carbon-14 dioxide dominate all other radioactive releases combined (see Figure IV-2). We consequently assume that releases of carbon-14 will account for most of the repository's risk, should the repository be constructed in the unsaturated zone. Although it would violate the standards by a factor of four, the unsaturated repository would be safe; orders of magnitude safer than routine hazards that society accepts, and well within international and national recommendations.

Since the carbon-14 would escape as a gas, carbon-14 dioxide, one could argue that it would affect the entire world's population. If the individual lifetime risk (3 x 10^{-9}) is extrapolated to 10 billion people, the Linear Model predicts 4,000 health effects and the Linear Quadratic Model, 400 to 2,000 health effects. We still believe that the individual risks are so small that they ought to be ignored, even if 10 billion people are exposed. People in their daily lives accept risks much larger than 3 x 10^{-9} without the least hesitation. On the other hand, some people believe that any exposure to radiation, however small, is dangerous. As Sakharov pointed out in the first discussion of carbon-14 doses 35 years ago, "Two world wars have also added less than 10% to the death rate of the 20th century, but this does not make war a normal phenomenon."

AQUEOUS AND GASEOUS RELEASES

(Percentages of the total curies released in 10,000 year)



Matrix Flow Model **Fracture Flow Model**

Figure IV-2

(Adapted from Barnard, et al, 1992)

V. Implementation Problems

Predicting the Future

The fundamental problem encountered in attempting to implement the standards is that they call for quantitative prediction of the probabilities and consequences of future events out to 10,000 years. This time span is well beyond the range of engineering experience and, indeed, of recorded history. While science can provide some insights into the probable future course of events associated with a particular geological site or a particular design of an engineered barrier, scientific predictions over this time scale will remain very uncertain. The reason for this uncertainty lies in complexities of the many different scientific disciplines that must be brought together to predict repository performance. Only a few of these disciplines (e.g., astronomy) rest on fundamental laws that can be confidently extrapolated into the distant future. Many others, such as corrosion engineering (to some extent) and the social sciences (particularly) rely on empirical correlations whose extrapolation is open to question. All science necessarily must bring together hypothesis and observation. While we are certainly free to conjure up hypotheses about events thousands of years into the future, we have no way of making observations or conducting experiments that would test our hypotheses. This limits our ability to place all of the required disciplines on a firm, extrapolatable basis.

In the face of this situation, some adopt the notion that "history will repeat itself," that we must merely look into the past to predict the future. While this approach is helpful as a general guideline, it does not enable us to make confident predictions of specific future events. The conclusion that "history repeats itself" can only be reached in retrospect. It does not provide a reliable prediction.

The framers of the standards appear to have recognized, to some degree, the difficulties in predicting the future. They attempted to deal with them by calling for a "reasonable expectation" that for 10,000 years, a repository will release, within specified confidence limits, no more than the rule allows. However, this does not solve the problem. If one is unable to predict the future, how does one evaluate the uncertainty of one's predictions? Moreover, what does "reasonable expectation" mean?

There are thus two major difficulties: (1) the standards require predictions that are inherently impossible to defend, and (2) the standards are couched in language that tends to obfuscate this impossibility. This does not provide an understandable or workable basis for repository licensing.

Use of Probabilities in Nuclear Licensing

The standards are stated in the language of quantitative decision theory. They require that the probabilities of certain outcomes be less than specified values. This is an unusual requirement to find in a regulation; even in areas where probabilistic analysis has played a large role in safety discussions (such as nuclear reactor accident prevention), regulators have chosen to frame their requirements in a deterministic manner.

To decide whether a proposed facility complies with these standards, an implementing agency must determine the probabilities of various possible outcomes. Exact values are not needed, but quantified upper bounds are. For a HLW repository, the implementing agency is the NRC. The NRC is required to make its decision on the basis of a record established in a hearing before a licensing board. The license application prepared by the DOE will be part of this record.

The licensing hearings are adversarial proceedings. There is a fundamental difference in approach between decision theory and adversarial legal proceedings. The objective of decision theory is to integrate all available relevant information, including subjective opinions, into a single best estimate. Legal proceedings aim at finding the truth in the face of conflicting evidence.[1]

---

[1]Neither of these frameworks is inherently a better way of thinking than the other; it depends on the circumstances. For example, suppose one person answers a question "2" and another answers "6". A decision theorist would say the best answer is, roughly, 4±2; a trial lawyer would cross-examine to find out which of the two is lying! The decision theory approach would be appropriate if two geologists were estimating the size of an oil reservoir for their employer, but the trial lawyer's method would be far better if two witnesses were describing how many shots were fired by a murder defendant.

When witnesses in a nuclear licensing hearing disagree, the licensing board uses the record to decide whom it believes. The main way of doing this is to examine how well the opinions are supported by evidence.

Unfortunately, the probabilities of many important potential causes of radiation release from a repository cannot be quantified in an objective way. At most, upper .nds that are far above the true values can be placed on these quantities. This applies most strongly to future human actions and uncertainties in our knowledge of geology, metallurgy, and other sciences:

- If we know enough to objectively put a probability on the chances of an alternative scientific theory, we would know whether the theory is credible.

- It is well established that historians cannot reliably estimate probabilities of future human actions. (The failure of all experts to predict the sudden collapse of the Soviet Union is only the latest example.)

Lack of objective evidence does not prevent a decision theorist from assembling the subjective opinions of experts on such questions. But when this has actually been attempted, the experts have failed to reach agreement:

- A panel estimating scenario probabilities at the formerly proposed Hanford repository site (Davis and Runchal, 1984) could reach consensus on only 9 of 45 potential repository disruptions. For 19 of the 45, not even 75% agreement could be reached.

- Estimates of the probability of at least one human intrusion at the WIPP site by four independent expert panels (Hora et al., 1991) ranged from less than 0.01 to nearly 1.

A licensing authority has no basis for discerning fact among conflicting opinions and therefore has great difficulty relying on numbers of this kind.[2] Experts who testify in

---

[2]In an effort to ameliorate the problem of justifying these predictions, the standard specifies a "reasonable expectation" standard of proof. But evidence is still needed, even if less of it. The fundamental difference -- decision theory is satisfied with opinion, while judges require proof -- remains. As a decision-theory advocate points out (Guzowski, 1991), the theory is based on the

licensing hearings generally understand that they must give the licensing authority a factual basis to accept or reject their opinions, and so they try to give opinions that they can support with evidence. But because the probabilities of future disruptions of a repository are so hard to evaluate, only extreme upper bounds could be objectively supported. It is these upper bounds, we may anticipate, that will be included in a HLW repository license application and used by the licensing board to determine whether the repository complies with the standards.

Because the standards will be applied in an epistemological framework, inconsistent with that in which they were derived, they cannot be implemented in a coherent manner.[3] Regardless of the level of confidence in the probabilities of future events, it is likely that determination of compliance will not rely on how likely a release of radioactivity really is, but on a debate over whether distant upper bounds are sufficiently conservative. Because numbers that are defensible in a licensing proceeding will have little relation to the true probabilities, this debate will not be relevant to the safety of the repository.

This is not a reasonable way to make a decision that could have a significant effect on the public well-being. The EPA standards should be reformulated in a way that does not require an estimation of numerical probabilities over 10,000 years.

"subjectivist" interpretation of probability, in which "any coherently derived probability value is as 'correct' as any other probability value derived in the same way." If decision-theory experts differ, the judge has no way to decide among them.

[3]The EPA's conclusion that the standard is implementable without significant cost were based on a simple decision-theory analysis (Smith et al., 1982). The EPA analysis used many judgmental estimates that could not be defended in a licensing proceeding.

VI. Financial Impacts of 40 CFR 191

In its Regulatory Impact Analysis (RIA), the EPA concluded that the standards can be set to an unprecedented level of stringency without increasing costs (EPA, 1985a). This belief, in turn, reinforced the EPA's approach of setting the most conservative release limits thought to be technically achievable.

Since the time the EPA standard was promulgated in 1985, the commercial repository program has changed direction from parallel characterization of three potential sites to the characterization of one site chosen by Congress. Also, costs of site characterization have escalated to an estimated $6.3 billion. In view of these changes, a reassessment of the EPA's cost estimates is warranted.[1]

So far, analyzing compliance with the standards has cost the repository program roughly $190 million at Yucca Mountain and $300 million at the Waste Isolation Pilot Plant (WIPP). Two troublesome requirements have been studied in detail: the standards require a repository to endure human intrusions, and they impose overly-stringent limits on releases of gaseous carbon-14. A good repository could violate either of these requirements and the releases would not harm local populations. The financial consequences of not meeting the standards, however, would be astronomical. If a licensing board found that the Yucca Mountain site could not meet the standards, approximately $6.3 billion would be lost, and another $23 billion would be needed to find another licensable site. Similarly, if the WIPP site does not meet the standards, approximately $1.9 billion would be lost, and more than $13.7 billion would be needed to find another site.[2] We do not suggest that cost should influence a licensing decision. Rather, a good site should not be abandoned because two requirements that have little to do with public health and safety cannot be demonstrated.

---

[1]Besides understating costs, the EPA's RIA uses invalid assumptions to determine the costs and benefits. The Yucca Mountain Project is currently preparing a detailed critique of a recently proposed RIA (EPA, 1992).

[2]If the Yucca Mountain and WIPP sites cannot meet the standards, we doubt that any site will; regardless of how much is spent. The standards suffer genuine flaws (e.g., human intrusion) any one of which could stop any repository program.

Comparison of the EPA's and the DOE's Cost Estimates

The EPA has attempted to defend the standards' stringency on the basis that the stringency could be tolerated with no additional cost. The EPA's dismissal of financial impacts was based on a Regulatory Impact Analysis (EPA, 1985a). In this section we compare the EPA's estimated costs with more recent cost estimates by the DOE (DOE, 1989, 1990b). Our comparison shows about a factor of two difference between the two.

We have compared the EPA cost categories called "Research and Development" (R&D) and "Government Overhead" (EPA, 1985a) to the DOE cost category called "Development and Evaluation" (D&E) (DOE, 1989) (Table VI-1). We chose these categories because they are the most sensitive to regulations, although some adjustments were needed to make the comparison equitable. The EPA cost was adjusted so that it accounts for the same amount of HLW that the DOE evaluated: 96,000 metric tons (DOE, 1990b). The DOE cost was adjusted by subtracting the cost of Monitored Retrievable Storage and a second repository (modified D&E).

Table VI-1
Cost to Develop a Geologic Repository
(Millions of 1988 Dollars)

EPA COST ESTIMATE (R&D & Government Overhead)	DOE COST ESTIMATE (Modified D&E)
3,400 - 4,900	11,100

The EPA underestimated costs by roughly $6 to $8 billion. The discrepancy is primarily due to the EPA's optimistic projections of the cost of site characterization. The EPA originally estimated $173 million in 1978 dollars (equivalent to $287 million in 1988 dollars) for the characterization of one site[3] (EPA, 1982). The EPA also assumed that a maximum increase of 100% in these costs might result from the proposed standard, and EPA considered that estimate as "probably an overstatement" (ibid.). The latest cost projected for

[3]The EPA actually reported $520 million to characterize three sites.

characterizing Yucca Mountain and submittal of a license application is $6.3 billion (Gertz, 1992).

The EPA did not even consider the standards' financial impact to WIPP. To date, the DOE has spent approximately $711.6 million to construct the WIPP facility (Nuclear Waste News, October 8, 1992) and $300 million towards demonstration of compliance with 40 CFR Part 191. The DOE will spend over $840 million to keep the facility open for 5 years (estimated at $14 million/month) while the Department tries to comply with 40 CFR 191 (Energy Daily, October 13, 1992).

Financial Impacts of Abandoning a Technically Good Site

The EPA recognized several areas of uncertainty that might convince them to modify Subpart B of the standards. The final rule states that "[If] disposal systems that clearly provide good isolation cannot reasonably be shown to comply with the containment requirements, the Agency would consider whether modifications to Subpart B were appropriate" (EPA, 1985c). The draft regulatory impact analysis for 40 CFR Part 191 noted that "if our standards were stringent enough to prevent any of these first (four) sites from being able to comply, then the national program could be significantly delayed and site selection costs would probably increase substantially" (EPA, 1982).

The consequences of ruling out a good repository is higher when there are only two sites under investigation: Yucca Mountain and WIPP. If a new site selection process were to be undertaken, then Congress would need to pass new legislation authorizing this process. Considering the need for new legislation, the escalating institutional impacts, and costs of site characterization, a potential increase of 100% in site evaluation costs (D&E cost category) is not an unreasonable estimate (Cotton, 1991).

For Yucca Mountain, the site evaluation portion of the total system life cycle costs (TSLCC) is $6.75 billion (1988 dollars) (DOE, 1990b). Additional spent fuel storage costs also need to be considered for the period of time during which a new site is selected and licensed and a repository is constructed. Williams et al. (1992) calculated the additional at-reactor storage costs for a 10-year delay in repository deployment. Added to these costs are the program overhead costs for the additional period resulting from having to begin a new siting process. The DOE estimates in its fee adequacy study that it would take 25 to 35 years to site, license, and construct another repository (DOE, 1990a). Assuming that in just 10 years, another site could be found that meets the standards, the approximate costs would be $22.8 billion (Table VI-2).

Table VI-2
Cost to Find Another Repository
(Millions of 1988 Dollars)

Additional D&E costs (2 x 6.75b)	13,500
Additional at-reactor storage costs	9,100
Additional program overhead costs	200
	22,800

If the WIPP site were abandoned* due to compliance difficulties, approximately $1.9 billion would be lost. The loss comprises the cost of constructing the facility and keeping it open for five years while WIPP completes the performance assessments and testing needed to comply with 40 CFR 191. If WIPP fails to comply with the standards, at least $13.7 billion would be needed to find another site. The $13.7 billion comprises siting and program management costs that are comparable to Yucca Mountain's. Additional costs due to at-generator storage of transuranic waste for a number of years and for decommissioning the WIPP facility were not included.

Both programs will spend $8.2 billion ($6.3 billion at Yucca Mountain and $1.9 billion at WIPP) to prove that hypothetical deaths will be averted thousands of years from now. Should they fail, we seriously doubt that different sites and an additional $36.5 billion ($22.8 billion to replace Yucca Mountain and $13.7 billion to replace WIPP) would improve the chances of meeting the standards. For the standards' aspirations cannot be achieved. In the words of the National Academy of Science, "[T]he demand for accountability in our political system has fostered a tendency to promise a degree of certainty that cannot be realized. Pursuing that illusionary certainty drives up costs without delivering the results promised or comparable benefits. The consequence is frustration and mistrust" (NAS, 1990).

Abandoning a Site Because of the Potential for Human Intrusion

The standards require that the consequences of human intrusion be included along with natural disturbances in the calculations that seek to demonstrate compliance with the numerical release limits. This requires an estimation of probabilities and consequences of human intrusion activities that may occur during the next 10,000 years. Introducing assumptions about human activities and the probabilities that they may occur at a repository site over the next 10,000 years, results in a great deal of subjectivity in the adjudicatory licensing process (see Chapter V).

Probabilities of many potential releases of radioactivity from a HLW repository cannot be calculated in an objective manner and can only be estimated subjectively by using expert judgment.[4] Writers on the subject agree that human intrusion scenarios are among the release modes that can only be estimated subjectively.

The impossibility of an objective prediction of human intrusion was recognized by the EPA when it promulgated its standard. In the report in which it "evaluate[ed] how effective mined geologic repositories are for isolating these wastes from the environment," the Agency said that "any structured mathematical estimate of drilling frequency into a potential repository site is not very meaningful" (Smith et al., 1982, pp i, 96). The EPA also stated in the Federal Register notice of the draft regulation, "we can only guess at the frequency of some actions (such as drilling for resources)" (EPA, 1982,p. 58200).

In preliminary studies of waste disposal facilities in salt formations (such as the Waste Isolation Pilot Plant), nearly all potential radionuclide releases come from human intrusion by intrusive drilling (Smith et al., 1982 and SNL, 1991). Compliance with the standards is determined by the frequency of intrusion. (This frequency influences the consequences as well as the probabilities of intrusion scenarios, because in some scenarios the effects of multiple intrusions add together.)

---

[4]A review published by Ross (1989) more than three years ago concluded that "It appears that a technical consensus has emerged on the impossibility of obtaining probabilities of many scenarios by any means other than expert judgment." The same conclusion is reached by a recent site-specific study by Guzowski(1991), and we are aware of no published evaluation of scientific literature that contradicts Ross's observation.

In issuing the 1985 regulation, the EPA tried to alleviate the difficulty posed by probabilities of human intrusion by providing "guidance" for making some of the necessary guesses. The guidance provided a maximum frequency for intrusive drilling and recommended that no intrusion scenario with greater consequences needed to be considered. Even if this guidance is adopted by implementing agencies, it fails to resolve the issue. The EPA required that probabilities and consequences of intrusion scenarios be aggregated with those of natural disturbances into a single "complementary cumulative distribution function" (CCDF). To calculate the CCDF, probabilities and consequences of human intrusion scenarios with lesser consequences than the EPA's drilling scenario must be determined. The numbers are no easier to determine for these scenarios (such as solution mining near the WIPP (SNL, 1991)) than for intrusive drilling.

The mixture of probabilities that are specified by the EPA (non-zero for intrusive drilling, and zero for all more severe scenarios) with probabilities that must be justified on a site-specific basis yields an entirely illogical result. Because probabilities of human intrusion are so hard to justify, a defensible determination of these probabilities may be the highest hurdle than needs to be crossed to get a license. But probabilities are needed only for scenarios less severe than drilling into the repository (which itself would have very modest consequences at most repository sites). The importance of an intrusion scenario winds up being inverse to the severity of its consequences.[5]

All of this confusion could have real consequences. The WIPP is a multi-billion-dollar facility which will entomb large amounts of highly toxic material. Because human intrusion is the dominant contributor to the CCDF, the WIPP would be approved or rejected under the 1985 standard on the basis of the probabilities and consequences of certain human intrusion scenarios. Yet the scenarios are chosen to have small consequences, and the probabilities are, in the EPA's words, "not very meaningful" and "only [a] guess."

A standard that requires establishing the probabilities and consequences of human intrusion is inherently impossible to implement in an objective manner. In an effort to overcome these difficulties by providing additional guidance, the EPA has succeeded only in making the standards incoherent.

[5]The literal meaning of the EPA guidance is that a repository would be acceptable despite a human intrusion scenario with both high probability and high consequences, if the consequences were greater than the consequences of intrusive drilling.

The EPA should recognize the inherent differences between natural processes and those involving conscious human action by excluding explicit calculation of probabilities and consequences of human intrusion from its regulations. Otherwise, the DOE may be forced to abandon any site. The cost impact of such an outcome for the potential Yucca Mountain site would be approximately $29.1 billion ($6.3 billion lost on site characterization and $22.8 billion to find another licensable site) and for the WIPP site, approximately $15.6 billion ($1.9 billion lost in construction, testing and maintenance and $13.7 billion to find another site).

Abandoning a Site Because of Potential Carbon-14 Releases

Of the release limits established in 40 CFR 191, it appears that an unsaturated site (a site, such as Yucca Mountain, where the repository is located above the water table) would have the most difficulty in meeting the release limits for carbon-14. This results from the occurrence of carbon-14 in spent fuel, its relatively long half-life (5,730 years), its proclivity to enter the gaseous state as carbon dioxide, and the rapid transport of gases through the unsaturated zone (Van Konynenburg, 1991; Ross, 1992a, 1992b, and Park, 1992).

When the EPA began development of 40 CFR 191 in the late 1970's, the reprocessing of commercial spent fuel was still considered to be a strong possibility in the U.S. Had this taken place, the carbon-14 in the spent fuel probably would have been released to the atmosphere during reprocessing, as is the case for U.S. defense waste and for commercial waste in other countries where reprocessing takes place today. However, when spent fuel became the commercial high level nuclear waste form in the U.S., carbon-14 became one of the radionuclides to be contained in a repository.

Initially, all of the U.S. candidate sites for a repository were located below the water table, in the saturated zone. In such locations, release of radionuclides would occur primarily by aqueous transport. However, the DOE subsequently began to study unsaturated horizons, and in 1987, Congress focused the site characterization effort on Yucca Mountain, for which the unsaturated zone is the potential repository horizon. Gaseous release of radionuclides thus acquired greater importance.

The standards limit carbon-14 releases to an average of 0.7 curies per year (assuming 70,000 MTHM). This release must be even less if other radionuclides are also released (see the sum of fractions rule at 40 CFR 191, Appendix A). To put the 0.7 curies in perspective, a typical nuclear power plant releases, without any regulatory restriction, approximately 10 curies of carbon-14 each year, and a typical reprocessing plant approximately 850 curies. Moreover, carbon-14 is part of our daily diet, and is present abundantly in nature (global inventory is 230 million curies) (DOE, 1992).

The expected release rate from a potential repository at the Yucca Mountain site would be so small that it would be inconsequential from the standpoint of radiation dose received by any individual. For example, if the repository's entire inventory of carbon-14 were released in just one year, a maximally exposed individual would receive less than 0.5 mrem. During the same year, this individual would receive 360 mrem from background radiation (U.S. average) and 1.3 mrem from the carbon-14 otherwise present within his or her own body.

Efforts to meet the carbon-14 release limit have generally focused on improved engineered barriers, since transport of carbon dioxide throughout the fractured, porous, unsaturated zone of Yucca Mountain is likely to be relatively rapid (Ross, 1992b). To provide a "reasonable expectation" that thousands of waste containers will retain carbon dioxide for a time on the order of 10,000 years, the DOE is forced to consider containers of multiple-layer design. These containers could cost approximately $3.2 billion more than conventional containers (DOE, 1992); yet they still may not solve the problem. Materials science and engineering are simply not able to make confident predictions about container integrity 10,000 years into the future. In fact, common engineering practice is to fabricate equipment and structures on the basis of available understanding, and then to periodically inspect and repair or replace items exhibiting premature failures. Often "surprises" occur in times much shorter than 10,000 years. It is simply unreasonable to believe that anyone could confidently support such a prediction.

VII. Conclusion

We agree with the EPA that deep geologic repositories offer exceptional protection, but we disagree that the safety of a repository can ever be demonstrated in terms of standards that are far more stringent than other regulations:

- These are standards that would force a repository to be millions of times safer than walking down the street or driving a car;

- These are standards that would be violated by almost any source of radiation. Examples include: diagnostic medicine, mines (coal, phosphorous, lead, zinc and copper), natural deposits of uranium ore, nuclear power plants, coal-fired power plants, our homes and the soil beneath them (i.e., radon sources); and

- These are standards that would require 10,000-year predictions, particularly predictions of human actions, that are inherently impossible to defend. The failure of all experts to predict the sudden collapse of the Soviet Union is only the latest example of our inability to predict human actions.

From all these perspectives, the standards are seen to be excessive and flawed. Moreover, the ten years and $490 million that the WIPP and Yucca Mountain programs have expended on this rule have not begun to unravel its ambiguities. On the contrary, the more time and money expended on the standards, the less coherent they appear.

We stated earlier that repositories offer exceptional protection. Suppose the WIPP and Yucca Mountain repositories were constructed and humans inadvertently drilled into them. The local populations (excluding the intruders) would probably not suffer a single fatality, even if each area were 600 times more populous than it is today. Indeed, chances are that a local resident would die from a bee sting or be struck by lightning before he would be harmed by the repository.

One may ask, *If repositories are so safe, why is it so difficult to meet the standards?* The difficulty comes in demonstrating that the repositories are as safe as the standards require. The standards challenge the DOE to convince a skeptical public and most likely a court that a repository will endure all the "significant processes and events" that could occur in 10 thousand years. If the demonstrations fail, the standards would force the DOE to abandon two, possibly good, repository sites at a loss of $36.6 billion.

Congress and the President have now directed the EPA to develop totally different standards that would truly protect the individuals near the Yucca Mountain site[1] rather than concentrating on billions of people thousands of miles away. The Congress and the President have also directed the EPA to seek advice from the National Academy of Sciences and reconsider the standards for human intrusion. Perhaps the arguments presented in this paper will help carry Congress's initiative to an equitable conclusion.

---

[1]This legislation applies only to the Yucca Mountain site.

References

ACNW (Advisory Committee on Nuclear Waste), 1992, Letter from Dade Moeller (ACNW) to Robert M. Bernero, Director, Office of Nuclear Material Safety and Safeguards, NRC, February 25, 1992.

ACNW (Advisory Committee on Nuclear Waste), 1990, Letter from Dade Moeller to James R. Curtis, Commissioner, NRC, September 11, 1990.

ACRS (Advisory Committee on Reactor Safeguards), 1985a, Letter, David A. Ward, Chairman (ACRS), to Nunzio J. Palladino, Chairman (NRC), July 17, 1985.

ACRS (Advisory Committee on Reactor Safeguards), 1985b, Letter, David A. Ward (ACRS), to Nunzio J. Palladino, NRC, October 16, 1985.

Barnard, Wilson, Dockery, Gauthier, Kaplan, Eaton, Binghan, and Robey, 1992, "An Initial Total-System Performance Assessment for Yucca Mountain" (SAND91-2795), Sandia National Laboratory, Albuquerque, New Mexico, June, 1992.

Beebe, Gilbert, 1981, (Proceedings of the Seventeenth Annual Meeting of the National Council on Radiation Protection and Measurements), "NCRP proceedings No. 3, Critical Issues in Setting Radiation Dose Limits," 1982, National Council on Radiation Protection and Measurements, Bethesda, Maryland, pp. 73-87.

BEIR V, (Committee on the Biological Effects of Ionizing Radiation), 1990, "Health Effects of Exposure to Low Levels of Ionizing Radiation" (BEIR V), National Academy Press, Washington, D.C.

Cotton, Thomas A, 1990, "United States Approach to High-Level Radioactive Waste Repository Licensing, National Academy of Sciences/National Research Council, Washington, D.C., September 18-19, 1990.

Cotton, Thomas A., 1991, "High-Level Waste Disposal Regulations: Time for a Change?," Proceedings of the Second Annual International Conference on High-Level Radioactive Waste Management, April 28 - May 3,1991.

Davis, J. D., and A. K. Runchal, 1984, "Disruption Scenario Analysis for a Nuclear Waste Repository in Hanford Site Basalts, Washington State," in R. G. Post, ed., Waste Management '84, University of Arizona, Tucson, p. 419-425.

DNEPP (Dutch National Environmental Policy Plan), 1988, "Premises For Risk Management, Risk Limits in the Context of Environmental Policy," Second Chamber of the States General, session 2137 nos 1-2, the Netherlands, 1988-1989.

DOE (U.S. Department of Energy), 1992, "Technical Assistance to the U.S. Environmental Protection Agency on 40 CFR Part 191, August, 1992, Chapter 9 Carbon-14, and Appendix E, "Regulatory Overview and Recommendations on a Repository's Release of Carbon-14."

DOE (U.S. Department of Energy), 1990a, "Nuclear Waste Fund Fee Adequacy: An Assessment" (DOE/RW-0291P), November, 1990.

DOE (U.S. Department of Energy), 1990b, "Preliminary Estimates of the Total-System Cost for the Restructured Program: An Addendum to the May 1989 Analysis of the Total System Life Cycle Cost for the Civilian Radioactive Waste Management Program, (DOE/RW-0295P,) December, 1990.

DOE (U.S. Department of Energy), 1983a, Letter, William A. Vaughan, Assistant Secretary, Environmental Protection, Safety, and Emergency Preparedness (DOE), to the Honorable Kathleen Bennett, Assistant Administrator for Air, Noise, and Radiation (EPA), May 2, 1983.

DOE (U.S. Department of Energy), 1983b, Letter, William A. Vaughan (DOE), to Mr. Charles Elkins, Acting Assistant Administrator for Air, Noise, and Radiation (EPA), June 21, 1983.

DOE, (U.S. Department of Energy), 1989, "Analysis of the Total System Life Cycle Cost for the Civilian Radioactive Waste Management Program, Office of Civilian Radioactive Waste Management", (DOE/RW-036), May, 1989.

EEI (Edison Electric Institute), 1983a, Letter, John J. Kearney, Senior Vice President, Edison Electric Institute, to Central Docket Section, EPA, May 2, 1983.

EEI (Edison Electric Institute), 1983b, Letter, John J. Kearney, EEI, to Central Docket Section, EPA, June 20, 1983.

EPA (U.S. Environmental Protection agency), 1985a "Final Regulatory Impact Analysis, 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-level and Transuranic Radioactive Wastes,"(EPA 520/1-85-027), August, 1985.

EPA (U.S. Environmental Protection Agency), 1985b, "Background Information Document--Final Rule for High-Level and Transuranic Radioactive Wastes" (EPA 520/1-85-023), August, 1985, p. 8-49.

EPA (U.S. Environmental Protection Agency), 1985c, Final Rule, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Federal Register, vol. 50, no. 182, September 19, 1985.

EPA (U.S. Environmental Protection Agency), 1982a, Proposed Rule, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Federal Register, vol. 47, p. 58196, December, 1982.

EPA (U.S. Environmental Protection Agency), 1982b, "Draft Regulatory Impact Analysis for 40 CFR Part 191", (EPA 520/1-82-924), U.S. EPA, Washington, D.C. 1982.

EPA (U.S. Environmental Protection Agency), 1992a, letter from Michael H. Shapiro, Deputy Assistant Administrator for Air and Radiation, EPA to Paul L. Ziemer, Assistant Secretary, Environment, Health and Safety, DOE, September 11, 1992.

EPA (U.S. Environmental Protection Agency), 1992b "Regulatory Impact Analysis For EPA's High-Level Standard (40 CFR Part 191)" draft (402-R-007) Office of Radiation Programs Office of Air and Radiation, U.S. EPA's, Washington, D.C., August, 1992.

Galpin, F.L., Clark, R.L., and Petti, C, 1992, "An Inside Look at the 40 CFR 191 Containment Requirements," Proc. of the Third Int'l Conf. on High Level Radioactive Waste Management, American Nuclear Society, La Grange Park, IL, pp. 1047-1054.

Gertz, Carl P., 1992, "Yucca Mountain Site Characterization Project Status and Budget," Presentation to Nuclear Waste Technical Review Board, Panel on Structural Geology & Geoengineering, January 7-8, 1992.

Guzowski, R. V., 1991, "Evaluation of Applicability of Probability Techniques to Determining the Probability of Occurrence of Potentially Disruptive Intrusive Events at the Waste Isolation Pilot Plant" (SAND90-7100), Sandia National Laboratories, Albuquerque, New Mexico, December 1991.

Hora, S. C., D. von Winterfeldt, and K. M. Trauth, 1991, "Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant" (SAND90-3063), Sandia National Laboratories, Albuquerque, New Mexico, December, 1991.

ICRP 26, (International Commission on Radiological Protection, Publication 26), 1977, Pergammon Press, New York.

IEAL (International Energy Associates Limited), 1987, "Regulatory Strategies for High-level Radioactive Waste Management In Nine Countries" (IEAL-R/87-93), prepared for Pacific Northwest Laboratory by IEAL, 3211 Germantown Road, P.O. Box 10107, Fairfax, Virginia, December, 1987.

Kabele, T. J., and M. A. Bauser, 1992, EPA Standard 40 CFR 191 Workshop, Marriot Hotel, Crystal City, Virginia, September 1992.

NAS (National Academy of Sciences), 1990. "Rethinking High-Level Radioactive Waste Disposal", National Research Council, National Academy Press, Washington, D.C., 1990.

NCRP 91, (National Council on Radiation Protection and Measurements, Report No. 91), 1987, "Recommendations on Limits for Exposure to Ionizing Radiation," National Council on Radiation Protection and Measurements, Bethesda, Maryland.

NCRP 94, (National Council on Radiation Protection and Measurements, Report No. 94, 1987 "Exposure of the Population in the United States and Canada From Natural Background," National Council on Radiation Protection and Measurements, Bethesda, Maryland.

NCRP 100, (National Council on Radiation Protection and Measurements, Report No. 100), 1989, "Exposure of the U.S. Population from Diagnostic Medical Radiation," National Council on Radiation Protection and Measurements, Bethesda, Maryland.

NCRP 64, (National Council on Radiation Protection and Measurements Report No. 64), 1980, "Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations," National Council on Radiation Protection and Measurements, Bethesda, Maryland.

NRC (U.S. Nuclear Regulatory Commission), 1991, Letter from Robert M. Bernero, Office of Nuclear Material Safety and Safeguards (NRC) to Margo T. Oge, Office of Radiation Programs (EPA), December 3, 1991.

NRC (U.S. Nuclear Regulatory Commission), 1983, Letter, John G. Davis, Director, Office of Nuclear Material Safety and Safeguards (NRC), to Central Docket Section (EPA), May 10, 1983.

NRC (U.S. Nuclear Regulatory Commission), 1985a, Memorandum, Lando W. Zech, Commissioner (NRC), to Samuel J. Chilk, Secretary (NRC), October 25, 1985.

NRC (Nuclear Regulatory Commission), 1985b, Memorandum, William J. Dircks, Executive Director for Operations, NRC, to R. F. Fraley, Executive Director, Advisory Committee on Reactor Safeguards, NRC, December 23, 1985.

NWTRB (Nuclear Waste Technical Review Board), 1990, First Report to the U.S. Congress and the U.S. Secretary of Energy from the NWTRB, U.S. Government Printing Office, Washington, D.C., March 1990.

NWTRB (Nuclear Waste Technical Review Board), 1991, Third Report to the U.S. Congress and the U.S. Secretary of Energy from the NWTRB, U.S. Government Printing Office, Washington, D.C., May 1991.

Okrent, David, 1992a, letter to Ms. Margo T. Oge, Director, Office of Radiation Programs, U.S.E.P.A., Washington, D.C., March 30, 1992.

Okrent, David, 1992b, letter to Ms Margo T. Oge, Director, Office of Radiation Programs, U.S.E.P.A., Washington, D.C., April 7, 1992.

Okrent, David, 1992c, letter to Ms Margo T. Oge, Director, Office of Radiation Programs, U.S.E.P.A., Washington, D.C., June 4, 1992.

Okrent, David, 1992d, letter to Dr. William P. Reilly, Administrator, U.S.E.P.A., Washington, D.C., June 22, 1992.

ORNL (Oak Ridge National Laboratory), 1992, Letter from Allen G. Croff, Associate Director, Chemical Technology Division to R. F. Williams, Electric Power Research Institute, February 9, 1992.

Park, U-S., 1992, "Regulatory Overview and Recommendations on a Repository's Release of Carbon-14," Science Applications International Corporation, 101 Convention Center Drive, Suite 407, Las Vegas, Nevada 89109, January 1992.

Pflum, Chris G., 1988, "A Comparison of the Ways Different Countries Manage High-Level Radioactive Wastes," Prepared for the U.S. Department of Energy, Yucca Mountain Project Office, Las Vegas, Nevada, August, 1988.

Plan (The President's Reorganization Plan No. 3), 1970.

Ross, B., 1992a, "The Technical Basis for Regulation of Gas-Phase Releases of Carbon-14," Disposal Safety, Inc., 1660 L Street NW, Suite 314, Washington, D.C. 20036.

Ross, B., Amter, S., and Lu, N., 1992b, "Numerical Studies of Rock-Gas Flow in Yucca Mountain" (SAND91-7034), Sandia National Laboratory, Albuquerque, New Mexico.

Ross, B., 1989, "Scenarios for Repository Safety Analysis," Eng. Geol., vol. 26 pp. 285-299.

SAB (Science Advisory Board), 1984, Letter, Herman E. Collier, Jr., Chairman, High-level Radioactive Waste Disposal Subcommittee, Science Advisory Board (EPA), to Mr. William D. Ruckelshaus, Administrator (EPA). February 17, 1984.

SAB (Science Advisory Board), 1992, EPA Subcommittee on Carbon-14, Presentation to the Advisory Committee on Nuclear Waste. U.S. Nuclear Regulatory Commission, Bethesda, Maryland, September 25, 1992.

Sinclair, Warren K., 1980, (Proceedings of the Sixteenth Annual Meeting of the National Council on Radiation Protection and Measurements), "NCRP Proceedings No. 2, Quantitative Risk in Standards Setting," 1981, National Council on Radiation Protection and Measurements, Bethesda, Maryland, pp. 3-32.

Smith, C. B., Egan, D. J., Jr., Williams, W.A., Gruhlke, J.M., Hung, C.-Y., and Serini, B.L., 1982, "Population Risks from Disposal of High-Level Radioactive Wastes in Geologic Repositories" (EPA 520/3-80-006), U.S. Environmental Protection Agency, Washington, D.C., December, 1982.

SNL (Sandia National Laboratories), 1991, "Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant" (SAND91-0893), Sandia National Laboratory, Albuquerque, New Mexico, December, 1991.

UNSCEA (United Nations Scientific Committee on the Effects of Atomic Radiation), 1988, "Sources, Effects and Risks of Ionizing Radiation," United Nations, New York.

Van Konynenburg, R.A., 1991, "Gaseous Release of Carbon-14: Why the High Level Waste Regulations Should Be Changed," Proc. of the Second Int'l. Conf. on High Level Radioactive Waste Management, American Nuclear Society, La Grange Park, Illinois, pp. 313-319.

Wagner, T., 1991, "The Complete Guide to the Hazardous Waste Regulations," 2nd ed., Van Nostrand Reinhold, New York.

Williams, W.A., 1980 "Population Risks from Uranium Ore Bodies" (EPA 520/3-80-009), U.S. Environmental Protection Agency, October, 1980.

Williams, J.W. et al., 1992, "Economic Analysis of Including an MRS Facility in the Waste Management System: A Revisit," Proceedings of the Third Annual International Conference on High-Level Radioactive Waste Management, April 12-16, 1992.

WISP (Waste Isolation Systems Panel), 1983, "A Study of the Isolation System for Geologic Disposal of Radioactive Wastes," National Academy Press, Washington, D.C.

Woolfolk, Steven, 1992, "Dosimetry Calculations to Support White Paper 40 CFR 191" (SAIC-92/1200), Science Applications International Corporation, Golden, Colorado, October 9, 1992.

END

DATE
FILMED
11/23/93