CARBON-14 RELEASES FROM AN UNSATURATED REPOSITORY: A SENSELESS BUT EXPENSIVE DILEMMA

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ABSTRACT

The purpose of the U.S. Environmental Protection Agency (EPA) *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 191 or standards)is to protect public health and safety. The 1985 rule was developed on the basis of the assumption that the repository would be located in a geologic formation that lies below the water table. It was therefore assumed that the principal mechanism of pollutant migration would be via dissolution of radionuclides in ground water and transport by aqueous means.

We now find the nation examining the suitability of an unsaturated site, Yucca Mountain. At this site, and for other potential unsaturated sites, it is appropriate to examine gaseous releases and transport of pollutants in order to determine site adequacy. When the provisions of the 1985 standard are applied to Yucca Mountain, specifically the limits for carbon-14, we can release in 10,000 years no more than 7,000 curies of carbon-14 in the form of carbon dioxide. Meanwhile, the U.S. Department of Energy (DOE) and others indicate that the repository may release about 8,000 curies of carbon-14 dioxide, an amount that exceeds the standard by 10 to 20 percent.

For the first 1,000 to 2,000 years after the repository is closed, it is expected that the host rock will contain the carbon-14 dioxide. For longer periods of containment, we would need to rely on a more durable waste package, one utilizing a multiple-layer design. Such an approach could be very costly. Estimates indicate the repository program cost would increase by approximately $3.2 billion if the multiple-layer waste package is required.

The original basis of the 1985 standards was that, in a site below the water table, the limit for carbon-14 was technically achievable. It was not a standard based on a release level that would prevent a danger to public health. If we examine the danger to public health of the release of 8,000 curies of carbon-14 dioxide during an 8,000-year period, this release would not pose a significant threat to the average individual. Industry and natural sources release many times this amount of carbon-14 dioxide each year. The question therefore becomes: is it appropriate to spend an additional $3.2 billion on waste packages when the expenditure does not measurably improve the public health?

A situation exists in which the 1985 rule has an unintended result. It appears that a potential repository at Yucca Mountain can release its inventory of carbon-14 dioxide without endangering public health, yet the site may not be able to satisfy a standard that has as its ultimate purpose the protection of public health. Thus, an alternative approach is needed. The EPA should regulate carbon-14 dioxide under a more equitable standard, similar to those in the clean air regulations, or not regulate it at all.

CARBON-14 INVENTORY

By law, the repository can hold no more than 70,000 metric tons of heavy metal (MTHM). Approximately 7,000 MTHM comprises defense waste which contains little or no carbon-14. The remaining 63,000 MTHM comprises spent fuel from nuclear power plants; approximately 60% from pressurized water reactors (PWR) and 40% from boiling water reactors (BWR). With the above assumptions, carbon-14 inventories can be estimated.

Based on nitrogen impurities and experimental data, Van Konynenburg (1) estimates the total carbon-14 inventory at 71,000 curies. Park (2) adjusted this estimate to account for spent nuclear fuel with a higher burn-up and reports 78,000 curies.

The literature reports that one to ten percent of the carbon-14 inventory can be rapidly released as carbon-14 dioxide. The one percent value (3) is probably too low and the ten percent value (4) may not be the upper bound. The term "rapid release" means that the carbon-14 dioxide escapes immediately after the waste container fails. The rate at which the gas escapes has been investigated (5), but not determined. For the purposes of this report, the rapid release fraction is assumed to be 8,000 curies as a maximum value.

The remaining carbon-14 will gradually oxidize and reach the accessible environment. Some or all may escape as a gas; some or all may dissolve and escape in the ground water; and some or all of the carbon-14 dioxide may partition between the gaseous and aqueous phases (6). Given these uncertainties, performance assessments completed by the NRC staff (7) and the DOE (8) have not attempted to model the gradual release of carbon-14. However, even if these 70,000 curies of carbon-14 are ignored, the other 8,000 curies (i.e., the rapid release fraction) dominates all other releases combined (8).

THE PROBLEM

In July, 1987, the First District Court of Appeals (court) remanded 40 CFR Part 191. Besides correcting problems identified by the court, the EPA could take advantage of the rulemaking and correct other problems that the DOE and recently Congress have disclosed.

The Nuclear Waste Policy Act (Act) directs the EPA to issue generally applicable standards, and the amended Act directs the DOE to characterize only Yucca Mountain, an unsaturated site. The standards were issued after the Act was passed but before it was amended. At that time, saturated sites were the leading contenders for a repository. Consequently, the standards were not intended to control gases that could be released through fractures in unsaturated rock.

Information developed by the DOE and others indicates that, when applied to gases, namely carbon-14 dioxide, the standards become overly stringent - millions of times more stringent than the clean air regulations (9). The stringency would not affect a saturated repository but would discourage the development of any unsaturated repository.

COST TO CONTAIN CARBON-14 DIOXIDE

Using a statistical model to calculate the cumulative failure distribution for high-level radioactive waste packages, Bullet (10) showed that multiple-barriers can extend the life of a waste package. Such a package could possibly keep releases of carbon-14 dioxide within the standards' limits. To estimate the costs of this package, we assumed that one barrier would be fabricated from a ceramic; a material known to have very low corrosion rates. The other barriers would be fabricated from metals whose characteristics and costs are known comparably better.

Considerable research and development (R&D) will be necessary to produce ceramics and predict their performance (11). Currently, no facility in the U.S. can fabricate a ceramic large enough to hold spent fuel. An R&D program that begins now (1993) and ends in 2001 (the year of the license application) would cost at least $80 million (see Table I). These costs would be in addition to the R&D costs of developing the reference waste package (3).

It was assumed that the carbon-14 waste package and the reference waste package would contain the same amount of spent fuel: either three PWR or four BWR assemblies. Approximately 25,000 of these packages would fill the repository.

The carbon-14 package comprises three barriers. A high-nickel alloy (Alloy 825) was selected for the outermost barrier (@ $97,000); a ceramic (titania or alumina) three inches thick, for the middle barrier (@ $80,000); and stainless steel, 0.39 inches thick, for the inner barrier (@ $36,000). The steel does not actually function as a barrier, but serves as a form around which the ceramic is cast. Thus the carbon-14 package would cost about $213,000 apiece.

Fabricated entirely from Alloy 825, the smaller reference waste package would cost about $88,000 apiece. This alloy was chosen for the carbon-14 package and the reference package primarily because cost-data were available (12). Also, researchers and manufacturers claim that cost of Alloy 825 and ceramics are comparable (DOE, 1991).

The cost of 25,000 carbon-14 packages plus R&D totals $5.4 billion. The cost of 25,000 reference packages plus R&D totals $2.2 billion. The difference, $3.2 billion, constitutes the cost of containing carbon-14 dioxide (see Table II).

BENEFITS TO PUBLIC HEALTH AND SAFETY

Carbon-14 dioxide does not pose any measurable risk to the average individual. According to a draft subcommittee report from the EPA's Science Advisory Board (13), if an unsaturated repository released half of its carbon-14 inventory over 10,000 years, the average individual would be exposed to a lifetime dose of 0.01 millirems (mrem). Many countries, such as Canada, do not even regulate individual doses that are this low. The 0.01 mrem corresponds to a lifetime risk of 3×10^{-9} (13), about four times as much as the standards allow. Yet this individual has about a hundred times greater chance of being struck by lightning than being harmed by a repository's carbon-14.

While impacts to individuals are negligible, carbon-14 dioxide does pose some risk to large populations over thousands of years. If the individual lifetime risk (3×10^{-9}) is extrapolated to 10 billion people for 10,000 years, the carbon-14 dioxide would, theoretically, cause 4,000 premature deaths. While seemingly catastrophic, the 4,000 deaths are actually negligible compared to the 1.4 trillion deaths that will transpire during 10,000 years. Moreover, nuclear-generated electricity has already saved many more lives than a repository could take.

In view of the negligible impacts to both individuals and large populations, the standards should tolerate higher releases of carbon-14 dioxide. As stated earlier, a reference waste package within an unsaturated repository could release 8,000 curies of carbon-14 dioxide, about 20 percent more than the standards allow. Unless the EPA relaxes its standards, the DOE would be forced to design and fabricate an expensive waste package that would completely contain the 8,000 curies for 10,000 years.

Under the 1985 standards, a repository cannot release more than 0.7 curies of carbon-14/year for 10,000 years. By comparison, a typical nuclear power plant releases, without any restriction, about twenty four curies of carbon-14/year; a coal-fired power plant more than 100 curies; and a typical reprocessing plant about 860 curies. Natural sources release another 28,000 curies/year.

If an average of three waste packages failed per year, one curie of carbon-14 dioxide would be released and the standards would be violated. As stated earlier, a more durable package could cost $213,000 each, or $5.4 billion for 25,000 including an additional $82 million for research and development. By comparison, the reference waste package could cost $88,000 each or $2.2 billion for 25,000. The difference between these two types of waste packages, $3.2 billion, constitutes the cost of meeting the current (1985) limits for carbon-14 dioxide. Stated another way, the DOE must spend $400 million to contain one curie of carbon-14 dioxide, while the world's industries release thousands of curies each year.

COSTS VERSUS BENEFITS

The U.S Nuclear Regulatory Commission (NRC) requires applicants to employ "reasonably demonstrated technology" that can reduce, in a cost-effective manner, a population's exposure to radiation. The NRC values a "favorable cost-benefit ratio" at $1,000 per person-rem (10 CFR 50, Appendix I). Most utilities use a higher ratio; the DOE uses $10,000 to $15,000 per person-rem. When it is no longer cost-effective to reduce a population's exposure to radiation, the exposure is said to be as low as reasonably achievable or ALARA.

Whether it is cost-effective to contain carbon-14 dioxide depends on the number of people who benefit. If costs are distributed over a large, world population, the benefits appear cost-effective. If costs are distributed over a much smaller, local population, the benefits are not justified.

A cost/benefit analysis of reducing the world's exposure to carbon- 14 for 10,000 years would be consistent with the objectives of the EPA standards. Here the collective dose is taken to mean the world's exposure to carbon-14 dioxide. The cost, $3.2 billion, would reduce 10 billion persons' exposure to carbon-14 dioxide by 8,000 curies. Each curie of carbon-14

TABLE I
Ceramic Research and Development Costs ($1,000)

	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	FY 99	FY 00	FY 01	Total
ACTIVITY										
Design	500	1000	1000	1000	1000	1000	1000	1000	1000	8500
Process Development	200	500	1500	2000	2000	2000	2000	2000	2000	14200
Fabrication Equipment Development	50	100	500	2000	2000	2000	2000	2000	2000	12650
Nondestructive Examamination	50	100	200	200	200	200	200	200	200	1550
Material Characterization & Testing	200	1000	2000	4000	4000	4000	4000	4000	4000	27200
Prototype Fabrication & Testing	50	100	500	1000	2000	2000	2000	5000	5000	17650
TOTAL	1050	2800	5700	10200	11200	11200	11200	14200	14200	81750

TABLE II
Waste Package Costs

Waste Package Concept	Package Quantity	Barrier Position	Barrier Material	Unit Cost($1,000)	Assembly Cost($1,000)	Total Cost($1,000)
Carbon-14	25000	Outside	Alloy 825	95	2	2,425,000
		Middle	Ceramic	75	5	2,000,000
		Inside	Steel	31	5	900,000
				201	12	5,325,000
Reference	25000	N/A	Alloy 825	83	5	2,200,000
Additional Cost for Carbon-14 Package				118	7	3,125,000
Additional Cost for Research and Development						82,000
Additional Cost to the Repository Program						3,207,000

dioxide would expose the world to 400 person-rems (14). Thus the cost-benefit ratio is $3.2 billion / 8,000 curies x 400 person-rem per curie or $1,000/person-rem.

Although marginally cost-effective, the above analyses was not designed for repositories that must protect 10 billion people for 10,000 years. Composed of microrem doses over thousands of years to billions of people, the high collective dose inflates the risk and thereby makes expensive but trivial benefits appear cost-effective. Indeed, the NRC discourages any type of analyses when individual doses are extremely low. The NRC (15) states:

> As a practical matter, consideration of dose rates in the microrem per year range and large numbers of hypothetical individuals potentially exposed ... may unduly complicate the dose calculations.... The Commission believes that inclusion of individual doses below 0.1 mrem per year (0.001 mSv per year) introduces unnecessary complexity into collective dose assessments and could impute an unrealistic sense of the significance and certainty of such dose levels."

Additionally, costs and benefits must be discounted over the time during which they are realized. Clearly spending $1,000, in contemporary dollars, to avert one person-rem thousands of years from now would not be cost-effective.

More traditional analyses would examine a local population's exposure to carbon-14. Often called ALARA, these analyses must be completed by most NRC applicants and licensees (16). Here the local population is taken to mean a "population reasonably expected to be within 50 miles of the [repository]" (17). Approximately 12,000 people live within 50 miles of Yucca Mountain (DOE, 1992).

The cost, $3.2 billion, would reduce 12,000 persons' exposure to carbon-14 dioxide by 8,000 curies. We conservatively assume that the 8,000 curies would expose each of the 12,000 people to the same radiation dose that the maximally exposed individual would receive: 0.5 mrem or 0.0005 rems (4). Thus the cost/benefit ratio is $3.2 billion / 12,000 persons x 0.0005 rems or $533 million/person-rem.

No nuclear industry has ever been compelled to spend $533 million to reduce a collective dose by one person-rem. Moreover, the collective dose is caused by a radionuclide that the world's industries freely and routinely release. From all these perspectives, it is not cost-effective to contain carbon-14 dioxide for 10,000 years.

THE SOLUTION

The standards must change. The containment requirements (40 CFR 191.13) should apply only to solid and liquid releases, and the individual protection requirements (40 CFR 191.15) should limit exposures from radioactive gases to 10 mrem/year. Without these changes, the standards would not be generic, they would not be consistent with the clean air regulations, and the standards could force the DOE to needlessly spend billions of dollars.

Regardless of the source, radioactive gases should be regulated in a consistent manner. In developing the National Emissions Standards for Hazardous Air Pollutants (NESHAP) (40 CFR Part 61) the EPA found that a maximum individual dose of 10 millirems per year (mrem/yr) provides an ample margin of safety. This same dose limit would be appropriate for the radioactive gasses that a repository might release. The dose could appear in the individual protection requirements along with the current 25 mrem/yr limit that an individual could receive through all pathways.

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