POTENTIAL USE OF DOSE STANDARDS
FOR HIGH-LEVEL WASTE DISPOSAL

I. INTRODUCTION

The 1985 high-level waste (HLW) standards of the U.S. Environmental Protection Agency (EPA) contain three principal provisions:

1) A limit on the total quantity of radioactive material projected to be released to the "accessible environment" over 10,000 years,

2) An individual dose limit for "undisturbed performance" during the first 1,000 years, and

3) A limit on the concentrations of radionuclides in certain groundwaters, also for "undisturbed performance" during the first 1,000 years.

The first criterion - the material release limit - is the most substantive of the three because it applies for a full 10,000 years and because it restricts releases following disturbances to the repository as well as releases from undisturbed performance. EPA used the material release limit format for this portion of the standards so that evaluations of compliance could avoid the large uncertainties inherent in trying to project population locations and lifestyles far into the future. Compliance with the second and third criteria - the individual and groundwater protection requirements - can probably be demonstrated by merely showing that no releases will occur during the first 1,000 years if the repository is not disturbed. Therefore, calculations of doses far in the future would probably not be necessary when evaluating compliance with EPA's 1985 standards.

EPA is now revising its HLW standards. One alternative under consideration would use a dose limit as an alternative standard to be used if EPA's material release limit proves unduly restrictive for a particular repository. Another possibility is addition of a dose standard as a "cross-check" to ensure that the releases permitted by EPA's material release limit do not cause unacceptable impacts to individuals or populations. This paper discusses possible formulations of individual- and population-dose standards and the advantages and disadvantages of dose standards for implementation in the NRC's licensing process. This paper also describes current NRC practice for estimating long-term doses in other licensing and rulemaking activities.

II. FORMULATION OF INDIVIDUAL DOSE STANDARDS

When calculating individual doses caused by releases from a repository, two basic projections are needed: the locations of individuals affected by releases and the lifestyles of the persons at those locations. (The metabolic characteristics of humans are assumed to remain unchanged in the future.)

A. Location.

The two repository sites of current interest in the U.S. - the Waste Isolation Pilot Plant (WIPP) and Yucca Mountain - are both located in arid environments far away (tens of kilometers) from any current human residence. Radioactive materials released from repositories at these sites would be unlikely to reach current population locations until far in the future when radioactive decay and dilution of the radionuclides would have significantly reduced the resulting doses. However, current population locations may change over the next several thousand years. There is, therefore, a need to consider the potential for such changes when developing individual dose standards for repository performance.

One approach for standard-setting would be to hypothesize an individual (or group of people) located at the boundary of the repository. The advantage of this approach is its conservatism - it would ensure that no credible set of circumstances could ever cause an individual to receive a larger dose. The disadvantage of this approach is its extreme degree of conservatism. Even at a distance of two kilometers from a repository, the dose to an adult from drinking contaminated well water might exceed 1 rem/year.[1] Therefore, it appears to be necessary to more realistically project future human locations by considering the effectiveness of "passive" institutional controls, including markers and land-use records, and the relative hostility of the arid environments at the WIPP and Yucca Mountain sites.

At the opposite extreme, one could assume that current population locations will remain unchanged indefinitely. The advantage of this "static biosphere" assumption is that it recognizes the relative isolation of the WIPP and Yucca Mountain sites. The disadvantage is that it may be a non-conservative assumption. Potential changes at a repository site, including population growth and increased use of groundwater supplies, may lead to higher doses than would be projected based on current conditions.

The dose-related provisions of EPA's 1985 standards take an intermediate approach. EPA defines an "accessible environment" which includes groundwaters more than five kilometers away from a repository. In most cases, EPA's

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1 See EPA's "Background Information Document for Final Rule" EPA 520/1-85-023, 1985, Pigford, T.H., "The National Research Council Study of the Isolation System for Geologic Disposal of Radioactive Wastes," UCB-NE-4042, 1983, and Wick, O.J. and M.O. Cloninger, "Comparison of Potential Radiological Consequences from a Spent-Fuel Repository and Natural Uranium Deopsits," PNL-3540, 1980.

standards would require an assumption that an individual is located at the five kilometer distance and uses groundwater obtained there.2 EPA's specification of a five kilometer distance, while somewhat arbitrary, is a compromise between the two extreme assumptions discussed above.

B. Lifestyle.

Within a population group exposed to a release of radioactive material, there will be significant variations in the doses received by individuals. Conservative dose estimates are often based on a "maximally exposed individual" who is hypothesized to obtain all of his drinking water from a contaminated source, use that source to raise all his own food, etc. As with a conservative assumption about the location of the individual, a conservative lifestyle assumption is attractive because it ensures that no credible set of circumstances could cause a higher dose to any individual. The disadvantage is the extreme degree of conservatism. Few, if any, future individuals are likely to ever receive doses as large as those estimated for the "maximally exposed individual."

The International Commission on Radiological Protection (ICRP)3 has recommended that waste disposal standards be expressed in terms of the average dose in the "critical group." The critical group is to be "representative of those individuals in the population expected to receive the highest dose." Averaging the doses projected for the critical group eliminates some of the extreme conservatism associated with the "maximally exposed individual" concept.

The dose-related provisions of EPA's 1985 standards limit the dose to "any member of the public," a concept that appears to be the same as the "maximally exposed individual." However, EPA says nothing about the lifestyle of that individual. EPA merely specifies that "all potential pathways . . . from the disposal system to people shall be considered . . ."

III. FORMULATION OF POPULATION DOSE STANDARDS

Estimation of the population dose associated with a repository would presumably involve estimation and summation of the individual dose anticipated for each person exposed to releases from the facility. This would require fairly detailed demographic information about the population exposed to a release, including the number of individuals exposed, their locations, and

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2Certain low quality groundwaters are not included. This exception may be important for WIPP.

3"Radiation Protection Principles for the Disposal of Solid Radioactive Waste," ICRP Publication 46, 1985.

the usage rates for each person for each pathway of exposure. As a practical matter, a truncation of the summation of individual doses may be necessary, either as a function of distance from the facility or at some de-minimis or "negligible risk" individual dose rate.

A. Sizes of Populations.

The most conservative estimates of population sizes might be produced by estimating the "carrying capacity" of each exposure pathway. For example, the amount of groundwater available to wells might determine the maximum size of the population that could be supported. In practice, however, the "carrying capacity" of most exposure pathways is unknown and would be difficult to determine without making some rather arbitrary assumptions about future human lifestyles. Speculation about potential technological advances, such as agricultural techniques for arid environments, would compound implementation difficulties.

The least conservative approach, and probably the most realistic for the WIPP and Yucca Mountain sites, would be a "static biosphere" in which current population sizes and locations would remain unchanged in the future. The WIPP and Yucca Mountain sites are quite remote from current population locations, and there is no apparent motive for population growth near those sites. Nevertheless, this would be a non-conservative approach since population growth near the sites cannot be ruled out.

When EPA developed its standards, an intermediate approach was used. EPA used a "global average biosphere" for the population dose estimates that underlie the release limits of its standards. EPA's approach has the advantage of generality, but it might significantly over-estimate population doses at relatively isolated sites like WIPP and Yucca Mountain.

B. Truncation.

When estimating population doses, a truncation of the summation of individual doses may be necessary, either as a function of distance from the facility or at some de-minimis or "negligible risk" individual dose rate. Some radiation protection experts extend the "negligible risk" concept to conclude that truncation is necessary, as a matter of principle, arguing that collective doses composed of very small individual doses are meaningless for regulatory purposes. Potential releases of carbon-14 from Yucca Mountain represent an extreme case where individual dose rates are minuscule, but the world-wide population dose is sizeable.

The National Council on Radiation Protection and Measurements (NCRP), in its 1987 recommendations (Report No. 91), recommends truncation of population dose estimates for individual dose contributions below 1 mrem/yr, arguing that such dose rates represent a "negligible individual risk level." The NCRP describes this risk level as ". . . trivial compared to the risk of fatality associated with ordinary, normal societal activities," and recommends that such risks "be dismissed from consideration." In contrast, the 1990 recommendations of the International Commission on Radiological Protection (ICRP) state that

"The Commission does not recommend the use of this technique" (Publication 60, Paragraph 293). Instead, the ICRP recommends truncation in only two situations: "when the subsequent [individual dose] contributions are common to all alternatives or it is no longer possible to distinguish between options" (Publication 55, Paragraph 149). Given the lack of consensus within the radiation protection community, the question of truncation of carbon-14 doses will likely be one of the most difficult ones EPA must face in reissuing its HLW standards.

IV. RELEASE LIMIT ALTERNATIVES

EPA's 1985 standards contain a material release limit restricting the total amount of radioactive material projected to be released to the environment. The release limit was derived from a goal of 1,000 premature fatal cancers over 10,000 years from disposal of 100,000 metric tonnes of spent fuel. The release limit format eliminated the need to determine long-term population locations and lifestyles as part of a site-specific licensing review.

If EPA's standards are revised in a way that emphasizes protection of individuals, the release limit format could be retained. To do so, EPA would formulate a safety goal in terms of the maximum allowable individual dose. EPA would then determine the generic location and lifestyle assumptions needed to convert the dose goal into a limit on concentrations of radioactive material permitted to be released into the environment. The derivation of such release limits would not differ in concept from derivation of the effluent concentration limits of the NRC's radiation protection regulations in 10 CFR Part 20.

A variation on the release limit format would be reliance on EPA's groundwater protection requirements to provide protection for individuals. EPA's 1985 standards require that concentrations of radionuclides in certain groundwaters be limited to EPA's drinking water standards. EPA could demonstrate that other pathways (e.g., irrigation of food crops) would not contribute unacceptable doses when concentrations are maintained at drinking water levels. Doing so would eliminate potential speculation about such pathways far in the future.

The advantages and disadvantages of a release limit standard based on protection of individuals would be the same as for the current population-based release limits. Release limits are much easier to implement in a licensing review than are dose limits because assumptions about long-term locations and lifestyles of people do not need to be evaluated. On the other hand, release limits can be either too stringent or not stringent enough if site-specific conditions are different from the generic assumptions used to derive the release limits.

V. CURRENT PRACTICES IN NRC

The current practices in NRC for projection of individual dose rates into the future are addressed in this section. In the past, some branches in the Office of Nuclear Material Safety and Safeguards (NMSS) adopted a standard lifestyle and location for the exposed individuals. (The approach adopted by the Fuel Cycle Safety Branch of NMSS in 1981 is still current.) More recently, in the Division of Low-Level Waste Management, the Low-Level Waste Management Branch (LLWB) developed a Standard Review Plan (NUREG-1200) and a Performance Assessment Methodology that provides guidance to applicants and the staff for assessing long-term projections of radionuclide releases to the general environment in terms of doses to the maximum exposed individual. LLWB and Waste Management Branch, Office of Nuclear Regulatory Research (RES) have embarked on a program for expanding the staff capability for assessing low-level radioactive waste disposal and for developing a regulatory guide on low-level waste (LLW) performance assessment. This is necessary because the assessment of individual dose rates for LLW sites is complex. This complexity reflects differences in the inventories and physical and chemical forms of buried radioactive wastes, the methods for their disposal, and the differences in the standards that regulate this disposal.

The major issues that need to be addressed when dose rates are projected are posed below as questions.

Q1. Who is exposed?

Q2. What are their dietary habits (do they grow their own food, drink well water, swim or bathe in contaminated surface water, etc.)? What are their metabolic characteristics (breathing rate, lung clearance, excretion rates, amount of water ingested per day)?

Q3. Where are they exposed (at the boundary of the site, at the nearest residence, or other locations)?

Q4. When are they exposed (at 100, 1,000, 10,000 years post-operations or longer or different time frames)?

Q5. What pathways lead to significant exposures (inhalation, ingestion of contaminated foods and/or drinking water, exposure to airborne contamination or nuclides on the ground surface)?

Q6. What is the impact of future natural processes and events on dose rates (how accurately can the model parameters be predicted into the future)? Will all these factors remain constant in the future?

Each Branch below was requested to address these questions in the order given above. The answers reflect only their own response to these questions.

A. Radiation Protection and Health Effects Branch (RPHEB), RES

The Environmental Policy Section, RPHEB, RES, developed a generic model to predict the annual dose rate to an individual as a result of residual radioactive contamination at decommissioned nuclear facilities. The model is described in the draft report, "Residual Radioactive Contamination from Decommissioning," NUREG/CR-5512, 1990.

For the long-term projection of dose rates, RPHEB assumes that:

1. The person exposed is a farmer who resides on the site of a nuclear facility after it has been decommissioned.

2. The farmer grows 25% of his food locally and uses contaminated well water for irrigation of his crops and for drinking. He eats no fish or shellfish.

3. His exposure occurs at a decommissioned site that contains sufficiently low residual radioactivity for release to unrestricted use at any time in the future.

4. The time reported for individual exposure corresponds to the time of the peak dose rate that occurs within the 10,000-year period following decommissioning. This criterion was recommended to RES by the Below Regulatory Concern (BRC) Steering Committee.

5. For all terrestrial pathways, both external (due to immersion, direct radiation and ground shine) and internal exposures (due to inhalation and ingestion of food and water) are considered. Aquatic pathways were not considered.

6. Erosion and leaching following decommissioning are the only natural processes and events to be considered.

The parameters used in the models are the most commonly used values found in the literature, based on prudently conservative assumptions, not the extreme values.

B. Uranium Recovery Branch (LLUR), NMSS

The long-term public health and environmental standards for the control of uranium and thorium mills are based upon a derived release-rate standard, not upon dose-rate standards. In developing ~~the release-rate~~ standard, EPA evaluated several alternative post-closure radon emission limits and eventually established a release-rate standard of 20 pCi per square meter per second averaged over the surface of the tailings pile. EPA estimated that under this post-closure standard, radon emissions from tailings piles, on a national basis, would be significantly reduced such that 570 lung cancer deaths per century would be avoided. While EPA indicated that the total number of lung cancer deaths avoided over the effective life of the control was not calculable, EPA believed "it should exceed tens of thousands."

EPA used a two-step process to establish the standard. The AIRDOS-EPA model was used to convert the generic release rates of radon emitted from a "model tailings pile" into an intake of radon and its daughters (curies/year). The computer codes RADRISK and DARTAB were then used to convert these intake rates into risk values. Annual dose rates for a cohort (population) were generated as an intermediate step in the calculation of risk by the RADRISK computer code, but not presented explicitly in the report.

For the long-term projection of dose rates:

1. Two populations are exposed: a regional population and a national population (excluding the former regional population).

2. Only airborne radon gas and its daughters reach the receptors in the long term. For inhalation exposures, no dietary habits need to be considered.

3. The regional population was exposed at selected distances ranging from 600 meters out to 80 kilometers from the tailings pile.

4. The control and stabilization of uranium mill tailings ensures, to the extent reasonably achievable, an effective life for 1,000 years, and in any case, for at least 200 years. This control and stabilization will provide a barrier which will effectively minimize the potential for misuse and spread of the tailings, limit the average radon emission from the surface of the tailings piles to no more than the standard release rate, protect against flooding, and protect from wind and water erosion.

5. Both external and internal exposure occur as a result of the dispersion of radon gas and its daughters as they pass over the exposed persons.

6. Surface water and groundwater contamination were evaluated, as described in NUREG-0706, "Final Generic Environmental Impact Statement on Uranium Milling," September 1980, and in EPA 520/1-83-008-1, "Final Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing (40 CFR 192)," September 1983. In the latter document, the impacts of erosion, flooding and precipitation on dose rates were considered to be site-specific and were therefore only discussed qualitatively.

C. Low-Level Waste Management Branch (LLWM), NMSS

For the long-term projection of dose rates, LLWM assumes that:

1. A hypothetical individual is exposed for his lifetime.

2. The dietary habits adopted are those in GENII, a computer code that could be used for the dose calculations. (See "GENII - The Hanford Environmental Radiation Dosimetry Software System," PNL-6584, September 1988.)

3. The exposed individual is at the site boundary. Criteria for protection of individuals off-site are established in 10 CFR Part 61 as a performance objective for "Protection of the general population from releases of radioactivity." This performance objective (10 CFR 61.41) establishes annual dose limits of 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem

to any other organ of any member of the public. Reasonable efforts would be made to maintain releases of radioactivity in effluents to the general environment as low as reasonably achievable.

4. The time frame to be reported for compliance to the individual dose-rate criteria in 10 CFR Part 61 for exposure is undefined at this time. The Branch, as part of the development of additional guidance for performance assessment, will address this issue to provide further guidance on the time frame over which individual exposures will be calculated. Two major options are being considered: (1) evaluation of individual exposures to the time of peak dose with no period of time specified following closure; and (2) evaluation of individual exposures to the time of peak dose with truncation at a specified time period even if the peak dose has not yet been achieved at that time.

5. The pathways to be analyzed for demonstrating protection of the general population from releases of radioactivity are groundwater, surface water, air, soil, plants and animals. These pathways are explicitly set out as requirements of 10 CFR 61.13(a) and 10 CFR 61.41.

6. The manner in which future processes and events should be addressed is directly related to the time period for compliance. The Branch has not established a formal position on how future impacts of natural processes and events should be addressed in assessing individual dose rates. However, the staff presently believes that projections of possible future conditions of the site should be based on projections of current site conditions and processes. In addition, the Statements of Consideration to the final rule state that natural processes affecting the disposal site should be occurring at a consistent and definable rate such that the modeling of the site will represent both present and anticipated site conditions after closure.

D. <u>Decommissioning and Regulatory Issues Branch (LLDR), NMSS</u>

Decommissioning dose evaluations include the dose effects of residual contamination and evaluations of disposals performed under Sections 20.302 and 20.304 of 10 CFR Part 20. Current policy is to carry dose calculations out to 1000 years. For some nuclides, especially uranium and thorium, the doses from daughter products become substantially higher at periods in excess of 10,000 years. However, there are very large uncertainties over time periods on the order of 1,000 years or longer, and it may not be reasonable to assess hypothetical scenarios during these time frames. Decommissioning decisions, though, are very sensitive to the cutoff time period. A balance needs to be reached between doses in the long-term that may exceed the release criteria by factors of 5 to 10, and the very large costs required to dispose of materials contaminated with uranium and thorium.

For long-term projection of dose rates, LLDR assumes that:

1. The exposed individuals are intruders who reside on and farm the decommissioned site.

2. Dietary habits include the consumption of reasonable fractions of food grown onsite and the consumption of reasonable quantities of well water. Standard breathing rates, metabolic rates, and ingestion and inhalation rates are used. These standard rates are based on reasonably conservative rather than highly conservative data.

3. The intruders construct a residence in the most contaminated area of the released site, and consume well water from a well located at the most conservative groundwater location.

4. Intruders are exposed to ionizing radiation as soon as the property is released (up to a cutoff time of 1,000 years).

5. The most significant pathways are dependent upon the nuclides that remain, and the site specific geohydrologic conditions. The limiting pathways are: for gamma-emitting nuclides, direct exposure; for beta-emitting nuclides, generally the agricultural pathway; and, for alpha-emitting nuclides, the inhalation pathways.

6. There is no mitigation of the source terms for the site by long-term processes. However, some assumptions that were used in the development of the release limits for uranium and thorium take credit for erosion processes. (See Branch Technical Position (BTP), "Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations," 46 FR 52061, October 23, 1981.) The BTP assumes that the contamination by uranium and thorium will not be present over long periods of time. The cutoff time of 1,000 years eliminates consideration of natural processes over geologic periods of time.

E. Fuel Cycle Safety Branch (IMSB), NMSS

This Branch conducts safety analyses and environmental reviews for the operations at the following nuclear facilities: natural uranium conversion plants and production plants, uranium enrichment plants, enriched fuel processing and fabrication plants, and independent spent-fuel storage facilities (including any Monitored Retrievable Storage (MRS) Facility). Some of the sites formerly used for processing thorium and uranium at these facilities are known today to be contaminated with residual radioactive materials. In many cases, the total amount of contaminated soil is large, but the activity concentrations of radioactive materials present are sufficiently low as to justify their disposal on privately-owned lands or storage onsite rather than transport them offsite to a licensed radioactive materials disposal (commercial) site.

For these facilities, long-term projections of dose rates are used to determine methods acceptable to the NRC for disposal of certain radioactive materials. Secondary standards for onsite disposal, which are based on soil concentration, were derived using the dose rates as primary standards. IMSB published these concentrations, and the basis for their derivation, in a Branch Technical

Position (BTP), SECY-81-576, "Disposal or Onsite Storage of Residual Thorium or Uranium (Either as Natural Ores or Without Daughters Present) from Past Operations," October 5, 1981.

For the long-term projection of dose rates, the Branch Technical Position assumes that:

1. The person exposed is the maximally-exposed individual.

2. Dietary factors are as given in Regulatory Guide 1.109. This person is assumed to grow 60% of his food at the burial site.

3. This individual resides in a structure built on land that has been decontaminated to one of the derived standard concentrations specified in the BTP.

4. The basis for the long-term projection of doses is 1,000 years after onsite disposal. Although the BTP does not refer to this period, IMSB adopted as a basis for this position EPA 520/1-83-008-1, "Final Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing (40 CFR 192)," September 1983.

5. The pathways considered are those given in Regulatory Guide 1.109 for inhalation, ingestion and direct radiation.

6. Impacts due to natural processes and events are those given in EPA 520/1-83-008-1. In that document, the impacts of erosion, flooding and precipitation on dose rates were considered by the EPA to be site specific and therefore were only discussed qualitatively.

VI. SUMMARY AND CONCLUSIONS

EPA is considering revisions to its 1985 standards that would require long-term individual dose projections. A potential uncertainty in evaluating compliance with a long-term individual dose criterion is determining the location where doses are to be estimated. The dose-related provisions of EPA's 1985 standards limit the dose to "any member of the public in the accessible environment" which, in most cases, will be an individual located five kilometers from a repository in the direction that maximizes the estimated dose. If EPA retains the 1985 formulation, there should be little uncertainty about the location where doses are to be estimated.

Assumptions about future lifestyles, while less important than future locations of individuals, can significantly affect projected doses. The dose-related provisions of EPA's 1985 standards appear to apply to the dose projected for the "maximally exposed individual," but do not specify the characteristics of that individual. If EPA revises its standards in a way that requires long-term dose calculations, those characteristics will need to be determined, either through an NRC rulemaking or during the license review process. As noted previously in Section V, there is currently no standard practice within the NRC for estimating doses far into the future.

A limit on projected population doses is being considered by EPA as an alternative to EPA's 1985 table of radionuclide release limits. Estimation of population doses would require assumptions about the sizes of the populations using each potential exposure pathway. Truncation of individual dose contributions to the population dose estimate might be necessary, either as a function of distance from a repository or at some lower "cutoff" individual dose rate.

Specification of a "static biosphere" assumption appears to be the most reasonable approach for both individual and population dose estimates far into the future. The "static biosphere" is not the most conservative assumption possible, but it is a realistic representation of possible future conditions. When one considers the difficulties involved in making long-term projections of possible evolutions of the biosphere, any attempt to more realistically project biosphere conditions is likely to be highly speculative and contentious in a formal licensing review.

There is no consensus within the radiation protection community regarding truncation of individual dose contributions to a population dose estimate. If EPA adds a population dose criterion to its standards, the question of truncation will need to be addressed.