# Maximum Individual & Vicinity-Average Dose for a Geologic Repository Containing Radioactive Waste

Thomas H. Pigford

# Maximum Individual & Vicinity-Average Dose for a Geologic Repository Containing Radioactive Waste

Thomas H. Pigford*

## Introduction

International practice protects the public from nuclear radiation by ensuring that the reasonable maximum radiation dose received by a member of the public is less than a specified limiting dose.[1] However, recent proposals[2] would adopt a new less stringent standard for protecting public health from geologic disposal of radioactive waste. The proposed standard would be much more lenient than dose limits now in use in this country and abroad.[3] Here we consider the proposals to calculate an average dose to a future (and unknowable) population in the general vicinity and to allow that average dose as large or larger than what we now limit for the reasonable maximum exposure to individuals. In so doing, the many people exposed to above-average doses would be unprotected. Also, the proposed "vicinity-average dose"

* Dr. Pigford is Professor Emeritus in the Department of Nuclear Engineering at the University of California, Berkeley. He received his B.S. (Chem. Eng.) and went on to earn his master's and doctorial degrees from Massachusetts Institute of Technology.

1 See, e.g., Carl A. Johnson, *National Reseach Council Report "Technical Bases for Yucca Mountain Standards": A State of Nevada View,* Proceedings International Conference on High-Level Waste Management, Las Vegas (1996).

2 U.S. Congress HR-1020 (Fred Upton 1995), S-167 (Bennett Johnston 1995), S-1271 (Larry Craig 1996); Electric Power Research Institute (EPRI), A Proposed Public Health and Safety Standard for Yucca Mountain: Presentation and Supporting Analysis (1994); Nuclear Energy Institute, *NEI Comments on Behalf of the Nuclear Industry on Selected Findings and Recommendations of the NAS Report,* Technical Bases for Yucca Mountain Standards, (1995) and John H. Kessler, *Initial EPRI Reaction to the NAS Yucca Mountain Standards Recommendations,* Proceedings International Conference on High-Level Waste Management, Las Vegas (1996).

3 Thomas H. Pigford, *Personal Supplementary Statement,* Appendix E, Technical Bases for Yucca Mountain Standards, (1995); Thomas H. Pigford, *The Yucca Mountain Standard: Proposals for Leniency,* Proc. Materials Research Society: Scientific Basis for Radioactive Waste Management (1995) and Thomas H. Pigford, *The Yucca Mountain Standard: How Lenient Should if Be?* Proceedings International Conference on High-Level Waste Management, Las Vegas (1996).

standard has ill-defined notions of a future population "in the vicinity."[4] It would invite manipulation, such as increasing the "vicinity" size, to obtain lower calculated radiation doses.

People living outside the vicinity can also be exposed to radioactivity from the geologic repository, by consuming contaminated food grown in the vicinity near Yucca Mountain and by importing water extracted from wells in the vicinity. For example, a 1994 proposal by Amargosa Resources Inc. would purchase rights to ground water in the Amargosa Valley, to supply more water to Las Vegas.[5] By protecting the subsistence farmer who could use the most contaminated water near Yucca Mountain, individuals outside the vicinity would receive lower individual doses and would also be protected.[6]

### The Effect of the Proposed Vicinity-Average Dose Limit on Concentration of Radioactivity in Ground Water

The traditional subsistence-farmer calculation of dose, together with dose limits in the range of 10 to 100 mrem/year,[7] effectively limit the concentration of key radionuclides in ground water near a geologic repository. Over two decades ago the U.S. Nuclear Regulatory Commission (NRC) adopted 10 mrem/year to the public as the design criterion that controls radiological emissions from nuclear power plants.[8] It is appropriate to adopt 10 mrem/year as the U.S. design criterion for a geologic waste repository,[9] tenfold lower than the 100

---

4    The proposed legislation speaks vaguely of limiting the exposure of "an average member of the general populaton in the vicinity of the Yucca Mounain site." Similar words are used in recommendations by the EPRI, *supra* note 2 (EPRI and Kessler). From EPRI's account of how it would calculate the exposure (dose), as discussed in detail in the present report, it is evident that what is meant is the average individual dose, averaged over the entire population in the vicinity. Clearly, this is the "vicinity-average" dose.

5    Mary Hynes, *Group Wants to Grab Water from Amargosa Valley,* Las Vegas Review Journal, May 12, 1994.

6    Protecting individuals according to an individual dose limit would not necessarily ensure suitable protection of large populations. Protective criteria for cumulative population doses have been included in the proposals reviewed herein.

7    Robert W. Fri et al., Technical Bases for Yucca Mountain Standards (1995).

8    10 C.F.R. Part 50, Appx. I (1996), NRC, Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low as is Reasonably Achievable" for Light-Water-Cooled Nuclear Power Reactor Effluents — initially promulgated May, 1975.

9    Thomas H. Pigford et al., A Study of the Isolation System for Geologic Disposal

mrem/year limit recently proposed[10] for geologic repositories. Both the proposed higher dose limit of 100 mrem/year and the new proposed lenient method of calculating doses to compare to that limit will allow higher concentrations of contaminants in ground water.

Focusing only on the vicinity-average dose violates the long-established principle in protecting public health from radiation. The International Commission on Radiological Protection emphasizes that calculations should be made of the maximum individual dose.[11] The individual receiving that dose should be protected, so that all other individuals will be protected. In the present report, the person receiving that calculated maximum dose is referred to as the "reference subsistence farmer" (see the Appendix for discussion of various interpretations of "maximum individual doses").

### Probability of a Well Intersecting Contaminated Ground Water

The following quantitative estimates illustrate the maximum radiation dose that could be experienced if the vicinity-average dose were to be as high as that now proposed. Vicinity-average doses are calculated based on probabilities of locations and habits of future people, as estimated by the Electric Power Research Institute (EPRI)[12] and its consultant.[13] The maximum dose is calculated for a reference subsistence farmer who uses contaminated well water withdrawn from near the repository for drinking water and for growing a substantial portion of his food.[14] One of the probabilities that EPRI estimates is the probability that any well drilled in the vicinity of Yucca Mountain to supply water could intersect ground water contaminated by radioactivity from a repository at Yucca Mountain.

---

of Radioactive Wastes (1983).

[10]  *Supra* note 2.

[11]  In the modern terminology of the EPA, we speak of "the reasonable maximum exposure," where exposure is measured by dose.

[12]  *See* EPRI *supra* note 2.

[13]  Robert E. Wilems, *Illustrative Probabilistic Biosphere Model For Yucca Mountain Individual Risk Calculations,* Proceedings Waste Management 1994.

[14]  Comparing the calculated subsistence-farmer to a specified limit is the practice now in effect for waste-disposal projects in the U.S. and in Sweden, Finland, UK, Switzerland, Canada, and Japan; *see, e.g.,* Robert W. Andrews, Timothy F. Dale & Jerry A. McNeish, Total System Performance Assessment — An Evaluation of the Potential Yucca Mountain Repository, Yucca Mountain Site Characterization Project, INTERA, Inc. (1994).

Most of the radioactivity that will ultimately be released from Yucca Mountain will appear in a ground-water aquifer flowing beneath Yucca Mountain. There is a predictable flow direction for that aquifer, and people now live and farm 20 or more miles downstream. However, many of the future residents could reasonably be expected to live in other directions away from Yucca Mountain, where they might receive lower doses.[15] The probability that a future person will be exposed to contaminated ground water is the ratio of the dose averaged over all individuals in the entire vicinity to the maximum dose received by individuals who use contaminated ground water. Other probabilities estimated by EPRI that could further reduce the calculated average dose are discussed later.

EPRI's calculational method assumes that these future people are uniformly distributed over the vicinity, except for an unpopulated exclusion area of four mile radius surrounding the repository. EPRI assumes a repository one mile in radius, and it assumes that the future population to be considered will live in a disk-shaped area extending from four to fourteen miles. For clarity, one can first assume that all future people are subsistence farmers. EPRI assumes that the number of wells per unit area is proportional to population density. Multiplying the calculated area by the assumed population density (people per square mile) will yield the total number of people to be considered.

EPRI next assumes that the undergrrond plume of contaminated water is two miles wide (the breadth of the repository), that it spreads in the direction of ground-water flow, that all radionuclides remain in this rectangular plume, and that the concentration of contaminants is essentially constant throughout the plume. Transverse dispersion is neglected. For long-lived radioactive contaminants a nearly constant concentration of contaminants in the plume will be reached after very long operation of the repository. All subsistence farmers living above the underground plume are assumed to extract and use ground water. They will receive the maximum radiation dose (within the assumptions of this calculation). Those not living over the large rectangular plume will receive no dose.

---

[15] Transport of contaminated ground water to other locations for irrigation is neglected in EPRI's calculational model.

Thus, the probability that any person in the vicinity will receive the maximum dose is the ratio of the number of people living directly above the plume to the total number living in the vicinity. This is the ratio of average to maximum dose, assuming all people are subsistence farmers. In calculating that ratio, the population density cancels out and the dose ratio is simply the ratio of plume area to total vicinity area. For EPRI's assumptions, that ratio is:

$$\frac{vicinity\text{-}average\ dose}{maximum\ dose} = \frac{plume\ area}{vicinity\ area} = \frac{b(r_2 - r_1)}{\pi(r_2^2 - r_1^2)} = \frac{b}{\pi(r_1 + r_2)}$$

where      b is the breadth (width) of the repository footprint

               $r_1$ is the inner radius of the population zone

               $r_2$ is the outer radius of the population zone

Using the EPRI parameters of b = 2 miles, $r_1$ = 4 miles, and $r_2$ = 14 miles, we obtain the dose ratio of 0.035. The reciprocal of 0.035 is 28, which is the ratio of maximum dose to vicinity-average dose of this assumed population.

If the safety limit is specified so that the allowable average dose is 100 mrem/year,[16] the maximum dose would be 2,800 mrem/year (2.8 rem/year).[17] This far exceeds the 10 mrem/year, the typical limit for the reasonable maximum individual exposures for public in the vicinity of licensed nuclear facilities in the U.S.

Future people could live closer to the repository than the 4-mile limit assumed by EPRI. Institutional controls on where future people can live cannot be expected to endure for the long times involved in dose calculations.[18] Also, persons living more than 14 miles away should be included. Therefore, we will repeat EPRI's calculation but assume no exclusion area (other than the repository itself).[19] It is

[16] *See* I. M. Barraclough, S. F. Mobbs & J. R. Cooper, Radiological Protection Objectives for the Land-Based Disposal of Solid Radioactive Wastes, 3 **Documents of the National Radiation Protection Board** No. 3 (1992); P. A. Davis et al., The Disposal of Canada's Nuclear Fuel Waste: The Biosphere Model, BIOTRAC, for Postclosure Assessment (1992) and W. T. Farris et al., Columbia River Pathway Dosimetry Report,1944–1992, Hanford Environmental Dose Reconstruction Project, Pacific Northwest Labs (1994).

[17] Throughout we illustrate "dose" by quoting values of the *annual* dose.

[18] *See* Fri et al., *supra* note 7.

[19] Drilling a well into the repository is treated as human intrusion. Because of the possibility of bringing cuttings of solid radioactive waste to the surface, a different calculational approach is appropriate; *see* Andrews et al., *supra* note 14.

better to assume an outer radius of at least 35 miles, the distance to the nearest surface water in the vicinity of Yucca Mountain. The result is a value of 0.018 for the ratio of average to maximum dose. Allowing an average dose of 100 mrem/year would result in a calculated maximum dose of 5,600 mrem/year (5.6 rem/year). At this unacceptable dose level there would be a chance of roughly 1 in 8 for the exposed person to suffer a lifetime cancer fatality.

Similarly, if an outer-zone radius of 100 miles is assumed, a dose ratio of 0.0063 results. For an average-dose limit of 100 mrem/year, the corresponding maximum individual dose would be 15,000 mrem/year (15 rem/year).

## Early Time Corrections

The dose ratios calculated above represent steady-state calculations, assuming that the contaminant plume has progressed to the assumed outer boundary of the vicinity. However, contaminated ground water is expected to move slowly towards the environment beyond Yucca Mountain. During early times, when the underground contaminant front has propagated only a short distance beyond the edge of the repository footprint, fewer wells will intersect contaminated ground water. As compared to the steady-state calculations, there will be less chance that any well in the general vicinity will produce contaminated water for farming than later, when the contaminant plume extends to the outer boundary. The location probability will be lower, as will the ratio of average dose to maximum dose. For example, for a plume length of only 3 miles, repository breadth of 2 miles, and vicinity outer radius of 35 miles, the ratio of vicinity-average dose to maximum dose would be 0.0016. If a dose of 100 mrem/year is allowed for the vicinity-average individual, a farmer using water extracted from the contaminant plume could receive an individual dose of 62,000 mrem/year (62 rem/year).

## Validity of EPRI's Calculational Model

EPRI's calculational model that led to the above equation for the vicinity-average dose is based on a rough approximation of the underground contaminant plume. It requires a long period of constant

rate of release of contaminant from the repository into the lower aquifer. This is a good approximation for solubility-limited radionuclides. Errors for the soluble fission products have not been evaluated. EPRI's method requires that the half lives of the key radionuclides be long compared to the transport time from the repository to the outer radius of the population "vicinity". The key radionuclides (Tc-99, I-129, Np-237, etc.) meet this criterion.

EPRI assumes no transport of radionuclides by dispersion away from the assumed rectangular plume. Although coefficients for transverse dispersion are typically small, the long times involved can result in appreciable dispersive transport. The contaminant plume will then appear more as a cigar shape rather than a rectangle. The concentration of the key radionuclides will then decrease with distance away from the repository, and the location of maximum concentration and dose will be near the repository. However, the steady-state concentration is not expected to decrease markedly over a distance of several miles in the direction of ground-water flow. Dispersive broadening of the contaminant plume does not necessarily cause a large change in the dose ratio calculated from EPRI's rectangular-plume model. In calculating the dose ratios estimated above, dispersion will not only decrease the average dose to some of the people living over the stylized rectangular plume, but it will also increase the average dose to people who live outside the rectangle. More detailed calculations of dispersive transport show that the dose ratio calculated by EPRI's rectangular-plume model can be a useful approximation, if the other stated assumptions are satisfied.

EPRI's model for the above calculation is clear if one assumes that all people are subsistence farmers. However, only a fraction of the people are expected to be subsistence farmers. For a given concentration of contaminant in ground water, introducing that fraction will not reduce the calculated dose to the reference subsistence farmer. However, there will be additional people who may be less exposed to radioactivity. If all such people are assumed to obtain their water and food from noncontaminated sources, the vicinity-average dose will be reduced by that fraction. Thus, for an allowable vicinity-average dose, both the allowable contaminant concentration and the calculated

subsistence-farmer dose will correspondingly increase. For example, assume a 35-mile outer radius of the vicinity, and assume 10% of local people are subsistence farmers. For an allowable 100 mrem/year vicinity-average dose, the corresponding subsistence-farmer dose at steady state would be 56 rem/year. It appears that this correction for population dilution may not have been included in EPRI's calculations.

Subject to the assumptions of EPRI's calculational model, the "location probability" that any well in the vicinity will intersect the contaminant plume does have a scientific basis for relating the "vicinity-average dose" to the reference subsistence-farmer dose.

### Further Reduction in Average Dose by Postulated Habits of Future People

The above calculations are based on assumptions of the location of future people. EPRI's method assumes that all persons exposed by using contaminated ground water have the same diets and living habits, e.g., all are subsistence farmers. However, EPRI goes further.[20] They postulate several additional probabilities that could further reduce the calculated doses below the dose calculated for a subsistence farmer. For example, EPRI proposes that a person might reside in the area for only part of his lifetime. Not all persons living over the contaminated plume will be subsistence farmers. Some of the water and food consumed could be derived from noncontaminated sources, such as bottled water. Wells penetrating the contaminated plume might not extract contaminated water. The presence of contamination in ground water could be detected, resulting in postulated decontamination of the water or greater use of water from other sources. These are "habit probabilities", which are EPRI's guesses of the probabilities that doses to future individuals who could be exposed to contaminated ground water will not be reduced below that of the subsistence farmer. These are distinct from the "location probability" that any well in the vicinity will intersect the contaminant plume, as outlined above.

In the context of EPRI's report, the habit probabilities can be interpreted as EPRI's guesses of the ratio of average dose to all people

---

20  *See* D. Charles & G. M. Smith, Project 90 Conversion of Releases From the Geosphere to Estimates of Individual Doses to Man, Swedish Nuclear Regulatory Commission, SKI Technical Report 91:14 (1991).

who live over the contaminated plume to the subsistence-farmer dose. A low habit probability does not mean that the reference subsistence farmer would not exist. It means that there might be fewer subsistence farmers relative to all other individuals who receive lower doses. Therefore, the dose to the reference subsistence farmer will still be included in the dose calculations.

EPRI does not base these probabilities on scientific grounds.[21] It points out that the limited quantity of water in the vicinity of Yucca Mountain makes it likely that the population that depends solely on groundwater for its water needs will be limited in size. One of the habit probabilities reflects the assumed technology for detecting radioactivity and clean-up of well water before use, expected by EPRI to be more effective for a future population with advanced technology.[22] For a small population, more appropriate for the Yucca Mountain vicinity, it postulates net habit probabilities of 0.11 assuming present technology and 0.0038 for advanced technology. Each value would multiply the probability of intersecting the plume, as calculated above, to result in even lower vicinity-average dose relative to the subsistence-farmer dose. Thus, the corresponding ratios of average dose to maximum dose and the maximum dose that could result if the allowed average dose is 100 mrem/year (0.1 rem/year) are listed in Table 1.

The annual doses of 50 rem and 1,400 rem that could theoretically be received by the reference subsistence farmer are of uncertain reliability, because the habit probabilities are only EPRI guesses. Further, for doses in the range of hundreds of rem and above, radiation

---

[21]  EPRI's guesses of habit probabilities are used here only to illustrate the consequences of adopting a probabilistic approach for estimating habits of future people. The report, *supra* note 7, endorses estimating such probabilities based on assumed habits of future people. It does not believe that there is scientific basis for estimating such probabilities, but it believes that EPA should adopt such estimates on the grounds of policy. The report does not explain how it would estimate habit probabilities, nor does it illustrate the consequences of its proposed probilistic analysis. I have strongly dissented; *see Personal Supplementary Statement, supra* note 3.

[22]  It is arguable whether the possibility that future humans will detect radioactivity in water and remove it before using the water should be included in performance assessment. A goal of geologic disposal is to dispose of the waste sufficiently carefully so that future humans need not take action to protect themselves. Society now has sensitive means of detecting contaminants in soil and ground water. There are many instances in present society wherein contamination is known but remediation is difficult or impracticable. It is not reasonable to presume constant monitoring of ground water for tens and hundreds of millennia, let alone continued technical and financial capability to perform such testing far into the future.

effects would become acute, including prompt life threatening, rather than the latent cancer and genetic effects assumed implicitly when calculating the lower doses (ca. 10 mrem/year) that could be considered for licensing.

Table 1
Subsistence-Farmer Doses that Could Result from
100 mrem/year Vicinity-Average Dose

|  | Small population current technology | Small population, advanced technology |
|---|---|---|
| EPRI's habit probability | 0.11 | 0.0038 |
| EPRI's location probability | 0.018 | 0.018 |
| Calculated ratio of vicinity-average dose to subsistence-farmer dose * | 0.002 | 0.00007 |
| Calculated ratio of subsistence-farmer dose to vicinity-average dose | 500 | 14000 |
| Subsistence-farmer dose for 0.1rem/year average dose, rem/year | 50 | 1400 |

Assumes 35 mile outer radius of population zone.
• The dose ratio is equal to the product of the location probability and the habit probability. The subsistence-farmer dose is for a subsistence farmer who uses contaminated ground water from a well near the repository.

The corresponding concentrations of contaminants in ground water would be millions of times higher than normally considered safe.[23]

EPRI's calculational model and its estimated habit probabilities can lead to even greater estimated doses to the reference subsistence farmer due to early-time corrections, as discussed earlier.

## Conclusion Concerning Vicinity-Average Allowable Dose

These calculations illustrate that determining compliance on the basis of a vicinity-average dose, allowed to reach a level of 100 mrem/year, could expose some individuals to doses that would not be tolerable in any reasonable analysis of public-health protection. Public health is better protected by limiting the reasonable maximum individual dose, as calculated for the reference subsistence farmer. Limiting that dose is consistent with the recommendation of the National Council on Radiation Protection and Measurements, the

[23] The calculations do not consider self-limiting effects on ground water concentrations, such as solubility.

NRC's general public protection standard, the recommendation by the International Commission for Radiological Protection, and the current international consensus on health protection for geologic disposal.[24]

## Ground-Water Protection

These calculations have much significance for ground-water protection. The probabilities suggested by EPRI,[25] Wilems,[26] and by the TYMS committee[27] all serve to allow a greater concentration of contaminants in ground water, by large factors. In its repromulgation of 40 C.F.R. § 191 the Environmental Protection Agency (EPA) added the requirement that a geologic repository should meet requirements imposed by the Safe Drinking Water Act. If those requirements are to apply to the proposed Yucca Mountain repository, the ground water would have to meet maximum contaminant levels (MCLs). There is now some uncertainty as to what MCLs would be appropriate. Whatever levels are set, there is the danger of exceeding those levels by adopting the more lenient vicinity-average dose limit now proposed by industry and Congress, as discussed above.

The traditional method of calculating MCLs is to assume that a person drinks the contaminated water as his only source of drinking water. The assumption is akin to that of the subsistence farmer, but doses due to drinking contaminated water are typically more than tenfold less than doses from eating food grown in contaminated water. If the proposed vicinity-average dose were used, with a dose limit of 100 mrem/year, and assuming the probabilities adopted for Table 1, drinking the contaminated ground water could result in annual doses about tenfold lower than those estimated in Table 1 for the subsistence farmer. Even without invoking EPRI's "habit probabilities", the allowable doses from drinking contaminated ground water could still be far above any tolerable levels for drinking water. Therefore, ground-water protection could easily be compromised by the proposed lenient vicinity-average dose standard.

---

24  *See* references, *supra* note 3.
25  *See* EPRI, *supra* note 2.
26  *See* Wilems, *supra* note 13.
27  *See* Fri, *supra* note 7.

Relaxing the Performance Requirements for a Geologic Repository

These calculations also illustrate how adopting probabilities[28] of future human activities and locations could relax[29] the performance requirements for a geologic repository. For example, EPRI and the National Research Council's TYMS Committee proposed such probabilistic analyses after learning of calculations by the Yucca Mountain project[30] that the maximum calculated dose to the reference subsistence farmer was as high as 30 rem/year.[31] EPRI's probabilities in Table 1, proposed for a small population, would reduce the vicinity-average dose estimates to 60 mrem/year (assuming current technology for water purification) and to 2 mrem/year (assuming advanced technology for water purification). The subsistence-farmer dose of 30 rem/year (30,000 mrem/year) is 3,000 times greater than the allowable individual dose of about 10 mrem/year now adopted in the U.S. and abroad. However, the far more lenient limit of 100 mrem/year proposed[32] for the vicinity-average dose would not be exceeded. For those who allow the low vicinity-average dose to obscure the high individual dose, the repository would be said to be safe!

EPRI also estimates habit and location probabilities for a large population in the vicinity surrounding Yucca Mountain. Assuming advanced technology for detecting and mitigating contamination in ground water, EPRI's probabilities are 0.5 for the location probability and $5 \times 10^{-8}$ for the habit probability, resulting in a ratio of average dose to reference subsistence farmer dose of $2.5 \times 10^{-8}$. If the reference subsistence farmer dose is 30 rem/year, as quoted above from the 1994 Yucca Mountain report, the vicinity-average dose would be only $7.5 \times 10^{-7}$ rem/year. Although the reference subsistence farmer dose greatly exceeds any reasonable limit for an individual dose, the calculated

[28]  *See* Fri, *supra* note 7, EPRI *supra* note 2, Kessler, *supra* note 2 and Wilems, *supra* note 13.

[29]  *See* Johnson, *supra* note 1, Pigford references *supra* note 2.

[30]  *See* Andrews et al., *supra* note 14.

[31]  The Yucca Mountain project acknowledges that the calculated dose is much too high and would be unacceptable. It believes that the high dose is largely a result of extreme conservatism in the choice of parameters and in modeling release of radiocativity and its transport through the geosphere. It has underway several analysis and experimental programs that are expected by the project to provide a technical baiss for reducing the calculated dose.

[32]  *See* references, *supra* note 2, except Nuclear Energy Institute.

vicinity-average dose would be far below the 100 mrem/year level proposed[33] for public health protection.

If compliance with health protection standards were to be based on the very low vicinity-average dose calculated above, the geologic repository would seem to be better located in the midst of a metropolitan desert community, such as Las Vegas! A contributor to this bizarre conclusion is EPRI's expectation that the force and technology of a large population would result in likely detection and mitigation of contaminated well water. Also, the aquifer under Yucca Mountain could supply contaminated water to only a limited number of people. The additional people would have to obtain water and food from uncontaminated sources, would receive low doses, and would reduce the vicinity-average dose. If a vicinity-average dose limit were adopted and if the much higher dose to the reasonable maximally exposed individual were ignored, calculated population dilution by a metropolitan area like Las Vegas could make Yucca Mountain compliance easy, even if high individual doses could occur. Whether the repository would be safe would be obscured by the faulty logic of a vicinity-average dose limit.

### The National Research Council's TYMS Report

The TYMS report[34] proposes to develop probabilities that could lower the calculated average dose to a hypothetical critical group of individuals in the vicinity. The critical group would include the individual receiving maximum dose and all others whose doses are within tenfold of the maximum.[35] The committee's proposal was developed after the committee reviewed the high individual doses calculated by the Yucca Mountain project[36] and after it reviewed EPRI's probabilistic approach described above. I have strongly

---

[33] *Id.*

[34] *See* Fri, *supra* note 7.

[35] Because of mathematical errors in Appendix C of the report, *supra* note 7 (*see Personal Supplementary Statement, supra* note 3, Thomas H. Pigford, Invalidity of the Probabilistic Exposure Scenario Proposed by the National Research Council's TYMS Committee, Report UCB-NE-9523, Rev. 1, May (1996)), these two ICRP criteria for the critical group could not both be fulfilled by the method endorsed by the TYMS committee.

[36] *See* Andrews et al., *supra* note 14.

dissented from the Committee's proposed probabilistic critical group on the grounds that there is no scientific basis for predicting probabilistic distributions of habits of future people, that it would be an unjustifiably lenient approach to public health protection, and that it would do irreparable damage to the Yucca Mountain project.[37]

One cannot yet estimate how low the calculated individual dose would be using the TYMS approach, because the TYMS report does not present example estimates of the probabilities that it advocates, nor does it explain how such probabilities would be obtained. It does acknowledge that there is no scientific basis for estimating such probabilities.

However, the TYMS report does indicate that the authors may have been thinking of the same kinds of probabilities that were described to the committee by EPRI. Appendix C of the TYMS report speaks of calculating the probability that future people will be present over the contaminated plume of ground water. This is akin to EPRI's location probability described above. Also, the TYMS report and a member of the TYMS committee[38] speak of the benefits of a future society monitoring ground-water quality and either treating or avoiding use of contaminated sources. This is a key feature of EPRI's habit probability, particularly for an assumed future large population with advanced technology.

Basing performance assessment on such conjured probabilities and adopting a vicinity-average dose limit that requires estimates of such probabilities are not the ingredients of a standard that would build confidence by the scientific community and the public. The above calculations illustrate that a standard that would limit the reasonable maximum individual dose to a subsistence farmer is a far more reliable means of ensuring public health protection from geologic disposal.

## Summary

A new standard for protecting public health from the Yucca Mountain repository for radioactive waste is proposed. It would limit

---

37 *See* Pigford references, *supra* note 3.

38 Chris G. Whipple, *Comments Regarding the NAS Report on Yucca Mountain Standards*, Proceedings International Conference on High-Level Waste Management, Las Vegas (1996.)

the average radiation dose to a future population in the general vicinity, instead of limiting the maximum dose to an individual. The standard would allow the *vicinity-average* dose to be almost tenfold higher than what is now adopted in this country and abroad as a limit for the *maximum* dose. Calculational methods proposed by an advocate of the new standard predict doses to individuals that could exceed internationally accepted levels by factors of several thousand and more. Concentrations of radioactivity in ground water in the vicinity could exceed safe concentrations by factors of thousands. Safety problems of a repository with a high maximum individual dose could be obscured by low calculated values of the vicinity-average dose.

Instead, the standard for Yucca Mountain should limit the annual radiation dose to the reasonable maximally exposed individual. For estimating compliance with radiation protection standards for geologic disposal, national and international radiation protection agencies and bodies have long calculated reasonable maximum exposures for future subsistence farmers, who drink contaminated ground water and obtain a substantial portion of their food from crops irrigated by it. If the reasonable maximum dose estimate is within acceptable limits, the doses to others, who by definition should receive lower doses, will also be acceptable [see Appendix]. This is accepted international practice for protection of public from disposal of radioactive waste in geologic repositories. Subsistence farming is not rare. Family farms are a way of life for many residents in the Amargosa Valley, who use ground water from an aquifer that flows under Yucca Mountain.[39]

The project needs a standard stringent enough to build confidence in the face of legal and political challenges. At present no scientific bases exist to support a policy less stringent than that now used in the U.S. and in other countries. Policy makers must reject pressures for short-term expediency and economy lest, by enacting policy that compromises scientific validity and credibility, they undermine public confidence and end needed nuclear research and application.

---

39  *Supra* note 1.

## Appendix
## Various Interpretations of "Maximum Individual Dose"

The dose to the "reference subsistence farmer" should not be confused with a dose to the "hypothetical maximally exposed individual", as used in many studies. The "reference subsistence farmer" would be the individual who receives the highest dose, among all those individuals considered in calculating radiation doses. However, some individuals could receive higher doses, such as individuals with unusual sensitivity to radiation or with unusual diets. It has been the policy or practice in the international community to calculate protection to future individuals whose diets and sensitivity to radiation are typical of present-day people in the vicinity.

Further, the reference subsistence-farmer doses calculated in performance assessment of geologic repositories are not the maximum doses that could be received even by a subsistence farmer. As explained elsewhere,[40] it is the practice to express uncertainties in geosphere parameters as probabilistic distributions of those parameters. The doses calculated are the expected values of the resulting probabilistic distribution of doses, not the doses at the high-dose end of the distribution. The highest dose of that distribution is referred to by EPA as the Theoretical Upper Bound Estimate (TUBE). It is calculated by assuming most unfavorable and conservative values of each parameter that affects the dose calculation. This extremely conservative deterministic calculation of the TUBE is not the calculated subsistence-farmer dose referred to herein. Here "dose" is understood to be calculated as the mean of the probabilistic distribution of doses. The probabilistic distribution of doses is to be calculated based on scientifically based distributions of parameters that affect those calculations.

Thus, several examples of calculation of doses to a "hypothetical maximally exposed individual" are far more conservative and extreme than the subsistence-farmer calculation that is international practice. In the current language of the EPA, the dose calculated to the reference subsistence farmer could be better construed as the calculated "reasonable maximum dose".

---

40  *See* Andrews et al., *supra* note 14.