APPENDIX A

BIOGRAPHICAL INFORMATION ON COMMITTEE MEMBERS

Robert W. Fri, *Chair*, is President of Resources for the Future, an independent nonprofit research organization in Washington, DC, that conducts research and policy analysis on issues affecting natural resources and environmental quality. He received a B.A. in physics from Rice University and an M.B.A. from Harvard University. He has served in government as Deputy Administrator of the U.S. Environmental Protection Agency (1971-73) and Administrator of the Energy Research and Development Administration (1975-77) and been a member of numerous committees advising government and resources industries.

John F. Ahearne is Executive Director of Sigma Xi, The Scientific Research Society. He received his B.S and M.S. degrees from Cornell University and his Ph.D. in plasma physics from Princeton University. His professional interests are risk assessment and science policy. He was a commissioner of the U.S. Nuclear Regulatory Commission (1978-83) and its chairman (1979-81). He is a member of the National Research Council's Board on Radioactive Waste Management and has served on a number of the Council's committees examining issues in risk assessment and the future of nuclear power.

Jean M. Bahr is Associate Professor, Department of Geology and Geophysics, Institute for Environmental Studies, and Geological Engineering Program, at the University of Wisconsin, Madison. She received her B.A. degree in geology and geophysics from Yale University and M.S. and Ph.D. degrees in applied earth sciences (hydrogeology) from Stanford University. She is a member of the National Research Council's Board on Radioactive Waste Management.

R. Darryl Banks is Director of the Program on Technology and the Environment at World Resources Institute in Washington, DC. He received his B.A. degree from Coe College and, as Rhodes Scholar, his Ph.D. from Oxford University. He has worked in the U.S. Congress as a Congressional Science Fellow (1976-77) and a staff member of the Office of Technology Assessment (1977-78). He worked in the Office of Research and Development of the U.S. Environmental Protection Agency (1978-81) before becoming Deputy Commissioner of the New York State Department of Environmental Conservation (1983-92) where he specialized in hazardous waste management issues.

Robert J. Budnitz has been President of Future Resources Associates, Inc. in Berkeley, California since 1981 before which, he was at the U.S. Nuclear Regultory Commission (1978-1980) and was a member of the technical staff and held several management positions at the Lawrence Berkeley Laboratory of the University of California (1967-78). He received his B.A. degree from Yale University and his Ph.D. in physics from Harvard University. His professional interests are in environmental impacts, hazards, and safety analysis, particularly of the nuclear fuel cycle. He has served on numerous investigative and advisory panels of scientific societies, government agencies, and the National Research Council.

Sol Burstein, is a registered professional engineer and member of the National Academy of Engineering. He retired in 1987 as Vice Chairman and Director of Wisconsin Energy Corporation, the holding company for Wisconsin Natural Gas Company and Wisconsin Electric Power Company, of which he also served as Vice President and Director. His career with Wisconsin Electric spanned 21 years, prior to which he spent over 19 years in engineering design and construction work at Stone & Webster. He currently is an independent consultant. He specializes in utility management and nuclear and mechanical engineering. He received a B.S.M.E. degree from Northeastern University and a D.Sc (hon) from the University of Wisconsin at Milwaukee. He has served on numerous industry and government advisory committees and is a member of the National Research Council's Board on Radioactive Waste Management.

Melvin W. Carter is Neely Professor Emeritus of Nuclear Engineering and Health Physics at the Georgia Institute of Technology. He specializes in public health engineering and radiation protection. He received his B.S. degree in civil engineering and an M.S. in public health engineering from Georgia Institute of Technology and his Ph.D. in radiological health from the University of Florida. Before joining the faculty at Georgia Institute of Technology, he had extensive experience in radiologic health as director of government laboratories, including the National Environmental Research Center in Las Vegas (1968-72). He is a Past President of the International Radiation Protection Association and has served on numerous advisory committee of scientific societies; he is also a member of the National Research Council's Board on Radioactive Waste Management.

Charles Fairhurst is Professor of Civil Engineering at the University of Minnesota in Minneapolis, where he has taught since 1956 after having received his B.Eng and Ph.D degrees in mining from Sheffield University, England. His specialties are rock mechanics and mining engineering. He consults internationally on geologic isolation of radioactive wastes and rock mechanics. He is a member of the National Academy of Engineering and the Royal Swedish Academy of Engineering Sciences. He is also Chairman of the National Research Council's Waste Isolation Pilot Plant Committee.

Charles McCombie is Technical Director of NAGRA, the Swiss Cooperative for the Disposal of Radioactive Waste. He has 25 years experience in the nuclear field, more than 15 of which are in radioactive waste management. He serves on a number of international committees advising European and international organizations on radioactive waste management issues. His formal training is in physics with a B.Sc from Aberdeen University, Scotland, and a Ph.D. from Bristol University, England.

Fred M. Phillips is Professor of Hydrology, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology. He specializes in isotope hydrology and paleoclimatology. He received his B.A. degree from the University of California at Santa Cruz and his Ph.D. in hydrology from the University of Arizona.

Thomas H. Pigford has been Professor of Nuclear Engineering at the University of California, Berkeley since 1959. He is an international consultant in the geologic disposal of radioactive waste. He specializes in the nuclear fuel cycle, nuclear safety, environmental analysis of nuclear systems, and prediction of the release of radionuclides from buried solid waste and their transport through geologic media. He has received many awards for his achievements in engineering, including the Robert E. Wilson Award and the Service to Society Award from the American Institute of Chemical Engineers, the Arthur H.

Compton Award from the American Nuclear Society, and the John Wesley Powell Award from the U.S. Geological Survey. He is a member of the National Academy of Engineering and has served on many of the panels and boards of the National Research Council. He was a member of the Presidential Commission on the Accident at Three Mile Island. He is Scientific Master for the U.S. District Court, Hanford Nuclear Reservation Litigation. He earned a B.S. from the Georgia Institute of Technology and a M.S. and Sc.D. in chemical engineering from the Massachusetts Institute of Technology.

Arthur C. Upton is Professor Emeritus of Environmental Medicine at the New York University School of Medicine and currently is Clinical Professor of Environmental and Community Medicine at the Robert Wood Johnson Medical School as well as Clinical Professor of both Pathology and Radiology at the University of New Mexico School of Medicine. He is a member of the Institute of Medicine and has served on numerous committees of the National Research Council, prominently including the series on biological effects of ionizing radiation. He received a B.A. and M.D. from the University of Michigan.

Chris G. Whipple is Vice President of ICF Kaiser Engineers in Oakland, California. He holds a B.S. degree from Purdue University and a Ph.D degree in engineering science from the California Institute of Technology. His professional interests are in risk assessment, and he has consulted widely in this field for private clients and government agencies. Prior to joining ICF Kaiser Engineers, he conducted work in this and related fields at the Electric Power Research Institute (1974-90). He served on the National Research Council's Board on Radioactive Waste Management from 1985 to 1995, and as its Chair from 1992 to March 1995.

Gilbert F. White is Emeritus Distinguished Professor of Geography and Emeritus Director of the Institute of Behavioral Science at the University of Colorado in Boulder. He is a specialist in the social and economic aspects of natural hazards, particularly those associated with water resources. He has served in many government and academic posts, including as President of Haverford College (1946-55) and Professor of Geography at the University of Chicago (1956-69) before joining the University of Colorado in 1970. He is the recipient of many awards, including the Tyler Prize for Environmental Achievement (1987) and the Hubbard Medal of the National Geographic Society (1994). He has served on numerous advisory committees for scientific societies, governments, and the National Research Council. He also chaired the Technical Review Committee on Socio-Economic Effects of Nuclear Waste Disposal for the State of Nevada. He received S.B., S.M., and Ph.D. degrees in geography from the University of Chicago and is a member of the National Academy of Sciences and a foreign member of the Russian Academy of Sciences.

Susan D. Wiltshire is Vice President of JK Research Associates, Inc. in Beverly, MA. She specializes in public policy formulation, strategic planning, and citizen and community involvement in technical programs. She has been a member of a number of National Research Council committees, including the Board on Radioactive Waste Management, and has been president of the League of Women Voters of Massachusetts. She serves on advisory committees to the U.S. Environmental Protection Agency and the National Council on Radiation Protection and Measurements. She holds a B.Sc. degree in mathematics from the University of Florida.

APPENDIX B

CONGRESSIONAL MANDATE FOR THIS REPORT

Letter of J. Bennett Johnston to Robert W. Fri, May 20, 1993

Energy Policy Act of 1992 (P.L. 102-486)
Section 801

Excerpts from the Conference Report (Cong. Rec. H-12056)

Text of the Energy Policy Act of 1992

TITLE VIII--HIGH-LEVEL RADIOACTIVE WASTE

SEC. 801. NUCLEAR WASTE DISPOSAL.

(a) Environmental Protection Agency Standards.--

(1) Promulgation.--Notwithstanding the provisions of section 121(a) of the Nuclear Waste Policy Act of 1982 (42 U.S.C. 10141(a)), section 161 b. of the Atomic Energy Act of 1954 (42 U.S.C. 2201(b)), and any other authority of the Administrator of the Environmental Protection Agency to set generally applicable standards for the Yucca Mountain site, the Administrator shall, based upon and consistent with the findings and recommendations of the National Academy of Sciences, promulgate, by rule, public health and safety standards for protection of the public from releases from radioactive materials stored or disposed of in the repository at the Yucca Mountain site. Such standards shall prescribe the maximum annual effective dose equivalent to individual members of the public from releases to the accessible environment from radioactive

materials stored or disposed of in the repository. The standards shall be promulgated not later than 1 year after the Administrator receives the findings and recommendations of the National Academy of Sciences under paragraph (2) and shall be the only such standards applicable to the Yucca Mountain site.

(2) Study by National Academy of Sciences.--Within 90 days after the date of the enactment of this Act, the Administrator shall contract with the National Academy of Sciences to conduct a study to provide, by not later than December 31, 1993, findings and recommendations on reasonable standards for protection of the public health and safety, including--

(A) whether a health-based standard based upon doses to individual members of the public from releases to the accessible environment (as that term is defined in the regulations contained in subpart B of part 191 of title 40, Code of Federal Regulations, as in effect on November 18, 1985) will provide a reasonable standard for protection of the health and safety of the general public;

(B) whether it is reasonable to assume that a system for post-closure oversight of the repository can be developed, based upon active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered or geologic barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits; and

(C) whether it is possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years.

(3) Applicability.--The provisions of this section shall apply to the Yucca Mountain site, rather than any other authority of the Administrator to set generally applicable standards for radiation protection.

(b) Nuclear Regulatory Commission Requirements and Criteria.--

(1) Modifications.--Not later than 1 year after the Administrator promulgates standards under subsection (a), the Nuclear Regulatory Commission shall, by rule, modify its technical requirements and criteria under section 121(b) of the Nuclear Waste Policy Act of 1982 (42 U.S.C. 10141(b)), as necessary, to be consistent with the

Administrator's standards promulgated under subsection (a).

(2) Required assumptions.--The Commission's requirements and criteria shall assume, to the extent consistent with the findings and recommendations of the National Academy of Sciences, that, following repository closure, the inclusion of engineered barriers and the Secretary's post-closure oversight of the Yucca Mountain site, in accordance with subsection (c), shall be sufficient to--

(A) prevent any activity at the site that poses an unreasonable risk of breaching the repository's engineered or geologic barriers; and

(B) prevent any increase in the exposure of individual members of the public to radiation beyond allowable limits.

(C) Post-Closure Oversight.--Following repository closure, the Secretary of Energy shall continue to oversee the Yucca Mountain site to prevent any activity at the site that poses an unreasonable risk of--

(1) breaching the repository's engineered or geologic barriers; or

(2) increasing the exposure of individual members of the public to radiation beyond allowable limits.

Text of Conference Report
[CR page H-12056]

TITLE VIII--HIGH-LEVEL RADIOACTIVE WASTE

Section 801 addresses the Environmental Protection Agency's (EPA) generally applicable standards for protection of members of the public from release of radioactive materials into the accessible environment as a result of the disposal of spent nuclear fuel or high-level or transuranic radioactive waste. Administrator's authority to establish these standards is embodied in section 161b. of the Atomic Energy Act of 1954, Reorganization Plan No. 3 of 1970, and section 121(a) of the Nuclear Waste Policy Act of 1982.

Section 801 builds upon this existing authority of the Administrator to set generally applicable standards and directs the Administrator to establish health-based standards for protection of the public from release or radioactive materials that may be stored or disposed of in a repository at the Yucca Mountain site. The provisions of section 801 make clear that the standards established by the authority in this section would be the only such standards for protection of the public from releases of radioactive materials as a result of the disposal of spent nuclear fuel or high-level radioactive waste in a repository at the Yucca Mountain site. Any other generally applicable standards established pursuant to the Administrator's authority under section 161b. of the Atomic Energy Act of 1954, Reorganization Plan No. 3

of 1970, and section 121(a) of the Nuclear Waste Policy Act of 1982 would not apply to the Yucca Mountain site.

The provisions adopted by the Conferees in section 801 require the Administrator to promulgate health-based standards for protection of the public from releases of radioactive materials from a repository at Yucca Mountain, based upon and consistent with the findings and recommendations of the National Academy of Sciences. These standards shall prescribe the maximum annual dose equivalent to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of in the repository. The provisions of section 801 do not mandate specific standards but rather direct the Administrator to set the standards based upon and consistent with the findings and recommendations of the National Academy of Sciences.

The Administrator is directed to contract with the National Academy of Sciences to conduct a study to provide findings and recommendations on reasonable standards for protection of the public health and safety by not later than December 31, 1993. In carrying out the study, the National Academy of Sciences is asked to address three questions: whether a health-based standard based upon doses to individual members of the public from releases to the accessible environment will provide a reasonable standard for protection of the health and safety of the general public; whether it is reasonable to assume that a system for post-closure oversight of the repository can be developed, based upon active institutional controls, that will prevent an unreasonable risk to breaching the repository barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits; and whether it is possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years. In looking at the question of human intrusion, the Conferees believe that it is also appropriate to look at issues related to predications of the probability of natural events.

In carrying out the study, the National Academy of Sciences would not be precluded from addressing additional questions or issues related to the appropriate standards for radiation protection at Yucca Mountain beyond those that are specified. For example, the study could include an estimate of the collective dose of the general population that could result from the adoption of a health-based standard based upon doses to individual members of the public. The purpose of the listing of specific issues is not to limit the issues considered by the National Academy of Sciences but rather to attempt to focus the study on concerns that have been raised by the scientific community.

Under the provisions of section 801, the Administrator is directed to promulgate standards within one year of receipt of the findings and recommendations of the National Academy of Sciences, based upon and consistent with those recommendations. The Conferees do not intend for the National Academy of Sciences, in making its recommendations, to establish specific standards for protection of the public but rather to provide expert scientific guidance on the issues involved in establishing those standards. Under the provisions of section 801, the authority and responsibility to establish the standards, pursuant to a rulemaking, would remain with the Administrator, as is the case under existing law. The provisions of section 801 are not intended to limit the Administrator's discretion in the exercise of his authority related to public health and safety issues.

The provisions to modify its technical requirements and criteria for licensing of a repository to be consistent with the standards promulgated by the Administrator within one year of the promulgation of those standards. In modifying its technical requirements and criteria, the Nuclear Regulatory Commission (NRC) is directed to assume, to the extent consistent with the findings and recommendations of the National Academy of Sciences, that civilization will continue to exist and that post-closure oversight of the repository will continue, and to include in its technical requirements and criteria, engineered barriers to prevent human intrusion. As with the Administrator, the provisions of section 801 are not intended to limit the Commission's discretion in the exercise of its authority related to public health and safety.

The provisions of section 801 address only the standards of theEnvironmental Protection Agency, and comparable regulations of the Nuclear Regulatory Commission, related to protection of the public from releases of radioactive materials stored or disposed of at the Yucca Mountain site pursuant to authority under the Atomic Energy Act, Reorganization Plan No. 3 of 1970, the Nuclear Waste Policy Act of 1982, and this Act. The provisions of section 801 are not intended to affect in any way the application of any other existing laws to activities at the Yucca Mountain site.

APPENDIX C
A PROBABILISTIC CRITICAL GROUP

Although the components of a probabilistic computational approach have considerable precedent in repository performance, we are not aware that they have previously been combined to analyze risks to critical groups. We have therefore outlined in this appendix a fairly explicit example of how this approach might be implemented for the case of exposure through contaminated ground water. The main purposes of this example are to show that the approach is feasible and to illustrate the steps necessary to perform such a calculation. The example uses a Monte Carlo method for modeling exposure consistent with that employed in the hydrologic modeling of radionuclide transport. In presenting this appendix, we do not intend it as a detailed recommendation, but an exploration of at least the more important issues that are likely to arise in an actual compliance calculation. The additional detail in this appendix is warranted because the technique has not been applied to this problem in the past, as far as we are aware.

The following outline of steps is designed to provide an illustrative example of the types of calculations that could be employed in an exposure scenario analysis. The specific process described here is only one of a variety of alternatives that EPA might consider during its rulemaking. It is based on a number of choices and general considerations, some of which are reviewed below prior to a description of the steps themselves.

a. Technical feasibility of the calculations requires specification of one or more exposure scenarios. As described in Chapter 3, a scenario includes parameter values or distributions that provide quantitative descriptions that include where people live, what they eat and drink, and what their sources of water and food are. A given scenario might include the lifestyle and activities of only farmers or a mix of economic lifestyles and activities of farmers, miners, defense workers, and casino operators, for example. It might be based on actual current activities in the area of interest, on current activities in some adjacent area, or potentially on any number of hypothetical future activities.

The only technical consideration in the selection of an exposure scenario is whether the specified scenario provides sufficiently well defined parameters or parameter distributions to make calculations feasible. The selection of the exposure scenario, along with its associated parameter values, is fundamentally a policy choice and therefore an appropriate responsibility of rukemakers. Broad participation in this policy decision by the various affected interested parties and acceptance of the scenario as a reasonable basis for performance assessment are likely to be essential to acceptance of any results of the analysis (NRC, 1993).

b. Even for a narrowly specified set of parameters, it is possible that the calculation procedure can be manipulated to obtain results closer to those desired by the analyst. It might not be possible to eliminate all opportunities for this type of manipulation. However, careful consideration of these possibilities during the rulemaking process might help to develop guidelines for calculations to address some of the potential pitfalls. For example, we were particularly concerned with avoiding strategies that would reward uncertainty in the temporal or spatial distribution of radionuclides in ground water. A procedure in which larger uncertainty in transport parameters leads to a reduction in calculated risk, relative to the risk that would be calculated were transport parameters less uncertain, would provide a strong disincentive to reduce uncertainty through site-characterization activities. A second issue is how to quantify properly the risk in areas of low-population density, because the probability of an individual receiving a dose in these areas is dependent on whether any individual is present in the area at the time when radionuclides are present in the underlying ground water. A critical feature of this model, therefore, is that a method must be incorporated for calculating the probability that people are present over the contaminated plume of ground water.

c. The method illustrated in this appendix employs a fully probabilistic treatment of all aspects of the exposure scenario. This results in a computationally intensive procedure. It might be possible to reduce the computational requirements by treating parts of the calculation deterministically or analytically.

d. The illustrative example focuses on exposures and risks associated with ground-water use. The fact that gaseous releases are not included in this example should not be interpreted as a judgment that such releases can be excluded from performance assessment and compliance evaluation. A separate exposure scenario, with a different critical group, would be required for evaluation of the gaseous exposure pathway. In the end, however, one pathway will result in the maximum risk and define the critical group whose protection would be the primary metric for setting the standard.

Example Steps Required for Implementation of a Monte Carlo Analysis

Step 1: Identify general lifestyle characteristics of the larger population that includes the critical group.

The first step is to identify the type of people who would be likely to receive the highest doses and therefore be at greatest risk. These people make up a group that might be considerably larger than the critical group, but of which the critical group will be a subset. As noted earlier, this step involves subjective choices that should be part of the rulemaking process. For purposes of illustration, this example assumes a farming community scenario, based on present-day conditions in the Amargosa Valley.

Step 2: Quantify important characteristics, distributions of characteristics, and geographic location of the chosen population.

The second step addresses two aspects of the exposure analysis. First, any analysis of exposure will require specific information on the living patterns, activities and other characteristics of potential members of the exposed population that can be used as input to deterministic or probabilistic simulations. Second, if identification of the characteristics of currently occupied land and technologies (such as soil type, slope, depth to ground water, well depth, etc.) provides a technical basis for limiting the simulation area for exposure analysis, significant reduction in the computational effort required for the calculations would result.

In a Monte Carlo simulation, each of the pertinent parameters is represented by a distribution of values, from which one value for each is randomly selected for each of many calculations. For the purpose of this example, we assume that each of these factors could be quantified using surveys and studies of the existing population in the region. Correlations between factors would need to be identified, such as relationships between farm density and soil type or depth to ground water. Analysis of these data would provide a basis for a model of the farming economy that can be used to identify geographic areas in the basin that have the potential for farming and ground-water use. It is important to note that these areas would not necessarily correspond to the current areas of highest population density or water use, since there might be areas of arable land that have not been developed due to restricted access (anywhere in the Nevada Test Site, for example). There might be areas where higher rates of water use could be easily sustained but have not been implemented by some farmers, or for a variety of other reasons.

Step 3: Simulation of radionuclide transport and identification of potential exposure areas

The third step is to identify the potential intersections of potentially farmable areas and areas beneath which radionuclide-contaminated ground water occurs. Delimiting the intersections of these areas can further reduce the computational effort.

The physical location and chemistry of the plume of contamination can be identified by performing a series of Monte Carlo simulations of the release and transport of the wastes through the unsaturated zone to the water table and in the saturated zone. Each simulation will generate a plume path (direction, width, depth below the water table, thickness) and its surface footprint. This footprint can be overlaid on the map of potential farm density or water use to determine a potential exposure area. If the model employs an appropriate sampling of the input parameters controlling radionuclide release and transport, each of the many plume realizations can be considered an equally likely outcome of radioactive waste disposal at Yucca Mountain. If the number of plume simulations is sufficiently large, the series of calculations defines the statistical characteristics of the problem.

Step 4: For each plume realization, identify critical "snapshots" of radionuclide distribution at time(s) for which the plume underlies exposure area(s) identified in step 3.

Even if the plume evolution were perfectly predictable, and hence the potential exposure area perfectly constrained, not all inhabitants of this exposure area would be at risk. There will be a long period of plume history (that does not even begin until radionuclides reach the saturated zone) during which radionuclide contaminated ground water will not have reached the aquifer beneath a potential exposure area. Inhabitants of a potential exposure area living there during these periods are at no risk. Once the plume reaches the aquifer beneath an exposure area, the risk to inhabitants will vary with time as the areal extent of the plume and radionuclide concentrations in the contaminated ground water change during plume migration. If the critical group comprises a set of individuals who have the greatest average risk, then the temporal as well as spatial distribution of risk must be considered in identifying the group. The purpose of this step is to account for the temporal variation in risk by identifying a) the time at which inhabitants of a potential exposure area will be at maximum risk and b) the corresponding radionuclide distribution in ground water at that time. The subsequent exposure analysis can then be conducted employing the radionuclide distribution for this critical time.

Each of the simulations produces a realization of plume evolution in space and time. The spatial distribution of radionuclide concentrations in ground water at an instant in time constitutes a plume snapshot. If rates of plume evolution are slow, as would be expected from performance assessment calculations conducted to date for Yucca Mountain, a snapshot for an instant in time is also likely to be representative of the plume distribution over the course of a human lifetime, or even over many generations. Examining a series of snapshots generated by a simulation, one can identify the period(s) of time, for each simulation, during which peak radionuclide concentrations or high total (volume integrated) activities are present beneath the area(s) delimited in step 3. These periods should correspond to the times at which the population in the exposure area would be at significant risk. Determining the time of greatest risk might not be straightforward, however, because times of peak concentration (possibly over a very limited area) might not coincide with times of greater plume extent, that would have somewhat lower concentrations but greater total activity.

Step 5: Generate exposure realizations

Having identified the time period of maximum potential exposure for each plume realization, it is also necessary to determine the spatial distribution of potential doses and health effects to identify the critical group and to calculate the risk to an average individual in that group. The next step, then, is to use the plume snapshots in the Monte Carlo series of exposure simulations.

For each of the plume snapshots selected in step 4, a large number of Monte Carlo simulations would be performed. For each exposure simulation, statistical distributions of population characteristics as determined in step 2 would be sampled to generate a distribution of farms with associated inhabitants, wells, crops, livestock, and support services within and surrounding the exposure area (as determined in step 3). Well depth and screened interval, rates of water use, food sources and consumption rates, etc. would also be determined by sampling from the parameter distributions. The number of exposure simulations must be large enough to produce an adequate sampling of exposure parameter distributions.

Each simulation should cover a large enough region outside the exposure area to allow adequate definition of dose variations between the exposure area and the surrounding region. Exposures outside the area overlying the plume could result from local export of water or food from the exposure area, factors that must be included in the exposure analysis. Some exposures might also occur to inhabitants living over the plume but outside areas of intense farming or water use.

Step 6: Calculation of dose distributions for exposure realizations

The spatial relations between plume boundaries and well locations in the exposure realizations will determine which wells have the potential, constrained by well depth and screened interval, to produce water leading to human exposures. For a known concentration, rates of water use for drinking and irrigation will determine the activity extracted from the ground, and the subsequent distribution of that activity to humans, crops, livestock, etc., and the resulting dose to each inhabitant represented in the exposure realization.

Step 7: Interpretation of exposure simulation results to identify critical subgroups

For each of the plume realizations, the results of the exposure simulations can be combined to yield a spatial distribution of expected dose, which can then be used to identify the geographic area inhabited by the critical subgroup for a given plume realization.

For example, the individual doses of the combined plume and exposure simulations could be divided into subsets based on geographic location of the inhabitants. The sizes of the subareas should be adjusted to provide adequate resolution of the spatial variation in individual dose and to account for the variations in the scenario-specific population density over the simulation region. This could result in a highly variable grid size. A sufficient number of individuals must be simulated in each subarea to allow computation of a meaningful average dose. For each subarea, an average individual dose could be computed as the arithmetic mean of the individual doses in that subarea generated by the exposure simulations. The product of this average dose and the factor relating doses to health effects (5×10^{-2} fatal cancers/Sv) would be the average lifetime risk for an individual in the subarea.

The procedure for identifying the critical subgroup for one of the plume realizations would begin by delineating the subarea of the simulation region with maximum average risk plus additional subareas in which the risk is greater than or equal to one-tenth the risk in the subarea with maximum risk. These subareas constitute a trial area for a critical subgroup that is homogeneous with respect to risk. The average risk in this trial area is calculated as the arithmetic mean of the subarea risks. A critical sub-group can be considered homogeneous if it satisfies the criteria detailed in Chapter 2.

Step 8: Calculation of average risk to members of the critical group

The procedure outlined in step 7 will generate a risk for the critical subgroup corresponding to each of the plume realizations. The arithmetic average of these critical subgroup risks over all plume realizations is the technically appropriate representation for the critical-group risk. The variability in risks between critical subgroups is related primarily to the variability in potential plume concentrations and locations resulting from the probabiliistic simulations of release and transport mechanisms. Using the average critical subgroup risk provides an estimate of the risk to the critical group exposed to the average plume. Additional insight might be obtained by examining the cumulative distributions of the critical subgroup risks.

APPENDIX D

THE SUBSISTENCE-FARMER CRITICAL GROUP

In Chapter 2 we recommend that the form of the standard be a limit to the risk to the average individual in a future critical group. This appendix summarizes the steps that could be involved in assessing compliance with such a standard for a particular exposure scenario that defines the critical group as including a subsistance farmer exposed to a maximum concentraton of radionuclides in ground water.

The risk involved here is the risk of ill health from a radiation dose. Risk entails probabilities as well as consequences. A risk analysis must entail the development of probabilistic distributions of doses to future individuals for various times in the future and the development of probabilistic distributions of consequences (health effects) from those doses[5].

There are various means of constructing risk measures from such probabilistic distributions to be compared with a risk limit. The risk measure recommended in Chapter 2 is the expected value of the consequences, determined by integrating the probabilistic distribution of consequences over the entire range of estimated consequences.

The conceptual approach to analyzing risks to future individuals from a geologic repository will be illustrated here for undisturbed performance (e.g., not including human intrusion, meteoric impact, etc.). Radionuclides can be released via air or water pathways. The steps in calculating risks for the water pathways are summarized here. Similar steps are involved in calculating risk to future individuals via air pathways. For this illustration, radionuclides in waste solids are calculated to eventually dissolve in water and undergo hydrogeologic transport to the saturated zone and subsequently transport via an aquifer to the biosphere. A plume of contaminated ground water will spread out underground, downstream from Yucca Mountain, to places where it might be susceptible to human use. Calculating the space- and time-dependent probabilistic distributions of concentrations of radionuclides in the ground-water plume is the purpose of geosphere performance analysis.

Calculation of Geosphere Performance

As described in Chapter 3, there are many different possible mechanisms and pathways for the dissolution-transport processes. For example, dissolved radionuclides might be transported to the lower aquifer by slow processes that provide time for local sorptive equilibrium with the rock. In other locations, radionuclides might be transported via fast pathways resulting from episodic local saturation, with little time for diffusion into the surrounding rock matrix.

The analysis must begin with what might be, in principle, a time-dependent statistical distribution of such scenarios of release and

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[5] A probabilistic distribution of a variable can be thought of as the probability per unit increment of that variable as a function of that variable.

transport. Enough scenarios must be identified that will reasonably sample the events that can contribute to important releases of radionuclides. The probability of each of these geosphere scenarios must be estimated so that the resulting analysis can reasonably approximate the statistical distribution of consequences that would be expected.

For each geosphere scenario there are large uncertainties in the parameters used in the equations for release and transport. For full probabilistic analysis, a state-of-knowledge distribution for each parameter must be developed. Using the equations of transport, these probabilistic distributions of input quantities can be projected into a probabilistic distribution of ground-water concentration, which will vary with position and time. Although many useful calculations are made with analytic techniques (NRC, 1983), detailed results require discretizing input quantities, followed by event-tree transport calculations of a large number of combinations of input quantities (EPRI, 1994) or by Monte Carlo/Latin Hypercube sampling of a smaller number of data combinations, as used by the WIPP and Yucca Mountain Projects (Wilson et al., 1994). Semianalytical adjoint techniques that help create probabilistic distributions from the discretized results are also available. Any of these numerical techniques can yield useful probabilistic distributions, if done properly. The choice is better left to the analyst, who must consider limitations of time, budget, and computer power. Estimates of errors introduced by sampling techniques should be included when such techniques are used to reduce the number of discrete calculations.

These space- and time-dependent probabilistic distributions of concentrations in ground water, with emphasis on ground water beyond the repository footprint, are the input quantities needed for calculating radiation doses, consequences, and risks for the biosphere scenarios. Similar approaches are followed for calculating the space and time dependent concentrations of radionuclides released to the atmosphere.

Many analysts employ system software that feeds geosphere results directly into biosphere calculations, bypassing the display of probabilistic distributions of concentrations in ground water.

Calculation of Biosphere Performance

For the biosphere scenario involving the subsistence-farmer critical group, ground water is assumed to be withdrawn at the location of temporal-maximum concentration of radionuclides. The time of that maximum concentration specifies the time at which the doses, consequences, and risk are being calculated at that location. In the era of temporal-maximum concentration, the concentrations at a given location vary little over a human lifetime, so the ground-water concentration can be assumed constant in calculating lifetime doses and risks for that critical group. The critical assumption in this model, then, is that a subsistence farmer extracts water from the location of maximum concentration of radionuclides in the aquifer, provided that no natural geologic feature precludes drilling for water at that location.

The subsistence farmer is assumed to use the extracted contaminated water to grow his food and for all his potable water. Conservatively, the farmer is to receive no food from other sources. A pumped well to extract ground water can perturb the local flow of ground water, so that concentrations of contaminants in the extracted water can be less than in the unperturbed ground water. The extent of concentration reduction depends on the extraction rate (Charles and Smith, 1991). A reasonable extraction rate can be calculated assuming that the subsistence farmer or even the entire critical group uses a single well for extracting ground water.

If the subsistence farmer's water is obtained from commercial pumping of the underground aquifer at the point of maximum local contamination[6], the effect of commercial rates of water extraction on the withdrawn concentration can be included in the analysis. Obviously, for commercial water withdrawal, it is the withdrawal location rather than the location of the subsistence farmer that is important.

The vertical variation of concentration in ground water at a given surface position can be obtained from the geosphere analysis. If methods of predicting the vertical location of the point of water withdrawal within the aquifer are defensible for the long-term future, then the effect of

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[6] There is a current proposal for commercial withdrawal of ground water from the aquifer near Yucca Mountain. This water could be distributed to local communities as well as others that might exist or be developed farther from Yucca Mountain.

withdrawing at locations other than that of the vertical maximum concentration can be included. Otherwise, arbitrary assumptions of well depth would diminish confidence in the resulting calculated risk.

The largest radiation exposure to future humans from contaminants in ground water is predicted to result from internal radiation from ingested or inhaled radionuclides. For the water pathways, eating food contaminated by irrigation or by other use of contaminated ground water for growing food is expected to be the source of largest dose, greater than doses from drinking water (NRC, 1983). Therefore, realistic prediction of doses and risks to future humans requires knowledge of their diets and amounts of food and water consumed. Such information for the distant future is unknowable. Therefore, as is done in all other biosphere scenarios, we must assume that future humans have the same diets as ourselves (including food and water consumption). This amounts to the unavoidable policy decision that geologic disposal is to protect future humans whose diets are the same as ours or whose diets would not lead to greater radiation doses from using contaminated water than would the diets of people today.

All biosphere scenarios must also rely on data for the uptake of radionuclides from contaminated water into food. Here, one can rely on scientific data for the typical soil conditions and for the kinds of foods assumed for this analysis. For a given food chain and for drinking, the amount of radioactivity ingested in a given time, or over a human lifetime, is proportional to the concentration of radionuclides in the extracted ground water.[7]

The ingredients of the biosphere approach described here, beginning with specified concentrations in extracted ground water, are identical with those of the widely used GENI computer code developed by Napier et al. (1988). The GENI code is used by the WIPP Project in predicting doses to future individuals who utilize contaminated water for drinking and for growing food and who receive no food from outside sources. It is an example of what could be used or updated for calculating subsistence-farmer doses.

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[7] This assumes uptake factors, i.e., distribution coefficients for a given radiochemical species in a given plant or other organism immersed in contaminated water, that are independent of radionuclide concentration.

The GENI code includes intake-dose parameters recommended by ICRP and other agencies. Therefore, employing GENI or a similar code to predict radiation doses to future humans who inadvertently use contaminated water requires the additional assumption that future humans have the same dose-response to ingested radioactivity as do present humans. All biosphere scenarios adopt this assumption. Of course, it is expected that the intake-dose parameters will be updated when new information is available.

Given the probabilistic distribution of concentration of radionuclides in extracted ground water at a given future time and location, the human-uptake-response model, such as GENI, can predict the statistical distribution of radiation doses to the subsistence farmer. Because the ground-water concentrations vary little over a human lifetime, it is necessary only to sum the dose commitments for a human who uses that contaminated water over his/her lifetime. The result is a probabilistic distribution of lifetime dose commitments, easily converted to lifetime average annual dose commitments.

The probabilistic distribution of lifetime dose commitments can be converted into a distribution of consequences by multiplying each value of dose commitment by the appropriate dose-risk parameters, obtainable from ICRP and others. If the constant dose-risk parameter of the linear hypothesis is used, the probabilistic distribution of consequences will differ from that of doses by only a constant multiplier. Here, by adopting dose-risk parameters developed for present humans, we are assuming that future humans will have the same present risk when exposed to a given radiation dose. All biosphere scenarios adopt this assumption. Of course, it is expected that the dose-risk parameters will be updated when new information is available.

Each value of the consequence is then multiplied by the probability distribution function for that consequence, and this integrand is then integrated over all consequences. The result is the calculated risk to the subsistence farmer from ground-water pathways, expressed either as the lifetime risk or as the lifetime average annual risk. To this risk from the ground-water pathways are to be added other calculated risks for the subsistence farmer, who is the individual at maximum risk within the critical group.

To obtain the risk to the average member of the critical group, for compliance determination, it can be arbitrarily assumed for simplicity that there is a uniform distribution of individual risk within that group.[8] Because ICRP's homogeneity criterion specifies that the critical group should have no more than a tenfold variation in individual dose, and because large departures from the linear dose-response theory are not expected for this calculation, the expected value of the risk to the average individual will be about one-half that of the maximally exposed subsistence farmer.[9]

The expected value of risk to the average individual within the subsistence-farmer critical group is to be compared with the risk limit that is to be selected for compliance. The regulator can specify how far below or above the specified risk limit the calculated risk must be for compliance decision.[10]

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[8] Adopting any distribution, uniform or otherwise, for the risks within a critical group projected to exist in the distant future, ca. 100,000 years and beyond, is **arbitrary**, because the habits, location, etc. of that future group of people are not knowable to us. Whether one postulates some distribution, as is done here, or calculates a distribution based on the assumed relevance of the current site-specific population, adopting any such distribution for the future is arbitrary.

[9] Because of the large uncertainties in the calculated doses and risks to any of these individuals, the uncertainty of uniformity of risk within the group cannot introduce an important uncertainty in the result. An uncertainty of 2 or 3 in the calculated dose is not expected to be important.

[10] UK's NRPB specifies the calculation of a 95% confidence interval for the expected or central value of risk. The upper value of this confidence interval is what is compared with a regulatory limit [Barraclough *et al., 1992]*.

APPENDIX E
PERSONAL SUPPLEMENTARY STATEMENT OF THOMAS H. PIGFORD

INTRODUCTION AND SUMMARY

This supplementary statement clarifies two alternative methods of calculating radiation exposures to people in the far future. They are the exposure scenarios involving the "probabilistic critical group" described in Appendix C and the "subsistence-farmer critical group" described in Appendix D. Both exposure scenarios involve critical groups, as recommended by the International Commission on Radiation Protection (ICRP). ICRP also recommends that the critical group include the person at highest exposure. The objective is to ensure that if the individual at calculated maximum exposure is suitably protected, no other individual doses will be unacceptably high [ICRP, 1985ab].

I believe that this objective can be reasonably met if exposures and risks are calculated using the subsistence-farmer scenario and if the calculated risks meet the Standard's performance criterion. The subsistence-farmer is the individual at calculated maximum risk. Thus, the subsistence-farmer approach is conservative and bounding. Its use represents wide national and international consensus for safety assessment when characteristics of exposed populations are not known. In contrast, the probabilistic critical-group calculation is based on arbitrary choices of reference populations, is not well defined, is not mathematically valid, and is subject to manipulation. It could lead to much lower calculated doses and risks. There is no indication, however, that this country needs to adopt a calculational approach that is so much more permissive than current national and international practice. Its adoption would undermine confidence in the adequacy of public health protection and jeopardize future success of the Yucca Mountain project.

A policy decision common to exposure scenarios in Appendices C and D of the Report is that future humans will have diets and food-water intake similar to that of people now living in the vicinity. In both exposure scenarios, calculations are to be made for future people who do not have extreme sensitivity to radiation, who have the same response to radiation as present people, and who do not have abnormal diets. This Supplementary Statement speaks of calculating maximum and average doses and risks to such future humans, not to persons who may be at greater risk because of unusual diets or unusual sensitivity to radiation.

COMMENTS AND EXPLANATION

1. Among the many possible exposure scenarios, the subsistence-farmer exposure scenario is the most conservative. It is bounding. All future people will be protected if the calculated subsistence-farmer dose/risk meets a prescribed safety limit.

Future humans can be exposed to radiation by drinking well water containing radionuclides and consuming food grown from that contaminated well water.[11] [12] In addition to assuming diets and food-water intake typical of that of present humans, it is also necessary to assume how much of the lifetime intake of food and water is affected by

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[11] Calculated concentrations of radionuclides in ground water are a function of location and time. Exposure calculations translate these concentrations into estimates of dose and risk to future people. The method of exposure calculation is the "exposure scenario"; it is sometimes called the "biosphere scenario".

[12] The Committee is also concerned with the persons exposed to "the highest concentration of radiation in the environment". The environment includes air, water, and soil. The radiation in that environment consists of photons, free electrons, and alpha particles from radioactive decay of radionuclides. The "concentrations" of such radiation are rarely calculated, but could be deduced from calculated radiation fluxes. Evidently the Committee has in mind possible exposure from external radiation, such as doses to the skin from swimming in contaminated water or from being immersed in contaminated air. However, studies presented to the Committee show that such doses and risks from external radiation in the environment are minor compared to doses and risks from inhalation and ingestion of radionuclides that may be released to the environment from a geologic repository [Napier *et al.*, 1988].

water contaminated with radioactivity, as well as how near the withdrawal well is to the repository. These "human activity" assumptions are most difficult to deal with.

Future people are deemed to be suitably protected if their calculated lifetime radiation doses and risks are less than a prescribed dose or risk limit. The calculational method should be constructed so that if the person receiving the calculated maximum dose is suitably protected, then all future people with similar diet and dose response will also be protected [ICRP, 1985aab]. To ensure such protection we should assume conservatively that some future individuals are subsistence farmers who use contaminated ground water for drinking and for growing their food over their entire lifetime.[13] To ensure that no future person receives a greater lifetime dose, we assume that the water used by the subsistence farmer is extracted from the location of maximum concentration in ground water.

The subsistence farmer calculation is the most conservative for the type of people assumed for dose/risk calculations. It is bounding. It is patterned from the widespread practice, current and historical, of calculating dose and risk to maximally exposed individuals where the exposure habits of real people cannot be specified or calculated. It is also the most stringent exposure scenario.

2. There is international consensus to calculate doses and risks for subsistence-farmers in determining compliance with a safety limit for geologic disposal. There is no such consensus for the probabilistic critical group proposed by the Committee.

There is considerable precedence, in the U.S. and abroad, for basing dose and risk predictions on a subsistence farmer, or on a critical

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[13] Large uncertainties in the calculation of radionuclide concentrations in the geosphere mean that calculated doses and risks to the subsistence farmers will also be extremely uncertain. Consequently, dose/risk estimates will be little affected whether all or only a "substantial portion" of the subsistence farmer's intake of water and food is contaminated by the extracted ground water.

group that includes that subsistence farmer, as defined above.[14] Projects for high level waste disposal in the UK, Sweden, Finland, Canada, and Switzerland follow similar practices [Barraclough *et al.*, 1992; Charles et al., 1990; Vieno *et al.*, 1992; Davis *et al.*, 1993]. Switzerland's geologic disposal project defines the critical group as a self-sustaining agricultural community located in the area(s) of the highest potential concentration. Switzerland assumes that no food and water are obtained from outside sources [Switzerland, 1985, 1994; van Dorp, 1994].

In discussing the choice of critical groups and exposure scenarios for long-term waste management, UK's National Radiological Protection Board (NRPB) [Barraclough *et al.*, 1992] states:

> ".... it is appropriate to use hypothetical critical groups. For the purposes of solid waste disposal assessments, these are assumed to exist, at any given time in the future, at the place where the relevant environmental concentrations are highest, and to have habits such that their exposure is representative of the highest exposures which might reasonably be expected."

and, for long-term estimates of radiation dose and risk, Barraclough *et al.*, state:

> " ... the 'reference community' replaces the critical group, and is located so as to be representative of individuals exposed to the greatest risk, at the point of highest relevant environmental concentrations. .... The reference community should normally comprise 'typical' subsistence farmers, i.e., perhaps a few families who produce a range of food to feed themselves."

Likewise, the U.S. Yucca Mountain project estimates radiation doses to future individuals on the basis of conservative subsistence farmers whose entire food and water are contaminated with radionuclides from the proposed repository [Andrews *et al.*, 1994; Wilson *et al.*, 1994]. The GENII code [Napier *et al.*, 1988; Leigh, *et al.*, 1993] is used to define the biosphere scenario and to calculate doses to subsistence farmers.

The U.S. Nuclear Regulatory Commission (USNRC) calculates radiation doses to future individuals who could be affected by geologic

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[14] Many of these projects adopt the term "maximally exposed individual" instead of the "subsistence farmer". The dose/risk assumptions are the same.

disposal [McCartin *et al.*, 1994; Neel, 1995]. To calculate future human exposures, USNRC assumes a hypothetical farm family of three persons who obtain all their drinking water from a contaminated well. Well water is used to grow a large portion of the family's vegetables, fruits and grains. All of the family's beef and milk is obtained from farm animals fed on vegetation irrigated by contaminated well water [Napier, *et al.*, 1988]. The assumed farm family's well is not restricted to the location of the present population[15]. Well depth and withdrawal rate are not constrained by present practice in the vicinity of Yucca Mountain. These assumptions meet the criteria for the conservative subsistence farmer described above. They meet the ICRP criteria for calculating doses for geologic disposal [Neel, 1995].

There are numerous other relevant examples. The U.S. WIPP project to dispose of transuranic waste in bedded salt calculates radiation doses based on a biosphere scenario that is the equivalent of the conservative subsistence-farmer approach. They use the GENII code [Napier, *et al.*, 1988; Leigh, *et al.*, 1993] to calculate individual doses once concentrations in water have been estimated. The estimated doses can be converted to risks by using the dose-risk conversion factors. Sandia National Laboratories recently used the subsistence-farmer calculation to evaluate doses and risks from DOE-owned spent fuel emplaced in a tuff repository [Rechard, 1995]. DOE's Hanford Environmental Dose Reconstruction Project [Farris, 1994ab] adopts variants of the subsistence farmer approach to calculate doses when occupancy factors and locations of actual exposed people are not sufficiently known. When the location, occupancy, and food source of real people cannot be identified, as in specifying a generically safe level in drinking water or in calculating long-term performance of geologic disposal, dose/risk estimates are based on the more conservative approach involving the hypothetical maximally exposed individual.

Thus, adopting the subsistence-farmer approach is the consensus among the several geologic disposal projects in other countries and in the U.S., including the USNRC plans for calculating individual doses for a high-level waste repository. It is adopted to calculate doses when actual location and habits of potentially exposed people are not known.

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[15] No one in the present population lives nearer than 20 miles from Yucca Mountain.

On the other hand, the Committee has identified no reference wherein the kind of probabilistic exposure analysis of future human activities, as proposed in Appendix C, has been adopted for geologic disposal.

3. The reference population for the Committee's probabilistic exposure can be chosen arbitrarily.

The Committee's probabilistic exposure calculations are to be based on extrapolation of location and habits of an arbitrarily selected reference population. The Committee acknowledges (cf. Appendix C) that the selection of the reference population for probabilistic analysis would be arbitrary. The population might be present inhabitants in the vicinity, inhabitants in some adjacent area, or inhabitants of an entirely different community[16], or inhabitants of a hypothetical future population. It could evidently be any population of the past, present, or future. The Committee would only require sufficient parameters to enable a calculation to be made.

The Committee illustrates the probabilistic method by adopting an arbitrary reference population consisting of those people living 20 or more miles away from Yucca Mountain.[17]

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[16] It has been suggested by proponents of the Appendix C approach that the population of Las Vegas could be a suitable reference population instead of the population in the region surrounding Yucca Mountain.

[17] No people now live nearer than 20 miles from Yucca Mountain because the nearer land is publicly owned.

4. The subsistence-farmer calculation of dose and risk fulfills recommendations of the International Commission on Radiological Protection (ICRP), the probabilistic critical-group calculation does not.

The International Commission on Radiological Protection (ICRP) endorses calculating the average dose to a homogenous[18] critical group. The group should include the person at highest exposure and risk. ICRP's critical-group concept has been useful in evaluating the safety of <u>operating</u> facilities, where habits of the present population at risk can be included in the analysis of doses and risks.

However, because the habits and population at risk in the far future are not known, ICRP recommends (see "Radiation Protection Principles for the Disposal of Solid Radioactive Waste", ICRP-46 [ICRP, 1985a]):

> "When an actual group cannot be defined, <u>a hypothetical group or representative individual</u> should be considered who, due to location and time, would receive the greatest dose. The habits and characteristics of the group should be based upon <u>present knowledge</u> using <u>cautious,</u> but <u>reasonable,</u> assumptions. For example, the critical group could be the group of people who might live in an area near a repository and whose water would be obtained from a nearby groundwater aquifer. Because the actual doses in the entire population will constitute a distribution for which the critical group represents the extreme, this procedure is intended to <u>ensure that no individual doses are unacceptably high</u>." [emphasis added]

ICRP-43 also endorses the single hypothetical individual when dealing with conditions far in the future:

> "In an extreme case it may be convenient to define the critical group in terms of a <u>single hypothetical individual</u>, for example when dealing with conditions well in the future which cannot be characterized in detail" [ICRP, 1984b]. [Emphasis added.]

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[18] ICRP recommends that the group include the most exposed individual and that there be no more than a tenfold variation in exposure within the critical group.

On the basis of the above quotes from ICRP, I concur with UK's NRPB and others that the subsistence farmer is the appropriate <u>single hypothetical individual</u> to be considered for dose and risk calculations for the distant future. The diet and dose response of the subsistence farmer are to be based on <u>present knowledge,</u> as recommended by ICRP. It is <u>cautious</u> and <u>reasonable</u> that there can exist in the future a farmer whose food intake is largely that grown in contaminated water. Because the subsistence-farmer calculation is bounding, it represents <u>the extreme of the actual doses in the entire population</u>. Protecting the subsistence farmer will <u>ensure that no individual doses are unacceptably high</u>. [Emphasis shows connection to ICRP-46 and ICRP-43 recommendations.]

Those wishing to identify a critical group can imagine a group that would include the subsistence farmer, subject to ICRP's homogeneity criterion that the dose or risk to individuals within the group should vary no more than tenfold.[19]

The full-time subsistence farmer, who receives no food and water from noncontaminated sources, is obviously the bounding scenario. We assign a probability of unity that he can exist. Some part-time farmers will be included in the data for the Committee's probabilistic analysis, because they exist now in the Amorgosa Valley. However, because the Committee's method is expected to synthesize a continuous probabilistic distribution function of occupancy and exposure to radiation, the full-time subsistence farmer will <u>not</u> be found on that distribution. Speculation that the Committee's probabilistic approach will yield the full-time subsistence farmer as the individual with maximum exposure is not valid. Methods of Appendices C and D do not converge.

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[19] The Committee makes much of the claim that the probabilistic exposure scenario of Appendix C can predict the dose/risk variation within the calculated critical group, so that the average dose within the group can be calculated. However, the ratio of maximum to average dose/risk must lie between one and ten, if the critical group meets ICRP's homogeneity criterion. An assumed linear variation results in a ratio of two, as assumed in the subsistence-farmer approach. I have already noted that the large uncertainties in calculating geosphere performance, together with the additional uncertainties inherent in the Committee's proposed probabilistic exposure calculations, do not justify such attempts to refine the ratio beyond that assumed above. Again, calculated exposures from the probabilistic scenario are of questionable validity, whereas the subsistence-farmer results are conservative and bounding.

The probabilistic approach can yield a maximum value of the dose/risk calculated by that method. However, that maximum is <u>not</u> the maximum to which future people can be exposed. It is not bounding. Although the probabilistic approach may suffice for those who desire a self-consistent calculational exercise as a matter of policy, it cannot fulfill the desired goal that "if the individual at calculated maximum risk is suitably protected, all other individuals will also be protected."

The Committee justifies its probabilistic scenario on ICRP's use of the words "based upon present knowledge". By attempting to extrapolate data on the present nearby population to predict probabilities of location, number, and exposure of future people, the Committee overextends its use of <u>present knowledge</u>. The Committee's probabilistic approach is neither "cautious" nor "reasonable". It can lead incorrectly to low values of calculated doses and risks to a group selected as "the critical group". The Committee's probabilistic procedure cannot <u>ensure that no individual doses are unacceptably high</u>. It does not fulfill the recommendations of ICRP quoted above. (see Comments 6 and 7).

According to the Committee, probabilities of habits and behavior of future humans can be derived from data on any arbitrarily chosen reference population, whether past, future, hypothetical, or present. The Committee adopts the present population only to illustrate the probabilistic method. However, past, future, or hypothetical reference populations could not provide the kind of "present-knowledge" human data that the Committee claims must be used to satisfy ICRP's recommendation. Therefore, the Committee's definition of reference population does not satisfy the Committee's interpretation of ICRP guidance concerning use of "present knowledge" for establishing a critical group.

The Committee does not claim that its probabilistic exposure scenario can predict the habits of future generations; it only presents what is said to be a self-consistent calculation of individual risks based on assumed extrapolation from an arbitrary reference population. Even if correctly formulated, the Committee's probabilistic approach can tell us nothing about whether a subsistence farmer family can and will exist during any of the thousands of generations when people can be at significant risk. Common sense tells us that it is not reasonable to assume that the probability that a subsistence-farmer will <u>not</u> exist during one of the many thousands of future generations is necessarily low. The subsistence farmer is the bounding scenario for calculating doses and risks to the types of people who, by policy, are to be protected. Therefore, protecting a critical group that includes the subsistence farmer is necessarily the only cautious and reasonable approach that will fulfill ICRP's goal of ensuring that no individual doses are unacceptably high. Clearly, the Committee's less stringent probabilistic approach cannot ensure that no individual doses are unacceptably high.

The Committee wishes to avoid calculating dose/risk to a single individual or to a family of subsistence farmers as adopted by NRPB and USNRC (see Comment 2). The Committee does not explain why. As quoted above, ICRP-46 accepts a "representative individual" for calculation, and ICRP-43 endorses the single hypothetical individual when dealing with conditions far in the future:

The Committee's argument against the subsistence farmer appears in the following statement in Chapter 2 of the Committee's report:

> "... we believe that a reasonable and practicable objective is to protect the vast majority of members of the public while also ensuring that the decision on the acceptability of a repository is not prejudiced by the risks imposed on a very small number of individuals with unusual habits or sensitivities. The situation to be avoided, therefore, is an extreme case defined by unreasonable assumptions regarding the factors affecting dose and risk, while meeting the objectives of protecting the vast majority of the public." [From Chapter 2, emphasis added]

The objectives are laudable, but the Committee and others [EPRI, 1994] infer that it is necessary to calculate doses and risks to groups of future people rather than to an individual such as a subsistence farmer, contradicting ICRP [ICRP 1984,1985].

The Committee infers, in the above quote, that it is the subsistence farmer (or maximally exposed individual) who is to be ruled out because of "unusual habits or sensitivities." The Electric Power Research Institute (EPRI) reaches a similar conclusion and so states. The Committee and EPRI have apparently adopted words by UK's NRPB:

> "The purpose of the critical group concept ....is to ensure that the vast majority of members of the public do not receive unacceptable exposures, whilst at the same time ensuring that decisions as to the acceptability or otherwise of a practice are not

> prejudiced by a very small number of individuals with unusual habits." [Barraclough, *et al.*, 1992]

Both the Committee and EPRI have taken the NRPB words out of context and have misinterpreted NRPB. As is apparent from the full quotes of NRPB (see Comment 2), the individuals with "unusual habits" whom NRPB refers to are those with unusual sensitivities to radiation and with unusual diets.[20] It is a mistake to assume that the NRPB statement about "a very small number of individuals" refers to the subsistence farmer, because NRPB endorses the use of the subsistence farmer.

Because the Committee's probabilistic approach cannot predict the actual habits of future people, and because it will predict lower doses and risks than would be calculated for a subsistence farmer, there will be no way of knowing whether the Committee's objective to protect the vast majority of members of the public will be fulfilled.

5. There is consensus that the subsistence-farmer approach is consistent with the critical-group concept.

The USNRC adopts a critical group that consists of a subsistence-farmer family of three people [McCartin, *et al.*, 1994]. According to Neel [1995] this is the "reference-man" concept developed by ICRP. Neel also states that a similar approach has been taken by a working group within BIOMOVS, the international Biospheric Model Validation Study, for making long term assessments of dose. BIOMOVS is a cooperative effort by selected members of the international nuclear community to develop and test models designed to quantify the transfer and bio-accumulation of radionuclides in the environment.

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[20] Some precedence for excluding such individuals arises from UK's recent Sizewell Inquiry, which concerned a proposal to construct a new operating facility that could affect existing populations. A study of present population revealed that several individuals subsisted almost entirely on clams obtained in the vicinity. Because of the unusual diet, UK did not include those individuals in its analysis of the critical group.

In speaking of the critical-group concept, USNRC states:

> " ....the specific individuals who may receive the highest exposures and greatest risks in future time cannot be identified. In these circumstances, it is appropriate to **define** a hypothetical critical group (those persons who receive the highest exposures) because this approach avoids the need to forecast future lifestyles, attitudes to risk, and developments in the diagnosis and treatment of disease." [Neel, 1995]

USNRC's hypothetical critical group is the subsistence-farmer family.

In the same sense, UK's NRPB warns that:

> "...site-specific calculations relating to the biosphere and human behavior should not continue beyond about 10,000 years into the future. Beyond that, simple reference models of the biosphere and human behavior should be adopted in order to calculate the risks to hypothetical reference communities." [Barraclough, *et al.*, 1992]

The reference models adopted by NRPB and by the UK Department of Environment [1994] are for a group involving the subsistence farmer defined herein. (see Comment 2)

Representatives of geologic disposal projects in other countries indicate that their subsistence farmer calculations are consistent with ICRP recommendations.

6. The health standard for geologic disposal of high-level waste must provide adequate and reasonable protection of public health, but it must not be so stringent as to preclude practicable disposal.

The Committee is concerned that the subsistence-farmer approach is unnecessarily stringent.[21] It prefers the less stringent calculations of doses and risks based on probabilistic calculations of locations and habits of future people. It prefers the calculation of doses and risks based on the probabilistic exposure scenario of Appendix C. That calculation is clearly less stringent than the calculation of dose and risk to a hypothetical subsistence farmer. This is far more important than trying to justify a dose/risk calculation on one of several different interpretations of what ICRP says about exposure scenarios for the long-term.

In the written record of this study there is abundant information, contributed by knowledgeable scientists, concerning the stringency of calculating doses and risks to subsistence farmers as well as information on possible benefits of the Committee's proposed probabilistic approach. That information bears on several questions relevant to this study. Would compliance with a given dose/risk limit be unreasonably difficult if the doses and risks were calculated for subsistence farmers? Would the more conservative subsistence-farmer calculation ensure greater confidence in the adequacy of health protection? Would it do so at the expense of ruling

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[21] The Committee may not have fully understood the assumptions specified for the subsistence-farmer calculation. In Chapter 3, the Committee incorrectly states:

> "...the approach in Appendix D specifies *a priori* that a person will be present at the time and place of highest nuclide concentrations in ground water and will have such habits as to be exposed to the highest concentration of radiation in the environment."

> The subsistence farmer cannot be exposed to the highest nuclide concentration in ground water. That concentration exists deep underground. Nuclide concentrations in ground water concentrations are calculated for undisturbed flow. Withdrawing ground water by a well will dilute the radionuclide concentration [McCartin *et al.*, 1994]. Appendix D does not deal with "concentrations of radiation in the environment" (see Footnote 2).

out the nation's present approach to solving the important problem of disposing of high-level radioactive waste? Is the untried and less conservative probabilistic approach for calculating habits of future humans justified?

These questions cannot now be answered definitively. I concur with the Committee that no judgment can yet be made about whether the proposed Yucca Mountain repository could meet requirements consistent with the recommended standard regardless of what exposure scenario is adopted. We can, however, learn much from the concerns that are not addressed in the Report.

Preliminary calculations of dose/risk to future people who might live near a repository conceptually similar to that proposed for Yucca Mountain were presented, at the Committee's invitation, by DOE contractors [Andrews *et al.*, 1994; Wilson *et al.*, 1994], by representatives of industrial groups, and by others. For such preliminary calculations very conservative assumptions were made concerning geochemical, hydrological, and engineering features. Doses were calculated for the subsistence-farmer. Some of the reported doses were high enough to indicate the need for better data and more detailed analysis.[22]

The Electric Power Research Institute [EPRI, 1994] and its contractor [Wilems, 1993] recommended incorporating probabilities that reduce the calculated doses/risks. Both recommended probabilities that take into account living patterns not yet included in the exposure calculations. These include the probabilities that future people will not be present full time at their residences, that only a small fraction of their food will be contaminated with radioactivity, etc. To illustrate, Wilems

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[22] The Committee states in Chapter 2:

> "...it is possible to construct scenarios in which an individual could receive a very high dose of radiation, even though only one or two people might ever receive such doses."

The Committee's statement does not properly reflect the studies presented to the committee. Some calculated doses to subsistence farmers were high. The studies made no attempt to estimate the number of subsistence farmers who might receive these doses. The Committee seems to disagree with ICRP recommendations [ICRP, 1984, 1985] that even a single hypothetical individual could replace the critical group for dose calculations when the future population is unknown. (See Comment 4) assumed probability values and calculated much lower dose/risks, thereby making it easier to meet a given dose/risk limit. In like manner, the Committee's probabilistic exposure approach will predict much lower doses and risks than those calculated for subsistence farmers. (see Comment 7).

The Committee proposes to derive probabilities for future populations from data on living habits of an arbitrarily selected reference population. Many arbitrary assumptions are required. The main effect is to predict lower doses and risks, as was illustrated by Wilems. The Committee's probabilistic approach will clearly be less stringent than the subsistence-farmer approach used in the dose/risk calculations by DOE [Andrews, 1994; Wilson, 1994].

Developing probabilities for any future population that might live in the vicinity of Yucca Mountain is problematical. If the selected reference population is the current population of Amorgosa Valley, these people live 20 or more miles away. The probabilities for future people are to be extrapolated from a study of this reference population. Future people who live closer to Yucca Mountain will have to dig deeper wells. The Committee proposes using existing well data to calculate the probability of finding and extracting ground water nearer Yucca Mountain.

The Committee believes that the extent of nonarable land near Yucca Mountain can lead to lower expected probabilities that future individuals would use underlying contaminated ground water. On the other hand, well water is frequently withdrawn and transported for farming at other locations. Already there is a proposal to extract ground water in the vicinity of Yucca Mountain for commercial use. Where farms are located is not important; where the contaminated ground water is withdrawn is important.[23] The Committee's conclusion that future inhabitants will be at no risk if not living over contaminated ground water [Appendix C] is not defensible and is one of the many unjustified assumptions that will reduce the calculated dose/risk.

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[23] The Committee does indicate [Appendix C] that other sources of water should be considered for areas <u>outside</u> the calculated plume of contaminated ground water. The calculated plume will be very broad, however. The Committee gives no recognition to the importance of considering transport of contaminated well water to farmers who will live within the projected area of the underground plume.

Arbitrary assumptions could result in low probabilities of exposure or to a conclusion that a less stringent calculation of doses and risks is warranted. For example, one such assumption is that the future population could be large in number but confined to present population boundaries, effectively imposing a 20-mile exclusion distance. Another such assumption is that, if not confined to present boundaries, future populations would use wells no deeper than used by the present population 20 or more miles away, so future people nearer the repository would have to import food and water produced farther from Yucca Mountain. Such assumptions would certainly result in low probabilities and lower calculated doses and risks. The assumptions are arbitrary and not defensible.

One might argue that the benefits of the arid climate and present low population near Yucca Mountain will be lost if doses and risks are calculated for individuals exposed to radioactivity extracted from wells. However, there are advantages and disadvantages. The arid climate and lack of flowing surface water may invite people to use water extracted from wells. At other sites flowing surface water may dilute the contaminated ground water before it is used by humans [NRC, 1983]. However, at least two projects in other countries are calculating doses/risks to subsistence farmers who are assumed to use contaminated ground water directly, similar to what would occur at Yucca Mountain. These projects expect that they can meet performance goals similar to those suggested in this study.

There is no evidence that would justify adopting a calculational method for Yucca Mountain compliance that is less stringent than the subsistence-farmer method adopted in other countries. The recent individual dose/risk calculations for the proposed Yucca Mountain repository are preliminary. They involve many conservative and unrealistic assumptions about engineering features. The hydrogeological, environmental, and engineering-design features of Yucca Mountain do not suggest that a less stringent calculational approach is necessary. Indeed, there are many features that can favor long-term performance.[24]

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[24] A repository in unsaturated tuff at Yucca Mountain may have much greater dilution of many radionuclides than repositories in those other countries that calculate doses from using ground water contaminated by waste buried in saturated rock. For radionuclides whose release from waste solids is limited

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If a less stringent approach were justified, it would be far better to adopt a less restrictive value of the dose/risk limit than to adopt a probabilistic exposure calculation that will be so difficult to defend. The probabilistic exposure approach is neither cautious nor reasonable. It cannot ensure that no future individual will receive an unacceptable dose or risk.

7. Calculational techniques described in Appendix C are not mathematically valid. They can be manipulated to produce even lower calculated doses/risks.

The Committee proposes to establish full distributions, with respect to space and time, of numbers of future populations and of their water and food sources in the area surrounding Yucca Mountain. The surrounding area is to be divided into subareas. Each subarea can be arbitrarily large and can contain as many people as one chooses. Based on the assumed and extrapolated probabilities of location and living habits of future people, and using calculated concentrations of contaminants in ground water, doses and risks to individuals in each subarea are to be calculated.[25] The arithmetic average of all individual doses/risks in a

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(...continued)

by solubility, the release rate from the solid waste will be far less for the unsaturated repository, because of the low infiltration rate of ground water in the unsaturated zone. Contaminants in this infiltration flow will be highly diluted when they reach the underlying aquifer. Water flow past waste packages in saturated rock will be far greater, as will the release rate of such radionuclides to ground water. It would be premature to conclude that Yucca Mountain would be at a disadvantage relative to other repositories. There is no basis for proposing a less-stringent calculation of doses and risks for Yucca Mountain.

[25] The Committee's probabilistic method will yield calculated individual doses and risks that will depend on the population density and number of people in a subarea. The Committee has not explained how the growth in population is to be predicted; how the probabilistic distributions of number of people with respect to location and time, together with probabilistic distributions of parameters of occupancy, food source, etc., can result in a map of potential

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subarea is to be calculated. The subarea that is calculated to have the highest average dose/risk, together with additional subareas in which the average subarea risk is greater than or equal to one tenth of the risk in the subarea with maximum average risk, is said to define a critical subgroup. The average subgroup risk is said to be calculated as the arithmetic mean of the average risks of the selected subareas. The process is repeated for many different samplings of parameters that affect the probabilistic distributions, to produce new values of the critical-subgroup risks. The critical-group risk is said to be the arithmetic average of all calculated critical-subgroup risks. (see Appendix C)

However, the Committee's interpretation of ICRP would require calculating doses/risks for individuals over a large area, properly utilizing the many probability distribution functions of the geosphere and biosphere to calculate probabilistic distributions and expected values of consequences, selecting the individuals whose risks are within the top ten percent, and calculating the average risk of that critical group. This method is mathematically inconsistent with the Committee's proposed subarea/subgroup method. It would be fortuitous if the two methods were to produce the same result. The subarea method will tend to calculate lower doses and risks.

The Committee's subarea method will not necessarily yield a critical group that includes the individual at maximum exposure and risk. That individual may be located in a subarea wherein are many individuals at much lower exposure. The subarea size and boundaries are arbitrary. There could result so low an arithmetic average dose for that entire subarea that it would not be selected for calculating the critical group. The resulting "critical group" would not meet the ICRP criterion that the individual of greatest exposure should be included.

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farm density or water use; how many such maps will have to be generated and how they are to be used in conjunction with the many equivalent maps of sampled plume concentration; how population changes from the many expected cycles of climate change are to be calculated; how the expected values of consequence to individuals at various times and locations are to be obtained without simultaneously sampling distribution functions of geosphere performance and biosphere performance; and how the probability distribution functions are to be generated if any of the other arbitrary reference populations suggested by the Committee are adopted.

Further, to achieve a lower calculated average dose in a subarea, one would need only to move the outer boundaries of the subarea farther from Yucca Mountain, to add more people exposed to lower doses. Applied to all subareas, arithmetic average doses would decrease, as would the average dose for the calculated "critical group." The repository would appear to be safer! The calculated critical-group doses and risks would be much lower than those for a critical group that includes a subsistence farmer. Or, to lower the calculated risk, a different reference population could be selected. The calculated lower doses and risks would be obtained with an illusion of safety, but with a serious loss of credibility.

8. Calculated uncertainties in terms of confidence levels should be used to test compliance.

Large uncertainties are inherent in predictions of the transport of radionuclides to the environment far into the future. Even larger uncertainties would be introduced by the probabilistic approach based on current-population data. The Committee does not discuss how information on uncertainties is to be conveyed and used in compliance determinations.

The performance measure of risk recommended by the Committee is the expected value of the probabilistic distribution of consequences. The Committee recommends that the expected value be compared directly to the risk limit to determine compliance. However, uncertainty should be considered in determining compliance. The expected value (or mean value) conveys nothing about uncertainty. Basing compliance on the expected-value comparison is not sufficient.

A technique commonly used to convey uncertainty is to express the "confidence range" of the result. UK's NRPB illustrates presentation of the results in terms of the 95 percent confidence level. This states a range of values of dose or risk, such that 95 percent of the possible values of the distribution are calculated to fall within that range. NRPB then compares that range with a dose or risk limit [Barraclough *et al.*, 1992] . Effectively, the upper value of the range becomes the dose or risk value for determining compliance. Methods of calculating confidence levels are well documented.

Presenting 90 or 95 percent confidence levels is done extensively for the geologic disposal projects in Sweden and Finland. It is a technique commonly used in the U.S., particularly when the results are important to public understanding and acceptance [e.g., Farris *et al.*, 1994ab].

9. The Yucca Mountain project needs a soundly based standard for performance assessment and compliance. The U.S. program needs to share the benefits of an international approach towards developing standards and technology for geologic disposal.

A standard and regulatory guidance to ensure public health and safety in the long-term for geologic disposal must include both a regulatory limit as well as guidance on assumptions of habits of future individuals and population groups to be adopted in calculating those individual doses and risks. I agree with and support the Committee's recommendation that the measure of performance best suited to assure public health and safety for the long term is the dose and risk to future individuals. That measure was adopted by the National Research Council's Waste Isolation Systems Committee (WISP) [NRC, 1983], after review and analysis of the release limits then proposed by EPA, and was subsequently incorporated in EPA's standard, 40 CFR 191. The WISP Panel concluded that individual dose is a traditional and sound measure in assessing public-health protection.[26] It was also noted that most, or possibly all, other countries undertaking geologic disposal use individual dose (or individual risk) as a performance measure. Adopting the same performance measure as other countries would provide a framework for interchanging and sharing information with other countries on the developing technology for geologic disposal. The technical approach to design and performance analysis, for the purpose of ensuring long-term safety, depends greatly on the performance criterion that is adopted.

The EPA release-limit standard has now been set aside for Yucca Mountain after considerable effort has been expended in designing for compliance with that standard. Adopting a performance measure based

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[26] I agree that individual risk is better than dose as a measure of performance, because it allows for possible future changes in the dose/risk conversion factor. As has already been explained in the Panel's report, calculated values of radiation dose would include probabilistic analysis of uncertainty and probabilities, if calculable, of being exposed to the radiation.

on individual dose and risk is an important step towards developing a standard that has a clear basis for protection of public health. The international consensus favoring individual dose/risk is likely to ensure understanding and support of its adequacy for protecting public health. Both the technical community and the general public can be reasonably expected to see the virtues in individual dose/risk as a performance measure.

However, acceptance of the use of individual dose/risk for ensuring safety cannot be expected if methods of calculating doses and methods of assessing compliance are not visibly sound, suitably conservative and understandable. Selecting an exposure scenario to be used in calculating long-term doses is a crucial step that can greatly affect the magnitude of calculated individual doses and risks. If calculated risks to the bounding subsistence farmer are found be within compliance limits, then no future individual doses would be unacceptably high.[27] In contrast, the probabilistic exposure calculation is too vaguely defined, subject to too many arbitrary and unconservative policy decisions and subject to too many questions of validity to meet any reasonable test of acceptability, once the shortcomings of that approach have been sufficiently understood.

Adopting the probabilistic exposure calculation would again put the U.S. repository program on a course divergent from that in other countries. One must expect continued questioning, by the scientific community, by the public, and by geologic programs in other countries, of why the U.S. finds it necessary to adopt such a unconservative approach to regulating geologic disposal. The U.S. program needs to share the benefits of an international approach towards developing standards and technology for geologic disposal, including how to calculate individual doses and risks for compliance determination.

The U.S. geologic disposal program needs a standard, including regulatory guidance, that can be clearly implemented and that can be expected to survive challenges. Serious challenges are likely to arise many years hence when an application is finally submitted to the regulatory agency for licensing determination. By that time an enormous investment of public and electric-utility funds will have been expended in the development of repository technology and in the performance analysis to assure compliance with the new performance standard. Of the total

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[27] See Comment 4.

funds expended, most will have been to develop technological and geosphere information, to produce designs of engineering barriers that can assure safety, to produce calculations of individual risk for determining compliance, and for administration and services. The cost of constructing the repository is expected to be small in comparison. Therefore, it is essential that the new regulatory standard and guidance be on firm ground so that this enormous effort, measured in money and time, is not wasted. Adopting an individual dose/risk standard is a step in that direction. Adopting the probabilistic exposure calculation, however, would leave the U.S. program vulnerable to future challenge on grounds of reasonable assurance of safety.

I advocate an approach that ensures that all individuals are suitably protected, that is based on sound science and logic, and that does not compromise scientific validity and credibility under the aegis of policy.

Adopting the unconservative probabilistic exposure scenario will undermine public confidence. The scientific community and the public will find it difficult to understand why the Committee endorses the probabilistic exposure scenario that is demonstrably less stringent in protecting public health than the subsistence-farmer approach, the approach that has been adopted for geologic disposal projects in other countries and in the U.S.

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APPENDIX F

THE COMMITTEE CHAIR'S PERSPECTIVE ON APPENDIX E

ROBERT W. FRI

In Appendixes C and D, we have presented alternative approaches that EPA might wish to consider in selecting an exposure scenario to be used in calculating compliance with the standards. As noted in Chapter 3 of the report, these approaches differ chiefly in the assumptions and calculational methods used in estimating the exposure of future persons who might be near the repository site. However, there is little scientific basis for predicting events far into the future, such as where people will live, and so developing an exposure scenario for testing repository compliance with the standards is inherently a policy choice.

Throughout our report, we have avoided making recommendations that involve policy choices on the grounds that there is by definition a limited scientific basis for selecting one policy alternative over another. We have instead tried to use available technical information and judgment to suggest a starting point for the rulemaking process that will lead to a policy decision. As noted in Chapter 3, a majority of the committee considers the approach of Appendix C to be more clearly consistent with the technical criteria that define the critical group in the exposure scenario, and therefore believes that EPA should propose an approach along the lines of Appendix C. The committee recognizes, however, that other approaches might meet these criteria.

I believe that, in his personal statement, Dr. Pigford has become an advocate for a particular choice. He clearly prefers the approach of Appendix D and presents arguments both for his position and against the alternative. He is of course entitled to make this argument. It is important, however, to understand that the argument being presented is fundamentally a policy argument rather than a scientific one.

Nevertheless, the issue raised here is an important one. Dr. Pigford advocates an assumption that results, in his words, in calculating ". . .the extreme of the actual doses in the entire population". In contrast, Chapter 2 of the report adopts the basic principle of the International Commission for Radiological Protection that the standard should avoid ". . .an extreme case defined by unreasonable assumptions regarding factors affecting dose and risk". Although Appendix D and Dr. Pigford postulate a subsistence-farmer scenario based on cautious, but reasonable, assumptions (as described in Chapter 2), some members of the committee believe that the approach advocated by Dr. Pigford could become just such an extreme case.

Determining when the assumptions in an exposure scenario pass from cautious to extreme is thus a crucial issue in the rulemaking process. As such, it requires the fullest and most open public discussion.

GLOSSARY

Accessible environment	Those portions of the environment directly in contact with or readily available for use by human beings. Includes the earth's atmosphere, the land surface, aquifers, surface waters, and the oceans. In 40 CFR 191, the environment outside a surface defined as enclosing a controlled area.
ALARA	An acronym for "as low as reasonably achievable", a concept meaning that the design and use of sources, and the practices associated therewith, should be such as to ensure the exposures are kept as low as is reasonably practicable, economic and social factors being taken into account.
Backfill	The material used to refill the excavated potions of a repository or of a borehole after waste has been emplaced.
Becquerel	International unit of radioactivity. Symbol Bq = 1 disintegration per second.

Biosphere	The region of the earth in which environmental pathways for transfer of radionuclides to living organisms are located and by which radionuclides in air, ground water, and soil can reach humans to be inhaled, ingested, or absorbed through skin. Humans can also be exposed to direct irradiation from radionuclides in the environment.
Borehole	A cylindrical excavation in the earth, made by a rotary drilling device.
Canister	A closed or sealed container for nuclear fuel or other radioactive material, which isolates and contains the contents; it might rely on other containers (e.g. a cask) for shielding.
Collective dose	The sum of the individual doses received in a given period of time by a specified population from exposure to a specified source of radiation.
Critical group	Originally defined for dose by the ICRP (ICRP, 1977, p.17; ICRP, 1985b, pp.3-4) as a relatively homogeneous group of people whose location and habits are such that they are representative of those individuals expected to receive the highest doses as a result of the discharges of radionuclides. The definition is extended to risk in Chapter 2 of this report.
Critical pathway	The dominant environmental pathway through which a given radionuclide reaches the critical group.

Disposal	Permanent isolation of spent nuclear fuel or radioactive waste from the accessible environment with no intent of recovery, whether or not such isolation permits the recovery of such fuel or waste.
Disposal package	The primary container that holds, and is in contact with, solidified high-level radioactive waste, spent nuclear fuel, or other radioactive materials, and any overpacks that are emplaced at a repository.
Dose	A measure of the radiation received or absorbed by a target.
Dose rate	Absorbed dose per unit time.
Engineered barrier system	The waste form, cladding, backfill, and canister, all of which are intended to retard disperson of radionuclides.
Exposure	Irradiation of persons or materials. Exposure of persons to ionizing radiation can be either: 1. external exposure, irradiation by sources outside the body; or 2. internal exposure, irradiation by sources inside the body.
Fault	A surface or zone of rock fracture along which there has been displacement.

Geologic repository	A system that is intended to be used for, or might be used for, the disposal of radioactive wastes in excavated geologic media. A geologic repository includes: (1) the geologic repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste.
Ground water	Water that permeates the rock strata of the Earth, filling their pores, fissures and cavities. (It excludes water of hydration.)
Ground water transport	The principal means by which radionuclides can be mobilized from an underground repository and moved into the biosphere. Avoiding or minimizing such transport is the basis for selecting and designing repository systems.
Half-life	In physics, the time required for the transformation of one-half of the atoms in a given radioactive decay process, following the exponential law (physical half-life).
High-level radioactive waste	The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations. Other highly radioactive material that the U.S. Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation. Also referred to as high-level waste (HLW).

IAEA	International Atomic Energy Agency is an autonomous intergovernmental organization established by the United Nations. It is authorized to foster research and development in the peaceful uses of nuclear energy, to establish or administer health and safety standards, and to apply safeguards in accordance with the Treaty of the Non-Proliferation of Nuclear Weapons.
ICRP	The International Commission on Radiological Protection is an international organization that develops guidance and standards for radiological measurement and protection of public and occupational health. The ICRP is composed of a Chairman and never more than 12 other members. The selection of the members is made by the ICRP from nominations submitted to it by the National Delegations to the International Congress of Radiology and the ICRP staff itself. Members of the ICRP are chosen on the basis of their recognized activity in the fields of medical radiology, radiation protection, physics, biology, genetics, biochemistry, and biophysics. The ICRP's rules require that its members be elected every four years.
Linear model	Also, linear dose-effect relationship; expresses the health effect, such as mutation or cancer as a direct (linear) function of dose.
Natural background radiation	The amount of radiation to which a member of the population is exposed from natural sources, such as terrestrial radiation due to naturally occurring radionuclides in the soil, cosmic radiation originating in outer space, and naturally occurring radionuclides deposited in the human body.

NCRP	National Council on Radiation Protection and Measurements is an organization of nationally recognized scientists who share the belief that significant advances in radiation protection and measurement can be achieved through cooperative effort. It conducts research focusing on safe occupational exposure levels and disseminates information.
Performance assessment	Analysis to predict the performance of the system or subsystem, followed by comparison of the results of such analysis with appropriate standards or criteria.
Population dose	The sum of the doses to all the individuals in a specified group. In units of person-sievert or person-rem. (Also called collective dose.)
Radioactive decay	The spontaneous transformation of a nuclide into one or more different nuclides accompanied by either the emission of energy or particles. Unstable atoms decay into a more stable state, eventually reaching a form that does not decay further or is very long-lived.
Radioactive waste	Any material that contains or is contaminated with radionuclides at concentrations or radioactivity levels greater than the exempt quantities established by the competent authorities and for which no use is foreseen.
Radionuclide	A radioactive species of an atom characterized by the constitution of its nucleus.
Rem	A unit of dose equivalent to one-hundredth of a sievert (1 cSv).

Repository	Any system licensed by the U.S. Nuclear Regulatory Commission that is intended to be used for, or can be used for, the permanent deep geologic disposal of high-level radioactive waste and spent nuclear fuel, whether or not such system is designed to permit the recovery, for a limited period during initial operation, of any material placed in such system. Such term includes both surface and subsurface areas at which high-level radioactive waste and spent nuclear fuel handling activities are conducted.
Risk	In the context of this study, risk is the probability of an individual receiving an adverse health effect and includes the probability of getting a dose.
Saturated zone	That part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.
Seismic	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
Sievert	International Unit (SI) of equivalent radiation dose. The product of the absorbed dose and the quality factor of the radiation. Symbol Sv.
Spent fuel	Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

Stochastic health effects

Random events leading to effects whose probability of occurrence in an exposed population (rather than severity in an affected individual) is a direct function of dose; these effects are commonly regarded as having no threshold; hereditary effects are regarded as being stochastic; some somatic effects, especially carcinogenesis, are regarded as being stochastic.

Storage

Retention of high-level radioactive waste, spent nuclear fuel, or transuranic waste with the intent to recover such waste or fuel for subsequent use, processing, or disposal.

Tuff

Rock formed from consolidated volcanic ash.

Units

Units[a]	Symbol	Conversion Factors
Becquerel (SI)	Bq	1 disintegration/sec = 2.7 x 10^{11} Curies
Curie	Ci	3.7 x 10^{10} disintegrations/sec = 3.7 x 10^{10} Becquerels
Gray (SI)	Gy	1 Joule/kg = 100 rads
Rad	rad	100 ergs/gram = 0.01 Grays
Rem	rem	0.01 Sievert
Sievert (SI)	Sv	100 rems

[a] International Units are designated SI.

Unsaturated zone

The zone between the land surface and the regional water table. Generally, fluid pressure in this zone is less than atmospheric pressure, and some of the voids might contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the fluid pressure locally may be greater than atmospheric. Also referred to as vadose zone.

Vadose zone	See definition for unsaturated zone.
Volcanism	The process by which magma and the associated gases rise into the crust and are extruded onto the earth's surface and into the atmosphere.
Waste form	The radioactive waste materials and any encapsulating or stabilizing matrix.
Waste package	The waste form and any containers, shielding, packing and other absorbent materials immediately surrounding an individual waste container.
Water table	The upper surface of the saturated zone on which the water pressure in the porous medium equals atmospheric pressure.

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