2/39

AN INITIAL APPROACH FOR DEFINING POTENTIAL SITE-SPECIFIC REFERENCE BIOSPHERES AND CRITICAL GROUPS FOR EXPOSURE SCENARIOS

Prepared for

Nuclear Regulatory Commission
Contract NRC-02-93-005

Prepared by

Patrick A. LaPlante and Mark S. Jarzemba
Center for Nuclear Waste Regulatory Analyses

and

Robert B. Neel and Chris A. McKenney
U.S. Nuclear Regulatory Commission

June 1996

3/39

CONTENTS

4/39

CONTENTS (cont'd)

5/39

ACKNOWLEDGMENTS

This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the Nuclear Regulatory Commission (NRC) under Contract No. NRC-02-93-005. The activities reported here were performed on behalf of the NRC Division of Waste Management (DWM). The report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC. The authors would like to thank Pat Mackin and David Thorne for technical reviews, Wes Patrick for programmatic review, and Barbara Long for editorial assistance and document preparation. The authors would also like to thank members of the Revision to EPA Standard and NRC Regulations Key Technical Issue team for their contributions to discussions relevant to material in this report.

QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: No CNWRA-generated original data is contained in this report.

ANALYSES AND CODES: No computer codes were used for analyses contained in this report. However, prior analyses using the GENII-S code are discussed and referenced in this document.

6/39

1 INTRODUCTION

1.1 BACKGROUND

The Energy Policy Act of 1992 (U.S Congress, 1992) directed the Environmental Protection Agency (EPA) to consider the findings and recommendations of the National Academy of Sciences (NAS) when promulgating an environmental standard for a proposed high-level waste (HLW) geologic repository at Yucca Mountain (YM), Nevada. Consequently the NAS Report on Technical Bases for YM Standards (National Research Council, 1995) provided recommendations for developing exposure scenarios for risk assessments and suggested that the concepts of critical group (International Council on Radiation Protection, 1977; International Council on Radiation Protection, 1985) and reference biosphere be used for this purpose.

1.2 SCOPE AND PURPOSE

This report presents an initial approach for identifying potential reference biospheres and critical groups for development of exposure scenario options to support review of EPA standards and development of corresponding NRC implementing regulations for a proposed HLW repository at YM consistent with NAS findings and recommendations. The approach described in this document can be applied to development of potential exposure scenarios for disruptive events, human intrusion, and undisturbed repository performance. However, examples are provided only for the undisturbed case. In the context of this report, an exposure scenario is considered to be a general conceptual model of the processes by which humans could be exposed to radioactive materials assumed to be released from the proposed HLW repository at YM. This general conceptual model is used as a framework for conducting additional analyses to understand details of processes and characteristics applicable to the site. The approach described in this report is expected to be refined when additional information becomes available.

7/39

2 RECOMMENDATIONS OF THE NATIONAL ACADEMY

In response to direction from Congress to advise the EPA on selected aspects of environmental standards for a potential HLW repository at YM, the NAS Committee on Technical Bases for YM Standards provided a number of recommendations (National Research Council, 1995). One of these recommendations is for EPA to establish a risk-based standard. Additional recommendations, conclusions, and suggestions in the NAS report develop and explain NAS proposals that exposure scenario(s) be defined to implement such a risk-based standard. Current indications are that EPA is considering developing a dose-based standard and therefore, the concepts presented in this report will consider dose rather than risk, except when citing specific statements by the NAS. Exposure scenarios require specification of critical group(s) and reference biosphere(s) for use in dose calculations. This chapter summarizes the recommendations and findings of the committee on these topics to aid the NRC staff in reviewing the revised EPA standard and in developing the corresponding NRC implementing regulation.

2.1 REFERENCE BIOSPHERE

The biosphere represents the environment in which the critical group exists and therefore influences the lifestyle of the critical group and defines important exposure pathways. For defining exposure scenarios, the committee recommended establishing a specific set of assumptions for the biosphere, including sources of food and water (National Research Council, 1995). The NAS further recommended that these assumptions reflect current technologies and living patterns (National Research Council, 1995). Assumptions should be defined through a public rulemaking because they are matters of both science and policy judgment. The level of detail to be incorporated in such a rulemaking remains unspecified and will ultimately be a matter of implementation policy (see section 6.2). In their summary discussion on the need for rulemaking, the committee stated "several parameters important to risk-based assessment require determination by rulemaking" and stressed the need for "full public participation in the rulemaking process, particularly in devising the biosphere models, identifying critical groups, and defining intrusion scenarios...." (National Research Council, 1995). The intent of the committee appears to be to define the biosphere through rulemaking to a point where speculation is reduced to a reasonable level.

On other matters relevant to the specification of reference biosphere(s), the committee concluded that the probabilities and consequences of modifications to transport processes and reservoirs generated by climate change, seismic activity, and volcanic eruptions at YM are sufficiently boundable that such factors can be included in performance assessments that extend over periods on the order of about one million years (National Research Council, 1995). Therefore, it may be necessary to include the effects of disruptive scenarios in specific biosphere model(s).

2.2 CRITICAL GROUP

In setting a YM standard, the individual or group to be used in the risk calculations must be determined. The committee recommended that a critical group approach be used (National Research Council, 1995). The critical group concept is designed to ensure that no individual risks are unacceptably high by assessing compliance for the set of individuals within the overall population considered to be at highest risk. Groups with lower exposures need not be included in the analysis since the maximally exposed group is protected. Nonetheless, a variety of potentially exposed groups will need to be considered in order to determine which group is maximally exposed. The committee stated that normally

8/39

a critical group would not consist of a single individual but rather a few tens of individuals (National Research Council, 1995). The critical group risk was defined by the committee as the mean of the risk to members of the group. The intent was 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." For example, factors which enhance sensitivity include pregnancy, age, or existing health problems (National Research Council, 1995). Unusual habits include those behaviors which would be exhibited by only a few members of the group (Ibid). A key factor in determining the critical group is defining what constitutes "cautious and reasonable" assumptions regarding the lifestyles and composition of the group (see definition of critical group in section 3.1). Committee disagreements regarding the two example exposure scenario approaches in appendices C and D of their report are related to this determination (Ibid). The committee indicated there may be different critical groups defined for different exposure scenarios and pathways (Ibid).

Location and lifestyle are important characteristics of the critical group. The committee did not provide specific recommendations for determining these characteristics. However, the report presents examples of two different approaches that could be used. The appendix C ("Probabilistic Critical Group") approach relies on interrelationships among known site characteristics (e.g., depth of water table, soil types, and topography) and current population practices and lifestyles (e.g., farming) to identify areas where humans could exist in the future (National Research Council, 1995) and practices they might engage in. In this approach, the committee agreed with the International Council on Radiation Protection (ICRP) recommendations that present knowledge and cautious, but reasonable assumptions be used in defining the characteristics of the critical group (National Research Council, 1995). To the contrary, the appendix D ("Subsistence Farmer Critical Group") approach assumes that critical group lifestyle characteristics are those of the maximally exposed subsistence farmer located at the plume maximum concentration, regardless of whether such a farmer exists in the region today. While the majority of the committee recommended an approach consistent with appendix C (National Research Council, 1995), they left open the option to use other methods that meet the general criteria outlined for definition of the critical group.

In further discussion relevant to defining exposure scenarios and critical groups, the committee recommended that analysis of human intrusion be treated separately from undisturbed repository performance. Furthermore, they stated it is reasonable to define a region in which invasive human activities are to be regarded as intrusion and to exclude that region from calculation of undisturbed repository performance (National Research Council, 1995). In their example, the NAS limits consideration of critical group drinking water wells for the undisturbed scenario to locations outside the repository footprint. Additional recommendations regarding human intrusion are (i) EPA should require a conditional risk-only calculation for the intrusion scenario and (ii) this calculation should not include risks to the intruder or risks arising from material brought directly to the surface as a consequence of the intrusion (National Research Council, 1995). These recommendations, combined with the committee view that the intrusion consequence analysis should rely on the same biosphere and critical group assumptions used in the undisturbed analysis (National Research Council, 1995), can also be interpreted as limiting the location of the nearest (intrusive) critical group to outside the repository footprint. The committee recognized that such issues are a matter of policy and other approaches are valid.

2.3 EXPOSURE SCENARIO

The committee defined the term scenario as a special type of conceptual model used in performance assessment that generally describes how radionuclides might migrate from the repository and affect humans. An exposure scenario uses the reference biosphere and critical group definitions to specify the pathways by which persons may be exposed to radionuclides released from the repository (see definitions in chapter 3). Exposure pathways define the geosphere and biosphere transport routes which facilitate movement of radioactive material from the repository to individuals in the critical group. Important factors affecting exposure pathways include a variety of geosphere and biosphere characteristics, such as groundwater flow and transport conditions, where people live, what they eat and drink, technologies they use, and other lifestyle characteristics. Once a general scenario is formed (e.g., wastes dissolved in groundwater, transported by natural processes to an agricultural zone, and used for irrigation), then more specific conceptual models of geosphere and biosphere processes are incorporated to improve the scenario definition. This report considers general scenarios using the current understanding of biosphere information with the recognition that more specific geosphere and biosphere information may be obtained for future iterations.

Determining potential exposure scenarios for future populations over long time frames required making assumptions about future human behavior. The committee recognized this and supported the recommendations of the ICRP which include using present knowledge and cautious but reasonable assumptions in making future projections. The committee concluded that, while there is no scientific basis for making projections on the nature of future societies, it is also not possible to avoid specifying certain assumptions about future populations in a standard for protection of public health. The committee recommended against placing the responsibility for postulating and defending an exposure scenario on the license applicant (National Research Council, 1995). Consequently, they strongly recommended that exposure scenario(s) for compliance assessment be determined as a matter of policy using a rulemaking process with full public participation (National Research Council, 1995). The committee noted that exposure scenario assumptions should be selected "not to identify possible futures, but to provide a framework for the analysis and evaluation of repository performance for the protection of public health." (National Research Council, 1995).

As additional guidance for the development of exposure scenarios, the committee presented the aforementioned two example scenarios, stipulating that other approaches which are equally valid could be used in the final standard. In these approaches, the committee provided general attributes of exposure scenarios. First, any exposure scenario should be consistent with the critical group approach (see critical group definition in chapter 3). Second, the committee recommended against an approach where a large number of future scenarios are specified putting the applicant or regulator in the undefensible position of claiming to have considered a sufficient number of scenarios (National Research Council, 1995). Third, the committee noted that there are multiple release pathways from the repository and each might have its own exposure scenario and critical group; however, only one of these groups will contain the person(s) at highest risk. Finally, the committee stressed the importance of determining the types of scenarios that might be excluded from the analysis prior to licensing (National Research Council, 1995).

3 CRITERIA FOR CHOOSING POTENTIAL BIOSPHERES AND CRITICAL GROUPS

The NAS recommendations provide a basis for developing criteria to select potential exposure scenarios comprised of a reference biosphere, critical group, and the method of radionuclide entry into the biosphere. Scenarios provide a framework for analysis and evaluation of repository performance to protect public health. As noted previously, exposure scenarios are not intended to identify possible futures (National Research Council, 1995). General criteria for defining potential reference biospheres and critical groups are provided in this chapter. First, important terms are defined consistent with NAS recommendations.

3.1 DEFINITIONS

Critical Group—The critical group is a part of an exposure scenario which specifies the individual(s) to be used in the dose calculations. The critical group should be representative of those individuals in the population who, based on cautious but reasonable assumptions, have the highest dose resulting from repository releases. The group should be small enough to be relatively homogeneous with respect to diet and other aspects of behavior that affect exposure. The critical group includes individuals at maximum exposure and is homogeneous with respect to dose (National Research Council, 1995).

Homogeneous—According to the NAS, a group can be considered homogeneous if the distribution of individual dose in the group lies within a total range of a factor of 10, and the ratio of the mean of individual exposures in the group to the standard is less than or equal to one-tenth. If the ratio of the mean group dose to the standard is greater than or equal to one, the range of dose within the group must be within a factor of three for the group to be considered homogeneous. For groups with ratios of mean group dose to the standard between one-tenth and one, homogeneity requires a range of exposure interpolated between these limits (National Research Council, 1995). Whether such a quantitative definition of homogeneity can be adopted for NRC standards or performance calculations remains to be determined once preferred methods for dose calculation are better understood (e.g., propagation of uncertainties from geosphere modeling might complicate implementation of the NAS homogeneity definition). It may be preferable to devise a more qualitative definition of homogeneity which still limits the potential for manipulating the average dose by including wide ranging critical group characteristics.

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, groundwater, and soil can reach humans to be inhaled, ingested, or absorbed through the skin is called the biosphere. Humans can also be exposed to direct irradiation from radionuclides in the environment (National Research Council, 1995).

Reference Biosphere—The reference biosphere is a standardized set of assumptions about the environment in which the critical group exists (National Research Council, 1995). It is part of an exposure scenario. These assumptions include but are not limited to (i) annual rainfall, (ii) length of the growing season, and (iii) location of air, water, and food supplies accessible to humans.

Exposure Scenario—Exposure scenarios specify those geosphere and biosphere pathways that can transport radionuclides released from a repository to a human receptor (i.e., critical group) in the biosphere. An exposure scenario also describes where people may live, the sources of their food and

11/39

water, and other lifestyle characteristics (National Research Council, 1995). The critical group and reference biosphere are parts of an exposure scenario.

3.2 GENERAL CRITERIA FOR CHOOSING POSSIBLE REFERENCE BIOSPHERES

The type of biosphere selected will influence the types of possible critical groups that can be supported. The reference biosphere serves to limit speculation and confusion for the license applicant and other participants regarding biosphere assumptions and parameters that should be used in dose calculations. Following are general criteria for choosing possible reference biospheres:

- The postulated reference biosphere (hereafter called 'biosphere') must have a reasonable chance of occurring in the YM region over the regulatory period of interest.
- The biosphere must be based on reasonable assumptions. This appears similar to the recommended NAS concept to avoid defining the critical group as "... an extreme case defined by unreasonable assumptions regarding the factors affecting dose" (National Research Council, 1995).
- A reasonable amount of knowledge (i.e., limited speculation) about the biosphere exists.
- The biosphere assumptions reflect current technologies and living patterns (National Research Council, 1995).

Every conceivable biosphere need not be considered, as some of these biospheres would be based on unreasonable assumptions. Current understanding of the site characteristics suggests the following reasonable assumptions regarding selection of any biosphere for YM:

- The biosphere climatic environment is arid and likely to remain arid or semiarid within the next 10,000 yr. This assumption is consistent with conclusions from an expert elicitation on future climate in the YM vicinity (DeWispelare et al., 1993). This assumption does not preclude consideration of a pluvial period biosphere (see section 4.1.2).
- Biosphere characteristics such as types and sizes of farms, lengths of growing season, crop selections, and irrigation rates are consistent with those of an arid or semiarid climate.
- Groundwater accessed by wells is the primary source of water for irrigation and drinking.

3.3 GENERAL CRITERIA FOR CHOOSING POSSIBLE CRITICAL GROUPS

The choice of critical groups must take into account the biosphere and the method of entrance of radionuclides into the biosphere. Following are general criteria for choosing critical groups.

- Postulated critical group lifestyles are based on reasonable assumptions supported by information and data regarding the practices of existing local populations, including regular activities, eating habits, and conditions relevant to the YM area. The definition of what is reasonable is a matter of policy.

12/39

- Postulated critical group locations are based on reasonable assumptions supported by information and data regarding both the characteristics of existing local populations and other analogous populations living under similar biosphere conditions.

- Critical group selection protects the vast majority of members of the public while ensuring that the decision on the acceptability of the repository is not prejudiced by exposures imposed on a very small number of individuals with unusual habits or sensitivities (e.g., age, pregnancy, or existing health problems) (National Research Council, 1995).

- The postulated critical group must conform to the definition provided previously in this report (i.e., homogeneous, relatively small, includes individuals receiving highest dose, etc.).

- The critical group must not be located on federally controlled land during the period of active institutional control (e.g., Nevada Test Site, Bureau of Land Management and U.S. Air Force lands). It is reasonable to expect existing controls will be in effect for 100 to 200 years, and therefore, this criterion avoids the use of unrealistic postulation of early settlements on these lands.

4 DEFINITION OF POTENTIAL BIOSPHERES AND CRITICAL GROUPS

In this chapter, the aforementioned criteria are used to define potential biospheres and critical groups. These are then combined to illustrate potential exposure scenarios at a general level of detail in chapter 5. To enhance consideration and review of the options, each potential biosphere, critical group, and exposure scenario discussed herein includes a description of the associated state of knowledge. These descriptions reflect the extent to which staff are able to characterize exposure pathways. The state of knowledge is categorized in three levels: low, medium, and high. The rating is based on the amount of existing relevant data. For example, any part of an exposure scenario that exists today could be characterized by measured or observed data; this would not be possible for aspects of an exposure scenario that may occur in the future.

4.1 POSSIBLE BIOSPHERES

Considering the biosphere selection criteria and the results of previous evaluations, general climatic conditions in the vicinity of YM can be characterized by two possibilities: one corresponding to current conditions that are warm and dry and another corresponding to regional pluvial or pluvial-trending conditions (hereafter called pluvial) which are cooler and wetter than current conditions (Wescott et al., 1995; DeWispelare et al., 1993; Wilson, et al., 1994). To limit speculation, a separate biosphere was chosen to represent each climatic possibility. Another approach is to consider the two climates as parts of one biosphere with conditions which cycle between the current arid climate and predicted pluvial conditions over long time periods. This report discusses these climates as separate biospheres, however, this does not preclude the option of considering these as two parts of one biosphere. The two possible biospheres are presented in sections 4.1.1 and 4.1.2.

All major pathways through the biosphere that could lead to exposures of any critical group should be considered. Pathways insignificant to the total dose can be screened from the analysis. From an implementation standpoint, it may be easier to exclude pathways that contribute a dose less than some specified percentage of the "maximum" pathway. For example, for a particular critical group, the dose from the groundshine pathway may be negligible when compared to the dose solely from the drinking water pathway.

4.1.1 Current Yucca Mountain Biosphere

This biosphere incorporates current climatic conditions, water availability, and other relevant factors as determined by site specific data. In recent years, the NRC and CNWRA staffs have conducted preliminary analyses of site-specific characteristics and obtained information that can be used to discern relevant pathways through this biosphere (Wescott et al., 1995; LaPlante et al., 1995). Parameters from these studies are presented in appendix A. The somewhat more formalized, systematic approach developed by the Reference Biosphere Working Group (BIOMOVS II) to explore the pertinent pathways that might expose the critical group could also be adopted (BIOMOVS II Working Group, 1994). This approach uses current information and analyses to identify biosphere features, events, and processes (FEPs) that might occur and analyzes all relevant combinations of these FEPs to define the pertinent pathways. In ongoing work for BIOMOVS, Smith et al. (1996) has started defining a reference biosphere example for YM and recently released an update to the FEPs important to the YM site. This FEP list considers only today's biosphere and cannot be used, without modification, for a pluvial biosphere.

The current biosphere is a sparsely populated arid zone with the general groundwater flow from north to south toward areas of local farming activity in the Amargosa Valley. Site information and analyses suggest groundwater transport is likely the predominant pathway leading to human exposures for undisturbed performance (National Academy of Sciences, 1995; LaPlante et al., 1995; Wescott et al., 1995). A description of local meteorology, geography, hydrology, and water use information is currently being prepared for NUREG-1538. The biosphere supports alfalfa and hay farming, cattle and dairy ranching, and home gardening activities (TRW Environmental Safety Systems Inc., 1995; U.S. Department of Commerce, 1989; Mills, 1993; Eisenberg, 1996; Breshears et al., 1989); all of which could become important pathways for human exposures following release of radionuclides to the biosphere.

The state of knowledge regarding the current YM biosphere is categorized as medium to high. A large collection of site-specific parameter information is presented in appendix A. More detailed descriptions of site characteristics are provided in the source document (LaPlante et al., 1995); however, some non-site specific data have been used where necessary. Additional information on local characteristics has recently been identified (Eisenberg, 1996) and will continue to be investigated. Other information is obtainable but not yet acquired.

4.1.2 Pluvial Period Yucca Mountain Biosphere

A pluvial period biosphere characterized by cooler ambient temperatures and increasing rainfall (relative to the current arid biosphere) could be a consequence of the next glacial period. The NAS has indicated that a transition to a glacial climate during the next few hundred years is highly unlikely, but not impossible; during 10,000 yr is probable, but not assured; and virtually certain over a million year time scale (National Research Council, 1995). Some of the characteristics of this biosphere can be determined from the geologic and paleoclimatologic records in the area of YM and beyond. Spalding's (1985) study of plant microfossils found in ancient packrat middens at the NTS indicated conditions during the last glacial period (45,000 yr ago) were similar to those of the present northern Nevada climate (e.g., 2 °C cooler and 20 percent more winter precipitation than the present NTS area climate). During a more recent period (18,000 yr ago), the temperature was estimated to be as much as 7 °C cooler with a 70 percent increase in winter precipitation. Spaulding (1985) discussed evidence of increases and changes in terrestrial plants during this time period. In a formal elicitation of five climate experts, DeWispelare et al. (1993) predicted a temperature change of no more than 2 °C at YM over the next 10,000 yr period and as much as a doubling of rainfall (one expert's prediction) during the same period. In a summary of current information regarding impacts of the pluvial climate at YM, Wilson et al. (1994) noted indications from the geologic record of increases in infiltration resulting in water table rise and increases in surface water (e.g., pluvial lakes). Potential water table rise could affect the accessibility of water sources for exposure scenarios.

The state of knowledge regarding a YM pluvial biosphere is categorized as low. As previously noted, some inferences can be obtained from the geologic and paleoclimatologic records (U.S. Department of Energy, 1988; DeWispelare et al., 1993; Wilson et al., 1994; Spaulding, 1985). Other information (e.g., annual precipitation and yearly average temperature) and data on existing geologic conditions including results of modeling analyses can be found in DeWispelare et al., 1993. Additional estimates from expert judgments and predictive analyses are required to characterize many pathways through this biosphere.

4.2 POSSIBLE CRITICAL GROUPS

Prior to selecting one or a small set of critical groups, it is necessary to consider a range of possible groups that can be analyzed to determine which one is expected to contain those individuals in the general population most highly exposed (i.e., the actual critical group). It is important to understand that a critical group represents a sub-population of a larger potentially exposed population unit. Thus, defining potential critical groups is an attempt to determine the lifestyle characteristics that cause individual members of these sub-groups to receive the highest exposures. Therefore, a number of such groups may need to be considered before the group with the highest exposure (based upon reasonable assumptions) can be selected. The criteria provided in this report are focussed on defining these potential groups. To effectively define potential critical groups, the reference biosphere must be determined beforehand since the biosphere definition impacts the characteristics of the group. The current YM biosphere is assumed for examples presented in the following sections. This assumption is not intended to limit consideration of the same potential critical groups under the pluvial biosphere case.

At present, emphasis is placed on defining critical group lifestyle characteristics while a more limited consideration of possible locations is discussed. The approach used for specifying critical group locations is an important implementation issue which should be addressed prior to rulemaking. Some additional considerations for locating critical groups are provided in appendix B. These approaches were offered by some members of the working group and KTI team. Currently, the approach which appears to have the strongest support among cognizant staff identifies geographic areas with conditions suitable for the critical group (e.g., topography and access to water) then locates the group at a point within this area where projected radionuclide concentrations would lead to the highest exposures.

Two examples of potential critical groups are provided in sections 4.2.1 and 4.2.2. These examples were selected as the most reasonable options given currently available information. Other options were considered but not included because they did not meet the general criteria for selecting critical groups established in section 3.3, could not be supported by currently available information, or were inconsistent with NAS findings and recommendations. For example, no evidence has been found to support the assumption that a lifestyle consistent with the subsistence farmer approach discussed in appendix D of the NAS report currently exists in the YM region. Also, potential groups that would drill wells directly into the repository were excluded from consideration for the undisturbed case because such drilling constitutes human intrusion as defined by the NAS (National Research Council, 1995).

4.2.1 Amargosa Rancher/Farmer Population

Current farming practices using groundwater in the area down-gradient from YM suggest a farming critical group should be considered. The site-specific criteria for determining potential locations for this group follow.

- The groundwater must be reasonably accessible for use to irrigate farms using current technology (e.g., depth of water table does not limit well construction or pumping, given water use assumptions that are reasonable for arid farming conditions).

- The topography must be conducive to this type of ranching/farming (e.g., land slope may affect the potential for these activities).

- Land elevation must provide conditions suitable for crop growth.
- The soil type must be conducive to this type of ranching/farming.

This potential critical group was chosen considering the selected biosphere. Definition of the lifestyles and behaviors of this potential critical group is consistent with the NAS recommendations favoring use of present knowledge and cautious but reasonable assumptions, the use of currently observable data, and the Committee's understanding that no scientific basis exists to predict future human behavior (i.e., which types of activities will be favored in the future). The lifestyle characteristics of this group are consistent with lifestyles of existing populations in the YM area in the current biosphere.

4.2.1.1 State of Knowledge—High

The state of knowledge regarding this critical group is high. Information applicable to defining the characteristics of this potential critical group is discussed in sections 4.2.1.2 through 4.2.1.5. The characteristics of this potential critical group can be defined using currently obtainable information.

4.2.1.2 Critical Group Definition and Siting

This group has characteristics of ranchers/farmers which exist in the Amargosa Valley. Current practices in the area suggest this group is likely to grow alfalfa for livestock feed, but other crops are possible. Cattle are used for beef and milk production. It is assumed this critical group would obtain all its water from a local well and that water use cannot exceed the current maximum permitted pumping limit as determined by the Nevada Division of Water Resources. This limit is based on the concern that further increased water use would lead to unsustainable water mining and lowering of the water table. Potential locations for this group include the Amargosa Valley area and any other regions with characteristics similar to current farming areas (e.g., soil type, topography, depth to water table, and growing conditions). A reasonable approach is to select locations that are both suitable for ranching/farming activity and also have the highest projected plume concentrations for important radionuclides. Large scale farming at locations near the repository footprint may be infeasible because of the economics of constructing a high volume well to the depth of the water table (preliminary indications from CNWRA work in progress on economics of well drilling).[1]

4.2.1.3 Pertinent Exposure Pathways

The NRC and CNWRA staffs have conducted preliminary investigations relevant to this scenario using site-specific parameter information for sensitivity analyses to determine important pathways and parameters in the dose calculation (LaPlante et al., 1995; 1996). These investigations utilized available pathway models in the GENII-S code (Leigh et al., 1993), however, other pathway models may also be applicable for exposure assessments at YM. Pathways considered include (i) ingestion dose from contaminated animal products, crops, and drinking water; (ii) external dose from groundshine and airborne contaminants; and (iii) inhalation dose from resuspended material. The parameter values and ranges used to characterize these pathways are based to the extent possible on site-specific and site-relevant information (tables A1-5 in appendix A list parameter values used in their analyses). Local characteristics indicate current regional conditions near the site support a very limited number of critical

[1] Personal Communication: G. Wittmeyer, CNWRA, April 10, 1996.

group definitions. Specifically, a rancher/farmer group which uses groundwater for irrigation encompasses more potential exposure pathways than other groups and is likely to be the maximally exposed group for areas where farming is expected to occur. Results of Phase 2 of the NRC Iterative Performance Assessment (Wescott et al., 1995) and statements of the NAS committee support this perspective. Influential exposure pathways for most nuclides include direct deposition to crops ingested by humans and livestock and consumption of contaminated plant and animal products (LaPlante et al., 1995; 1996). Inclusion of these pathways in the rancher/farmer critical group helps ensure that the definition includes pathways expected to be important contributors to dose. The potential for disruptive events that can disperse contamination to other population centers (e.g., volcanic eruption) may require consideration of different pathways and potential critical groups.

4.2.1.4 Available Data

Data necessary for characterizing the lifestyles of this group have been documented in LaPlante et al. (1995) and Eisenberg (1996). In particular, chapter 2 of LaPlante et al. (1995) contains descriptions of local characteristics and data (used to define parameter values and distributions) obtained from numerous sources including the U.S. Census Bureau, the Nevada Agricultural Statistics Service, the Nevada Division of Water Resources, and the Department of Energy (DOE) [from site characterization work and Nevada Test Site (NTS) research]. Eisenberg (1996) summarizes information obtained from DOE and from an interview with a local resident while visiting the site. Available information indicates alfalfa hay farms[2] (TRW Environmental Safety Systems Inc., 1995), a large dairy farm[3] (TRW Environmental Safety Systems Inc., 1995), and home gardening activities (Nevada Division of Water Resources, 1995; Eisenberg, 1996) currently exist in the Amargosa Valley region. Beef cattle ranching exists in Nye County (U.S. Department of Commerce, 1989) and is known to be concentrated in areas north of the proposed site. However, it is estimated to exist to a small degree in areas south of the site such as Amargosa Valley and Pahrump (TRW Environmental Safety Systems Inc., 1995). Information from the Nye County Agricultural Extension Office (Mills, 1993) and Eisenberg (1996) suggests that home gardening of a variety of vegetables takes place in the region, but additional surveys of lifestyles may be necessary to confirm details such as the percentage of diet which comes from locally produced foods. Some analyses for the NTS suggest grazing of cattle occurs in the region (Breshears et al., 1989), while TRW data indicates grazing in areas south of YM (TRW Environmental Safety Systems Inc., 1995). Current DOE socioeconomic research products are unavailable because of recent budget constraints.[4] Earlier DOE studies relating to the NTS can be examined for additional information.

4.2.1.5 Data Needs

Some data necessary for defining locations for this group currently exist but require consolidation. For example, digital elevation data and topographic maps may provide land slope as a function of position. This could be important, as it is unlikely that a farm/ranch would be located on a plot of land with extreme slope. Similarly, information on the effects of elevation on crop production may aid the definition of potentially farmable areas. Aerial images may also provide locations of existing

---

[2] Personal Communication: Las Vegas Agricultural Extension Office, Nevada, January 27, 1995.

[3] Personal Communication: S. Marschke, Sanford Cohen and Associates, January 10, 1995.

[4] Personal Communication: W. Belke, NRC On-site Representative, Nevada, April 4, 1996.

farms. Figure 2-1 on page 2-3 of LaPlante et al. (1995) contains geographic population information (collected down to the census block level) for the YM area obtained from 1990 census data. This material can be reviewed along with more detailed population estimates from other sources to define areas where there is no current habitation [e.g., TRW Environmental Safety Systems Inc. (1995) has used utility records and other means of determining local population counts]. However, the desired spatial resolution may necessitate use of additional local surveys and socioeconomic data, existing aerial photographs, and discussions with local contacts. Some information on water table depths also exists but requires further compilation. Additional assumptions may be required to identify possible locations for this group based on the available information. Further documentation of expenses and likelihood of constructing deep wells for irrigation would provide enhanced justification for the present understanding that cost is prohibitive for this type of well drilling beyond certain depths (CNWRA work in progress).[5] Such information is important to determine the limits where this critical group can be located.

4.2.2 Local Resident Population

The presence of residential dwellings down-gradient from the potential repository site suggests habitants could be exposed regularly to contaminated groundwater under certain release and transport scenarios. Therefore, it is important to consider residents as members of a potential critical group. The residential critical group fulfills all of the general selection criteria. Two site-specific criteria were used to select this scenario.

- Water table depth does not limit well construction or pumping, given reasonable assumptions for residential living in arid zones (i.e., must be consistent with current practices).

- Topography must be conducive to residential development (e.g., land slope and other conditions must be suitable for development).

4.2.2.1 State of Knowledge—High

The state of knowledge regarding this critical group is high. Information applicable to defining the characteristics of this potential critical group is discussed in sections 4.2.2.2 through 4.2.2.5. The characteristics of this potential critical group can be defined using currently obtainable information.

4.2.2.2 Critical Group Definition and Siting

This potential critical group consists of individuals or families that live in the nearest habitable location to the plume maximum and use the water for drinking, household tasks, and home gardening. Lifestyles of this group are determined from examining similar groups near the YM site and in other arid locations throughout the country. Other approaches which could be used for locating a similar critical group are discussed in appendix B.

The critical group is located directly down-gradient from the repository, outside the repository footprint at the intersection of the location that can support this lifestyle and the maximum plume concentration for that area. Considering the long period of interest (e.g., possibly as long as 10^6 years), it is conceivable that as such residences move over time one might be placed at or near areas of highest

---

[5] Personal Communication: G. Wittmeyer, CNWRA, April 10, 1996.

concentration within the habitable zones near the potential site. One benefit to locating the group at the "habitable area plume maximum" for assessment purposes is to prevent arbitrary reduction in conservatism by the applicant (e.g., by defining critical group locations which are only in areas of low predicted radionuclide concentration). Selecting this location for the group is reasonably conservative and potentially much easier for the public to accept than using only currently occupied locations. Such assumptions are difficult to justify if the regulatory intent is to protect most members of the public now and in the future. Therefore, using the habitable area plume maximum location is more protective of potential local area residents.

4.2.2.3 Pertinent Exposure Pathways

This scenario is limited to the drinking water and (possibly) home gardening irrigation pathways because these are considered to be the primary contributors to dose, given present knowledge of residential living conditions and an undisturbed repository release scenario. A different set of pathways may be important for exposure scenarios involving disruptive events or human intrusions. Future work will need to determine the applicable exposure pathways for each disruptive event and human intrusion that is to be considered in the repository performance assessment.

4.2.2.4 Available Data

Information on local residents' activities regarding food sources and home gardening activities has been summarized by Eisenberg (1996). According to sources, a large proportion of residents' food supplies comes from sources external to the region, however, many residents have gardens where they grow small amounts of food for personal consumption, sale, or trade with other neighbors. More detailed information may be necessary to fully characterize this food supply. Currently, little information has been collected that can be used to determine characteristics that make areas desirable for residential settlement. Some data on water table depths are available (CNWRA work in progress)[6] which will be helpful in determining well depths that are cost-prohibitive for potential residents. General demographics of the regional population (down to an area the size of approximately one-fifth of Nye County) are available from the 1990 census data. This information includes age distributions, employment, income, marital status, and other standard demographic data. Information on smaller population groups in the area may be available, but has not been identified to date.

4.2.2.5 Data Needs

Further documentation of the costs and likelihood of constructing deep wells for residential use would allow an identification of areas that are cost-prohibitive for residential development (work is in progress on well depths, as previously noted). Furthermore, as discussed for the Amargosa rancher/farmer critical group, additional information is necessary to clarify the current lifestyles of residents in the YM area (e.g., are there any unique practices which place people at greater or lesser risk than expected?). As already noted, further identification of local food sources and consumption patterns is needed to more completely define ingestion pathways for local residents.

[6] Personal Communication: G. Wittmeyer, CNWRA, April 10, 1996.

5 GENERAL EXPOSURE SCENARIO EXAMPLES

The NAS committee recommended that exposure scenarios be defined using existing site characteristics to identify potential reference biospheres and critical groups in the local area. As an initial step, general conceptual models for exposure scenarios were determined which provide a framework for more detailed analysis and understanding of processes and characteristics. Available information on the characteristics of the YM region was used to define possible reference biospheres and critical groups in the previous sections of this report. Two examples of such scenarios are the Amargosa rancher/farmer and a local resident or small community. Both scenarios are based upon the same general conceptual model for release and transport of radionuclides which results in contamination of groundwater used by each critical group. For example, radioactive material is released from waste packages and is transported to the aquifer below the repository block where the flow of groundwater carries the material to an unspecified location down-gradient from which the critical group pumps the contaminated water to the surface using a water well. It is intended that potential critical groups will also be considered in the context of the pluvial biosphere, however, additional details of the pluvial biosphere need to be investigated before this can be done.

These examples represent the authors' understanding of reasonable scenarios to consider. They are not intended to preclude consideration of other potential scenarios which can be justified using the approach (e.g., selection criteria) discussed in this report. As new information and understanding are developed, these examples may be updated and new scenarios added. The potential exposure scenarios were chosen because they fulfill all of the general and site-specific selection criteria discussed in sections 3.2, 3.3, 4.2.1, and 4.2.2.

5.1 EXPOSURE SCENARIO 1—AMARGOSA RANCHER/FARMER

It is noted that gaseous release from the repository is not included in this scenario because (i) the most important radionuclide for gaseous release is probably ^{14}C (National Research Council, 1995), (ii) the recommended standard is for an individual dose (National Research Council, 1995), and (iii) available evidence indicates that ^{14}C is likely to be unimportant for individual dose (Wescott et al., 1995).

Biosphere: Current YM biosphere

Transport Pathway: Radionuclides enter the biosphere through contaminated well water used for irrigation and consumption

Critical Group: Amargosa rancher/farmer

State of Knowledge: High

5.2 EXPOSURE SCENARIO 2—LOCAL RESIDENT

Biosphere: Current YM biosphere

Transport Pathway: Radionuclides enter the biosphere through contaminated well water used for domestic purposes

21/39

Critical Group: Local resident/community

State of Knowledge: High

6 IMPLICATIONS FOR CONFORMING 10 CFR PART 60 TO THE EPA STANDARD

Following issuance of the EPA YM standard, an implementing rulemaking for 10 CFR Part 60 will be necessary. Because of anticipated flexibility in the EPA standards and NAS recommendations, a number of options are available to the NRC for developing this implementing rule. Section 6 outlines actions which the NRC should consider in preparing for review of the EPA standard and development of the implementing rule.

6.1 ADDITIONAL DEFINITIONS FOR 10 CFR PART 60

The following terms may need to be added to 10 CFR 60.2 (Definitions): average member of critical group, biosphere, critical group, exposure pathways, exposure scenario, homogeneous, and reference biosphere.

6.2 LEVEL OF DETAIL AND SCOPE

The following are options for the degree of specification of the reference biosphere(s), critical group(s), and exposure pathways in the regulation.

6.2.1 Option 1

Provide complete specification of exposure scenarios in one of two ways: (i) tabulate unit concentration pathway dose conversion factors (e.g., drinking water pathway, leafy vegetable pathway) or (ii) specify all numerical values of pathway, lifestyle, and other parameters as either point values or ranges.

If this option is selected, the NRC should provide defensible bases for all parameters during the public comment process. This option has the advantage of resolving issues prior to licensing, allowing public participation in the determination of assumptions, and removing modeling assumption issues from the licensing hearing. A disadvantage with this option is that the NRC will have to defend parameter choices in a public proceeding—a responsibility that will invite detailed scrutiny of assumptions and justifications and thus require commitment of additional time and resources by the NRC. Furthermore, the rulemaking will need to be inclusive of all critical groups under consideration (e.g., different groups may be defined for undisturbed and disruptive events scenarios) and thus will require sufficient time and resources to accomplish this level of completeness. Another difficulty with this approach is that additional information may become available after the rulemaking which could require modifications to the rule.

6.2.2 Option 2

Partially specify the exposure scenario(s) through definitions, criteria for selection of appropriate biospheres(s) and critical groups(s), and required pathways specified in the rule. Numerical parameterization of biosphere(s), critical group(s), and exposure pathways could be provided through a regulatory guide or by making selection and justification of these the responsibility of the applicant.

23/39

This approach allows a less resource-intensive NRC rulemaking, further exploration of issues by the NRC (outside of the rulemaking), and flexibility for the NRC to use the most current information at the time of licensing. However, issues regarding data and models would not be addressed in the rulemaking and would be open for litigation during licensing, potentially slowing down and complicating that process. This option may also be interpreted by some as not following the NAS recommendation that exposure scenario assumptions be determined through a rulemaking with full public participation.

7 REFERENCES

BIOMOVS II Working Group. 1994. An Interim Report on Reference Biospheres for Radioactive Waste Disposal. Technical Report 2. Swedish Radiation Protection Institute on behalf of BIOMOVS II Steering Committee. Stockholm, Sweden.

Breshears, D.D., T.B. Kirchner, M.D. Otis, and F.W. Whicker. 1989. Uncertainty in predictions of fallout radionuclides in foods and of subsequent ingestion. *Health Physics* 57(6): 943–953.

DeWispelare, A.R., L.T. Herren, M.P. Miklas, and R.T. Clemen. 1993. *Expert Elicitation of Future Climate in the Yucca Mountain Vicinity—Iterative Performance Assessment Phase 2.5*. CNWRA 93-016. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Eisenberg, N.A. 1996. Staff Visit to Amargosa Valley: Trip Report. Internal Memorandum to M. Federline, Acting Director, Division of Waste Management. Washington DC: Nuclear Regulatory Commission.

International Council on Radiation Protection. 1977. *Recommendations of the International Council on Radiation Protection*. ICRP Pub. 26. Annals of the ICRP: 1(3).

International Council on Radiation Protection. 1985. *Principles of Monitoring for the Radiation Protection of the Population*. ICRP Pub. 43. Annals of the ICRP: 15(1).

LaPlante, P.A., S.J. Maheras, and M.S. Jarzemba. 1995. *Initial Analysis of Selected Site-Specific Dose Assessment Parameters and Exposure Pathways Applicable to a Groundwater Release Scenario at Yucca Mountain*. CNWRA 95-018. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

LaPlante, P.A., S.J. Maheras, and M.S. Jarzemba. 1996. Preliminary Analysis of Important Site-Specific Dose Assessment Parameters and Exposure Pathways Applicable to a Groundwater Release Scenario at Yucca Mountain. *Scientific Basis for Nuclear Waste Management XIX*. W.M. Murphy and D.A. Knecht, eds. Pittsburgh, PA: Materials Research Society: Symposium Proceedings 412: 897–904.

Leigh, C.D., B.M. Thompson, J.E. Campbell, et al. 1993. *User's Guide for GENII-S: A Code for Statistical and Deterministic Simulation of Radiation Doses to Humans from Radionuclides in the Environment*. SAND 91-0561. Albuquerque, NM: Sandia National Laboratories.

Mills, L. 1993. *Beginning Desert Gardening*. Reno, NV: University of Nevada Cooperative Extension.

National Research Council. 1995. *Technical Bases for Yucca Mountain Standards*. Washington, DC: National Academy Press.

Nevada Division of Water Resources. 1995. Preliminary Summary of Ground Water Pumpage Inventory for Amargosa Valley Basin No. 230 from 1989 through 1993. Carson City, NV: Nevada Division of Water Resources. Unpublished.

25/39

Smith, G.M., B.M. Watkins, and R.H. Little. 1996. *Biosphere FEP List Development Specific to Yucca Mountain—Draft Report*. IE4288-2. Oxfordshire, United Kingdom: QuantiSci Inc.

Spaulding, G.W. 1985. *Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South Central Nevada*. Professional Paper 1329. Washington DC: U.S. Geological Survey.

TRW Environmental Safety Systems Inc. 1995. *Yucca Mountain Site Characterization Project Summary of Socioeconomic Data Analyses Conducted in Support of the Radiological Monitoring Program During Calendar Year 1994*. WBS 1.2.13.6. Las Vegas, NV: TRW Environmental Safety Systems Inc.

U.S. Congress. 1992. *Energy Policy Act of 1992*. Public Law No. 102-486. Washington, DC: U.S. Congress.

U.S. Department of Commerce. 1989. *Census of Agriculture, Volume 1: Geographic Area Series, Part 28: Nevada State and County Data*. AC87-A-28. Washington DC: U.S. Department of Commerce.

U.S. Department of Energy. 1988. *Site Characterization Plan: Yucca Mountain Site, Nevada Research and Development Area, Nevada*. DOE/RW-0199. Vols. 2 (Chapter 5) and 5. Washington DC: U.S. Department of Energy.

Wescott, R.G., M.P. Lee, N.A. Eisenberg, T.J. McCartin, and R.G. Baca, eds. 1995. *NRC Iterative Performance Assessment Phase 2*. NUREG-1464. Washington, DC: Nuclear Regulatory Commission.

Wilson, M.L., J.H. Gauthier, R.W. Barnard et al. 1994. *Total System Performance Assessment for Yucca Mountain—SNL Second Iteration (TSPA-1993)*. SAND 93-2675. Albuquerque, NM: Sandia National Laboratories.

26/39

APPENDIX A

EXAMPLE PARAMETER VALUES FOR AMARGOSA RANCHER/FARMER CRITICAL GROUP

27/39

Tables A-1 through A-5 list parameters, values, ranges, and sources of the data obtained from a preliminary investigation of site-specific parameters (LaPlante et al., 1995) which included lifestyle characteristics of the Amargosa Desert rancher/farmer. Some parameter values were derived from information provided by the source documents. Full descriptions of this information and complete bibliographic references are provided in LaPlante et al. (1995).

Table A-1. Parameters and values used in LaPlante et al. (1995) that are not specific to one pathway

Parameter	Distribution Type	Values	Source	Site Specific
Population Scale Factor	Constant	1.0	GENII-S	N
Human Dose Scale Factor	Constant	1.0	GENII-S	N
Soil Plow Depth	Constant	0.15 m	GENII-S	N
Surface Areal Soil Density	Uniform	Range: [180, 270] kg/m^2 (to 15 cm depth)	English and Nakamura (1989); etc.	Y
Upper Soil Root Fraction	Constant	1.0	Conservative Assumption	N/A
Soil Ingestion Rate	Constant	410 mg/d	GENII-S	N
Concentration Ratios	Constant	See LaPlante et al. (1995), Table 2-5, p. 2-10	International Atomic Energy Agency (1994)	N
Soil/Plant Scale Factor	Lognormal	GM=1 GSD= 2 CI: [0.26, 3.9]	International Union of Radioecologists (1989)	N
Mass Load	Constant	5.50E-5 g/m^3	Maheras et al. (1994)	N
Crop Resuspension Factor	Lognormal	GM=1.0E-5 GSD= 2.5 CI: [1.66E-6,6.03E-5] m^{-1}	Otis (1983)	Y
Crop Interception Fraction	Triangular	Median= 0.4 Minimum= 0.06 Maximum= 1.0	Anspaugh (1987)	Y

GM = geometric mean
GSD = geometric standard deviation
CI = 95% confidence interval for distribution

Table A-2. Parameters and values used in LaPlante et al. (1995) for the drinking water ingestion pathway

Parameter	Distribution Type	Values	Source	Site Specific
Drinking Water Consumption Rate	Lognormal	GM = 349 L/yr GSD= 1.78 CI: [113, 10.81] L/yr	Roseberry and Burmaster (1992)	N

GM = geometric mean
GSD = geometric standard deviation
CI = 95% confidence interval for distribution

Table A-3. Parameters and values used in LaPlante et al. (1995) for the animal product ingestion pathway

Parameter	Distribution Type	Value	Source	Site Specific
Beef/Milk Transfer Coefficients	Constant	See LaPlante et al. (1995), Table 2-5, p. 2-10	International Atomic Energy Agency (1994)	N
Animal Uptake Scale Factor	Lognormal	GM=1 GSD= 2 CI: [0.26, 3.9]	International Union of Radioecologists (1989)	N
Beef-Human Consumption Rate	Lognormal	GM= 59 kg/yr GSD= 1.65 CI: [22.1, 157] kg/yr	Kennedy and Strenge (1992); Hoffman et al. (1982)	N
Milk-Human Consumption Rate	Lognormal	GM= 100 L/yr GSD= 2.23 CI: [20.8, 482] L/yr	Kennedy and Strenge (1992); Hoffman et al. (1982)	N
Beef-Forage Growing Time	Uniform	Range: [37, 62] d	Stichler (1991); Breshears et al. (1989)	Y
Milk-Forage Growing Time	Uniform	Range: [37, 62] d	Stichler (1991); Breshears et al. (1989)	Y
Beef-Forage Yield	Uniform	Range: [0.34, 1.23] kg/m^2	Nevada Agricultural Statistics Service (1988)	Y
Milk-Forage Yield	Uniform	Range: [0.34, 1.23] kg/m^2	Nevada Agricultural Statistics Service (1988)	Y
Beef-Forage Irrigation Rate	Empirical	See LaPlante et al. (1995) p. 2-13	Nevada Division of Water Resources (1995)	Y
Milk-Forage Irrigation Rate	Empirical	See LaPlante et al. (1995) p. 2-13	Nevada Division of Water Resources (1995)	Y

Table A-3. (cont'd)

Parameter	Distribution Type	Values	Sources	Site Specific
Beef-Forage Irrigation Time	Uniform	Range: [3, 8] mo/yr	Mills (1993)	Y
Milk-Forage Irrigation Time	Uniform	Range: [3, 8] mo/yr	Mills (1993)	Y
Beef Holdup Time	Constant	20 d	Kennedy and Strenge (1992)	N
Milk Holdup Time	Constant	1 d	Kennedy and Strenge (1992)	N
Beef-Dietary Contaminated Water Fraction	Constant	1.0	Conservative Assumption	N/A
Milk-Dietary Contaminated Water Fraction	Constant	1.0	Conservative Assumption	N/A
Beef-Dietary Fresh Forage Fraction	Normal	Mean= 0.55 Std. Dev.= 0.13 CI: [0.30, 0.82]	Breshears et al. (1989)	Y
Milk-Dietary Fresh Forage Fraction	Normal	Mean= 0.55 Std. Dev.= 0.13 CI: [0.30, 0.82]	Breshears et al. (1989)	Y

GM = geometric mean
GSD = geometric standard deviation
CI = 95% confidence interval for distribution

Table A-4. Parameters and values used in LaPlante et al. (1995) for the terrestrial crop ingestion pathway

Parameter	Distribution Type	Values	Sources	Site Specific
Grain Yield	Uniform	Range: [0.471, 0.605] kg/m^2	Nevada Agricultural Statistics Service (1988)	Y
Leafy Vegetable Irrigation Rate	Empirical	See LaPlante et al. (1995) p. 2-13	Nevada Division of Water Resources (1995)	Y
Root Vegetable Irrigation Rate	Empirical	See LaPlante et al. (1995) p. 2-13	Nevada Division of Water Resources (1995)	Y
Fruit Vegetable Irrigation Rate	Empirical	See LaPlante et al. (1995) p. 2-13	Nevada Division of Water Resources (1995)	Y
Grain Vegetable Irrigation Rate	Empirical	See LaPlante et al. (1995) p. 2-13	Nevada Division of Water Resources (1995)	Y
Leafy Vegetable Irrigation Time	Uniform	Range: [3, 8] mo/yr	Mills (1993)	Y
Root Vegetable Irrigation Time	Uniform	Range: [2, 8] mo/yr	Mills (1993)	Y
Fruit Irrigation Time	Uniform	Range: [2, 3] mo/yr	Mills (1993)	Y
Grain Irrigation Time	Uniform	Range: [6, 8] mo/yr	English and Nakamura (1989)	Y
Leafy Vegetable Holdup Time	Constant	1 d	Kennedy and Strenge (1992)	N
Root Vegetable Holdup Time	Constant	14 d	Kennedy and Strenge (1992)	N
Fruit Holdup Time	Constant	14 d	Kennedy and Strenge (1992)	N
Grain Holdup Time	Constant	14 d	Kennedy and Strenge (1992)	N

Table A-5. Parameters and values used in LaPlante et al. (1995) for the external/inhalation exposure pathway

Parameter	Distribution Type	Values	Source	Site Specific
Home Irrigation Rate	Uniform	Range: [26, 84] in/yr	Mills (1993)	Y
Home Irrigation Duration	Uniform	Range: [6, 12] mo/yr	Mills (1993)	Y
Chronic Plume Exposure Time	Triangular	Median= 7116 hr/yr Minimum= 5548 hr/yr Maximum= 7117 hr/yr	NRC (1995); Wiley et al. (1991); etc.	Y
Inhalation Exposure Time	Triangular	Median= 7116 hr/yr Minimum= 5548 hr/yr Maximum= 7117 hr/yr	NRC (1995); Wiley et al. (1991); etc.	Y
Soil Exposure Time	Triangular	Median= 7116 hr/yr Minimum= 5548 hr/yr Maximum= 7117 hr/yr	NRC (1995); Wiley et al. (1991); etc.	Y

34/39

Sources for Tables A-1 through A-5: APPENDIX A

Anspaugh, L.R. 1987. *Retention by Vegetation of Radionuclides Deposited in Rainfall—A Literature Summary*. UCRL-53810. Livermore, CA: Lawrence Livermore National Laboratory.

Anspaugh, L.R., J.H. Shinn, P.L. Phelps, and N.C. Kennedy. 1975. Resuspension and redistribution of plutonium in soils. *Health Physics* 29: 571–582.

Breshears, D.D., T.B. Kirchner, M.D. Otis, and F.W. Whicker. 1989. Uncertainty in predictions of fallout radionuclides in foods and of subsequent ingestion. *Health Physics* 57(6): 943–953.

English, M., and B. Nakamura. 1989. Effects of deficit irrigation and irrigation frequency on wheat yields. *Journal of Irrigation and Drainage Engineering* 115(2): 173–184.

Hoffman, F.O., R.H. Gardner, and K.F. Eckerman. 1982. *Variability in Dose Estimates Associated with the Food Chain Transport and Ingestion of Selected Radionuclides*. NUREG/CR-2612. Oak Ridge, TN: Oak Ridge National Laboratory.

International Atomic Energy Agency. 1994. *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments*. Technical Report Series No 364. Vienna, Austria: International Atomic Energy Agency.

International Union of Radioecologists. 1989. *Sixth Report of the Working Group on Soil-to-Plant Transfer Factors*. Biltoven, The Netherlands: RIVM.

Kennedy, W.E., and D.L. Strenge. 1992. *Residual Radioactive Contamination From Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*. NUREG/CR-5512, Vol. 1. Richland, WA: Pacific Northwest Laboratory.

Maheras S.J., A.S. Rood, S.O. Magnuson, M.E. Sussman, and R.N. Bhatt. 1994. *Radioactive Waste Management Complex Low-Level Waste Radiological Performance Assessment*. EGG-WM-8773. Idaho Falls, ID: Idaho National Engineering Laboratory.

Mills, L. 1993. *Beginning Desert Gardening*. Reno, NV: University of Nevada Cooperative Extension.

Nevada Division of Water Resources. 1995. *Preliminary Special Hydrographic Abstract for Valley Basin No. 230 from the Nevada Division of Water Resources Water Rights Database*. Carson City, NV: Nevada Division of Water Resources. (Unpublished).

Nevada Agricultural Statistics Service. 1988. *Nevada Agricultural Statistics: 1, 1987-88*. Reno, NV: Nevada Agricultural Statistics Service.

Nuclear Regulatory Commission 1995. *NRC Iterative Performance Assessment Phase 2: Development of Capabilities for Review of a Performance Assessment for a High-Level Waste Repository*. R.G. Wescott, M.P. Lee, T.J. McCartin, N.A. Eisenberg, and R.G. Baca et al. eds. NUREG-1464. Washington, DC: Nuclear Regulatory Commission.

Otis, M.D. 1983. *Sensitivity and Uncertainty Analysis of the PATHWAY Radionuclide Transport Model*. Ph.D. Dissertation. Fort Collins, CO: Colorado State University.

Roseberry, A.M., and D.E. Burmaster. 1992. Lognormal distributions for water intake by children. *Risk Analysis* 12: 99–104.

Stichler, C. 1991. *Texas Alfalfa Production*. B-5017. College Station, TX: Texas Agricultural Extension Service.

Wiley, J.A., J.P. Robinson, T. Piazza, K. Garrett, K. Cirksena, Y.T. Cheng, and K.G. Martin. 1991. *Activity Patterns of California Residents*. Sacramento, CA: California Air Resources Board: Research Division.

APPENDIX B

CONSIDERATIONS FOR APPROACHES FOR DEFINING CRITICAL GROUP LOCATION

The definition of critical group implies the group is located where the highest plume concentration exists within the footprint of an area suitable for habitation (e.g., favorable local site conditions such as soil type, water table depth, and topography). Uncertainty regarding which areas of the YM region are potentially habitable and the possibility that most areas might be habitable, suggests that a clearer delineation of criteria to determine critical group locations might be useful. If the NRC plans to define exposure scenarios (reference biospheres and critical groups) in the implementing regulation, it may be necessary to justify the approach and bases for selecting locations. The approach must address the NRC mandate to protect public health and safety, however, it should also provide a regulatory framework that will reject a poor site but not arbitrarily disqualify a good one. Options for defining locations have been suggested in staff discussions. This appendix summarizes issues pertaining to these options. The intent is to provide background to facilitate thinking and future discussions among the staff. No selections are made, although some are clearly more consistent with the exposure scenario selection approach discussed in the body of this report.

Approach A: Only Use Existing Conditions—Under this approach, lifestyles and locations of critical groups are defined by existing conditions of the region surrounding the site. Predictions of future human actions (such as new developments of towns and cities) are avoided on the basis they are too speculative to provide useful information for licensing. This approach might include a public recognition that the approach will protect the majority of people currently in the region but not every individual who may live there in the future.

The bases for relying on existing conditions for definition of critical group locations include (i) these conditions are presently knowable and quantifiable using scientific analyses, thereby providing a basis for understanding locations of people in the region (predictions of specific future locations and human behaviors are unbounded and unknowable and thus are no less arbitrary nor do they provide a more reliable basis for exposure assessments); (ii) the approach limits options to a manageable level and simplifies efforts to define critical group locations; (iii) a clear basis for both selecting and excluding critical group options is provided with this approach; (iv) if accepted in a rulemaking, the approach could limit licensing contentions that a wide range of possible futures have not been considered; and (v) this approach avoids consideration of excessively speculative scenarios which might disqualify any waste site.

Potential problems with use of existing conditions alone include criticism that future generations living closer to the site (or to areas of higher estimated plume concentration) are not protected and that existing conditions include institutional controls that currently exclude large tracts of land near the site from being inhabited. The latter conflicts with the NRC historical intent to avoid reliance on institutional controls beyond 100-200 yr. Furthermore, the existence of institutional controls limits the usefulness of existing conditions to provide information on the desirability of land near the site for local residences and communities.

Approach B: Use Existing Conditions with Analog Data—This approach includes reliance on existing conditions for determining possible lifestyles supplemented by cautious and reasonable projections of future critical group locations based upon currently obtainable information from the site and/or from similar arid regions. This is similar to approach A with the added flexibility to consider data for analogous human populations with lifestyles similar to those that currently live in the areas surrounding the site.

The bases for approach A are applicable here, however, approach B allows assumptions about the location of potential human populations (e.g., where people might put houses or farms). This approach aims to protect a wider range of potential future inhabitants of the region, thereby reducing the potential for criticism that it is not inclusive of future generations.

A potential problem with expanding the possible options for critical group locations is that it may increase debate over the locations that are possible. This approach would require additional effort to document and justify assumptions that are considered reasonable and to exclude those judged to be unduly speculative.

Approach C: Low Probability Exclusion—In this approach, an exclusionary criterion is used that states unlikely critical group locations and lifestyles will not be considered in determining the critical group.

This approach implies that it is not reasonable to determine compliance based on postulated events which are not likely to occur. A scenario such as a close-in resident who drills into the plume maximum might be an example of such a low probability event. The development of a small town in close proximity to the site with a well drilled into the plume maximum may be a low probability given the many options available for local development areas, some of which may be more preferable than YM. This approach may be one way to determine when a scenario departs from protection of the majority and focuses on the extreme habits of a few individuals.

A difficulty with this approach is that it requires determination of a low probability cutoff point for excluding locations of critical groups. It also requires justification of the probability determined or assumed for an action (e.g., putting a house at a given location). Thus, the approach is susceptible to many differing opinions on the likelihood of such future actions.

Approach D: Expansion of Geologic Repository Footprint Area—This approach defines the geologic environment surrounding the repository block as part of the disposal system. The boundaries of this area are based on a set of restrictions (or criteria) defined by the NRC which ensure the area is as small as possible yet provides assurance that contamination and exposures outside the area are sufficiently low to protect public health and safety. For example, these restrictions might be based on (i) site characteristics known to restrict groundwater flow, transport, and radionuclide concentration to a definable area; (ii) land withdrawal size; or (iii) socioeconomic considerations. The area boundary is determined independent of a site's ability to comply with regulations. Once this area is established, performance assessment calculations would be conducted to determine if exposures outside the boundary meet applicable standards.

The approach accepts that present day regulations cannot restrict future human activity inside the area nor provide assurance of protection within this area. Although application of institutional controls and record keeping would provide added confidence that future generations would be informed of dangers within the area, no credit would be given for such protection due to uncertainties in maintaining these systems over long time periods. With this approach society would accept an area of no protection judging it to be sufficiently small in area and producing sufficiently small additional risk that the benefits of siting a facility outweigh the costs. The location of a critical group would be defined as the point beyond the boundary of this repository area that intersects the maximum plume concentration determined by release and transport modeling. In considering the expanded area as part of the waste disposal system, intrusive human activities in this area would be addressed by the stylized human intrusion calculation (as recommended by the NAS).

A similar concept, defining a 5 km controlled area boundary, has been applied by EPA in 40 CFR Part 191 for the Waste Isolation Pilot Plant (WIPP) site thereby setting a regulatory precedent. This approach is consistent with requests by the State of Nevada that the same level of protection used at WIPP be applied to YM. The approach clearly delineates a region where human activities do not need to be considered thereby limiting speculation about potential future human activities near the site which could lead to high exposures. This approach also explicitly identifies the area of land which is projected to be a potential hazard to future generations.

A difficulty of this approach is that it could be viewed as establishing an exclusion zone. The NAS has stated there is no technical basis for setting exclusion zones outside the repository footprint. Their rationale is based on the notion that institutional controls cannot be maintained for long time periods. An important difference is that the expanded footprint approach does not intend to protect individuals within the boundary of the expanded footprint area. While the NAS recommends a stylized calculation of the effects of human intrusions into the footprint area, it provides no specific rationale for why it is justifiable to set a human intrusion zone at the footprint boundary but not beyond. The rationale given for the stylized human intrusion restriction states that the calculation will show the resiliency of the repository system to the effects of an intrusion (i.e., preferential pathways). However, if the geologic barriers outside the footprint are considered part of the repository system, the same rationale could be used to define a larger area for the stylized calculation. Nonetheless, a primary difficulty remains in determining the restrictions that define the area boundary. Since WIPP regulations were designated for a different facility location, conditions might not exist at the YM site that would allow a defensible definition of such an area.

Approach E: Use Maximum Plume Concentration—This approach supplants the need to determine specific critical group locations by assuming that media source concentrations (e.g., groundwater and air) where the group exists are equivalent to the maximum plume concentrations of important radionuclides determined from transport analyses outside the repository footprint over the period of regulatory interest. Such an approach is implemented with the underlying philosophy that the dose analysis results are merely a conservative regulatory tool for ensuring health and safety and not an accurate prediction of actual anticipated conditions. The approach has the advantage of ensuring that no individuals are likely to receive higher exposures and therefore is protective of all potentially exposed individuals. Furthermore, this approach is easy to understand, it eliminates the possibly time consuming need for estimating locations of potential future populations, and is consistent with past risk assessment practices for conducting bounding analyses. Primary disadvantages include that the approach is very conservative, does not model actual expected conditions at the site, and thus, has a greater likelihood of arbitrarily disqualifying a good site.