EXECUTIVE SUMMARY

ES.1 INTRODUCTION AND BACKGROUND

The U.S. Environmental Protection Agency (EPA) is responsible for developing and issuing environmental standards and criteria to ensure that public health and the environment are adequately protected from potential radiation impacts from waste stored or disposed in Yucca Mountain, Nevada. The Yucca Mountain site is located in Nye County, approximately 150 kilometers (90 miles) northwest of Las Vegas, Nevada, and on the southwestern boundary of the Nevada Test Site. Yucca Mountain is an irregularly shaped elevated land mass six to 10 km wide (four to six miles) and about 40 km (25 miles) long. A waste repository would be about 300 meters (one thousand feet) below the crest of Yucca Mountain and about the same distance above the water table under the mountain.

The EPA is promulgating, in 40 CFR Part 197, site-specific environmental standards to protect the public from releases of radioactive materials disposed of or stored in the potential repository to be constructed at Yucca Mountain.[1] These standards provide the basic framework to control the long-term storage and disposal of three types of radioactive waste:

- Spent nuclear fuel (SNF), if disposed of without reprocessing
- High-level radioactive waste (HLW) from the reprocessing of spent nuclear fuel
- Other radioactive materials that may be placed in the potential repository

The other radioactive materials that could be disposed of in the Yucca Mountain repository include highly radioactive low-level waste, known as greater-than-Class-C waste, and excess plutonium resulting from the dismantlement of nuclear weapons. However, the plans for placement of these materials are uncertain and therefore, for the purpose of the present rulemaking, the information presented in this Background Information Document (BID) is limited to spent nuclear fuel and high-level radioactive waste.

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[1] It is important to note that no decision has been made regarding the acceptability of Yucca Mountain for storage or disposal. However, for the purposes of this document, the description of Yucca Mountain as “potential” will generally not be used but is intended.

ES.1.1 Purpose And Scope of The Background Information Document

The BID presents the technical information used by EPA to understand the characteristics of the Yucca Mountain site and to develop its rule, 40 CFR Part 197. Most of the technical information discussed in the BID is derived from investigations sponsored by the Department of Energy (DOE). However, where appropriate, information from other sources, such as the Electric Power Research Institute (EPRI) and U.S. Nuclear Regulatory Commission (NRC), and Nevada state and local agencies is presented to supplement the DOE data base, to fill data gaps, and to illustrate alternative conceptualizations of geologic processes and engineered barrier performance.

The scope of the BID encompasses the conceptual framework employed by the Agency for assessing radiation exposures and associated health risks. In general terms, this assessment discusses the radioactive source term characterization, movement of radionuclides from the repository at Yucca Mountain through the appropriate environmental exposure pathways, and the estimates of potential doses to members of a representative group of people living in the region around the repository site. It is not intended to be a technical critique of the investigations conducted by DOE and other parties. Nor is it a regulatory compliance or criteria document. The BID is simply a summary of the technical information considered by EPA in developing the rationale for, and specifics in, 40 CFR Part 197.

This executive summary highlights key chapters of the BID, particularly information concerning efforts in other nations to develop deep geological repositories (Chapter 3); current efforts to develop a repository at Yucca Mountain (Chapter 4); the types and inventories of waste likely to be disposed in Yucca Mountain (Chapter 5); geologic and hydrogeologic characteristics of the repository site and anticipated repository performance (Chapter 7); and pathways for human exposure to radionuclides potentially released from the site (Chapter 8). The reader is referred to the full text of the BID for information regarding ways in which radiological dose and risk are estimated (Chapter 6); potential exposure scenarios and compliance assessment issues for the Yucca Mountain repository (Chapter 9); and the comparative radiological risks associated with deep geological disposal and surface storage of spent nuclear fuel (Chapter 10).

ES.1.2 EPA's Regulatory Authority For The Rulemaking

The standards governing environmental releases from the potential Yucca Mountain repository have been developed pursuant to the Agency's responsibilities under the Energy Policy Act (EnPA) of 1992 (Public Law 102-486). Section 801 of this Act directed EPA to promulgate standards to ensure protection of public health from releases of radioactive material in a deep geologic repository to be built in Yucca Mountain by setting standards to protect individual members of the public. The EnPA also required EPA to contract with the National Academy of Sciences (NAS) to advise the Agency on the technical bases for the Yucca Mountain standards. The EnPA directed that these standards will apply only to the Yucca Mountain site and are to be based upon and consistent with the findings and recommendations of the NAS:

- *...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*.

ES.1.3 The National Academy of Sciences Recommendations

In the EnPA, the Congress asked the Academy to address three issues in particular:

- *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 of breaching the repository's engineered or geologic barriers or increasing exposure of individual members of the public to radiation beyond allowable limits; and*

- *Whether it will be 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*.

To address these questions, the Academy assembled a committee of 15 persons representing a range of scientific expertise and perspectives. The committee conducted a series of five technical meetings at which more than 50 nationally and internationally known scientists and engineers were invited to participate. In addition, the committee received information from the NRC, DOE, EPA, Nevada State and county agencies, and private organizations, such as the Electric Power Research Institute.

The committee's conclusions and recommendations are contained in its final report, entitled *Technical Bases for Yucca Mountain Standards*, which was issued on August 1, 1995. In this report, the committee addressed the key issues posed by Congress and reached the following conclusions:

- *...an individual-risk standard would protect public health, given the particular characteristics of the site, provided that policy makers and the public are prepared to accept that very low radiation doses pose a negligibly small risk.*

- *...it is not reasonable to assume that a system for post-closure oversight of the repository can be developed, based on active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits.*

- *...it is not possible to make scientifically supportable predictions of the probability that a repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years.*

In addition, the report offered the Agency several general recommendations as to the approach EPA should take in developing 40 CFR Part 197. Specifically, the NAS recommended:

- *...the use of a standard that sets a limit on the risk to individuals of adverse health effects from releases from the repository.*

- *...that compliance with the standard be measured at the time of peak risk, whenever it occurs. (Within the limits imposed by the long-term stability of the geologic environment, which is on the order of one million years.)*

- *...that the consequences of an intrusion be calculated to assess the resilience of the repository to intrusion.*

The EPA does not believe it is bound to adopt all of the positions advanced by the NAS in the Yucca Mountain rulemaking. The Agency has used the NAS report as the foundational starting point for the rulemaking. The Agency has carefully considered the recommendations of the NAS, but the role of the NAS recommendations is not to replace the rulemaking authority of the

Agency. The Agency will tend to accord greatest deference to the judgements of NAS about issues having a strong scientific component, the area where NAS has its greatest expertise. The EPA will reach final determinations that are congruent with the NAS analysis whenever it can do so without departing from the Congressional delegation of authority to promulgate, by rule, health and safety standards for protection of the public. The Agency believes that such determinations require the consideration of public comments and the Agency's own expertise and discretion.

ES.1.4 Prior Agency Action

In December 1976, EPA announced its intent to develop environmental radiation protection criteria for radioactive waste to ensure the protection of public health and the general environment. These efforts resulted in a series of radioactive waste disposal workshops, held in 1977 and 1978. Based on issues raised during workshop deliberations, EPA published a *Federal Register* notice on November 15, 1978 of intent to propose criteria for radioactive wastes and to solicit public comments on possible recommendations for Federal Radiation Guidance. In March 1981, EPA withdrew the proposed "Criteria for Radioactive Wastes" because it considered the implementation of generic disposal guidance too complex given the many different types of radioactive waste.

In 1982, Congress enacted the Nuclear Waste Policy Act (NWPA), which established the current national program for the disposal of SNF and HLW. The Act assigned to DOE the responsibility of siting, building, and operating an underground geologic repository for the disposal of these wastes and directed the EPA to "promulgate generally applicable standards for the protection of the general environment from off-site releases from radioactive material in repositories." In that same year, under the authority of the Atomic Energy Act (AEA), the EPA proposed a set of standards under 40 CFR Part 191, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." After a number of public hearings and comment periods, the EPA issued the final rule under 40 CFR Part 191 on August 15, 1985. Sections of this rulemaking were remanded by a Federal Court in 1987 and repromulgated by EPA in 1993.

In December 1987, Congress enacted the Nuclear Waste Policy Amendments Act (NWPAA). The 1987 Amendments Act redirected the nation's nuclear waste program to evaluate the suitability of the Yucca Mountain site as the location for the first SNF and HLW repository. Activities at all other potential sites were to be phased out.

In October 1992, the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA) was enacted. While reinstating certain sections of the Agency's 1985 disposal standards, the Act had the effect of exempting the Yucca Mountain site from these generic disposal standards. However, also in October 1992, the EnPA directed the EPA to promulgate site-specific radiation protection standards for the Yucca Mountain disposal system.

ES.2 CURRENT U.S. PROGRAMS FOR YUCCA MOUNTAIN

The DOE, NRC, and EPA each have legislatively defined roles in the management and disposal of SNF and HLW at the proposed Yucca Mountain disposal site. As stated in the NWPA, DOE is responsible for developing, constructing, and operating repositories for disposal of these wastes. The NRC has responsibility to license the repository and related facilities, and EPA is to promulgate radiation protection standards which the NRC is to adopt as the basis for its licensing actions. Affected state and local governments and Native American tribes have an oversight role in the program. The NWPAA designated the Yucca Mountain site in Nevada as the only site to be evaluated by DOE as a potential location for disposal of SNF and HLW, and established the Nuclear Waste Technical Review Board (NWTRB) to provide oversight of the DOE program.

ES.2.1 The Department of Energy

The DOE's Office of Civilian Radioactive Waste Management (OCRWM) was established by Congress in the NWPA specifically to provide management for the disposal of SNF from commercial nuclear power reactors. Under a 1985 Presidential Executive Order, the repository established by DOE is also to be used for disposal of HLW from DOE operations. The OCRWM charter includes responsibility for receipt of SNF from reactors at the reactor sites; interim storage of received SNF, as necessary, prior to disposal; transport of SNF to the site(s) for interim storage and disposal; and siting, design, licensing, and operation of a central interim storage facility and disposal facilities. In addition to its work at Yucca Mountain, DOE has developed alternative designs for a central interim storage facility (known historically as a Monitored Retrievable Storage (MRS) facility), but, as of March 2000, the Department has not established a site for such a facility.

In accord with the NWPAA, DOE has been evaluating Yucca Mountain as the disposal site for SNF and HLW. Characterization of the site is proceeding with surface-based and sub-surface activities. Design concepts for the engineered features of the repository are being developed. Recent DOE activities produced the Viability Assessment (VA) report, which is a Congressionally mandated appraisal of the viability of the Yucca Mountain project for geologic disposal of nuclear wastes. The VA report contains:

- A site description and a design for engineered features of the repository and waste package
- A Total System Performance Assessment, based on available data, describing the probable safety performance of the VA reference design (TSPA-VA)
- A plan and cost estimate for completing the license application (LA) to NRC for repository construction
- Cost estimates for constructing and operating the repository

The VA report was published in December 1998. It was followed by a draft environmental impact statement (DEIS) in 1999 and a final EIS is planned for late in 2000. The site-suitability recommendation, required by the NWPA, is planned to be submitted to the President in 2001 and a License Application (LA) would be submitted to NRC in 2002 if the site is found suitable for disposal. Significant recent accomplishments of the DOE program include:

- Completion of the Exploratory Studies Facility (ESF) and Cross Drift tunnels for gathering experimental data at the proposed repository horizon
- Initiation of various types of experiments in the tunnel alcoves and niches
- Completion of the Viability Assessment in December 1998
- Issuance of the DEIS in August 1999
- Selection of an improved repository design, EDA II, based on TSPA-VA results

ES.2.2 The Nuclear Regulatory Commission

The NRC is responsible for licensing and regulating the receipt and possession of SNF and HLW, at privately owned facilities and at certain facilities managed by DOE. This licensing responsibility includes the waste management and disposal facilities at Yucca Mountain. The NRC currently licenses temporary storage facilities at reactor sites, as well as commercial storage facilities at West Valley, New York, and Morris, Illinois.

NRC licensing of a repository at Yucca Mountain will be accomplished through review of a License Application (LA) submitted by DOE after completion of site approval procedures set forth in the NWPA. If the LA is found acceptable for review, NRC would review it to determine if there is reasonable assurance of compliance with regulatory standards. If expectation of compliance is established, DOE will be authorized to construct the repository. Subsequently, the LA will be amended to seek approval to receive and emplace wastes for disposal. Confirmatory testing is expected to continue throughout construction and disposal operations. After disposal is completed (a process expected to span about 50 years), the LA would be amended to request closure of the repository. After closure is authorized, post-closure monitoring would be expected to be required.

The NWPA requires both EPA and NRC to publish radiation-protection standards and regulations, for the storage and disposal of HLW. As previously noted, the EnPA directed the EPA to develop radiation protection standards for the Yucca Mountain site and for the NRC to develop implementing regulations that conform to the EPA's Yucca Mountain standards. The NRC's proposed (February 1999) 10 CFR Part 63 regulations require use of multiple barriers (natural and engineered) to achive compliance with regulatory standards, and implement the Commission's principles of defense-in-depth and risk-informed regulation. The proposed rule addresses licensing procedures, radiation exposure standards, criteria for public participation, records and reporting, monitoring and testing programs, performance confirmation, quality assurance, personnel training and certification, and emergency planning.

The NRC's proposed 10 CFR Part 63 regulations would be modified as necessary to conform to EPA's 40 CFR Part 197 standards after they are established.

ES.2.3 Nuclear Waste Technical Review Board

The NWPAA established the Nuclear Waste Technical Review Board comprised of eleven members recommended by the NAS and appointed by the President. These individuals are experts in the fields of science, engineering, or environmental sciences and represent a broad range of scientific and engineering disciplines, including hydrology, underground construction, hydrogeology, and physical metallurgy. No member of the Board may be employed by DOE, its contractors, or the National Laboratories. The current Board is composed of individuals with academic and public and private sector experience. The Board's mandate is to evaluate the technical and scientific validity of activities undertaken by DOE, regarding various aspects of the U.S. SNF and HLW management. For example, the NWTRB provided comments in April 1999 on DOE's Viability Assessment in a report entitled *Moving Beyond the Yucca Mountain Viability Assessment - A Report to the U.S. Congress and the Secretary of Energy*.

The NWTRB meets periodically in open public meetings. The Board reports to Congress and to the Secretary of Energy at least twice a year on technical issues associated with the Nation's SNF and HLW disposal program.

ES.2.4 State Governments and Native American Tribes

In both the NWPA and the NWPAA, the Congress provided for active State and Native American tribe participation in the Yucca Mountain site evaluation process. The legislation provides for financial assistance to the State of Nevada, and for affected tribes and units of local government, for participation in program activities. The State of Nevada and affected tribes or units of local government may also request assistance to mitigate any economic, social, public health and safety, and environmental impacts that are likely to result from site characterization activities at Yucca Mountain.

The Nevada legislature created the State's Nuclear Projects/Nuclear Waste Project Office (NWPO) in 1985 to oversee Federal high-level nuclear waste activities in the State. Since then, the NWPO has dealt primarily with the technical and institutional issues associated with DOE's efforts to characterize the Yucca Mountain site. In addition, the counties contiguous to Nye County, the host county for Yucca Mountain, have been determined to be affected parties and are participating in program oversight.

ES.3 SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE DISPOSAL PROGRAMS IN OTHER COUNTRIES

As in the United States, other countries that use nuclear power are establishing long-term programs for the safe management and disposal of SNF and HLW. These countries include Belgium, Canada, France, Germany, Japan, Spain, Sweden, Switzerland, and the United Kingdom. Management strategies of these countries may include SNF storage at and away from reactor sites, SNF reprocessing, HLW vitrification and storage, partitioning and transmutation of the waste into short-lived or stable forms, and disposal in deep geologic media.

Deep geologic disposal is considered by the international scientific community to be the most promising method for disposing of long-lived nuclear waste. As a consequence, all of the countries discussed in this document envision emplacing solid radioactive waste in a deep geologic formation located within their national borders.

Only the United States and Germany have identified candidate locations for disposal of HLW, i.e., the Yucca Mountain site in Nevada and the Gorleben site in Germany. Other countries are to varying degrees engaged in technical evaluations of the potential suitability of indigenous geologic formations for disposal. Some nations, such as France, have several geologic formations such as clay and granite, that might be used for disposal, and each alternative is being evaluated. Others, such as Canada, have focused on one type of geologic formation. (Canada is evaluating a crystalline rock formation in a setting with low seismic activity.) In addition, several countries, such as Canada and Sweden, have established underground research laboratories (URL's) and extended their research programs to include participation by other nations with similar candidate geologies.

The disposal strategies of all nations assume that waste isolation will be maintained by reliance on a combination of engineered and natural barriers between the emplaced waste and the environment. Currently the United States is, as a result of site characterization data interpretations, placing increasing emphasis on the role of engineered barriers in a potential repository site at Yucca Mountain. This is, in part, due to the unique repository environment and associated disposal strategy. Other countries, because of the characteristics of their available geologic formations, are also placing emphasis on engineered barrier systems and are designing these systems to ensure their long-term performance as a barrier to radionuclide release.
Table ES-1 summarizes the characteristics of disposal programs in other nations.

Table ES-1. Programs for HLW and SNF Disposal in Other Nations

COUNTRY	ESTIMATED WASTE AMOUNTS	MANAGEMENT ORGANIZATIONS	PROGRAM STATUS	PRIMARY REGULATORY AGENCY	TIME FRAME
Belgium	2,500 MTHM by 2000	National Agency for Radioactive Waste and Fossil Materials (ONDRAF)	Conducting studies at the Mol-Dessel Underground Research Lab (URL)	Federal Nuclear Inspection Agency (AFCN)	0peration around 2030
Canada	34,000 MTHM by 2000	Atomic Energy of Canada Ltd. (AECL)	Conducting studies at Whireshell URL	Atomic Energy Control Board (AECB)	Repository established by about 2025
Finland	2,440 MTHM	Posiva Oy	Investigating three potential sites	Finnish Centre of Radiation and Nuclear Safety	Repository operation expected around 2020
France	Not available	National Radioactive Waste Management Agency (ANDRA)	Working to identify suitable site locations	Directorate for Safety of Nuclear Installations (DSIN)	Repository operations not expected before 2020
Germany	9,000 MTHM by 2000	Institute for Radiation Protection	Selected potential repository site at Gorleben	Federal Ministry for Environment, Protection of Nature and Reactor Safety	Repository construction to begin around 2000
Japan	20,000 MTHM by 2000	Steering Committee on High-Level Radioactive Waste	Experiments being conducted at Tono uranium mine and Kamaishi iron ore mine	Atomic Energy Commission	Repository operation expected by 2035 to 2045
Spain	5,200 MTHM (vitrified waste)	Spanish National Radioactive Waste Company (ENRESA)	Developing conceptual design	Spanish Nuclear Safety Council	Not available
Sweden	8,000 MTHM by 2010	Swedish Nuclear Fuel and Waste Management Company (SKB)	Conducting feasibility studies; operates URL at Apsö	Ministry of the Environment and Natural Resources	Repository operation by 2008
Switzerland	1,800 MTHM by 2000	National Cooperative for the Storage of Radioactive Waste (NAGRA)	Considering appropriate repository medium	Nuclear Safety Division with the Federal Department of Transport, Communications, and Energy	Repository viability to be determined by 2000; commissioning of repository will not occur before 2020
United Kingdom	4,000 m^3 by 2000	British Nuclear Fuels, plc (BNFL)	Concentrating on deep disposal of low to intermediate level waste	Nuclear Installations Inspectorate; Radiochemical Inspectorate; Ministry of Agriculture, Fisheries, and Food; UK Atomic Energy Authority; Secretaries of State for Scotland and Wales	Need for repository not expected before 2040

Various nations and international agencies, in addition to the United States, have begun to give consideration to regulations and regulatory standards for SNF and HLW disposal. Some nations have developed broad risk or dose criteria, and some have supplemented such criteria with additional qualitative technical criteria concerning features of the disposal system. International organizations, such as the Nuclear Energy Agency, provide opportunities for discussion of regulatory criteria and also provide programs on issues of common interest.

Although the performance standards and the criteria for the various national regulations are similar, each nation has established specific requirements to meet its needs. Current information concerning the provisions of national and international criteria and objectives for the safety of long-lived radioactive waste disposal is presented in Chapter 3 along with a summary of the waste management programs of Belgium, Canada, Finland, France, Germany, Japan, Spain, Sweden, Switzerland, and the United Kingdom.

ES.4 WASTE CHARACTERISTICS

Current national plans call for existing and yet-to be-produced inventories of SNF and HLW to be disposed of in a Yucca Mountain geologic repository if it is approved for disposal. Each of these waste forms is described below.

ES.4.1 Spent Nuclear Fuel

Spent nuclear fuel is defined as fuel that has been withdrawn from a nuclear reactor following irradiation and whose constituent elements have not been separated by reprocessing. Generators of SNF include: commercial nuclear power reactors, which consist of pressurized water reactors (PWR) and boiling water reactors (BWR); reactors which are used in government-sponsored research and demonstration programs in universities and industry; experimental reactors, e.g., liquid-metal, fast-breeder reactors (LMFBR) and high-temperature gas-cooled reactors (HTGR); DOE Naval and nuclear-weapons production reactors; and Department of Defense (DOD) reactors.

Commercial power reactors are by far the largest source of SNF. Approximately 98 percent of the SNF from these reactors is stored at the reactor sites where it was generated. Spent nuclear fuel from government research and production reactors is currently stored at various DOE facilities. The fuels at these DOE facilities are Government-owned and, like commercial fuels, there are no plans for reprocessing.

The fuel for commercial nuclear reactors consists of uranium dioxide pellets encased in zirconium alloy (Zircaloy) or stainless steel tubes. During reactor operation, fission of some of the uranium produces energy, neutrons, and radioactive isotopes known as fission products. The neutrons cause further fission reactions and thus sustain the nuclear chain reaction. In time, the uranium, is depleted to such a level that power production becomes inefficient. Once this occurs, the fuel bundles are deemed "spent" and are removed from the reactor. Reprocessing of commercial SNF to recover the unfissioned uranium and the by-product plutonium for reuse as a fuel resource is currently not taking place in the United States.

The radioactive materials associated with SNF fall into three categories: (1) fission products; (2) actinide elements (atomic numbers of 89 and greater); and (3) activation products. Typically, fresh SNF contains more than 100 radionuclides as fission products. Fission products are of particular importance because of the quantities produced, their high radiological decay rates, their decay-heat production, and their potential biological hazard. Such fission products include: strontium-90; technetium-99; iodine-129 and -131; cesium isotopes; tin-126; and krypton-85 and other noble gases.

Activation products include tritium (hydrogen-3), carbon-14, cobalt-60, and other radioactive isotopes created by neutron activation of reactor components, fuel assembly materials, and impurities in cooling water or in the fuel pellets. The actinides include uranium isotopes and transuranic elements, such as plutonium, curium, americium, and neptunium. The exact radionuclide composition of a particular SNF sample depends on the reactor type, the initial fuel composition, the length of time the fuel was irradiated (also known as “burnup”), and the elapsed time since its removal from the reactor core.

As of January 1999, SNF from commercial reactor operations in inventory at various locations amounted to 37,700 metric tons of initial heavy metal (MTIHM)[2] . Based on the DOE/EIA Low Case assumptions of nuclear power capacity through the year 2030, the SNF inventory is

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[2] Commercial SNF reported in certain DOE documents is in units of metric tons of *initial* heavy metal (MTIHM) to avoid difficulties arising from the need to estimate ranges of varied heavy-metal content that result from different levels of enrichment and reactor fuel burn up. A metric ton (tonne) is 1,000 kilograms, corresponding to about 2,200 pounds.

expected to increase to 87,900 MTIHM. This is the amount that would be produced by existing commercial reactors under current licenses.

ES.4.2 Defense High-Level Radioactive Waste

High-level radioactive wastes are the intensely radioactive materials resulting from the reprocessing of SNF, including liquid waste produced directly in reprocessing, and any solid material derived from such liquid waste. High-level waste is generated by the chemical reprocessing of spent research and production reactor fuel, irradiated targets, and fuel from U.S. Naval propulsion reactors. The fission products, actinides, and neutron-activated products of particular importance are the same for HLW as for SNF assemblies.

Historically, weapons program reactors were operated mainly to produce plutonium. Reprocessing to recover the plutonium was an integral part of the weapons program. Naval propulsion reactor fuel elements were also reprocessed to recover the highly enriched uranium that remained after use. DOE decided in 1992 to phase out the domestic reprocessing of irradiated nuclear fuel of defense program origin, so only minimal amounts of HLW are expected to be added to the current inventory.

High-level radioactive waste that is generated by the reprocessing of SNF and targets contains more than 99 percent of the nonvolatile fission products produced in the fuel or targets during reactor operation. It generally contains about 0.5 percent of the uranium and plutonium originally present in the fuel. Most of the current HLW inventory, which is the result of DOE national defense activities, is stored at the Savannah River Site (126,300 m^3), the Idaho National Engineering and Environmental Laboratory (INEEL) (11,000 m^3), and the Hanford Site (239,000 m^3). A limited quantity of HLW is stored at the West Valley Demonstration Project (2,180 m^3). The HLW has, to date, been through one or more treatment steps, e.g., neutralization, precipitation, decantation, or evaporation. It is currently planned that this HLW will be solidified, using a vitrification process, for disposal. Vitrification of HLW is in progress at West Valley and the Savannah River Site. A vitrification facility for HLW at Hanford is being designed.

The DOE defense HLW at INEEL results from reprocessing nuclear fuels from naval propulsion reactors and special research and test reactors. The bulk of this waste has been converted to a stable, granular solid (calcine). At the Savannah River and Hanford Sites, the acidic liquid waste from reprocessing defense reactor fuel is or has been made alkaline by the addition of caustic soda and stored in tanks. During storage, this alkaline waste separates into three phases: liquid, sludge, and salt cake. The relative proportions of liquid and salt cake depend on how much water is removed by waste treatment evaporators during waste management operations.

Both alkaline and acidic HLW was generated at West Valley. The alkaline waste was generated by reprocessing commercial power reactor fuels and some Hanford N-Reactor fuels. Acidic waste was generated by reprocessing a small amount of commercial fuel containing thorium.

Projecting DOE defense HLW inventories is based on specific assumptions and may be subject to change. New treatment methods and waste forms are possible and may affect the future projections. Since all DOE defense production sites are progressing toward closure, there should be minimal amounts of waste added to the current inventory. Interim storage of DOE HLW will be required and will most likely continue to be at the site where the waste is produced. Current DOE policy states that DOE HLW will not be accepted at the geologic repository until six years after initial receipt of commercial SNF.

ES.4.3 Significant Radionuclides Contained in Spent Nuclear Fuel and High-Level Waste

Of the 70,000-tonne capacity limit for Yucca Mountain set by the NWPA, about 40,785 MTHM and 22,210 MTHM represent spent PWR and spent BWR fuel, respectively. About 7,000 MTHM of vitrified defense HLW and SNF represents the balance of the total specified repository inventory. For the Yucca Mountain site, radionuclide-specific activity levels are estimated by assuming that all spent nuclear fuel had been removed from the reactors 30 years before emplacement with burn-ups of 39,651 MWd/MTHM for PWR fuel and 31,186 MWd/MTHM for BWR fuel. Although the burn-up of SNF from which HLW is derived is generally uncertain, this is thought to affect the adjustment for decay only marginally. In addition, the radionuclide inventories in a repository at Yucca Mountain stemming from defense HLW are expected to be much less than those from commercial SNF.

The radionuclide inventory of the repository will change with time due to radioactive decay and ingrowth of radioactive decay products. For example, inventories of the initially prominent fission products cesium-137 and strontium-90, which have approximately 30-year half-lives, will decay to insignificant levels within 1,000 years, while some decay products, such as neptunium-237 with a half life of 2.1 million years, will not contribute significantly to doses until about

50,000 years after repository closure. Activity levels for very long-lived radioisotopes will be low but nearly constant for periods on the order of a million years. Overall, the radioisotope inventory of the wastes placed in the repository will decrease by about five orders of magnitude during the first 100,000 years after closure, and remain virtually constant thereafter.

ES.5 CURRENT INFORMATION ON A POTENTIAL WASTE REPOSITORY AT YUCCA MOUNTAIN

ES.5.1 Geologic Features of the Yucca Mountain Site

In terms of geologic designations, the site is situated in the southern section of the Great Basin, which is characterized by north-south mountain ranges separating narrow, flat valleys. As is typical of mountains in the region, Yucca Mountain is essentially a tilted fault block, with the west side steep and nearly vertical and the east side sloping to the adjacent valley floor. The crest elevation of the mountain is on the order of 1,500 to 2,000 meters (5,000 to 6,000 feet) above sea level and is about 650 meters (2,000 feet) above the adjacent valley floors.

The geologic features of the southern Great Basin are highly complex and varied, with rock formations ranging in age from 500 million to less than 400,000 years. The geologic structure at Yucca Mountain is dominated by a series of layers of rocks that were produced by explosive volcanic eruptions and are known as tuffs. The tuff layers have widely varying physical characteristics and are on the order of 10 to 15 million years old. The host rock of the potential repository is known as Topapah Spring tuff, which is a hard, fractured rock about 13 million years old.

Geologic features of the region that are important to the integrity of a radioactive waste repository in Yucca Mountain include faulting, seismicity, volcanism, and stability of the geologic regime.

ES.5.1.1 Major Fault Features of the Yucca Mountain Area

The geologic formations, of which Yucca Mountain is a part, contain numerous major faults as a result of deformation caused by tectonic movement. The faults are indicative of past and potential movement of the geologic structures and they are potential pathways for water to transport radioactivity released from the repository to the biosphere. The location of faults and the extent of recent movement along the faults are important to the location and design of surface facilities at the disposal site and to the design of the underground facilities into which the wastes would be placed for disposal.

There are more that 80 known or suspected Quaternary faults and fault rupture combinations within 100 kilometers (km) of the Yucca Mountain site. The DOE has determined that 38 of these faults are capable of generating a peak acceleration of one-tenth the acceleration of gravity (0.1 g) or greater at the ground surface of the proposed repository site; these are classified as relevant earthquake sources. An updated compilation of faults prepared by the U.S. Geological Survey identifies 67 faults with demonstrable or questionable evidence of Quaternary movement and capability for accelerations of at least 0.1 g at an 84 percent confidence limit. The NRC-supported program of the Center for Nuclear Waste Regulatory Analyses (CNWRA) has identified 52 Type I faults within a 100-km radius of the mountain. Eleven known or suspected Quaternary faults exist within 20 km (12 miles) of Yucca Mountain.

The three major faults in the immediate vicinity of the proposed disposal site are the Ghost Dance fault, which passes through Yucca Mountain; the Bow Ridge fault, which is just to the east of the mountain; and the Solitario Canyon fault, which is just to the west of the mountain. According to DOE's interpretation of available data, no movement on any of these faults has occurred during the past 10,000 years.

ES.5.1.2 Seismology of the Yucca Mountain Area

The fault systems and the seismic history of the Yucca Mountain area are the result of regional tectonics, which are dominated by the interaction of the North American and Pacific plates. The tectonic processes that are stretching the Great Basin and produced its major land forms are the result of the Pacific Plate moving northwest relative to the North American plate; the typical geologic structures of the region were developed on the order of 11 million years ago. The relative plate movements produced the past and recent seismic activity characteristics of the region, outlined below.

Seismicity in the region of Yucca Mountain is concentrated in several zones. The Southern Nevada Transverse Zone (SNTZ) is nearest to the Yucca Mountain site and is the most significant to repository performance. Historic earthquakes in the SNTZ have been of moderate magnitude with no documented surface rupture. The most recent earthquake in the vicinity of

Yucca Mountain was the Little Skull Mountain event, of Richter magnitude 5.6, in June 1992. This earthquake was centered 20 km southeast of Yucca Mountain and was associated with the Landers, California earthquake earlier that year. It caused minor structural damage to the Yucca Mountain project field office near the mountain but had no apparent effect on geologic features near the mountain. It was the largest earthquake ever recorded in the vicinity of the site, based on nearly 100 years of records.

Assessments of available data indicate that Yucca Mountain has not been subject to ground accelerations at the surface in excess of 0.2 g for over several tens of thousands of years. At the proposed waste emplacement depth of about 300 meters, the effects of ground motion are expected to be insignificant. Empirical evidence of damage to 71 rock tunnels in Alaska, California, and Japan resulting from earthquake shaking indicates that tunnel damage does not occur at peak surface accelerations of less than approximately 0.2 g and only minor tunnel damage occurs when the peak surface acceleration is between 0.2 and 0.5 g. Since ground acceleration is not expected to impose significant design demands on either the underground repository or surface facilities at Yucca Mountain, DOE does not consider seismicity to be a significant factor in repository performance.

The Department also believes that future tectonic events are unlikely to significantly alter the hydrologic characteristics of the Yucca Mountain site. This position is based on the assumption that the current state of faults and fractures at the site is the result of cumulative past tectonic events. The CNWRA has proposed, however, that a single tectonic event can cause significant changes in hydrologic characteristics. Currently, there are five alternative tectonic models which may form the basis for future assessment of relationships between tectonic phenomena and the hydrologic regime.

ES.5.1.3 Volcanism

Yucca Mountain is composed of layers of volcanic rocks which originated in silica-rich eruptions at what is now the Timber Mountain volcanic basin complex starting about 10 km north of Yucca Mountain. The principal eruptions took place approximately 11 to 15 million years ago, and ceased about 7.5 million years ago. After the silicic volcanism ended, there were two episodes of basaltic volcanic rock formation. The most recent of these, which produced minor ash deposits in the Lathrop Wells area to the southwest of Yucca Mountain, ended about 9,000 years ago.

DOE and NRC agree that a future occurrence of silicic volcanism is highly unlikely; the consequences of such an event, therefore, do not need to be considered in assessments of a waste repository at Yucca Mountain. The Department and the NRC have also recently reached agreement on the likelihood of future basaltic volcanic events and their possible consequences. One of the phenomena potentially associated with basaltic volcanism is sheet-like intrusion of molten or liquid basaltic rock along fractures in the overlying rocks, i.e., the formation of dikes. Given the history of volcanism in the Yucca Mountain region, there is some potential for magma from a basaltic volcanic event to either intersect the repository footprint and directly affect the waste or to form a nearby intrusive dike that might affect the waste isolation capability of the natural system. If such intrusions occur, they could mobilize wastes and/or alter ground water pathways. DOE and NRC are currently developing a mutually acceptable approach to estimating the likelihood and consequences of such intrusions.

ES.5.1.4 Geologic Stability

The NAS report, "Technical Bases for Yucca Mountain Standards," recommended that assessments of compliance with the Yucca Mountain standards be conducted for the time at which the greatest risk occurs, within the limits imposed by long-term stability of the geologic environment. The report also stated that long-term geologic stability for time periods on the order of one million years can be expected; i.e., the contribution of geologic and hydrologic features to overall repository system performance can be assessed for time periods of this duration. The NAS report concluded that there is no technical basis for selecting a shorter compliance period, such as 10,000 years. However, the NAS also stated that EPA may select a shorter period based on policy considerations.

The concept of geologic stability does not imply absence of geologic activity or absence of change in geologic processes. Rather, the concept implies that processes and events such as climate change, tectonic movement, and earthquakes will occur as in the past, and that variations within these processes and events will be boundable. The NAS report does not explicitly justify the assertion of million-year stability by providing a synopsis and interpretation of the documented geologic record. Some of the references cited in the report contain information about the geologic record, but none of the cited references interprets the record to indicate a million-year stability of the geologic regime or the processes associated with it. Until recently, DOE documents containing information about the geologic features of the Yucca Mountain site anticipated that performance assessments for a disposal system at the site would be evaluated in terms of EPA's 40 CFR Part 191 regulations, which require evaluation of performance for a period of 10,000 years. The 40 CFR Part 197 regulations specify the same time period.

The 10,000-year time frame for compliance with EPA's 40 CFR Part 191 regulations, which applied to Yucca Mountain until Yucca Mountain was exempted by the WIPP Land Withdrawal Act of 1992, was selected by the Agency because it was relatively brief compared to the time frame for long-term factors, such as tectonic motion, that might affect the natural environment and are not reasonably predictable over that period. On the other hand, the time period was long enough to bring into consideration factors such as degradation of engineered barriers and earthquakes that might affect disposal system performance and allow radionuclides to reach the accessible environment.

Available information generally supports the NAS assertion that the fundamental geologic regime at Yucca Mountain will remain stable over the next one million years. The overall picture that emerges from available information is that the site and region had a highly dynamic period of volcanism, seismicity, and tectonic action during the past, but that this very dynamic situation has matured into one where the magnitudes, frequencies, locations, and consequences of such phenomena relevant to long-term future disposal system performance can be bounded and projected with reasonable confidence.

Performance assessments define the expected behavior of the waste isolation system over time. Within the framework of expected repository performance, it is convenient to characterize future repository conditions over three time periods. A similar breakdown was presented by DOE in its 1998 Viability Assessment. In the first, short-term period, lasting about 100 to 1,000 years, the repository is characterized by intact waste canisters, high temperatures, and temperature gradients which serve as driving forces for transients such as chemical reactions, and the retention of short-lived and long-lived radioactivity in the canisters. Percolation water may or may not contact the canisters, depending on local conditions determined by the arrangement of waste packages in the repository and the pattern of percolation into the repository.

In the intermediate period, with a duration between 1,000 and 10,000 years, temperature gradients are diminished or gone and the engineered features of the repository start to degrade. During this time, canisters begin to corrode and only long-lived radioactivity remains; some of the radioactivity is released from a few canisters which are penetrated by water, but most is retained within the repository. Percolation water contacts and transports radioactive waste. Releases are dominated by technetium-99 and iodine-129.

In the long-term period, from 10,000 years to 1,000,000 years, the repository gradually evolves into an assemblage of the oxides, hydroxides, or carbonates of waste-package and waste-form materials at ambient conditions. Percolation water seeps through the repository level and transports radionuclides that can be mobilized to the environment, where the radionuclide concentrations are diluted and dispersed by ground water flow processes. Potential for radiation doses is dominated by neptunium-237 released from the repository.

ES.5.2 Hydrologic Features of the Yucca Mountain Site

The proposed repository depth in Yucca Mountain (about 300 meters or 1,000 feet) would locate it in a geologic formation not fully saturated with water (the unsaturated zone). The unsaturated zone depth to the water table beneath the repository horizon is variable but is on the order of 300 meters. Water that infiltrates into the mountain, percolates through the repository, and moves through the matrix of the geologic formations in the unsaturated zone will travel slowly, thereby delaying entry of radionuclides released from the repository into the saturated zone and ground water system. Fractures in the rocks within the unsaturated zone can act as conduits for relatively rapid movement of ground water through Yucca Mountain. Some radionuclides may be chemically trapped in rock formations in the unsaturated zone.

ES.5.2.1 Characteristics of the Unsaturated Zone

Water flows slowly through the pore space in the matrix of partially saturated rock (the degree of saturation in the Yucca Mountain formations is on the order of 80 to 90 percent) because there is little areal recharge. If the pore space becomes saturated, the water will flow more quickly under the existing hydrologic conditions. Also, water may flow quickly and preferentially through fractures in the rock matrix. There is experimental evidence of “fast paths” for flow in some rock fractures at Yucca Mountain. The fraction of total flow through these fast paths is uncertain, may be episodic, and may be a small percentage of the total ground water moving through the repository host rock. There is also evidence that some faults and fractures are barriers to flow because of solids deposited along the fractures which block potential flow paths.

The complexity of the geologic structures in the unsaturated zone and the complexity of flow in partially saturated media make it difficult to develop accurate models to predict flow rates and flow paths in the unsaturated zone below the proposed repository location. Water flow and storage in the unsaturated zone is three-dimensional and is controlled by structural, stratigraphic, thermal, and climatological features of the system. The presence of features such as fractured porous media, layered geologic units with widely varying hydrologic properties, tilted rock units, and bounding faults can be expected to result in phenomena such as flow in both the fractures and the matrix, diversion of flow by capillary barriers, lateral flow along discontinuities, perched ground water zones, and vapor movement.

Water quantities that enter the mountain from precipitation and that percolate through the geologic structures are spatially and temporally variable. The amount of water that percolates along different paths is highly variable. Infiltration pathways depend on variations in the properties of geologic units, the intersections of faults with the surface, and the presence of local fracturing in individual rock units. Variations in the time it takes water to infiltrate are related to the seasonality and relative infrequency of precipitation at Yucca Mountain. Over long time frames, variations will occur because of climate changes. The interplay of all of these factors may act to even out downward movement of ground water in the unsaturated zone with increasing depth from the surface. There is evidence of rapid movement of infiltrating waters along fracture zones in the rock.

Quantities of water that percolate through the mountain at the proposed repository depth cannot be measured directly. Recent estimates, based on analysis of site characterization data, place the percolation rate in the range of one to 10 mm/yr. Base-case performance assessments for the TSPA-VA used a range of three to 23 mm/yr, with an expected value (60 percent probable) of 7.7 mm/yr. Values in this range are as much as two orders of magnitude higher than values previously estimated using more limited data. The TSPA-VA also used a model of future climate involving “long-term average” conditions, with an expected infiltration rate of 42 mm/yr, and “superpluvial” conditions with an expected infiltration rate of 110 mm/yr.

Models of water flow in the unsaturated zone take into account potential for flow in both the matrix and fractures, the relative distribution depending on the quantities of ground water available. For example, at high percolation rates, a larger fraction may be transported laterally and/or transported in fractures, including fast-path fractures. The models also take into consideration the possibility that radionuclides may be removed from water that is intercepted by geologic media having a high capacity to chemically absorb and retain some radionuclides, such as the zeolite materials in the Calico Hills formation.

Using uncertainty distributions for the flow parameters, models are used to estimate values for performance factors, such as the time necessary for water to move through the unsaturated zone. Results of studies to date show that radionuclides, carried by water through fractures, cross the unsaturated zone much more rapidly than those in water that travels through the rock matrix. Similarly, radionuclides strongly sorbed on rocks, such as the Calico Hills zeolites, have transit times through the unsaturated zone 50,000 times longer than for radionuclides that are soluble and travel with the water. The conceptual models and transport parameters for water flow and radionuclide transport in the unsaturated zone, and the results obtained from use of the models, will be refined by DOE as additional data concerning the unsaturated zone are obtained from future site characterization work.

ES.5.2.2 Characteristics of the Saturated Zone

Water that percolates through the repository and the unsaturated zone below will enter the saturated zone where ground water fills the pore spaces and fractures within these rocks. The saturated zone at Yucca Mountain is located at depths on the order of 300 m below the repository horizon. Radionuclides transported to this zone will move toward the environment away from Yucca Mountain through ground water. Radionuclide concentrations in the saturated zone will be reduced by dilution caused by dispersion as radionuclides are transported away from the repository at rates and in directions according to the flow characteristics of the hydrologic regime. The saturated zone is, like the unsaturated zone, composed of numerous layers of rocks with widely different characteristics and complex structures resulting from the dynamic geologic history of the region . Flow rates and directions are of interest for evaluating compliance with EPA's standards, as are the locations at which radionuclides would be accessible to human use and the radionuclide concentrations at those locations.

The sequence of volcanic rocks within and below Yucca Mountain has been described hydrologically in terms of four hydrologic units characterized by their ability to transmit water. Beneath the volcanic rocks, at depths on the order of 2,000 meters at some locations, are older rocks which contain the Lower Carbonate Aquifer. The volcanic hydrologic units and the lower carbonate aquifer may all have a role in transporting radionuclides from the repository to the surrounding areas.

The thicknesses of the rock formations and the depth to water in the saturated zone vary significantly with distance and direction from the proposed repository location. For example, the volcanic rock units are believed to thin out and disappear to the south of Yucca Mountain where they are covered by the alluvial deposits of the Amargosa Desert. In this region, as illustrated by Figure ES.5-1, the formations containing the Lower Carbonate Aquifer are near the surface. Depths to ground water currently used for human consumption and activities such as irrigation are shallow in this area, i.e., on the order of a few tens of meters. Consequently, human habitation and water supply wells are currently located in this area.

Available data indicate that much of the outflow from the volcanic aquifers moves laterally into the alluvial aquifer as the volcanic rock formations thin out below it. The alluvial aquifer may also be receiving water from the carbonate aquifer. The data are not sufficient to indicate where and how these flow transitions occur. Comparison of recent water-level altitude maps with those completed in the 1950s indicates that aquifer development may have had a significant impact on water levels and flow directions. Pumping of the alluvial aquifer may have induced upward flow from the lower carbonate aquifer into the alluvial system.

Discharge from the alluvial aquifer system can occur by interbasin flow, leakage to underlying units, evaporation, and extraction for human use. Available data indicate that the major discharge area for the alluvial aquifer system is Alkali Flat, known also as the Franklin Lake Playa. The estimated discharge rate in this area is 10,000 acre-feet per year, primarily based on bare-soil evaporation. Some of the alluvial aquifer flow may also move further to the southwest and discharge in the Death Valley region, but the extent of this is unknown.

Estimates of rates and quantities of ground water flow in the saturated zone are based on estimates of values for hydraulic conductivity, hydraulic gradient, and effective porosity of the formations through which the water is flowing. Hydraulic gradient (i.e., the change in water level between two locations) is generally the parameter best known and most easily measured. In the Yucca Mountain region, three regions with distinct hydraulic gradients, designated as small, moderate, and large, have been identified. Their extent and characteristics are governed by the complexity and characteristics of the geologic formations.

Of particular interest to repository performance at Yucca Mountain is the high-gradient area, located about two miles north of the mountain. The cause of the gradient, in which water levels

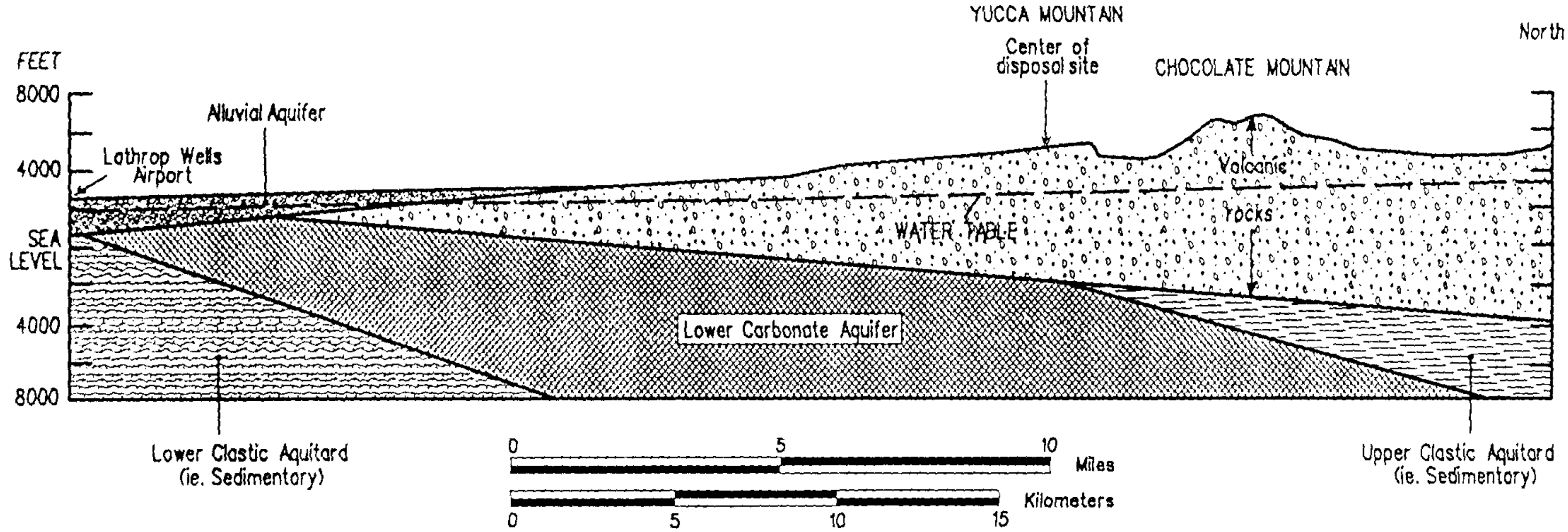

Figure ES.5-1. Schematic North/South Cross-Sectional Illustration of Thinning of Volcanic Units Beneath the Amargosa Desert [U.S. Geological Survey, *Structure of Pre-Cenozoic Rocks in the Vicinity of Yucca Mountain, Nye County, Nevada*, USGS Survey Bulletin 1647, 1985] decline by more than 900 feet over a distance of about a mile, is unknown. Possible causes include a flow barrier, a fault, an intrusive dike from volcanic rock flow, or changes in the detailed structure of the rocks. If the gradient is caused by a flow barrier of some type, a loss of this barrier due to future geologic movements could cause a rise in the water table in the area of the proposed repository. A rise in the water table would not be expected to intercept the repository, but it would decrease the thickness of the unsaturated zone and decrease the radionuclide travel time from the repository to the environment.

Ground water flow rates, like flow directions and quantities, are at present highly uncertain because of limited data and the complexity of the geologic structures that create the hydrologic regime. Flow rates in the alluvial aquifer, the volcanic rock aquifers, and the lower carbonate aquifer will differ because of the different rock characteristics for these geologic regimes. Ground water movement in the volcanic rocks of the saturated zone was estimated by DOE in 1993 to be in the range of 5.5 to 12.5 meters per year. A more recent estimate concluded that a flow rate of five meters per year is in the middle of the range of reasonable estimates. However, recent data from the Exploratory Studies Facility tunnel into Yucca Mountain suggest the existence of "fast paths" through the unsaturated zone that can allow water to move from the surface to depths as far as 300 m in 50 years. At present, DOE believes that only a small fraction of percolating water is transported to the repository level through these pathways. Flow rates in the lower carbonate aquifer have been estimated to be in the range of three to 3,000 meters per year, depending on location. Pressure gradients are such that water flow from the volcanic aquifers to the lower lying carbonate aquifer presumably does not occur. While reliable estimates of flow rates in the alluvial aquifers are not available, flow rates in these strata are believed to be lower than in the carbonate strata. This has the effect of preventing radionuclide from moving into the higher flow rate paths in the carbonate aquifer. The areal extent of the region where upward flow comes from the carbonate aquifer is highly uncertain.

If ground water containing radionuclides flows at a rate of five meters per year, it would take 1,000 years for the ground water to travel a distance of five kilometers and 4,000 years to travel a distance of 20 kilometers. Concentrations of soluble radionuclides in the ground water at these distances from the repository would depend on the initial concentration at the boundary of the repository, the dilution that occurs as a result of mixing of water from various sources, and the dispersion of radionuclides. Overall, the mixing, dilution, and dispersion processes have been estimated potentially to reduce radionuclide concentrations at distances on the order of 20 kilometers from the repository by a factor of 10 in comparison with the initial concentration.

Estimation of dispersion on a kilometer scale is difficult. The DOE used expert elicitation to fix this parameter. The experts estimated that the parameter could vary from 1 to 100 with an average assumed value of 10. The amount of concentration reduction that occurs may depend on the direction of flow (i.e., as a result of dispersion being controlled by rock structures along the flow path) as well as the distance over which flow has occurred.

Nye County, NV is currently drilling a series of 20 deep and shallow wells south of the Yucca Mountain site and in Amargosa Valley to monitor the behavior of the saturated zone. Some of the wells will measure hydraulic parameters of the alluvial and tuff aquifers. Other deep monitoring wells will be installed to measure the properties of the carbonate aquifer and to define how this aquifer connects with the shallower tuff and alluvial aquifers. These data will support modeling of the saturated zone flow and transport on both site-scale and regional-scale. Results to date indicate that the alluvium is complex and layered.

ES.5.3 Climate of the Yucca Mountain Region

The region surrounding Yucca Mountain currently has an arid climate, with total annual precipitation on the order of 170 mm (six inches) of water. Precipitation rates vary throughout the year, averaging about 18 mm/month during the fall and winter months and nine mm/month during the spring and summer months. Current climate conditions have apparently prevailed during the past 10,000 years, i.e., since the last ice age. Prior to the ice age, the climate cycled between wet and dry; during the wet periods, many of the valleys that are now dry contained lakes.

Future variations of precipitation and temperature are climate factors of considerable interest for predicting the performance of a repository at Yucca Mountain. These factors influence the percolation rate of water through the repository and the transport of radionuclides released from the repository to the environment.

Current arid conditions are expected to persist well into the future. These conditions are associated with the rain shadow caused by the Sierra Nevada Mountains to the west, which are still rising. In addition, increases in greenhouse gases and global warming may affect general atmospheric circulation and local climate conditions at Yucca Mountain. A panel of experts, convened by the CNWRA, estimated that an enhanced greenhouse effect would probably produce warmer conditions than have been experienced during the past few thousand years, with a likely increase in the upper limit of temperature in the Yucca Mountain region on the order of two to three degrees Celsius. The time period during which these elevated temperatures would persist would depend on assumptions about future human use of fossil fuels. In general, increased temperatures would be accompanied by lower precipitation rates and, therefore, lower rates of percolation through the repository. Opposite changes could occur, however, especially in connection with any future glacial periods.

Performance assessments in the Department's TSPA-VA assumed that the climate alternates between the present (dry) climate, a long-term average climate during which the precipitation rate is twice the current rate, and a superpluvial climate during which the precipitation rate is three times the current rate. The expected duration of the initial dry climate was 5,000 years. Subsequent dry periods would have an average duration of 10,000 years. The expected duration of the long-term average periods was 90,000 years. Two superpluvial periods of 10,000 years each were assumed to occur over the 1,000,000-year model period. About 90 percent of the 1,000,000-year model period was characterized as having long-term average climate. Climatic fluctuations were predicted to have virtually no impact on repository performance assessments over a 10,000-year time frame. Over the longer term, climate assumptions affect the time at which the peak dose rate occurs but not its magnitude.

ES.5.4 Repository Design Concepts Under Consideration for Yucca Mountain

Design concepts for a potential waste repository at Yucca Mountain have evolved significantly in response to information from sources such as site characterization data, repository system performance assessments, external technical reviews, and refinement of a waste isolation strategy. The original design concept envisioned vertical emplacement of simple steel canisters in individual boreholes; current plans call for end-to-end horizontal emplacement of large, complex waste packages in parallel, excavated drifts. Design details are expected to continue to evolve until a final design is selected for the License Application, if the site is approved for disposal.

The repository design can be characterized as a multi-barrier system that functions to delay the failure of the waste package, delay the release of radionuclides from the waste package, and mitigate the effects of radionuclide release. Key design factors important to repository performance and radionuclide release potential include the corrosion resistance of the waste package wall material; the use of techniques to deflect or delay contact of percolating water with the waste packages; and the use of techniques to stop or delay migration of releases to the environment.

One technique to delay waste package failure is to emplace the packages so that heat from the wastes will keep temperatures in the repository high enough to vaporize percolation water, for as long as possible. Corrosion by liquid water is thereby delayed until the heat emissions decrease to levels such that water can enter the repository. Another technique for delaying waste package failure is to use shields that deflect water dripping into the emplacement tunnels from contact with the packages. In general, various technologies and concepts are available for each of the basic functions for delaying waste package failure and decreasing radionuclide releases.

Key features of the design used by DOE in the recently completed TSPA for Site Recommendation issued in December 2000 include the following:

- Horizontal emplacement of 7,642 commercial SNF and 2,858 HLW canisters positioned end-to-end in parallel, excavated, concrete-lined drifts, with an initial thermal loading (to vaporize percolation water) on the surroundings corresponding to emplacement of 85 MTHM/acre of reference spent commercial reactor fuel

- Emplacement of waste canisters only between the Ghost Dance fault and the Solitario Canyon fault

- Disposal of 63,000 MTHM of spent commercial fuel and 7,000 MTHM equivalent of defense HLW in 120 miles of tunnels and drifts, over 840 acres of emplacement area, at depths on the order of one-eighth to one-quarter of a mile

- Construction of 29 surface buildings encompassing 800,000 square feet of floor space and serving the operational needs of 300 underground drift excavation personnel and 600 surface and subsurface operational personnel

- Use of commercial spent fuel waste packages that are two meters in diameter, six meters in length, with an Alloy 22 corrosion-resistant waste container.

- Protection of the waste containers using titanium drip shields, which decrease contact with water and extend the lifetime of the Alloy 22 containers.

Waste types to be disposed would include commercial SNF fuel in bare assemblies; canistered commercial SNF; canisters of vitrified defense HLW; SNF from nuclear defense programs; and other DOE-owned SNF such as unprocessed fuel from Hanford’s production reactors.

A plan view of the repository layout for the TSPA-VA is shown in Figure ES.5-2. In this diagram, the dense array of parallel lines in the subsurface emplacement block represents the drifts where the waste canisters would be emplaced. The waste package design features shown in Figure ES.5-3 are representative of those used in the VA reference design.

In the TSPA-VA, DOE evaluated several design options as variants to the base case. The options considered included use of backfill; use of drip shields to preclude water from impinging on the waste packages; use of a ceramic coating on the waste packages to defer corrosion; and whether or not to take credit for fuel rod cladding as a barrier to radionuclide mobilization and transport.

During early 1999, DOE evaluated alternative repository designs based on, and evolved from, the Viability Assessment design. These alternative designs were intended to reduce uncertainties in performance identified in the TSPA-VA analysis. DOE has selected, as the reference design for the Site Recommendation, a design whose key features include an area mass loading of 60 MTU/acre, drift spacings of 81 m, waste packages with 2 cm of Alloy 22 over 5 cm of 316L stainless steel, use of steel ground support, and use of drip shields. These design features significantly reduced uncertainties and technical issues associated with the VA reference design. The demonstration of this improved performance was conducted as the TSPA-SR. Engineered design concepts may continue to evolve to the design selected for the LA.

ES.5.5 Repository System Performance Assessments

Assessments of future repository system performance are currently used by DOE to aid repository design and, in association with the license application, will be used to demonstrate compliance with regulatory standards. The assessments are done using analytical models of factors that affect performance, such as the waste package corrosion rate, and computer codes that combine the models of performance factors with performance parameter values and modeling assumptions.

The NRC is developing independent capability to perform performance assessments in order to be able to review DOE’s license application. In addition, the Electric Power Research Institute has developed performance assessment methods that are used in its oversight of the government program, and EPA has developed methods that are used in support of its promulgation of the Yucca Mountain standards.

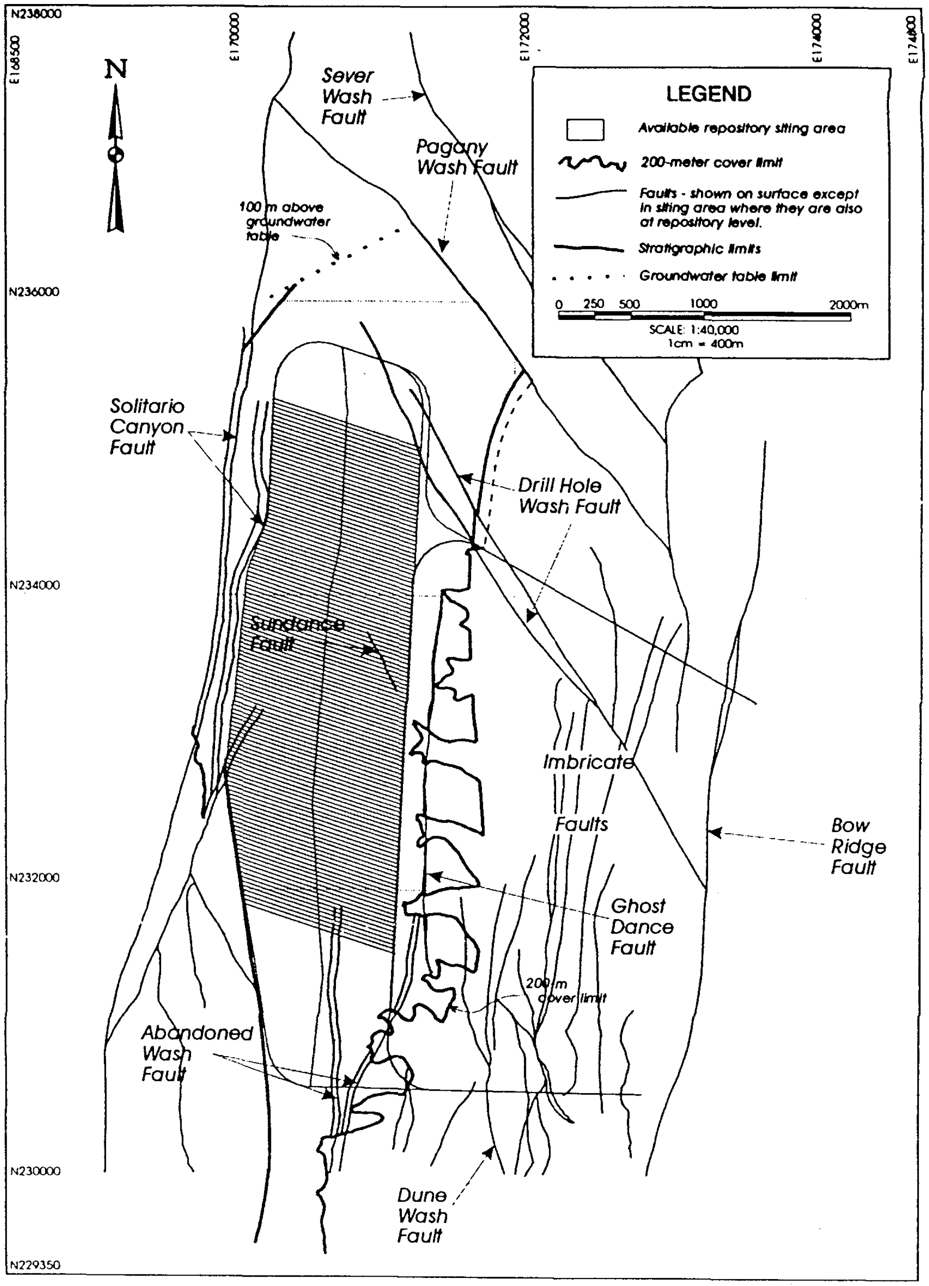

Figure ES.5-2. Repository Layout for the TSPA-VA Design

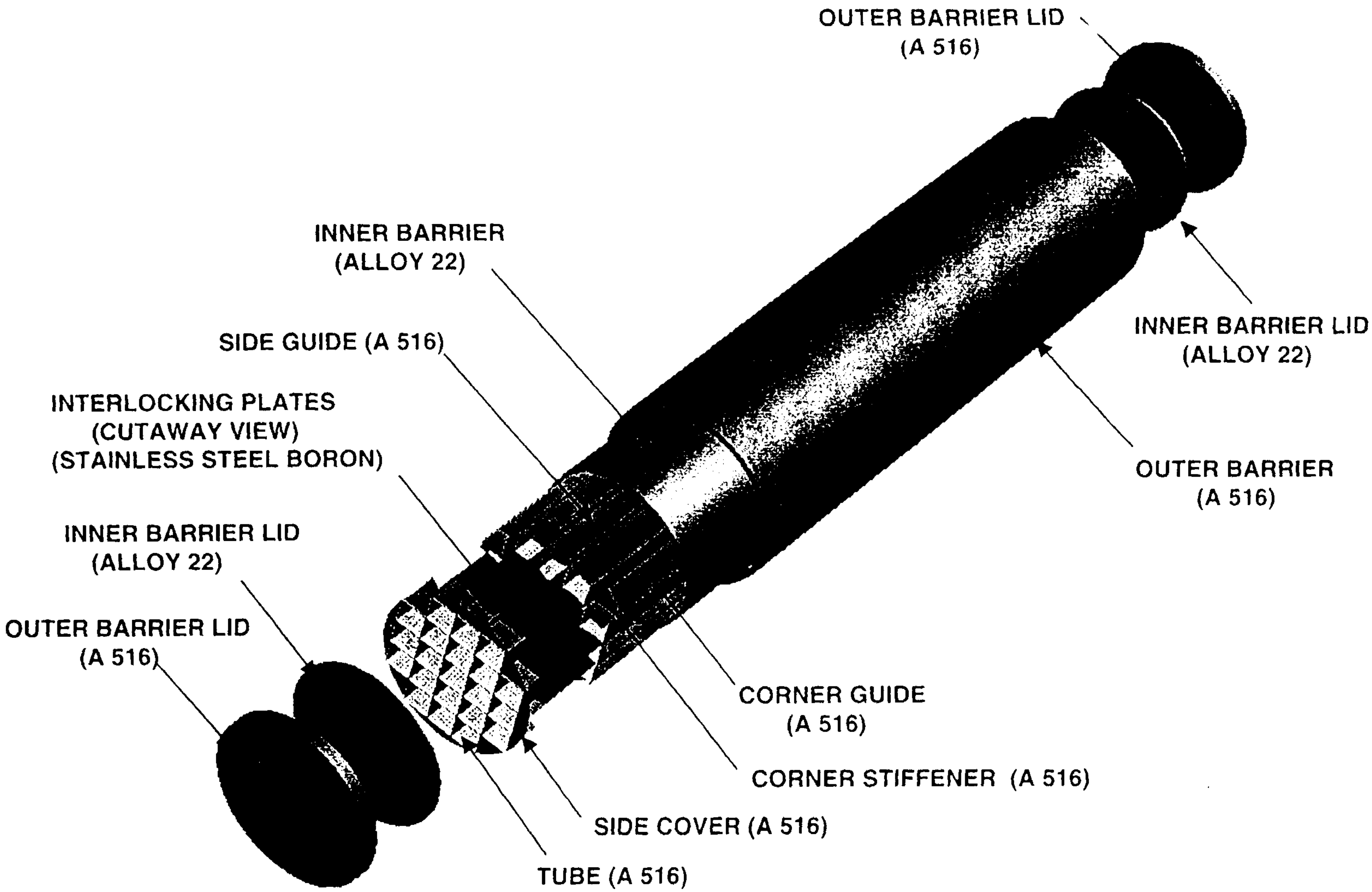

Figure ES.5-3. Waste Package for 21 PWR Uncanistered Fuel Assemblies

Prior to the TSPA-VA, DOE issued reports on its total system performance assessments in 1991, 1993, and 1995. They also serve as precursors of the TSPA results that will be submitted with the License Application to demonstrate compliance with regulatory requirements. The expected performance of the repository will be strongly dependent upon the combination of engineered barriers finally selected by DOE.

The performance assessment models and codes address engineered design features that affect repository system performance. They also consider geologic and hydrologic features that can affect performance, such as those discussed in Sections 4.1 and 4.2 of this BID, and uncertainties in these factors that affect uncertainties in demonstrating compliance with regulatory requirements. Types of uncertainties that are considered include uncertainties in measured values of performance parameters such as corrosion rates and hydrologic parameters; spatial variability of parameters such as percolation rate and temperatures around the repository; temporal variability of factors such as annual variation of precipitation and future climate change; and uncertainties in the analytical models as a result of simplifications or imperfect knowledge of the processes simulated by the models.

These uncertainties are taken into consideration by the codes used in TSPAs through use of probabilistic techniques in selecting the model parameters for the calculations. The numerical values for uncertain performance parameters used in the TSPA codes are characterized using a range of possible values. Calculational techniques are used to sample values from the distributions to produce a large number of individual TSPA results which collectively characterize the uncertainty in the overall system performance as a result of uncertainties in the individual factors. DOE uses the computer code GOLDSIM as the integrating shell to link the various component codes. GOLDSIM includes parameter sampling capability to assess uncertainty in dose rates as a function of uncertainty in the component models, and permits flexible implementation of alternative conceptual models are part of its framework.

During the first 10,000 years, based on the TSPA-SR nominal scenario assumptions, there are no releases from the repository. However, the TSPA-SR also accounts for the potential for disruption of the repository by igneous activity. Two scenarios are evaluated in the TSPA-SR. In the first igneous scenario, magma intrudes into the repository, completely destroying waste packages it encounters, carrying waste to the surface, where a violent eruption occurs. Waste materials, in this scenario, are then distributed along with the ash plume created by the eruption. In the second igneous scenario, magma intrudes into the repository, destroying waste packages it encounters, but does not progress to the surface. In this scenario, the damage to the repository permits water to contact the waste, leading to early releases from the repository. These two igneous scenarios are the only mechanisms in the TSPA-SR leading to releases in the first 10,000 years. The mean dose rate from these scenarios reached a maximum of 0.1 mrem/yr in the first 10,000 years.

Inadvertent drilling intrusion as a result of searching for water was assumed to occur at 100 or 10,000 years. The former value is based on the proposed NRC guidance for 10 CFR 63, and the latter reflects EPA's proposed position in the draft 40 CFR 197 that the waste package must degrade for a period of time before it would be unrecognizable to a driller. The mean peak dose calculated in the TSPA-SR for either intrusion time is 0.01 mrem/yr; there is virtually no difference between the mean peak dose for the two assumptions.

The NRC is developing its own performance assessment models and codes for use in pre-licensing technical exchanges with DOE, and, ultimately, for performing reviews of DOE's license application for a repository at Yucca Mountain. The NRC models are similar in concept and content to the DOE models in that they include models of the various factors relevant to disposal system performance and have the capability to address uncertainties. NRC's recent modeling has shown results similar to those developed by DOE in the TSPA-VA, even though significant differences in underlying assumptions exist between the two approaches. NRC has not yet updated their TSPA to reflect comparable conditions to the TSPA-SR.

The NRC has estimated that the 10,000-year dose rate is about 0.003 mrem/yr as compared to the equivalent TSPA-VA dose rate of 0.04 mrem/yr. At 100,000 years the NRC calculated dose rate is 0.2 mrem/yr while the equivalent value in the TSPA-VA is 5 mrem/yr. Reasons for the differences are not readily apparent because the parameters and modeling approaches used by the two agencies differed markedly. For example, the NRC did not assume credit for fuel rod cladding as an engineered barrier while in the TSPA-VA DOE did take credit for Zircaloy cladding. The NRC assumed that dilution of ground water radionuclide concentrations occurs during pumping by the dose receptor; the DOE assumed that this dilution did not occur.

The Electric Power Research Institute has also conducted performance assessments using models and codes which address the same general features and processes as those modeled by DOE. However, the codes differ in approach and detail from those used in the TSPA-VA. Differing parameters are also used by the two organizations. In spite of these differences, 10,000-year performance assessment results were in reasonable agreement. The 10,000-year dose calculated by EPRI was 0.08 mrem/yr as compared to the DOE TSPA-VA estimate of 0.04 mrem/yr. After 100,000 years the EPRI dose rates were about two orders of magnitude lower than the TSPA-VA results due, at least in part, to differing assumptions about the available inventories of iodine - 129 and technicium-99.

ES.6 BIOSPHERE PATHWAYS LEADING TO RADIATION EXPOSURE

In order to evaluate compliance of the repository system performance with regulatory requirements, potential radiation doses to humans from repository releases must be calculated. This evaluation requires estimating radionuclide releases; modeling their movement through the environment; selecting and characterizing the person(s) for whom the potential radiation dose is to be evaluated; and characterizing the pathways by which the person(s) receives the dose.

This estimation also requires assumptions concerning the location and exposure scenarios of an individual or group of individuals likely to be at greatest risk from potential radionuclide releases after repository closure and removal of institutional controls. Prior to closure, such assumptions are unnecessary because possible contamination levels can be measured with considerable accuracy both within and outside the repository.

Releases of radionuclides from the repository are not expected to occur sooner than several thousands of years in the future; the start of release might be deferred much longer if certain repository design features are used (i.e., those aimed at delaying the start of release, such as corrosion-resistant drip shields and waste packages). After release from the repository, the radioactivity would migrate through environmental pathways until it reaches the location of the person(s) selected for the evaluation of potential doses. Thus, radiation doses might first be incurred many thousands of years in the future, when locations and lifestyles of humans in the vicinity of Yucca Mountain might differ from those of the present. Human locations and lifestyles far in the future cannot, however, be reliably estimated. Therefore, evaluations of future potential radiation doses are based on an understanding of current patterns of human habitation, physiology, and activities as well as current technology. This approach to addressing future states was affirmed by the NAS who concluded in their study mandated by the EnPA that:

- *...based on our review of the literature we believe that no scientific basis exists to make projections of the nature of future human societies to within reasonable limits of uncertainty*

- *... it is not possible to predict on the basis of scientific analyses the societal factors required for an exposure scenario. Specifying exposure scenarios therefore requires a policy decision that is appropriately made in a rulemaking process conducted by EPA.*

ES.6.1 Current Demographics and Land and Water Use

The boundaries of the unincorporated town of Amargosa Valley (the closest population center to the repository site) encompass almost 500 square miles of the Amargosa Desert. The boundaries of the town include all of the area in which the highest potential doses from a repository at Yucca Mountain are anticipated. The remoteness and arid climate of the area are reflected by its population of only about 1,000 residents. Only about 11 percent of the land is held privately; the remainder is under Federal control.

Currently, agricultural activities in the Yucca Mountain region are restricted to the Ash Meadows area and the southern portion of Amargosa Valley. Two commercial alfalfa farms, a dairy farm, and one commercial sod farm operate full-time in the Valley; most other farms in the area operate on a part-time basis. Despite some difficulties, a wide range of crops and livestock can be raised. Alfalfa, hay and grass, wheat, fruits and melons, vegetable, cotton, nuts, poultry, beef cattle, dairy cattle, and fish are being or have been grown on farms and ranches in Amargosa Valley. However, because of local conditions, the population in the region does not currently grow significant quantities of leafy vegetables, root vegetables, and fruit and grain crops for its own use. Presently, no farming occurs closer than about 23 kilometers south of the repository site.

Primary uses of water in the Amargosa Valley include domestic, industrial, agricultural, mining, and recreational. Most residences are supplied by individual wells, though some trailer parks, public facilities, and commercial establishments are served by small private water companies. A number of springs also supply water, primarily to the resort area in Death Valley.

Water use data for Hydrographic Basin 230 (Amargosa Desert) in 1997 was 940 acre-feet for domestic, quasi-municipal, and commercial uses exclusive of mining and irrigation. As such, the usage is typical of a small rural residential community. The average per person use rate was 0.8 acre-feet per year. Since no major demographic changes are expected, these values should be representative of future communities in the regions.

At the present time nine farms varying in size from 65 to 800 acres are cultivating alfalfa in the area. It is estimated that a total of 2,500 acres is being cultivated in 1999 and that water usage for alfalfa irrigation is, as limited by current allocations, 5 acre-feet per acre. The nine alfalfa-growing operations have an average size estimated to be 255 acres. This results in an average annual water use for irrigation of 1,275 acre-feet per year. The domestic use of water by a small farming community of 25 people is estimated to be 10 acre-feet per year, so the average volume of water that would supply the annual water needs of a hypothetical future agricultural small community would be 1,285 acre-feet.

ES.6.2 Radiation Protection of Individuals

According to current understanding, contaminated ground water is the principal pathway by which a release of radionuclides from a repository at Yucca Mountain could cause radiation exposures to humans. Figure ES.6-1 illustrates the ground water pathway leading to human exposure from an undisturbed repository at Yucca Mountain. The major reservoirs (source terms) containing radionuclides at various times following closure are depicted as rectangles.

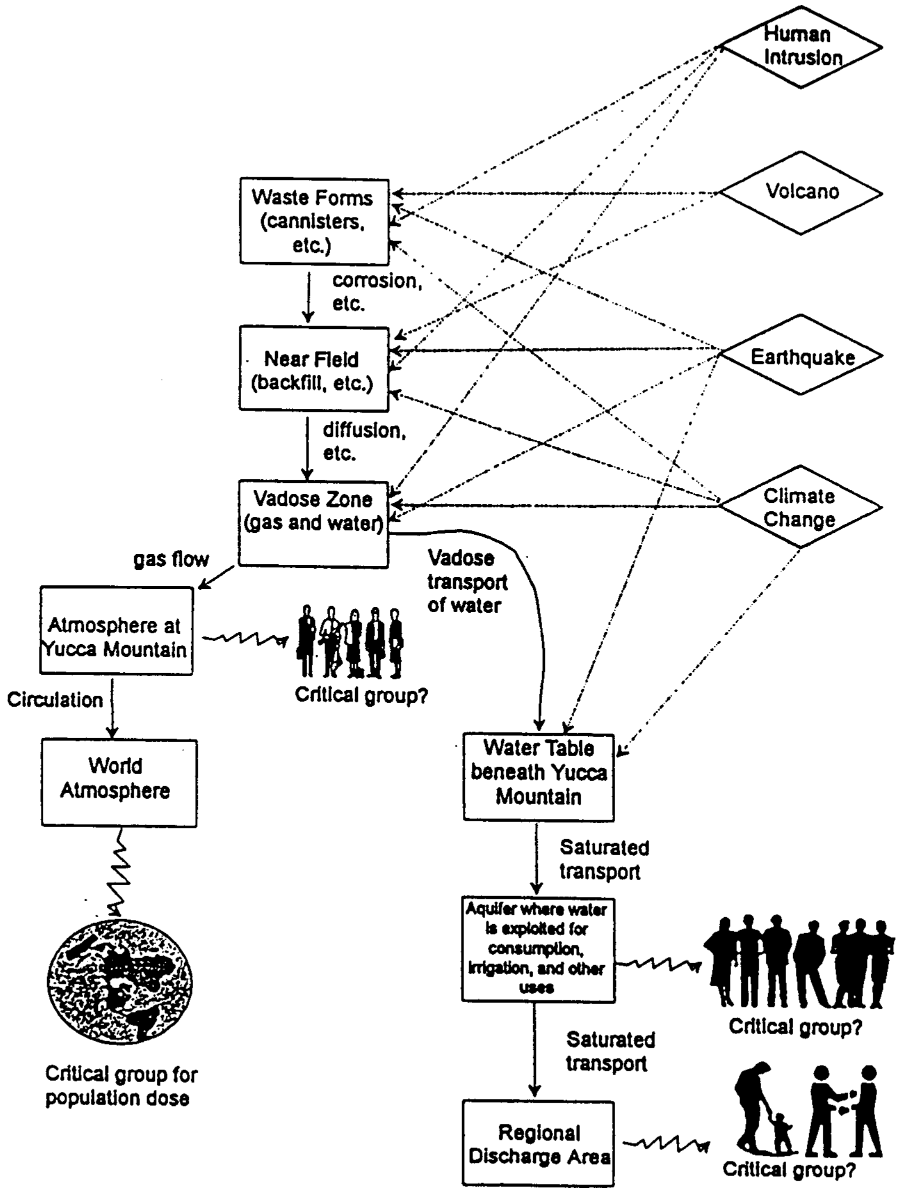

Figure ES.6-1. Schematic Illustration of the Major Pathways from a Repository at Yucca Mountain to Humans (copied from the NAS report, 1995)

Solid arrows between reservoirs represent the probable processes by which radionuclides are transported from one reservoir to another in an undisturbed repository. Major processes and events with the potential to modify normal behavior or drastically alter the physical integrity of reservoirs are shown in the figure as diamonds. These modifiers are connected by dashed lines to those reservoirs most likely to have the most significant impact.

Individuals in a human population may have greatly different responses to radiation exposure reflecting differences in factors such as age, life style, and family history. In addition, their potential exposure to radiation released from a repository at Yucca Mountain will depend on factors such as where they live and what they eat and drink. A wide range of radiation exposures and effects is therefore possible. Because of these variations, some specification of the exposure conditions to be considered in measuring compliance must also be part of the regulations. Specifying some variables in the compliance evaluations would provide a means to narrow and characterize the range of conditions for which evaluations of compliance are to be made. More than one approach is possible for assessing potential radiation doses to individuals down the hydrologic gradient from the repository.

ES.6.3 Dose Estimation Approaches

To determine the risk to exposed individuals resulting from contaminated ground water requires the development of a comprehensive exposure scenario that specifies discrete pathways and quantifies the intake of individual radionuclides. Pathways for human exposure from contaminated well water include internal exposure from the ingestion of drinking water, vegetables, fruits, dairy products, and meats. For persons engaged in agricultural activities, internal exposure may also result from the inhalation of airborne contaminants resuspended from soil irrigated with contaminated water. Over time, the buildup of soil contaminants could reach levels that also give significant external doses.

The implementation of an exposure scenario appropriate for a specified population requires a complex array of pathway parameter values that define potential radionuclide concentrations in various media to which individuals may be exposed. Exposure scenarios must also provide quantitative descriptions that include where individuals live, what they eat and drink, and what their sources of food and water are. Many key parameters needed to model human exposures at Yucca Mountain are highly site-specific and reflect the desert conditions of the sparsely populated Amargosa Valley. For example, the combined impacts of low rainfall, desert temperatures, and soil quality mandate extensive irrigation of farm crops and use of local ground water for cattle. Under these conditions, contaminated well water has the potential for developing unusually high radionuclide concentrations in all locally grown food products.

The Cricial Group Approach to Chatacterization of the Dose Receptor

The NAS report recommended the use of the critical group concept for the development of environmental standards. The critical group concept was first introduced by the International Commission on Radiation Protection (ICRP) in order to account for the variation in dose in a given population which may occur due to differences in age, size, metabolism, habits, and environment. This concept was adopted in total by the NAS panel, although the Academy differs from ICRP in the implementation of the concept. The ICRP defines the critical group in dose terms, while the NAS adapted the concept to individual risk. The critical group is defined by the ICRP as a relatively homogeneous group of people whose location and lifestyle are such that they represent those individuals expected to receive the highest doses (or be at highest risk) as a result of radioactive releases. As part of the critical group definition, the ICRP specifies the following additional criteria (also adopted by the NAS panel):

- Size - The critical group should be small in number and typically include a few to a few tens of persons.

- Homogeneity among members of the critical group - There should be a relatively small difference between those receiving the highest and the lowest doses. It is recommended that the range between the low and high doses not differ by more than a factor of ten or a factor of about three on either side of the critical group average.

- Magnitude of dose/risk - It is suggested that the regulatory limit defined by a standard exceed the calculated average critical group dose by at least a factor of ten.

- Modeling assumptions - In modeling exposure for the critical group, the ICRP recommends that dose estimates be based on cautious, but reasonable assumptions.

The ICRP does not, however, prescribe the lifestyle, habits, or conditions of exposure that may define a critical group into the future. Its generic recommendations suggest use of current knowledge and cautious, but reasonable, assumptions for characterizing future exposure scenarios.

To account explicitly for future uncertainties, the NAS report offered two probabilistic modeling approaches. The first, described in Appendix C of the NAS report, A Probabilistic Critical Group Approach, uses statistical methods and probability values to characterize members of the critical group. The second, The Subsistence-Farmer Critical Group, described in Appendix D of the report, also employs a probabilistic method, but identifies the subsistence farmer as the principal representative of the critical group.

The NAS Subsistence Farmer Critical Group model is quite similar to the RMEI approach (described below) that is used by EPA to characterize the dose receptor for purposes of rulemaking. The model described in Appendix D of the NAS report specifies *a priori* one or more subsistence farmers and makes assumptions designed to define a highly exposed farmer as representative of the critical group. Subsistence farming does not exclude commercial farmers who raise food for personal consumption, in addition to cash farm products. The NAS assumed the subsistence farmer of the future would have nutritional needs consistent with those of a present-day person. Like the subsistence farmer of today, most or all drinking water would be obtained from an on-site well also used in the production of all consumed food. The subsistence farmer is also assumed to live his/her entire life at the same location. Thus, the magnitude of the dose to a subsistence farmer will largely be defined by the radionuclide concentrations in ground water at the point of water withdrawal.

EPA's Reasonably, Maximally Exposed Individual as the Dose Receptor

EPA has developed a method for estimating potential radiation doses based on the concept of the reasonably, maximally exposed individual (RMEI). The RMEI concept, which involves estimating the dose to a person assumed to be at high risk based on reasonable (i.e., not overly or insufficiently conservative) assumptions, has been used in previous agency programs and guidance.

The total population that might be exposed from ground water pathways is very small. There are only about ten people living in community of Lathrop Wells in Amargosa Valley about 20 km from the Yucca Mountain site. If this small population was defined as the critical group, the exposure to the group would likely be on the same order as if the exposure was defined based on an RMEI living at that location. Thus, in the Yucca Mountain setting, there is no significant difference between the critical group and the RMEI.

The basic approach for estimating doses to be incurred by the RMEI is to identify and characterize the most important exposure pathway(s) and input parameters. By using maximum or near-maximum (e.g., 95th percentile) values for one or a few of the most sensitive parameters, while assuming average values for others, the resulting dose estimates should reasonably correspond to the near-maximum exposures to any member of the exposed population. The ultimate objective of the approach is to define an exposure well above average exposures, but within the upper range of possible exposures. The RMEI is not intended to represent the most extreme case.

ES.6.4 Exposure Scenarios

The EPA has considered four basic scenarios for estimating potential exposures of the RMEI in the Yucca Mountain area. The scenarios involve characteristics of the region and represent potential human habitation patterns and lifestyles in the Yucca Mountain region based on local climatic, geologic, and hydrologic conditions.

(1) *Subsistence (low technology) Farmer*. In this scenario, the farmer is assumed to live in the Yucca Mountain area and to be exposed chronically (both indoors and outdoors) to residual concentrations of radionuclides in soil through all exposure pathways. Contaminated water from the aquifer is the only source of water for these individuals. The location and habits of this individual will be consistent with historical locations, and easily accessible water (approximately 30-40 km from the disposal system). All the individual's food and water would come from contaminated sources.

(2) *Commercial Farmer.* Based upon economic factors and current technologies, certain areas around Yucca Mountain are suitable for commercial crop production. These areas are either currently being farmed (approximately 30 km from the Yucca Mountain disposal system) or could be economically viable based upon reasonable assumptions, current technology, and experience in other parts of the arid west. In addition, some parts of the region could possibly support emerging technologies such as hydroponic applications and fish farming. Exposure pathways in this scenario are the same as those described for the subsistence farmer.

(3) *Rural-Residential Person.* In this scenario, individuals are assumed to live closer to Yucca Mountain and to be exposed through the same pathways described for the subsistence farmer in Scenario 1. However, in this case the residents are not assumed to be full-time agricultural

workers. Instead, these individuals work primarily out of the area and engage only in light farming and recreational activities within it. Furthermore, it is assumed that all of the drinking water (2 liters/day) and some of the food production will involve use of water contaminated with radionuclides. This lifestyle is typical of most of the people currently living in the Amargosa Valley.

(4) *Domestic Use of an Underground Drinking Water Supply.* Based upon current water usage in the arid West, there could be an hypothetical water supply which could serve a community living north of Interstate 95 closer to the repository site (inside the Nevada Test Site).

For each of these four scenarios, there are eight exposure pathways to be evaluated:

- External radiation from radionuclides in soil
- Inhalation of resuspended soil and dust containing radionuclides
- Inhalation of radon and radon decay products from soil containing radium
- Incidental ingestion of soil containing radionuclides
- Ingestion of drinking water containing radionuclides transported from soil to potable ground water sources
- Ingestion of home-grown produce contaminated with radionuclides taken up from soil
- Ingestion of meat (beef) or milk containing radionuclides taken up by cows grazing on contaminated plants (fodder)
- Ingestion of locally-caught fish containing radionuclides

ES.6.5 Compliance Evaluation

The above discussion of receptor groups and exposure scenarios illustrates the factors involved in assessing compliance with radiation protection standards. In practice, the critical group and exposure scenarios to be used in assessing compliance with EPA's standards for Yucca Mountain will be implemented under regulations to be developed by the NRC in conformance with the EPA standards. The NRC regulations will be the basis for review of DOE's License Application.

The License Application from DOE will include assessments of potential radionuclide releases from the repository and assessment of compliance with regulatory standards under specified exposure conditions. Because of the long time frames and uncertainties involved in predicting repository performance, DOE will be required to demonstrate "reasonable expectation" of compliance with the standards. The term "reasonable expectation" conveys the concept that absolute numerical proof of compliance with the standards is neither necessary nor likely to be obtainable.

One of the key factors in evaluating compliance with EPA's Yucca Mountain standards is the radiation dose potential associated with each of the exposure pathways used by the receptor. The dose potential is characterized in terms of dose conversion factors, which relate radionuclide concentrations in the pathways for exposure, such as water and food consumed, to dose received. The dose consequence of radionuclides in the environment therefore depends on the relative importance of the various pathways for the exposed individual, which depends, in turn, on the lifestyle of the exposed individual. It is to be expected, for example, that the pathways and dose factors for a farmer residing in an arid environment, such as Yucca Mountain, will differ from those for an urban resident.

Dose conversion factors for assessing compliance with regulatory standards have been evaluated by DOE, EPA, and CNWRA for a wide variety of environmental conditions and receptor lifestyles. The DOE is currently acquiring data to enable characterization of dose factors specifically for environmental conditions and human activities in the Yucca Mountain region. The DOE plans to use site-specific dose conversion factors in the License Application.

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