APPENDIX C

GLOSSARY

This Glossary is provided for information and is not exhaustive.

absorption: The process of taking up by capillary, osmotic, solvent, or chemical action of molecules (e.g., absorption of gas by water) as distinguished from adsorption.

abstracted model: A model that reproduces, or bounds, the essential elements of a more detailed process model and captures uncertainty and variability in what is often, but not always, a simplified or idealized form. See *abstraction*.

abstraction: Representation of the essential components of a process model into a suitable form for use in a total system performance assessment. Model abstraction is intended to maximize the use of limited computational resources while allowing a sufficient range of sensitivity and uncertainty analyses.

adsorb: To collect a gas, liquid, or dissolved substance on a surface as a condensed layer.

adsorption: The adhesion by chemical or physical forces of molecules or ions (as of gases or liquids) to the surface of solid bodies. For example, the transfer of solute mass, such as radionuclides, in ground water to the solid geologic surfaces with which it comes in contact. The term *sorption* is sometimes used interchangeably with this term.

advection: The process in which solutes, particles, or molecules are transported by the motion of flowing fluid. For example, advection in combination with dispersion controls flux into and out of the elemental volumes of the flow domain in ground water transport models.

air mass fraction: The mass of air divided by the total mass of gas (typically air plus water vapor) in the gas phase. This expression gives a measure of the “dryness” of the gas phase, which is important in waste package corrosion models.

Alloy 22: A nickel-base corrosion resistant alloy containing approximately 22 weight percent chromium, 13 weight percent molybdenum, and 3 weight percent tungsten as major alloying elements and that may be used as the outer container material in a waste package design (see *outer barrier*).

alluvium: Detrital deposits made by streams on river beds, flood plains, and alluvial fans; especially a deposit of silt or silty clay laid down during time of flood. The term applies to stream deposits of recent time. It does not include subaqueous sediments of seas and lakes.

alternative: Plausible interpretations or designs based on assumptions other than those used in the base case that could also fit or be applicable, based on the available scientific information. When propagated through a quantitative tool such as performance assessment, alternative interpretations can illustrate the significance of the uncertainty in the base case interpretation chosen to represent the repository’s probable behavior.

ambient: Undisturbed, natural conditions such as ambient temperature caused by climate or natural subsurface thermal gradients, and other surrounding conditions.

anisotropy: The condition that physical properties vary when measured in different directions or along different axes. For example, in layered rock the permeability is often greater within the horizontal layers than across the horizontal layers.

annual frequency: The number of occurrences of an event expected in one year.

aqueous: Pertaining to water, such as aqueous phase, aqueous species, or aqueous transport.

aquifer: A subsurface, saturated rock unit (formation, group of formations, or part of a formation) of sufficient permeability to transmit ground water and yield water of sufficient quality and quantity for an intended beneficial use.

ash: Bits of volcanic rock that would be broken-up during an eruption to less than 2 mm [0.08 inches] in diameter.

basalt: A type of igneous rock that forms black, rubbly lavas and black-to-red tephras of the type commonly used as lava rocks for barbecues.

borosilicate glass: A predominantly noncrystalline, relatively homogenous glass formed by melting silica and boric oxide together with other constituents such as alkali oxides. A high-level radioactive waste matrix material in which boron takes the place of the lime used in ordinary glass mixtures.

boundary condition: For a model, the establishment of a set condition, often at the geometric edge of the model, for a given variable. An example is using a specified ground water flux from net infiltration as a boundary condition for an unsaturated flow model.

bound: An analysis or selection of parameter values that yields pessimistic results, such that any actual result is certain to be no worse or could be worse only with an extremely small likelihood.

breach: A penetration in the waste package caused by failure of the outer and inner containers or barriers that allows the spent nuclear fuel or the high-level radioactive waste to be exposed to the external aqueous environment and eventually permits radionuclide release.

burnup: A measure of nuclear reactor fuel consumption expressed either as the percentage of fuel atoms that have undergone fission or as the amount of energy produced per unit weight of fuel.

calibration: (1)The process of comparing the conditions, processes, and parameter values used in a model against actual data points or interpolations (e.g., contour maps) from measurements at or close to the site to ensure that the model is compatible with reality, to the extent feasible. (2) For tools used for field or lab measurements, the process of taking instrument readings on standards known to produce a certain response, to check the accuracy and precision of the instrument.

canister: A cylindrical metal receptacle that facilitates handling, transportation, storage, and/or disposal of high-level radioactive waste. It may serve as (1) a pour mold and container for vitrified high-level radioactive waste or (2) a container for loose or damaged fuel rods, non-fuel components and assemblies, and other debris containing radionuclides.

carbon steel: A steel made of carbon up to about 2 weight percent and only residual quantities of other elements. Carbon steel is a tough but ductile and malleable material used as baskets to maintain the spent fuel assemblies in fixed positions in the current waste package design.

Category 1 event sequences: Those event sequences that are expected to occur one or more times before permanent closure of a geologic repository.

Category 2 event sequences: Event sequences other than Category 1 event sequences that have at least one chance in 10,000 of occurring before permanent closure.

Center for Nuclear Waste Regulatory Analyses: A Federally funded research and development center in San Antonio, Texas, sponsored by the U.S. Nuclear Regulatory Commission, to provide the U.S. Nuclear Regulatory Commission with technical assistance for the repository program.

chain reaction: A continuing series of nuclear fission events that takes place within the fuel of a nuclear reactor. Neutrons produced by a split nucleus collide with and split other nuclei causing a chain of fission events.

cladding: The metal outer sheath of a fuel rod generally made of a zirconium alloy, and in the early nuclear power reactors of stainless steel, intended to protect the uranium dioxide pellets, which are the nuclear fuel, from dissolution by exposure to high temperature water under operating conditions in a reactor.

climate: Weather conditions including temperature, wind velocity, precipitation, and other factors, that prevail in a region.

climate states: Representations of climate conditions.

code (computer): The set of commands used to solve a mathematical model on a computer.

colloid: As applied to radionuclide migration, a colloidal system is a group of large molecules or small particles, having at least one dimension with the size range of 10^{-9} to 10^{-6} meters that are suspended in a solvent. Naturally occurring colloids in ground water arise from clay minerals such as smectites and illites. Colloids that are transported in ground water can be filtered out of the water in small pore spaces or very narrow fractures because of the large size of the colloids.

Colloid-Facilitated, Radionuclide Transport Model: A model that represents the enhanced transport of radionuclides by particles that are colloids.

commercial spent nuclear fuel: Nuclear fuel rods, forming a fuel assembly, that have been removed from a nuclear power plant after reaching the specified burnup.

common cause failure: Two or more failures that result from a single event or circumstance.

conceptual model: A set of qualitative assumptions used to describe a system or subsystem for a given purpose. Assumptions for the model are compatible with one another and fit the existing data within the context of the given purpose of the model.

consequence: A measurable outcome of an event or process that, when combined with the probability of occurrence, gives risk.

conservative: A condition of an analysis or a parameter value such that its use provides a pessimistic result, which is worse than the actual result expected.

continuum model: A model that represents fluid flow through numerous individual fractures and matrix blocks by approximating it as continuous flow fields.

corrosion: The deterioration of a material, usually a metal, as a result of a chemical or electrochemical reaction with its environment.

corrosion model: A theoretical representation of a corrosion process based on the application of a combination of fundamental electrochemical (chemical) and thermodynamic principles (or laws) with empirical parameters resulting from experiments, field measurements, or data obtained through industrial experience. Models can describe the penetration of a pit or a crack through a container wall as a function of time.

corrosion resistant alloy: An alloy that exhibits extremely high resistance to general or uniform corrosion in a given environment as a result of the formation of a protective film on its surface. Alloy 22, and other similar nickel-chromium-molybdenum alloys, are considered corrosion resistant alloys because they are extremely resistant to general corrosion in severe aqueous environments (e.g., high temperature brines containing acidic sulfur species).

coupling: The ability to assemble separate analyses or parameters in a performance assessment so that information can be passed among them to develop an overall analysis of system performance.

crevice corrosion: Localized corrosion of a metal surface at, or immediately adjacent to, an area that is shielded from full exposure to the environment because of close proximity between the metal and the surface of another material.

critical event: See *criticality*.

criticality: (1) A condition that would require the original waste form, which is part of the waste package, to be exposed to degradation, followed by conditions that would allow concentration of sufficient nuclear fuel, the presence of neutron moderators, the absence of neutron absorbers, and favorable geometry. (2) The condition in which nuclear fuel sustains a chain reaction. It occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle. The state is considered critical when a self-sustaining nuclear chain reaction is ongoing.

criticality accident: The release of energy as a result of accidental production of a self-sustaining or divergent neutron chain reaction.

data: Facts or figures measured or derived from site characteristics or standard references from which conclusions may be drawn. Parameters that have been derived from raw data are sometimes, themselves, considered to be data.

U.S. Department of Energy: A Cabinet-level agency of the U.S. federal government charged with the responsibilities of energy security, national security, and environmental quality.

design concept: An idea of how to design and operate the above-ground and below-ground portions of a repository.

diffusion: (1) The spreading or dissemination of a substance caused by concentration gradients. (2) The gradual mixing of the molecules of two or more substances because of random thermal motion.

diffusive transport: Movement of solutes because of their concentration gradient. The process in which substances carried in ground water move through the subsurface by means of diffusion because of a concentration gradient.

dike: A tabular body of igneous rock that cuts across the structure of adjacent rocks or cuts massive rocks.

dimensionality: Modeling in one, two, or three dimensions.

direct exposure: The manner in which an individual receives dose from being in close proximity to a source of radiation. Direct exposures present an external dose pathway.

dispersion (hydrodynamic dispersion): (1) The tendency of a solute (substance dissolved in ground water) to spread out from the path it is expected to follow if only the bulk motion of the flowing fluid were to move it. The tortuous path the solute follows through openings (pores and fractures) causes part of the dispersion effect in the rock. (2) The macroscopic outcome of the actual movement of individual solute particles through a porous medium. Dispersion causes dilution of solutes, including radionuclides, in ground water, and is usually an important mechanism for spreading contaminants in low flow velocities.

disposal container: A cylindrical metal receptacle designed to contain spent nuclear fuel and high-level radioactive waste that will become an integral part of the waste package when loaded with spent nuclear fuel or high-level radioactive waste. In the current waste package design, the inner container will have spacing structures or baskets to maintain fuel assemblies, shielding components, and neutron absorbing materials in position to control the possibility of criticality.

disruptive event: An unexpected event that, in the case of the potential repository, includes volcanic activity, seismic activity, and nuclear criticality. Disruptive events have two possible effects: (1) direct release of radioactivity to the surface, or (2) alteration of the nominal behavior of the system. For the purposes of screening features, events, and processes for the total system performance assessment, a disruptive event is defined as an event that has a significant effect on the expected annual dose and that has a probability of occurrence during the 10,000-year period of performance less than 1.0, but greater than a cutoff of 0.0001.

disruptive event scenario class: The scenario, or set of related scenarios, that describes the behavior of the system if perturbed by disruptive events. The disruptive scenarios contain all disruptive features, events, and processes that have been retained for analysis.

dissolution: (1) Change from a solid to a liquid state. (2) Dissolving a substance in a solvent.

distribution: The overall scatter of values for a set of observed data. A term used synonymously with frequency distribution or probability distribution function. Distributions have structures that are the probability that a given value occurs in the set.

drift: From mining terminology, a horizontal underground passage. The nearly horizontal underground passageways from the shaft(s) to the alcoves and rooms. Drifts include excavations for emplacement (emplacement drifts) and access (access mains).

drift scale: The scale of an emplacement drift, or approximately 5 meters in diameter.

Drift-Scale Heater Test: A test being conducted in the Exploratory Studies Facility to investigate thermal-hydrologic, thermal-chemical, and thermal-mechanical processes.

drip shield: A metallic structure placed along the extension of the emplacement drifts and above the waste packages to prevent seepage water from directly dripping onto the waste package outer surface.

edge effects: Conditions at the edges of the potential repository that are cooler and wetter because heat dissipates more quickly there than at the center of the repository.

effective porosity: The fraction of a porous medium volume available for fluid flow and/or solute storage, as in the saturated zone. Effective porosity is less than or equal to the total void space (porosity).

empirical: Reliance on experience or experiment rather than on an understanding of the fundamental processes as related to the laws of nature.

emplacement drift: See *drift*.

enrichment: The act of increasing the concentration of ^{235}U from its value in natural uranium. The enrichment (typically reported in atom percent) is a characteristic of nuclear fuel.

equilibrium: The state of a chemical system in which the phases do not undergo any spontaneous change in properties or proportions with time; a dynamic balance.

events: (1) Occurrences that have a specific starting time and, usually, a duration shorter than the time being simulated in a model. (2) uncertain occurrences that take place within a short time relative to the time frame of the model. For the purposes of screening features, events, and processes for the total system performance assessment, an event is defined to be a natural or human-caused phenomenon that has a potential to affect disposal system performance and that occurs during an interval that is short compared with the period of performance.

event tree: A modeling tool that illustrates the logical sequence of events that follow an initiating event.

expert elicitation: A formal process through which expert judgment is obtained.

Exploratory Studies Facility: An underground laboratory at Yucca Mountain that includes a 7.9-kilometer [4.9-mile] main loop (tunnel); a 2.8-kilometer [1.75-mile] cross-drift; and a research alcove system constructed for performing underground studies during site characterization. The data collected will contribute toward determining the suitability of the Yucca Mountain site for a repository. Some or all of the Exploratory Studies Facility may eventually be incorporated into the potential repository.

fault (geologic): A planar or gently curved fracture across which there has been displacement parallel to the fracture surface.

fault tree: A graphical logic model that depicts the combinations of events that result in the occurrence of an undesired event.

features: Physical, chemical, thermal, or temporal characteristics of the site or potential repository system. For the purposes of screening features, events, and processes for the total system performance assessment, a feature is defined to be an object, structure, or condition that has a potential to affect disposal system performance.

ferritic steel: A subclass of carbon steels characterized by a relatively low strength but good ductility as a result of the ferrite microstructure. A type of ferritic steel, mild steel, or low-carbon steel containing up to about 0.1 weight percent carbon is the metallic material most commonly used for construction purposes.

film flow: Movement of water as a film along a surface such as a fracture plane.

finite element analysis: A commonly used numerical method for solving mechanical deformation problems. A technique in which algebraic equations are used to approximate the partial differential equations that comprise mathematical models to produce a form of the problem that can be solved on a computer. For this type of approximation, the area being modeled is formed into a grid with irregularly shaped blocks. This method provides an advantage in handling irregularly shaped boundaries, internal features such as faults, and surfaces of engineered materials. Values for parameters are frequently calculated at nodes for convenience, but are defined everywhere in the blocks by means of interpolation functions.

flow: The movement of a fluid such as air, water, or magma. Flow and transport are processes that can move radionuclides from the proposed repository to the receptor group location.

flow pathway: The subsurface course that water or a solute (including radionuclides) would follow in a given ground water velocity field, governed principally by the hydraulic gradient.

fracture: A planar discontinuity in rock along which loss of cohesion has occurred. It is often caused by the stresses that cause folding and faulting. A fracture along which there has been displacement of the sides relative to one another is called a fault. A fracture along which no appreciable movement has occurred is called a joint. Fractures may act as fast paths for ground water movement.

fracture aperture: The space that separates the sides of a fracture, and the measured width of the space separating the sides of a fracture.

fracture permeability: The capacity of a rock to transmit fluid that is related to fractures in the rock.

frequency: The number of occurrences of an observed or predicted event during a specific time period.

galvanic: Pertains to an electrochemical process in which two dissimilar electronic conductors are in contact with each other and with an electrolyte, or in which two similar electronic conductors are in contact with each other and with dissimilar electrolytes.

galvanic corrosion: Accelerated corrosion of a metal resulting from electrical contact with a more noble metal or non metallic conductor in a corrosive electrolyte.

geochemical: The distribution and amounts of the chemical elements in minerals, ores, rocks, soils, water, and the atmosphere; and the movement of the elements in nature on the basis of their properties.

geologic-framework model: A digital, scaled, geometrically congruent , three-dimensional model of the geologic system.

ground water: Water contained in pores or fractures in either the unsaturated or saturated zones below ground level.

half-life: The time required for a radioactive substance to lose have its activity due to radioactive decay. At the end of one half-life, 50 percent of the original radioactive material has decayed.

heterogeneity: The condition of being composed of parts or elements of different kinds. A condition in which the value of a parameter such as porosity, which is an attribute of an entity of interest such as the tuff rock containing the potential repository, varies over the space an entity occupies, such as the area around the repository, or with the passage of time.

high-level radioactive waste glass: A waste form produced by melting a mixture of high-level radioactive waste and components of borosilicate glass at a high temperature (approximately 1,100 degrees centigrade).

hydrologic: Pertaining to the properties, distribution, and circulation of water on the surface of

the land, in the soil and underlying rocks, and in the atmosphere.

igneous: (1) A type of rock that has formed from a molten, or partially molten, material. (2) A type of activity related to the formation and movement of molten rock either in the subsurface (intrusive) or on the surface (volcanic).

infiltration: The process of water entering the soil at the ground surface. Infiltration becomes percolation when water has moved below the depth at which it can be removed (to return to the atmosphere) by evaporation or transpiration. See *net infiltration*.

inner barrier: The inner container in the current design of the waste package. Type 316NG stainless steel is the DOE preferred material of construction.

invert: A constructed surface that would provide a level drift floor and enable transport and support of the waste packages.

isothermal: Having a constant temperature.

license application: An application, to the U.S. Nuclear Regulatory Commission for a license to construct and operate a repository.

localized corrosion: Corrosion at discrete sites (e.g., pitting and crevice corrosion).

magma: Molten or partially molten rock that is naturally occurring and is generated within the earth. Magma may contain crystals along with dissolved gasses.

Mathematical Model: A mathematical description of a conceptual model.

matrix: Tuff rock material and its pore space exclusive of fractures. As applied to Yucca Mountain tuff, the ground mass of an igneous rock that contains larger crystals.

matrix diffusion: As used in the Total System Performance Assessment for the Site Recommendation conceptual models, the process by which molecular or ionic solutes, such as radionuclides in ground water, move from areas of higher concentration to areas of lower concentration. This movement is through the pore spaces of the rock material as opposed to movement through the fractures.

matrix permeability: The capability of the matrix to transmit fluid.

mean (arithmetic): For a statistical data set, the sum of the values divided by the number of items in the set. The arithmetic average.

mechanical disruption: Damage to the drip shield or waste package because of external forces.

median: A value such that one-half of the observations are less than that value and one-half are greater than the value.

meteorology: The study of climatic conditions such as precipitation, wind, temperature, and

relative humidity.

microbe: An organism too small to be viewed with the unaided eye. Examples of microbes are bacteria, protozoa, and some fungi and algae.

microbial influenced corrosion: Deterioration of metals as a result of the metabolic activity of microorganisms.

migration: Radionuclide movement from one location to another within the engineered barrier system or the environment.

mineral model: A description of the kinds and relative abundances of minerals that is used to approximate the true mineralogical system.

mineralogical: Of or relating to the chemical and physical properties of minerals, their occurrence, and their classification.

model: A depiction of a system, phenomenon, or process, including any hypotheses required to describe the system or explain the phenomenon or process.

near field: The area and conditions within the potential repository including the drifts and waste packages and the rock immediately surrounding the drifts. The region around the potential repository where the natural hydrogeologic system has been significantly impacted by the excavation of the repository and the emplacement of waste.

net infiltration: The amount of infiltration that escapes the zone of evapotranspiration, which is generally the zone below the zone of plant roots. See *infiltration*.

nominal behavior: (1) Expected behavior of the system as perturbed only by the presence of the potential repository. (2) Behavior of the system in the absence of disruptive events.

nominal features, events, and processes: Those features, events, and processes expected, given the site conditions as described from current site characterization information.

nominal scenario class: The scenario, or set of related scenarios, that describes the expected or nominal behavior of the system as perturbed only by the presence of the potential repository. The nominal scenarios contain all expected features, events, and processes that have been retained for analysis.

nuclear criticality safety: Protection against the consequences of a criticality accident, preferably by prevention of the accident.

U.S. Nuclear Regulatory Commission: An independent agency, established by the U.S. Congress under the Energy Reorganization Act of 1974, to ensure adequate protection of the public health and safety, the common defense and security, and the environment, in the use of nuclear materials in the United States. The U.S. Nuclear Regulatory Commission scope of responsibility includes regulation of the transport, storage, and disposal of nuclear materials and waste.

Nuclear Waste Policy Act (42 U.S.C. 10101 et seq.): The Federal statute enacted in 1982 that established the Office of Civilian Radioactive Waste Management and defined its mission to develop a federal system for the management, and geologic disposal, of commercial spent nuclear fuel and other high-level radioactive wastes. The Act also: (1) specified other federal responsibilities for nuclear waste management; (2) established the Nuclear Waste Fund to cover the cost of geologic disposal; (3) authorized interim storage under certain circumstances; and (4) defined interactions between federal agencies and the states, local governments, and Indian tribes. The act was substantially amended in 1987.

Nuclear Waste Policy Amendments Act of 1987: Legislation that amended the Nuclear Waste Policy Act to: (1) limit repository site characterization activities to Yucca Mountain, Nevada; (2) establish the Office of the Nuclear Waste Negotiator to seek a state or Indian tribe willing to host a repository or monitored retrievable storage facility; (3) create the Nuclear Waste Technical Review Board; and (4) increase state and local government participation in the waste management program.

numerical model: An approximate representation of a mathematical model that is constructed using a numerical description method such as finite volumes, finite differences, or finite elements. A numerical model is typically represented by a series of program statements that are executed on a computer.

Office of Civilian Radioactive Waste Management: A U.S. Department of Energy office created by the Nuclear Waste Policy Act of 1982 to implement the responsibilities assigned by the Act.

outer barrier: The outer container in the current design of the waste package. Alloy 22 is the U.S. Department of Energy preferred material of construction.

oxidation: (1) A corrosion reaction in which the corroded metal forms an oxide, usually applied to reaction with a gas containing elemental oxygen, such as air. (2) An electrochemical reaction in which there is an increase in the valence of an element resulting from the loss of electrons.

parameter: Data, or values, such as those that are input to computer codes for a total system performance assessment calculation.

patch: A circumscribed area of a surface. In the DOE modeling of waste package corrosion, it is the minimal surface area of the outer container over which uniform corrosion occurs, as opposed to localized corrosion in pits.

pathway: A potential route by which radionuclides might reach the accessible environment and pose a threat to humans. For example, direct exposure is an external pathway, and inhalation and ingestion are internal pathways.

permeability: The ability of a material to transmit fluid through its pores when subjected to a difference in head (pressure gradient). Permeability depends on the substance transmitted (oil, air, water, etc.) and on the size and shape of the pores, joints, and fractures in the medium and the manner in which they are interconnected.

phase: A physically homogeneous and distinct portion of a material system, such as the gaseous, liquid, and solid phases of a substance. In liquids and solids, single phases may coexist.

phase stability: A measure of the ability of a particular phase to remain without transformation.

pit: A small cavity formed in a solid as a result of localized dissolution.

pitting corrosion: Localized corrosion of a metal surface, confined to a small area, that takes the form of cavities named pits.

porosity: The ratio of openings, or voids, to the total volume of a soil or rock expressed as a decimal fraction or as a percentage. See also *effective porosity*.

pre-startup and startup testing: Activities to evaluate the readiness to receive, possess, process, store, and dispose of high-level radioactive waste.

probabilistic: (1) Based on or subject to probability. (2) Involving a variate, such as temperature or porosity. At each instance of time, the variate may take on any of the values of a specified set with a certain probability. Data from a probabilistic process are an ordered set of observations, each of which is one item from a probability distribution.

probabilistic risk assessment: (1) A systematic process of identifying and quantifying the consequences of scenarios that could cause a release of radioactive materials to the environment. (2) Using predictable behavior to define the performance of natural, geologic, human, and engineered systems for thousands of years into the future including probability distributions to account for uncertainty and variability.

probability: The chance that an outcome will occur from the set of possible outcomes. Statistical probability examines actual events and can be verified by observation or sampling. Knowing the exact probability of an event is usually limited by the inability to know, or compile, the complete set of possible outcomes over time or space.

probability distribution: The set of outcomes (values) and their corresponding probabilities for a random variable.

processes: Phenomena and activities that have gradual, continuous interactions with the system being modeled. For the purposes of screening features, events, and processes for the total system performance assessment, a process is defined as a natural or human-caused phenomenon that has a potential to affect disposal system performance and that operates during all or a significant part of the period of performance.

process model: A depiction or representation of a process, along with any hypotheses required to describe or to explain the process.

radioactive decay: The process in which one radionuclide spontaneously transforms into one or more different radionuclides, which are called daughter radionuclides.

radioactivity: The property possessed by some elements (i.e., uranium) of spontaneously emitting radiation (e.g., alpha particles, beta particles, or gamma rays) by the disintegration of atomic nuclei.

radiolysis: Chemical decomposition by the action of radiation.

radionuclide: Radioactive type of atom with an unstable nucleus that spontaneously decays, usually emitting ionizing radiation in the process. Radioactive elements are characterized by their atomic mass and atomic number.

range (statistics): The numerical difference between the highest and lowest value in any set.

receptor: An individual for whom radiological doses are calculated or measured.

relative permeability: The ability of a material to transmit fluid through its pores when subjected to a pressure gradient under unsaturated conditions. Relative permeability is a function of permeability (has a value between 0 and 1).

repository footprint: The areal extent of the underground repository facility.

retardation: Slowing or stopping radionuclide movement in ground water by mechanisms that include sorption of radionuclides, diffusion into rock matrix pores and microfractures, and trapping of large colloidal molecules in small pore spaces or dead ends of microfractures.

risk: The probability that an undesirable event will occur, multiplied by the consequences of the undesirable event.

risk assessment: An evaluation of potential consequences or hazards that might be the outcome of an action. This assessment focuses on potential negative impacts on human health or the environment.

rock matrix: See *matrix*.

runoff: Lateral movement of water at the ground surface, such as down steep hillslopes or along channels, that is not able to infiltrate at a specified location. See *runon*.

runon: Lateral movement of water along the ground surface from some upstream location that becomes available for infiltration. See *runoff*.

safety question: A question regarding the adequacy of structures, systems, and components important to safety and engineered or natural barriers important to waste isolation.

scenario: A well-defined, connected sequence of features, events, and processes that can be thought of as an outline of a possible future condition of the potential repository system. Scenarios can be undisturbed, in which case the performance would be the expected, or nominal, behavior for the system. Scenarios can also be disturbed, if altered by disruptive events such as human intrusion or natural phenomena such as volcanism or nuclear criticality.

scenario class: A set of related scenarios sharing sufficient similarities that they can usefully be aggregated for the purposes of screening or analysis. The number and breadth of scenario classes depend on the resolution at which scenarios have been defined. Coarsely defined scenarios result in fewer, broad scenario classes, whereas narrowly defined scenarios result in many narrow scenario classes. Scenario classes (and scenarios) should be aggregated at the coarsest level at which a technically sound argument can be made while still retaining adequate detail for the purposes of the analysis.

seepage: The inflow of ground water moving in fractures or pore spaces of permeable rock to an open space in the rock such as a drift. Seepage rate is the percolation flux that enters the drift. Seepage is an important factor in waste package degradation and mobilization and migration of radionuclides out of the potential repository.

seismic: Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.

shallow infiltration: The amount of infiltration that escapes the root zone and percolates downward into the unsaturated zone. See *net infiltration*.

site recommendation: A recommendation by the Secretary of Energy to the President that the Yucca Mountain site is suitable for development as the Nation's first high-level radioactive waste repository.

sorb: To undergo a process of sorption.

sorption: The binding, on a microscopic scale, of one substance to another. A term that includes both adsorption and absorption. The sorption of dissolved radionuclides onto aquifer solids or waste package materials by means of close-range chemical or physical forces is potentially an important process in a repository. Sorption is a function of the chemistry of the radioisotopes, the fluid in which they are carried, and the mineral material they encounter along the flow path.

sorption coefficient (K_d): Coefficient for a term for the various processes by which one substance binds to another.

source term: Types and amounts of radionuclides that are the source of a potential release.

spatial variability: A measure of how a property, such as rock permeability, varies at different locations in an object such as a rock formation.

speciation: The existence of the elements, such as radionuclides, in different molecular forms in the aqueous phase.

spent nuclear fuel: Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing. Spent fuel that has been burned (irradiated) in a reactor to the extent that it no longer makes an efficient contribution to a nuclear chain reaction. This fuel is more radioactive than it was before irradiation, and releases significant amounts of heat from the decay of its fission product radionuclides. See *burnup*.

stratigraphy: The science of rock strata. It is concerned with all characters and attributes of rocks as *strata* and their interpretation in terms of mode of origin and geologic history.

stress corrosion cracking: A cracking process that requires the simultaneous action of a corrodent and sustained (residual or applied) tensile stress. Stress corrosion cracking excludes both the fracture of already corroded sections and the localized corrosion processes that can disintegrate an alloy without the action of residual or applied stress.

structure: In geology, the arrangement of the parts of the geologic feature or area of interest such as folds or faults. This includes features such as fractures created by faulting and joints caused by the heating of rock.

tectonic: Pertaining to geologic forms or effects created by deformation of the earth's crust.

tephra: A collective term for all clastic materials ejected from a volcano and transported through the air. It includes volcanic dust, ash, cinders, lapilli, scoria, pumice, bombs, and blocks.

thermal-chemical: Of or pertaining to the effect of heat on chemical conditions and reactions.

thermal-hydrologic: Of or pertaining to changes in ground water movement due to the effects of changes in temperature.

thermal-hydrologic processes: Processes that are driven by a combination of thermal and hydrologic factors. These processes include evaporation of water near the potential repository when it is hot and subsequent redistribution of fluids by convection, condensation, and drainage.

thermal hydrology: The study of a system that has both thermal and hydrologic processes. A thermal-hydrologic condition, or system, is expected to occur if heat-generating waste packages are placed in the potential repository at Yucca Mountain.

thermal-mechanical: Of or pertaining to changes in mechanical properties of rocks from effects of changes in temperature.

thermodynamics: A branch of physics that deals with the relationship and transformations between work as a mechanical action and heat.

total system performance assessment: A risk assessment that quantitatively estimates how the potential Yucca Mountain repository system will perform in the future under the influence of specific features, events, and processes, incorporating uncertainty in the models and uncertainty and variability of the data.

transparency: The ease of understanding the process by which a study was carried out, which assumptions are driving the results, how they were arrived at, and the rigor of the analyses leading to the results. A logical structure ensures completeness and facilitates in-depth review of the relevant issues. Transparency is achieved when a reader or reviewer has a clear picture of what was done in the analysis, what the outcome was, and why.

transpiration: The removal of water from the ground by vegetation (roots).

transport: A process that allows substances to be carried in a fluid through (1) the physical mechanisms of convection, diffusion, and dispersion; and (2) the chemical mechanisms of sorption, leaching, precipitation, dissolution, and complexation. Types of transport include advective, diffusive, and colloidal.

tuff: A general term for all consolidated pyroclastic rocks. The most abundant type of rock at the Yucca Mountain site.

uncertainty: How much a calculated or measured value varies from the unknown true value.

uniform corrosion: A type of corrosion attack (deterioration) more or less uniformly distributed over a metal surface. Corrosion that proceeds at approximately the same rate over a metal surface. Also called general corrosion.

unsaturated zone flow: The movement of water in the unsaturated zone driven by capillary, viscous, gravitational, inertial, and evaporative forces.

variable: A non-unique property or attribute.

variability (statistical): A measure of how a quantity varies over time or space.

volcanism: Pertaining to volcanic activity.

watershed: The area drained by a river system including the adjacent ridges and hillslopes.

APPENDIX D

The following Risk Insights Baseline Report was issued in April 2004, and is reproduced here incorporating only minor editorial corrections.

RISK INSIGHTS BASELINE REPORT

Prepared for

U.S. Nuclear Regulatory Commission
Contract NRC–02–02–012

Prepared by

NRC and CNWRA Staffs

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

July 2004

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EXECUTIVE SUMMARY

As part of an ongoing effort to increase the use of risk information in its regulatory activities, the U.S. Nuclear Regulatory Commission (NRC) High-Level Waste Program is enhancing documentation of risk information and synthesizing the information to better support a risk-informed regulatory program. This effort is referred to as the Risk Insights Initiative. This report documents the results of the Risk Insights Initiative and provides the results in the form of the Risk Insights Baseline Report. The Risk Insights Baseline Report serves as a common reference for staff to use in risk-informing the NRC High-Level Waste Program, as it continues through prelicensing regulatory activities and prepares to review a license application that may be submitted by the U.S. Department of Energy (DOE) for a potential high-level waste repository at Yucca Mountain, Nevada.

The risk insights presented in this report address the staff current understanding of the repository system following cessation of repository operations and permanent closure of the repository through the 10,000-year compliance period (i.e., the postclosure period). The risk insights are drawn from the staff experience gained through the development and exercise of the Total-System Performance Assessment (TPA) computer code, technical analyses conducted by the staff to support prelicensing interactions with DOE, and analyses conducted by DOE and others. If DOE submits a license application for a potential repository at Yucca Mountain, staff will review the information provided by DOE and make its determinations based on information available at that time.

Background on Risk-Informed Regulation

In the Probabilistic Risk Assessment Policy Statement (60 FR 42622, August 16, 1995), NRC formalized its commitment to risk-informed regulation through the expanded use of probabilistic risk assessment in regulatory activities. In issuing the policy statement, NRC expected the implementation of probability risk assessment to improve the regulatory process in three ways: (i) incorporation of probabilistic risk assessment insights into regulatory decisions, (ii) efficient and effective utilization of agency resources, and (ii) reduction of unnecessary burden on licensees. The Probabilistic Risk Assessment Policy Statement in part says, “The use of probabilistic risk assessment technology should be increased in all regulatory matters to the extent supported by the state-of-the-art in Probabilistic Risk Assessment methods and data, and in a manner that complements the NRC deterministic approach and supports the NRC traditional defense-in-depth philosophy.” In a white paper staff requirements memorandum, Risk-Informed and Performance-Based Regulation (SECY–98–144, March 1, 1999), NRC stated that a risk-informed approach should use risk insights to focus regulatory attention on issues, commensurate with their importance to public health and safety.

The definition for risk in the white paper takes the view that assessing risk involves three questions: What can go wrong?; How likely is it?; and, What are the consequences? These three questions are referred to as the risk triplet. The traditional definition of risk, that is, probability times consequences, is fully embraced by the triplet definition of risk. For the high-level waste postclosure repository system, the risk is usually expressed in terms of probability-weighted dose, for comparison to the dose-based individual protection standard.

In the high-level waste program, performance assessment is the methodology that is used to assess the risks associated with postclosure performance of a repository system. The

high-level waste performance assessments include not only the system-level analyses performed to calculate probability-weighted dose, but also the supporting analyses performed to understand system-level results, the sensitivities and uncertainties in the system-level results, the capability of individual system components and processes, and interactions among the components and processes. Thus, risk insights may be expressed explicitly relative to system-level risk, such as probability-weighted dose, and also may be expressed in terms of surrogate measures (e.g., calculation of waste package failure rates, release rates of radionuclides from the waste package, and transport times of radionuclides to the compliance location), as long as the relationship between the surrogate measure and the system-level risk is understood. In the high-level waste program, risk insights are based on the quantitative results of performance assessments.

Developing the Risk Insights Baseline Report

Building on approximately 20 years of performance assessment activity, the high-level waste Risk Insights Initiative began in 2002. The early efforts of the Risk Insights Initiative were aimed at enhancing communication, among staff, of the more significant technical issues, and identifying and focusing staff attention on the more significant of the prelicensing agreements that had been established between NRC and DOE. Following these initial efforts, staff began development of its Risk Insights Baseline Report. The risk insights baseline provides a system-level perspective on the relative significance of system features, events, and processes by looking at how they might affect the waste isolation capabilities of the repository system during the postclosure period, and the potential effect on public health and safety.

To facilitate the application of the Risk Insights Baseline Report to its regulatory activities, staff organized the risk insights around the 14 postclosure performance assessment model abstractions, referred to as integrated subissues (Figure 1). Two other primary NRC documents related to the high-level waste program, NUREG–1762 (NRC, 2002) and NUREG–1804 (NRC, 2003), are also structured around these integrated subissues. Within each model abstraction, staff developed individual risk insights to address the important features, events, and processes, both natural and engineered, of the repository system, and to communicate how they relate to waste isolation capability and to estimates of risk. Staff did not attempt to develop risk insights to address all the components of a potential repository system at Yucca Mountain, but instead has focused on those components identified as most significant to waste isolation.

The risk insights are generally framed around the three aspects of the risk triplet. Risk insights are generally stated in terms of a scenario, essentially a statement of the feature, event, or process that might exist or occur in the postclosure repository system. The baseline provides context for understanding the likelihood that the feature, event, or process will exist or occur during the compliance period. For each risk insight, the baseline provides: (i) supporting quantitative analyses, and an interpretation of the analyses to the extent necessary to explain the relationship between the analyses and the risk insight; and (ii) a discussion of the uncertainties associated with the analyses and their interpretation.

To support the application of the Risk Insights Baseline Report, the staff grouped the risk insights into three categories of relative significance (high, medium, and low), based on

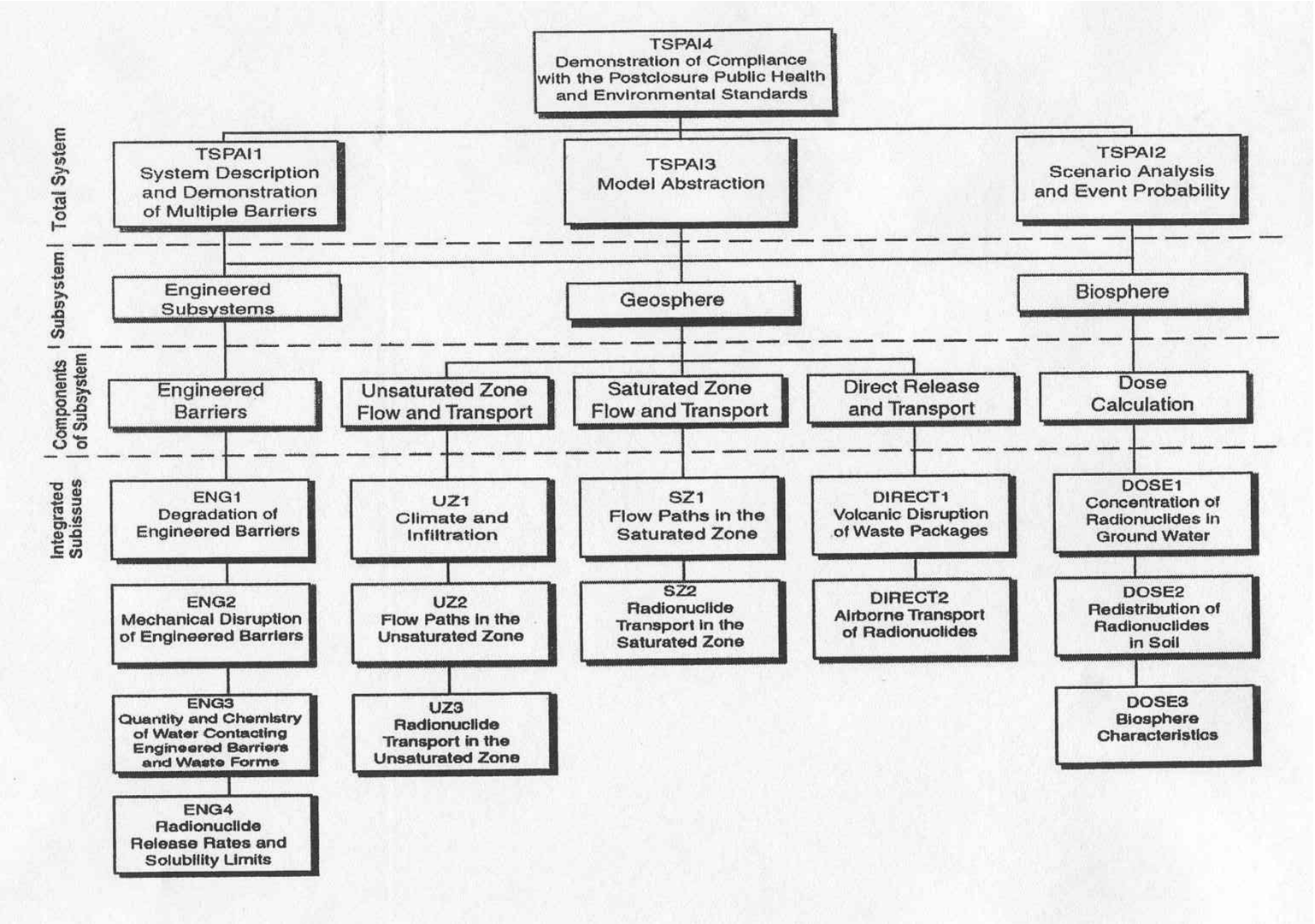

Figure 1. Components of Performance Assessment Review. (NRC, 2003, Figure A1-5)

contribution to, or effect on, the waste isolation capabilities of the repository system. Three criteria were considered in evaluating the significance of the risk insights:

- Effect on the integrity of waste packages
- Effect on the release of radionuclides from the waste form and waste package
- Effect on the transport of radionuclides through the geosphere and biosphere

In general, high significance is associated with features, events, and processes that could: (i) affect a large number of waste packages; (ii) significantly affect the release of radionuclides; or (iii) significantly affect the transport of radionuclides through the geosphere or biosphere. Medium significance is associated with a lesser effect on waste packages, radionuclide releases, or radionuclide transport, and low significance is associated with no or negligible effect.

General Risk Insights on Geologic Disposal

Geologic disposal has been internationally adopted as an appropriate method for ensuring protection of public health and safety for very long time periods (e.g., 10,000 years) because deep geologic disposal: (i) limits the potential for humans to come into direct contact with the waste; (ii) isolates the waste from a variety of natural, disruptive processes and events occurring on the surface of the earth; and (iii) limits the transport of radionuclides, after release to ground water, by the natural hydrological and chemical properties of geologic strata comprising a potential repository site. Additionally, it has been widely accepted that a geologic repository is to be comprised of multiple barriers as a means of providing defense-in-depth.

The inventory of high-level waste represents a significant risk if the inventory were quickly released to the biosphere. However, current performance assessments of a potential repository at Yucca Mountain indicate that the majority (i.e., greater than 99 percent) of the inventory is isolated from humans during the regulatory compliance period and beyond, because of the effectiveness of the engineered barriers and the attributes of the site (i.e., natural barriers). For example: (i) long-lived waste packages are expected to retain their integrity during the period of the highest thermal output of the waste, when the waste-form behavior is most uncertain; (ii) radionuclides are expected to be released slowly from the engineered barrier system once the waste packages degrade; and (iii) radionuclides are expected to travel slowly from the engineered barrier system to the area where potential exposures might occur because of the sorptive properties of the surrounding rock. Thus, multiple barriers, as a defense-in-depth approach, result in a robust repository system that is more tolerant of failures and external challenges.

Table 1 provides a general perspective on the capabilities and effectiveness of the site and design attributes for isolating the radionuclides considered in the ground water pathway. The site and design attributes are divided into three categories affecting waste isolation: (i) delay of the onset of initial release; (ii) release rates from the engineered barriers (principally the waste package and waste form); and (iii) transport in the geosphere. The effectiveness of each barrier is indicated by the letters D (for delay) or L (for limit), which are used to represent three levels of effectiveness, by the number of letters present.

Table 1. Representation of Effectiveness of the Attributes of Waste Isolation							
	Attributes of Waste Isolation						
	Onset of Release	Release Rate			Geosphere Transport		
Radionuclide	Waste Package	Waste Form	Solubility Limits	Solubility and Limited Water	Unsaturated Zone	Saturated Zone - Tuff	Saturated Zone - Alluvium
Am-241	DDD				DDD	DDD	DDD
Pu-240	DDD			L	DDD	DD	DDD
Pu-239	DDD			L	DDD	DD	DDD
Am-243	DDD			L	DDD	DD	DDD
Tc-99	DDD	LL			D	D	D
U-234	DDD			L	DDD	D	DDD
Ni-59	DDD	LLL	L	LL	DDD	D	DDD
C-14	DDD	LLL			D	D	D
Np-237	DDD			L	DDD	D	DDD
Nb-94	DDD	LL	LLL	LLL	D	DD	DDD
Cs-135	DDD	LL			DDD	DDD	DDD
Se-79	DDD	LL			DD	D	DD
U-238	DDD	L	LLL	LLL	DDD	D	DDD
Cm-246	DDD	L			D	DD	DDD
I-129	DDD	LL			D	D	D
Th-230	DDD	LL	L	LL	DDD	DD	DDD
Cl-36	DDD	LL			DDD	DDD	DDD
Ra-226	DDD	LL		L	DDD	DD	DDD
Pb-210	DDD	LL	L	LL	DDD	DD	DDD

Notes: D denotes delay time of at least 10,000 years (DDD); 1,000 years (DD); and 100 years (D)

L denotes limit on release of 10,000 (LLL), 1,000 (LL) and 100 (L) times less than 0.15 mSv (15 mrem)

Table 1 offers a general explanation for the risk currently estimated for the potential repository; namely, the variety and number of design and site attributes result in a very limited amount of the high-level waste inventory being transported by ground water to the compliance location. Additionally, from a defense-in-depth perspective, the importance of any one barrier is generally diminished as the number of relatively independent barriers increases. In other words, poor performance of one barrier does not cause a significant increase in the estimated risk; thus, confidence in the overall safety of the repository system is significantly enhanced when there are multiple and effective barriers.

Although the information presented in Table 1 provides a useful general overview of repository system capabilities for waste isolation, this approach does not address the uncertainties in estimating the behavior of the potential repository system. The technical details and uncertainties are the subject of the detailed risk insights provided for the 14 integrated subissues (Figure 1). Additionally, Table 1 addresses releases in the ground water pathway and does not address releases to the air pathway from a potential igneous event. Igneous activity has a potential for higher consequences than estimated for the ground water pathway. However, the risk is still estimated to be small from this scenario because the probability for igneous activity is orders of magnitude below the probability for ground water releases.

Detailed Risk Insights

NRC staff have identified, to date, detailed risk insights related to performance of the repository system during the postclosure regulatory period. The risk insights are organized by the 14 performance assessment model abstractions (i.e., the integrated subissues) (Figure 1). For each risk insight, NRC staff ranked the significance of the insight to waste isolation as a means of providing a transparent view of NRC current understanding of features, events, and processes associated with a potential repository at Yucca Mountain. Such a representation of the risk insights benefits the NRC high-level waste program by providing: (i) NRC staff with information to risk-inform prelicensing interactions and the review of a potential DOE license application; and (ii) other stakeholders and interested groups and individuals (e.g., State of Nevada, DOE, Advisory Committee on Nuclear Waste) with information regarding the focus of NRC interactions with DOE and its review of a potential license application. Table 2 summarizes the detailed risk insights, organized by the 14 integrated subissues (Figure 1), along with their significance rankings.

Table 2. Summary of Risk Insights Rankings: Significance to Waste Isolation

ENG1—Degradation of Engineered Barriers	
Persistence of a Passive Film	High Significance
Waste Package Failure	Medium Significance
Drip Shield Integrity	Medium Significance
Stress Corrosion Cracking	Medium Significance
Juvenile Failures of the Waste Package	Low Significance
ENG2—Mechanical Disruption of Engineered Barriers	
Effects of Accumulated Rockfall on Engineered Barriers	Medium Significance
Dynamic Effects of Rockfall on Engineered Barriers	Low Significance
Effects of Seismic Loading on Engineered Barriers	Medium Significance
Effects of Faulting on Engineered Barriers	Low Significance

Table 2. Summary of Risk Insights Rankings: Significance to Waste Isolation (continued)	
ENG3—Quantity and Chemistry of Water Contacting Engineered Barriers and Waste Forms	
Chemistry of Seepage Water	High Significance
ENG4—Radionuclide Release Rates and Solubility Limits	
Waste Form Degradation Rate	Medium Significance
Cladding Degradation	Medium Significance
Solubility limits	Medium Significance
Mode of Release from Waste Package	Low Significance
Effect of Colloids on Waste Package Releases	Medium Significance
Invert Flow and Transport	Low Significance
Criticality	Low Significance
UZ1—Climate and Infiltration	
Present-day Net Infiltration Rate	Medium Significance
Long-term Climatic Change	Medium Significance
UZ2—Flow Paths in the Unsaturated Zone	
Seepage	High Significance
Hydrologic Properties of the Unsaturated	Medium Significance
Transient Percolation	Low Significance
UZ3—Radionuclide Transport in the Unsaturated Zone	
Retardation in the Calico Hills Non-Welded Vitric Unit	Medium Significance
Matrix Diffusion in the Unsaturated Zone	Medium Significance
Effect of Colloids on Transport in the Unsaturated Zone	Medium Significance
SZ1—Flow Paths in the Saturated Zone	
Saturated Alluvium Transport Distance	Medium Significance
SZ2—Radionuclide Transport in the Saturated Zone	
Retardation in the Saturated Alluvium	High Significance
Matrix Diffusion in the Saturated Zone	Medium Significance
Effect of colloids on Transport in the Saturated Zone	Medium Significance
DIRECT1—Volcanic Disruption of Waste Packages	
Probability of Igneous Activity	High Significance
Number of Waste Packages Affected by Eruption	High Significance
Number of Waste Packages Damaged by Intrusion	Medium Significance
DIRECT2—Airborne Transport of Radionuclides	
Volume of Ash Produced by an Eruption	Medium Significance
Remobilization of Ash Deposits	Medium Significance
Inhalation of Resuspended Volcanic Ash	High Significance
Wind Vectors During an Eruption	Medium Significance
DOSE1—Concentration of Radionuclides in Ground Water	
Well-pumping Model	Low Significance
DOSE2—Redistribution of Radionuclides in Soil	
Redistribution of Radionuclides in Soil	Low Significance
DOSE3—Biosphere Characteristics	
Characterization of the Biosphere	Low Significance

METRIC TO ENGLISH SYSTEM CONVERSION FACTORS

The following table provides the appropriate conversion factors to allow the user to switch between the System Internationale or metric system and the English system of measure. Not all units or methods of conversions are shown. Unit abbreviations are shown in parentheses. All conversion factors are approximate. Multiply quantity in metric units by the appropriate conversion factor to obtain English unit equivalents. For additional unit conversions, refer to C.J. Pennycuick (1988).

Conversion Factors			
	To Convert	**To**	**Multiply By**
Length	Microns or micrometer (μm)	Inches (in)	3.94×10^{-5}
	Microns or micrometer (μm)	Feet (ft)	3.28×10^{-6}
	Millimeters (mm)*	Inches (in)*	0.0394
	Millimeters (mm)	Feet (ft)	0.0033
	Centimeters (cm)	Inches (in)	0.3937
	Centimeters (cm)	Feet (ft)	0.0328
	Meters (m)*	Inches (in)*	39.3701
	Meters (m)*	Feet (ft)*	3.2808
	Meters (m)	Yards (yd)	1.0936
	Kilometers (km)*	Miles (mi)*	0.6215
Area	Square centimeters (cm^2)	Square inches (in^2)	0.1550
	Square meters (m^2)*	Square feet (ft^2)*	10.7639104
	Square meters (m^2)	Square yards (yd^2)	1.1960
	Square meters/gram (m^2/g)	Square feet/pound mass (ft^2/lbm)	4882.4276
	Square kilometers (km^2)	Square miles (mi^2)	0.3861
Volume	Cubic centimeters (cm^3)	Cubic inches (in^3)	0.0610
	Cubic meters (m^3)*	Cubic feet (ft^3)*	35.3107
	Cubic meters/year (m^3/yr)	Cubic feet/year (ft^3/yr)	35.3107
	Cubic meters (m^3)	Cubic yards (yd^3)	1.3072
	Liters (L)	Pints (pt)	2.1142
	Liters (L)	Quarts (qt)	1.0571
	Liters (L)	Gallons (gal)	0.2642
Specific Volume	Milliliters/gram (ml/g)	Gallons/pound mass (gal/lbm)	0.1198
Velocity	Meters/second (m/s)*	Feet/second (ft/s)*	3.2808
	Centimeters/second (cm/s)	Inches/second (in/s)	0.3937
	Centimeters/second (cm/s)	Feet/second (ft/s)	0.0328
Acceleration	Meters/second (m/s^2)	Feet/second (ft/s^2)	3.2808
Mass	Milligrams (mg)	Pounds (lb)	2.205×10^{-6}
	Grams (g)	Ounces (oz)	0.0353
	Kilograms (kg)	Pounds (lb)	2.2046
	Metric ton (t)*	Tons (long)*	0.9843

Conversion Factors (continued)			
	To Convert	**To**	**Multiply By**
Density	Milligrams/cubic meter (mg/m^3)	Pounds/cubic foot (lbs/ft^3)	6.243×10^{-8}
	Grams/cubic centimeter (g/cm^3)	Pounds/cubic foot (lbs/ft^3)	6.243×10^{1}
	Grams/cubic meter (g/m^3)	Pounds/cubic foot (lbs/ft^3)	6.243×10^{-5}
	Kilograms/cubic meter (kg/m^3)	Pounds/cubic foot (lbs/ft^3)	0.0624
Force	Newton (N)	Pound-force (lbf)	0.2248
	Dyne (dyn)	Pound-force (lbf)	2.248×10^{-6}
Pressure	Grams per square centimeter (g/cm^2)	Pounds per square inch (psi)	0.0142
	Pascals (Pa)	Pounds per square inch (psi)	1.450×10^{-4}
	Kilopascals (kPa)	Pounds per square inch (psi)	0.1450
	Dyne/square centimeter (dyn/cm^2)	Pound-force/square foot (lbf/ft^2)	0.0021
	Kilopascals (kPa)	Atmosphere (atm)	0.0099
	Megapascals (MPa)	Kilo pounds per square inch (kpsi)	0.145037738
Power	Kilowatts (kW)	Hosepower (hp)	1.3405
Temperature	Celsius (°C)*	Fahrenheit (°F)*†	1.8000
	Kelvin (K)	Fahrenheit (°F)	1.8000
Δ Temperature	Celsius (°C)*	Fahrenheit (°F)*‡	1.8000
Thermal Conductivity	Watts/meter - K (W/m-K)	British Thermal Unit/hour/foot-Fahrenheit (BTU/hr/ft-°F)	0.5778
Activity	Becquerels (Bq)*	Curies (Ci)*	2.70×10^{-11}
Absorbed Dose	Gray (Gy)	Rad	100
Dose Equivalent	Sievert (Sv)	Rem	100
	Millisievert (mSv)*	Millirem (mrem)*	100
Permeability	Square meters (m^2)	Darcy	1.01325×10^{12}
	Square millimeters (mm^2)	Darcy	1013249.966

*Conversions with an asterisk are used in the current document.

†The formula for converting temperature in Celsius to Fahrenheit is $T_F = (1.8)T_c + 32$

‡The formula for converting relative temperature differences in Celsius to Fahrenheit is $T_F = (1.8)T_c$

REFERENCE:

Pennycuick, Colin J. "Conversion Factors: S.I. Units and Many Others." Vol. 48. p. 1974. Chicago, Illinois: University of Chicago Press. 1988.